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Comparison of Doppler Ultrasound and CT Angiography for Evaluation of Renal Artery Stenosis

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ABSTRACT

Background: Renal artery stenosis (RAS) is an important cause of secondary hypertension and progressive renal impairment. Accurate and timely diagnosis is essential for appropriate management. This study aimed to compare the diagnostic performance of Doppler ultrasound with CT angiography and to identify clinical predictors of RAS. **Methods:** A cross-sectional study was conducted on 120 patients with suspected RAS. Demographic, clinical, and laboratory data were collected. All participants underwent Doppler ultrasound and CT angiography. Diagnostic performance metrics of Doppler ultrasound, including sensitivity, specificity, positive predictive value (PPV), negative predictive value (NPV), and overall accuracy, were calculated using CT angiography as the reference standard. Multivariable logistic regression was performed to determine independent predictors of RAS. Clinical outcomes, including blood pressure control, renal function, and management strategies, were assessed at 6 months. **Results:** The study population had a mean age of 52.3 ± 9.6 years, with 60% males. Doppler ultrasound demonstrated a sensitivity of 79.4% (95% CI: 67.9–88.3), specificity of 84.6% (95% CI: 71.9–93.1), PPV of 87.1% (95% CI: 76.1–94.3), NPV of 75.9% (95% CI: 62.8–86.1), and overall accuracy of 81.7% (95% CI: 73.6–88.1). Multivariable analysis identified age ≥50 years (AOR 1.86, p = 0.041), hypertension duration >10 years (AOR 2.21, p = 0.013), current smoking (AOR 2.03, p = 0.028), eGFR <60 mL/min/1.73m^2 (AOR 2.34, p = 0.011), and resistant hypertension (AOR 2.82, p = 0.004) as significant predictors of RAS. CT-positive patients more frequently underwent revascularization and demonstrated greater improvements in blood pressure and renal function at 6 months ($p < 0.05$). **Conclusion:** Doppler ultrasound shows good diagnostic accuracy for detecting renal artery stenosis and can serve as a reliable initial imaging modality. Older age, prolonged hypertension, smoking, reduced renal function, and resistant hypertension are independent predictors of stenosis. Early detection and targeted management in high-risk patients may improve clinical outcomes.

INTRODUCTION

Renal artery stenosis (RAS) is increasingly recognized as a significant cause of secondary hypertension and progressive renal dysfunction. It represents a potentially reversible form of renovascular disease, and timely diagnosis can avert irreversible damage through revascularization or optimized medical therapy (1). The epidemiology of RAS is variable: in the general hypertensive population, its prevalence is modest, but in high-risk subgroups — such as those with resistant hypertension, recurrent heart failure, or unexplained renal impairment — the frequency rises substantially (2). Indeed, atherosclerosis accounts for the vast majority of RAS in older adults, while fibromuscular dysplasia (FMD) remains an important etiology among younger patients (3).

The pathophysiology of RAS centers on reduced renal perfusion, which activates the renin–angiotensin–aldosterone system (RAAS), leading to vasoconstriction, sodium retention, and hypertension; chronic ischemia can also impair renal function over time (4). Given the clinical burden, noninvasive screening is critical. Color-Doppler ultrasound (US) has been widely used as a first-line modality because it is safe, low-cost, and readily available. It allows assessment of peak systolic velocities, renal-aortic ratios, and intrarenal waveforms; prior studies have shown reliability in detecting significant RAS, though technical failures and operator dependency have limited its universal use (5,6). Spectral Doppler measurements, notably acceleration time and resistive index, provide additional hemodynamic insights, but their

sensitivity can vary, particularly in smaller or accessory renal arteries (7).

On the other hand, computed tomography angiography (CTA) has emerged as a powerful tool in the evaluation of RAS. Multidetector CT scanners offer high spatial resolution, three-dimensional reconstruction, and detailed anatomical delineation of both main and branch renal arteries (8). Although CTA involves ionizing radiation and iodinated contrast, its diagnostic accuracy often surpasses that of Doppler US, especially in detecting moderate-to-high grade stenoses. In certain populations, such as children, CTA demonstrates excellent sensitivity and specificity for RAS when compared to conventional angiography (9).

Nevertheless, despite growing evidence supporting CTA, Doppler US continues to play a critical role in the diagnostic pathway because of its noninvasive nature, reported cost-effectiveness, and lack of contrast-related risks. Still, comparative data on these two modalities remain limited in many settings, and there is a need to identify clinical predictors of RAS that may guide more targeted investigation. The aim of this study was to compare the diagnostic performance of Doppler ultrasound against CT angiography for the detection of renal artery stenosis and to identify independent clinical predictors of RAS in a cohort of patients with suspected disease.

METHODOLOGY

Study Design

This study was designed as a cross-sectional, observational study aimed at comparing the diagnostic performance of Doppler ultrasound with CT angiography for the evaluation of renal artery stenosis (RAS). The study also sought to identify clinical and demographic predictors of RAS and assess related patient outcomes.

Study Setting and Duration

The study was conducted at Shaheed Benazir Ali Bhutto Medical University, a tertiary care facility equipped with advanced imaging modalities including Doppler ultrasound and CT angiography. Data collection and patient follow-up were carried out over a period of twelve months, from 20/7/2023 to 2/3/2024.

Study Population and Sample Size

A total of 120 patients with clinical suspicion of RAS were recruited for the study. Inclusion criteria comprised adult patients aged 18 years or older with uncontrolled or resistant hypertension, unexplained renal impairment, or sudden worsening of blood pressure. Patients with known contraindications to contrast administration, pregnant women, and those with prior renal artery interventions were excluded. The sample size was determined to provide sufficient statistical power to detect differences in diagnostic performance and to perform multivariable regression analysis for predictor variables.

Data Collection and Variables

The study protocol was approved by the Institutional Ethics Committee of Shaheed Benazir Ali Bhutto Medical University *(No. F 1-1/2015/ERB/SZABMU/1158)*. Written informed consent was obtained from all participants prior to enrollment. Patient confidentiality was maintained throughout the study, and all procedures adhered to the principles outlined in the Declaration of Helsinki. Demographic and clinical data, including age, sex, body mass index (BMI), residence, duration of hypertension, diabetes status, and smoking habits, were collected using structured patient interviews and medical records review. Laboratory parameters, including serum creatinine and estimated glomerular filtration rate (eGFR), were recorded. Indications for imaging, renal artery involvement (unilateral or bilateral), and clinical outcomes were also documented.

Imaging Procedures

All patients underwent Doppler ultrasound evaluation performed by trained radiologists following standardized protocols for renal artery assessment, including peak systolic velocity, renal-aortic ratio, and waveform analysis. CT angiography was performed using a multidetector CT scanner with contrast enhancement, serving as the reference standard for diagnosis. Radiologists interpreting CT angiography were blinded to Doppler findings to minimize bias.

Outcome Measures

The primary outcome was the diagnostic accuracy of Doppler ultrasound, including sensitivity, specificity, positive predictive value (PPV), negative predictive value (NPV), and overall accuracy, using CT angiography as the gold standard. Secondary outcomes included clinical management decisions (revascularization versus medical therapy), changes in blood pressure and renal function at six months, procedure-related complications, hospital readmissions, and 30-day mortality.

Statistical Analysis

Data were analyzed using SPSS version 26.0. Continuous variables were summarized as means and standard deviations, while categorical variables were presented as frequencies and percentages. Cross-tabulations were used to evaluate associations between demographic/clinical variables and imaging outcomes, with chi-square or Fisher's exact tests applied as appropriate. Diagnostic performance metrics for Doppler ultrasound were calculated based on standard formulas. Multivariable logistic regression analysis was conducted to identify independent predictors of RAS, with adjusted odds ratios (AORs) and 95% confidence intervals reported. A p-value of <0.05 was considered statistically significant.

RESULTS

The study included 120 participants, most of whom were between 50 and 59 years of age, while nearly one-quarter were aged 60 years or older. Males represented a larger proportion of the sample compared to females. Regarding nutritional status, most participants had either a normal BMI or were overweight, with one-fifth classified as obese. The majority of individuals resided in urban areas. Hypertension duration varied, with equal proportions having less than 5 years and more than 10 years of disease, while the largest group reported 5–10 years of hypertension. About one-third of the participants had diabetes mellitus. Most respondents were never-smokers,

although a considerable proportion were current smokers. The most common indication for imaging was resistant hypertension, followed by screening or asymptomatic evaluation and unexplained renal impairment. In terms of disease involvement, unilateral renal artery stenosis was more frequent than bilateral involvement.

Table 1

Demographic Characteristics of Study Participants (n = 120)

Variable	Category	Frequency (n)	Percentage (%)
Age (years)	<40	20	16.7
	40–49	30	25.0
	50–59	40	33.3
	≥60	30	25.0
Sex	Male	72	60.0
	Female	48	40.0
Body mass index (BMI)	<18.5 (Underweight)	6	5.0
	18.5–24.9 (Normal)	48	40.0
	25.0–29.9 (Overweight)	42	35.0
	≥30 (Obese)	24	20.0
Residence	Urban	78	65.0
	Rural	42	35.0
Duration of hypertension	<5 years	36	30.0
	5–10 years	48	40.0
	>10 years	36	30.0
Diabetes mellitus	Yes	38	31.7
	No	82	68.3
Smoking status	Current smoker	28	23.3
	Former smoker	14	11.7
	Never smoker	78	65.0
Indication for imaging	Resistant hypertension	44	36.7
	Unexplained renal impairment	22	18.3
	Sudden worsening of BP	18	15.0
	Screening/asymptomatic evaluation	36	30.0
Renal artery involvement	Unilateral stenosis	78	65.0
	Bilateral stenosis	42	35.0

The cross-tabulation findings showed several important associations between patient characteristics and imaging outcomes. Longer hypertension duration demonstrated a significant relationship with imaging positivity, as individuals with more than 10 years of hypertension were more frequently identified as positive on both Doppler ultrasound and CT angiography ($p = 0.041$). Smoking status was also significantly associated with disease detection, with current smokers showing a higher proportion of positive findings on both modalities compared to non-smokers ($p = 0.032$). Renal function exhibited a notable pattern, where reduced eGFR, particularly in the 30–59 mL/min/1.73 m^2 category, was linked with a higher likelihood of stenosis detected by both Doppler and CT ($p = 0.029$). Resistant hypertension showed the strongest association, with significantly more positive cases on both imaging methods among patients with uncontrolled blood pressure ($p = 0.004$). In contrast, diabetes mellitus, BMI category, and the side of stenosis (unilateral vs bilateral) did not demonstrate statistically significant associations with imaging outcomes, as indicated by their higher p-values. Overall, the results suggest that disease chronicity, smoking behavior, renal impairment, and resistant hypertension are important predictors of imaging positivity in suspected renal artery stenosis.

Table 2

Cross-Tabulation of Clinical Variables with Imaging Modality Findings

Variable	Category	Doppler Positive (n=62)	Doppler Negative (n=58)	CT Angio Positive (n=68)	CT Angio Negative (n=52)	p-value
Hypertension Duration	<5 years	14	22	16	20	0.041
	5–10 years	28	20	30	18	
	>10 years	20	16	22	14	
Diabetes Mellitus	Yes	24	14	26	12	0.118
	No	38	44	42	40	
Smoking Status	Current smoker	18	10	20	8	0.032
	Former smoker	6	8	8	6	
	Never smoker	38	40	40	38	
Renal Function (eGFR)	≥60 mL/min/1.73m²	22	30	24	28	0.029
	30–59	30	20	32	18	
	<30	10	8	12	6	
Side of Stenosis	Unilateral	42	36	46	32	0.221
	Bilateral	20	22	22	20	
BMI Category	Normal (18.5–24.9)	24	24	26	22	0.384
	Overweight	22	20	24	18	
	Obese ≥30	16	14	18	12	
Resistant Hypertension	Yes	32	12	34	10	0.004*
	No	30	46	34	42	

The outcome analysis demonstrated that patients with CT-confirmed renal artery stenosis had significantly different clinical trajectories compared to those without stenosis. Revascularization was performed far more frequently in CT-positive patients, reflecting clinical necessity based on disease severity, while CT-negative individuals were predominantly managed medically ($p < 0.001$). Improvements in blood pressure at 6 months were also more commonly observed in the CT-positive group, likely due to targeted interventions such as revascularization, and this association was statistically significant ($p = 0.002$). Renal function outcomes followed a similar pattern, with CT-positive patients showing a higher proportion of meaningful improvement in kidney function compared to CT-negative individuals ($p = 0.030$), although the proportion experiencing worsening renal function did not differ significantly ($p = 0.18$). Procedure-related complications, including contrast-induced nephropathy and access-site hematoma, were infrequent overall and did not differ significantly between groups. Similarly, health service outcomes such as hospital readmission and 30-day mortality showed no significant differences between CT-positive and CT-negative patients. Overall, the results suggest that confirmed renal artery stenosis is associated with more active clinical management and greater improvement in both blood pressure and renal function, without adding significant procedural risks.

Table 3
Clinical Outcomes by CT Angiography Result (n = 120)

Outcome	CT-Positive (n = 68)	CT-Negative (n = 52)	Total (n = 120)	p-value
Management strategy				
Revascularization performed	30 (44.1%)	5 (9.6%)	35 (29.2%)	<0.001*
Medical management only	38 (55.9%)	47 (90.4%)	85 (70.8%)	
Blood pressure at 6 months				
Improved (clinically meaningful reduction)	30 (44.1%)	12 (23.1%)	42 (35.0%)	0.002*
No significant change	28 (41.2%)	30 (57.7%)	58 (48.3%)	
Worse	10 (14.7%)	10 (19.2%)	20 (16.7%)	
Renal function at 6 months (serum creatinine / eGFR)				
Improved (≥30% reduction in creatinine / ↑eGFR)	14 (20.6%)	4 (7.7%)	18 (15.0%)	0.030*
Stable	46 (67.6%)	38 (73.1%)	84 (70.0%)	
Worsened (≥30% rise in creatinine / ↓eGFR)	8 (11.8%)	10 (19.2%)	18 (15.0%)	0.18
Procedure / imaging-related complications				
Contrast-induced nephropathy (CIN)	6 (8.8%)	2 (3.8%)	8 (6.7%)	0.12
Access-site hematoma	4 (5.9%)	1 (1.9%)	5 (4.2%)	0.45
Health service outcomes				
Hospital readmission within 6 months	12 (17.6%)	8 (15.4%)	20 (16.7%)	0.76
30-day mortality	1 (1.5%)	0 (0.0%)	1 (0.8%)	0.999

The multivariable logistic regression analysis identified several significant predictors of renal artery stenosis. Age ≥50 years was associated with a nearly twofold increased likelihood of stenosis (AOR 1.86, 95% CI 1.08–3.54, p = 0.041). Longer hypertension duration (>10 years) significantly increased the odds of stenosis more than twofold (AOR 2.21, 95% CI 1.18–4.16, p = 0.013), and current smoking was also a significant risk factor (AOR 2.03, 95% CI 1.07–3.84, p = 0.028). Impaired renal function (eGFR <60 mL/min/1.73m^2) and resistant hypertension were among the strongest predictors, with patients having 2.34- and 2.82-fold higher odds, respectively (p = 0.011 and p = 0.004). Male sex, diabetes mellitus, and obesity (BMI ≥30 kg/m^2) were associated with higher odds but did not reach statistical significance. Overall, these findings indicate that older age, prolonged hypertension, smoking, reduced kidney function, and resistant hypertension are key independent risk factors for renal artery stenosis in this cohort.

Table 4
Multivariable Logistic Regression Analysis for Predictors of Renal Artery Stenosis

Predictor Variable	β Coefficient	Standard Error (SE)	Adjusted Odds Ratio (AOR)	95% CI for AOR	p-value
Age ≥ 50 years	0.62	0.28	1.86	1.08 – 3.54	0.041*
Male sex	0.48	0.26	1.62	0.98 – 2.88	0.067
Hypertension duration >10 years	0.79	0.32	2.21	1.18 – 4.16	0.013*
Diabetes mellitus	0.44	0.29	1.55	0.88 – 2.91	0.121
Current smoker	0.71	0.33	2.03	1.07 – 3.84	0.028*
eGFR < 60 mL/min/1.73m^2	0.85	0.34	2.34	1.22 – 4.45	0.011*
Resistant hypertension	1.04	0.37	2.82	1.37 – 5.76	0.004*
Obesity (BMI ≥ 30 kg/m^2)	0.38	0.31	1.46	0.86 – 2.68	0.214

DISCUSSION

In this study, Doppler ultrasound demonstrated good diagnostic performance for detecting renal artery stenosis (RAS) when compared to CT angiography, with sensitivity, specificity, PPV, and NPV in line with prior reports. Our sensitivity (79.4%) and specificity (84.6%) are somewhat lower than what earlier small studies reported for CT angiography, but remain clinically acceptable, suggesting that Doppler can function as a reliable first-line screening tool. This aligns with the findings of Halpern et al., who noted that CT angiography had much higher sensitivity compared to Doppler, but that specificity was comparable between the modalities (10).

Although Doppler has the advantage of being non-invasive and free of ionizing radiation or nephrotoxic contrast, its limitations remain. Operator dependence, limited acoustic windows, and technical failure in some arteries can lead to under-detection, as described in systematic reviews showing only moderate accuracy of duplex sonography when compared with angiography. Moreover, Doppler parameters such as peak systolic velocity (PSV) offer the best performance among sonographic markers, but even these can be affected by patient anatomy, cardiac output, or downstream resistance (11).

Our finding of significant predictors for RAS — specifically older age, prolonged hypertension duration, smoking, reduced eGFR, and resistant hypertension — is consistent with what is described in large-scale epidemiological reviews. For example, a recent meta-analysis showed that chronic kidney disease, advanced age, and hypertension are among the most robust risk factors for RAS. The identification of eGFR <60 as a strong predictor is particularly meaningful, because reduced renal function may both reflect and exacerbate hemodynamic compromise in RAS, and this demographic is often underdiagnosed (12).

In our cohort, resistant hypertension was the strongest predictor, which underscores the clinical importance of considering RAS in patients whose blood pressure remains uncontrolled despite multiple antihypertensive agents. This finding resonates with existing clinical guidelines and practice parameters: professional imaging standards emphasize that patients with difficult-to-control hypertension represent a high-risk group for RAS, justifying noninvasive work-up (13).

Furthermore, while revascularization was more common in CT-positive patients in our study, it is important to interpret this cautiously. Large randomized trials, such as the CORAL study, showed that renal artery stenting did not yield significant improvements in eGFR compared to medical therapy. In our cohort, although patients with radiographically confirmed stenosis improved in blood pressure and renal function, long-term benefits and risks remain uncertain, especially considering the potential for contrast-induced nephropathy or procedural complications (14).

From a technical perspective, advances in CT angiography continue to improve diagnostic yield. Earlier work showed that different three-dimensional reconstruction techniques (e.g., maximum-intensity projection) influenced sensitivity and specificity for high-grade stenosis. In addition, correlation between CT angiography

and Doppler ultrasonography remains strong in real-world settings: recent observational studies report high concordance between CTA and Doppler findings, supporting complementary use in clinical pathways (15, 16).

However, several limitations of our study should be acknowledged. Being a cross-sectional observational investigation, causality cannot be inferred, and selection bias may be present. We did not include a functional gold standard such as pressure gradient measurements (e.g., using a pressure wire), which can distinguish hemodynamically significant stenosis more precisely than imaging alone (17, 18). Previous work has shown discrepancies between angiographic or Doppler-derived measurements and trans-stenotic pressure gradient, highlighting the risk of overestimating stenosis severity (19).

Additionally, our study did not utilize contrast-enhanced ultrasound (CEUS), which has demonstrated high accuracy in grading RAS in some experimental studies. Incorporating CEUS or other emerging modalities could improve diagnostic yield in patients for whom traditional Doppler is technically limited. Implications for practice from our findings include supporting Doppler ultrasound as a first-line, noninvasive screening modality in patients at risk, particularly in settings where CT angiography may not be immediately available, contraindicated, or overly burdensome (20, 21). Given the strong association of risk factors such as age, prolonged hypertension, and reduced renal function, clinicians should maintain a high index of suspicion for RAS in these populations and consider early imaging. For patients with positive Doppler findings or high-risk profiles, CTA remains a valuable next step to confirm diagnosis and guide management decisions. Future research should aim to integrate functional assessment (e.g., pressure gradient or fractional flow reserve techniques), long-term follow-up after intervention, and cost-effectiveness analyses, particularly in resource-limited settings. Moreover, comparative trials of advanced modalities like CEUS or newer ultrasound techniques may clarify their role in the diagnostic algorithm for RAS. In summary, our study reinforces that while CT angiography remains the more sensitive tool, Doppler ultrasound offers a practical, reasonably accurate, and safe screening alternative. When combined with careful clinical risk assessment — particularly considering factors such as hypertension duration, renal function, and treatment resistance — it can help guide targeted imaging and management strategies in patients suspected of having RAS.

CONCLUSION

The study demonstrates that Doppler ultrasound is a reliable, non-invasive modality for the initial evaluation of renal artery stenosis, with good sensitivity, specificity, and overall diagnostic accuracy when compared to CT angiography. Older age, prolonged hypertension, current smoking, reduced renal function, and resistant hypertension were identified as independent predictors of RAS. Patients with confirmed stenosis were more likely to undergo revascularization and showed improved blood pressure control and renal function at six months. These findings underscore the importance of combining clinical risk assessment with imaging to optimize diagnosis and management of RAS.

Study Limitations

The study has several limitations. Being cross-sectional, it cannot establish causal relationships. The sample was recruited from a single tertiary care center, which may limit generalizability. Doppler ultrasound is operator-dependent, and variability in expertise could influence accuracy. Functional assessment of stenosis severity, such as trans-stenotic pressure gradients, was not performed, which may have limited evaluation of hemodynamically significant lesions. Long-term clinical outcomes beyond six months were not assessed, and contrast-enhanced ultrasound or MR angiography were not included, which could have provided additional diagnostic insight.

Recommendations

For clinical practice, Doppler ultrasound can be used as a first-line screening tool for patients at risk of RAS, especially those with resistant hypertension, reduced renal function, or prolonged disease duration. CT angiography should be reserved for confirmation of positive cases or when Doppler findings are inconclusive. Future research should include multicenter studies with larger cohorts, integration of functional hemodynamic assessment, and long-term follow-up to evaluate the impact of imaging-guided interventions on renal and cardiovascular outcomes. Additionally, comparative studies of newer imaging modalities such as contrast-enhanced ultrasound may provide further improvements in non-invasive detection of RAS.

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