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Original Research Article

Diagnostic Comparison of Doppler Ultrasonography and Non-Contrast MR Angiography for Detection of Renal Artery Stenosis: A Prospective Study Using Digital Subtraction Angiography as Reference Standard

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Conflict of interest: Nil

Abstract

Background: Renal artery stenosis (RAS) is a significant cause of secondary hypertension and progressive renal impairment. Non-invasive screening modalities are essential for early detection, particularly in patients with contraindications to contrast agents.

Objective: To compare the diagnostic performance of Doppler ultrasonography (USG) and non-contrast MR angiography (NC-MRA) for detecting RAS, using digital subtraction angiography (DSA) as the gold standard.

Methods: This prospective observational study included 60 patients (32 males, 28 females; mean age 43.40±15.74 years) with clinical suspicion of renovascular hypertension. All patients underwent Doppler USG, NC-MRA on a 3.0 Tesla system, and DSA. Significant stenosis was defined as ≥60% luminal narrowing. Sensitivity, specificity, predictive values, accuracy, and Cohen's Kappa were calculated.

Results: DSA confirmed significant stenosis in 73.3% of right and 48.3% of left renal arteries. For the right renal artery, Doppler USG showed sensitivity of 62.50%, specificity of 83.33%, and accuracy of 66.67% (κ=0.305, fair), while NC-MRA demonstrated superior sensitivity (83.33%), accuracy (80.00%), and moderate agreement (κ=0.444). For the left renal artery, both modalities performed excellently with sensitivity of 82.76%, specificity of 100%, accuracy of 91.67%, and κ=0.832 (excellent). At patient level, NC-MRA showed higher sensitivity (81.48% vs 74.07%) and accuracy (76.67% vs 70.00%).

Conclusion: NC-MRA provides more consistent diagnostic performance across both renal arteries, particularly for right-sided disease where Doppler USG has limited sensitivity. Doppler USG remains valuable for left renal artery evaluation and as a first-line screening tool in resource-limited settings.

Keywords: Renal Artery Stenosis, Doppler Ultrasonography, Non-Contrast MR Angiography, Digital Subtraction Angiography, Renovascular Hypertension.

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Introduction

Renal artery stenosis (RAS) is a clinically significant vascular disorder characterized by narrowing of one or both renal arteries, most commonly due to atherosclerosis (60-90% of cases) and less frequently due to fibromuscular dysplasia (10-30%). [1] RAS contributes to secondary hypertension and may exacerbate chronic kidney disease by reducing renal perfusion and activating the renin-angiotensin-aldosterone system (RAAS). Its prevalence ranges from 1% in mild hypertension to 10-40% in patients with refractory hypertension. [2] Digital subtraction angiography (DSA) remains the gold standard for RAS diagnosis but is invasive, carries risks of vascular injury, contrast-induced nephropathy, and radiation exposure.[3] These limitations have driven interest in reliable non-invasive imaging techniques. Doppler ultrasonography (USG) has been widely used as a non-invasive screening tool due to its safety, affordability, and absence of ionizing radiation or contrast medium. Various parameters including peak systolic velocity (PSV), renal-aortic ratio (RAR), and resistive index (RI) are used to define hemodynamically significant stenosis. Meta-analyses report sensitivities and specificities of approximately 85% and 92% for PSV criteria.[4] However, Doppler USG is operator-dependent and results may be compromised by obesity, bowel gas, or poor acoustic windows. Non-contrast MR angiography (NC-MRA) has emerged as an alternative, using specialized pulse sequences such as steady-state free precession (SSFP) and inflow inversion recovery to exploit intrinsic blood signal without exogenous contrast agents.[5] This technique avoids the risk of nephrogenic systemic fibrosis (NSF) associated with gadolinium-based agents in patients with renal impairment. Studies have reported NC-MRA sensitivity of 72.8-88.8% and specificity of 95-97.8% for detecting significant stenosis.[6,7]

Given the complementary strengths and limitations of these modalities, we conducted this prospective study to compare Doppler USG and NC-MRA as screening tools for RAS detection and grading, using DSA as the reference standard.

Materials and Methods

Study Design and Setting: This prospective observational study was conducted in the Department of Radiodiagnosis, Bombay Hospital, Indore, India, from 2023 to 2026. Institutional Ethics Committee approval was obtained prior to commencement, and written informed consent was obtained from all participants.

Study Population: Patients referred with clinical suspicion of renovascular hypertension were enrolled based on the following inclusion criteria: onset of hypertension before 30 years or after 50 years of age; moderate to severe hypertension in females aged 10-50 years; hypertension refractory to standard medical therapy; hypertension with abdominal or flank bruit; incidentally detected renal size asymmetry; hypertension with occlusive vascular disease in another territory; or unexplained progressive renal insufficiency.

Exclusion criteria included: refusal of informed consent; previously diagnosed and treated RAS; endocrine causes of secondary hypertension; pregnancy; serum creatinine >1.5 mg/dL; contraindications to MRI (claustrophobia, metallic implants, pacemakers); and bleeding disorders.

Sample Size Calculation: Based on the anticipated diagnostic sensitivity of NC-MRA (78%) from Utsunomiya et al.[8] with 95% confidence interval and 11% absolute precision, the minimum sample size was calculated as 54 patients. Accounting for 5% attrition, 60 patients were enrolled.

Imaging Protocols

Doppler Ultrasonography: Performed using a 3.5-MHz phased-array transducer after adequate fasting. Renal arteries were identified using color flow imaging via a posterior oblique approach. Spectral Doppler waveforms were obtained from segmental arteries at the superior, mid (anterior and posterior), and inferior poles. The angle of insonation was maintained at <60 degrees. Direct criteria included PSV >180 cm/s, RAR >3-3.5, and post-stenotic turbulence. Indirect criteria included pulsus tardus-parvus waveform, acceleration time >0.05-0.08 seconds, and inter-kidney RI difference >0.05-0.07.

Non-Contrast MR Angiography: Performed on a PHILIPS INGENIA CX 3.0 Tesla MRI system with a 16-channel phased-array body coil. Sequences included T1-weighted fat-suppressed, T2-weighted non-fat-suppressed, Time-of-Flight (TOF) MRA, Phase-Contrast (PC) MRA with cardiac gating, and 3D Steady-State Free Precession (SSFP) MRA.

Digital Subtraction Angiography: Served as the reference standard. Significant RAS was defined as luminal narrowing ≥60%.

Statistical Analysis: Statistical analysis was performed using SPSS version 22.0. Categorical variables were summarized as frequencies and percentages, while continuous variables were expressed as mean ± standard deviation. Associations were assessed using Pearson Chi-square test. Diagnostic performance measures including sensitivity, specificity, positive predictive value (PPV), negative predictive value (NPV), accuracy, and Cohen's Kappa were calculated. A p-value <0.05 was considered statistically significant.

Results

Demographic and Clinical Characteristics; The study population comprised 60 patients with mean age 43.40±15.74 years (range: 16-70 years), including 32 males (53.3%) and 28 females (46.7%). The largest age groups were 25-39 years (45.0%) and 55-70 years (33.3%). Mean BMI was 28.15±4.52 kg/m², with 46.7% overweight and 30.0% obese.

All patients (100%) had hypertension (86.7% Stage 2), with 100% receiving antihypertensive medication. Mean serum creatinine was 1.06±0.24 mg/dL (85.0% normal). eGFR showed 46.7% Stage G2 (mildly decreased), 33.3% Stage G3a, and 6.7% Stage G3b. Risk factors included obesity (28.3%), coronary artery disease (23.3%), smoking (16.7%), diabetes mellitus (15.0%), and peripheral artery disease (11.7%).

DSA Findings (Gold Standard): DSA confirmed significant stenosis (≥60%) in the right renal artery of 44 patients (73.3%) and the left renal artery of 29 patients (48.3%). Complete occlusion (Grade 3) was observed in 4 patients (6.7%) on the right side only.

Doppler Ultrasonography Findings: Quantitative Doppler parameters for the right renal artery showed mean PSV of 172.7±53.6 cm/s, RAR of 3.11±1.02, acceleration time of 0.075±0.028 seconds, and intrarenal RI of 0.768±0.034. For the left renal artery, values were PSV 136.2±53.1 cm/s, RAR 2.45±0.97, acceleration time 0.059±0.025 seconds, and RI 0.753±0.025. Qualitative findings suggestive of stenosis were more frequent on the right side: post-stenotic turbulence (66.7% vs 40.0%), spectral broadening (66.7% vs 40.0%), and tardus-parvus waveform (66.7% vs 40.0%).

Diagnostic Performance

Right Renal Artery: Doppler USG demonstrated sensitivity of 62.50% (95% CI: 47.35-76.05%), specificity of 83.33% (95% CI: 51.59-97.91%), PPV of 93.75%, NPV of 35.71%, and accuracy of 66.67% (κ=0.305, fair agreement). NC-MRA showed superior performance: sensitivity 83.33% (95% CI: 69.78-92.52%), specificity 66.67% (95% CI: 34.89-90.08%), PPV 90.91%, NPV 50.00%, accuracy 80.00% (κ=0.444, moderate agreement). The association with DSA was significant for both modalities (Doppler: χ^2=12.811, p=0.046; MRA: χ^2=19.827, p=0.003).

Left Renal Artery: Both modalities demonstrated identical excellent performance: sensitivity 82.76% (95% CI: 64.23-94.15%), specificity 100% (95% CI: 88.78-100%), PPV 100%, NPV 86.11%, accuracy 91.67% (κ=0.832, excellent agreement; χ^2=42.759, p<0.001).

Per-Patient Analysis: NC-MRA showed higher sensitivity (81.48% vs 74.07%) and accuracy (76.67% vs 70.00%) than Doppler USG, though both had low specificity (33.33%).

Table 1: Baseline Characteristics of Study Population (n=60)

Parameter	Value
Age (years), mean±SD	43.40±15.74
Male sex, n(%)	32 (53.3%)
BMI (kg/m²), mean±SD	28.15±4.52
Overweight/Obese, n(%)	46 (76.7%)
Stage 2 Hypertension, n(%)	52 (86.7%)
eGFR Stage G2/G3a/G3b, n(%)	52 (86.7%)
Diabetes Mellitus, n(%)	9 (15.0%)
Coronary Artery Disease, n(%)	14 (23.3%)

Table 2: Diagnostic Performance Summary

Artery	Modality	Sensitivity	Specificity	Accuracy	Kappa
Right	Doppler US	62.50%	83.33%	66.67%	0.305 (Fair)
Right	NC-MRA	83.33%	66.67%	80.00%	0.444 (Moderate)
Left	Doppler US	82.76%	100%	91.67%	0.832 (Excellent)
Left	NC-MRA	82.76%	100%	91.67%	0.832 (Excellent)

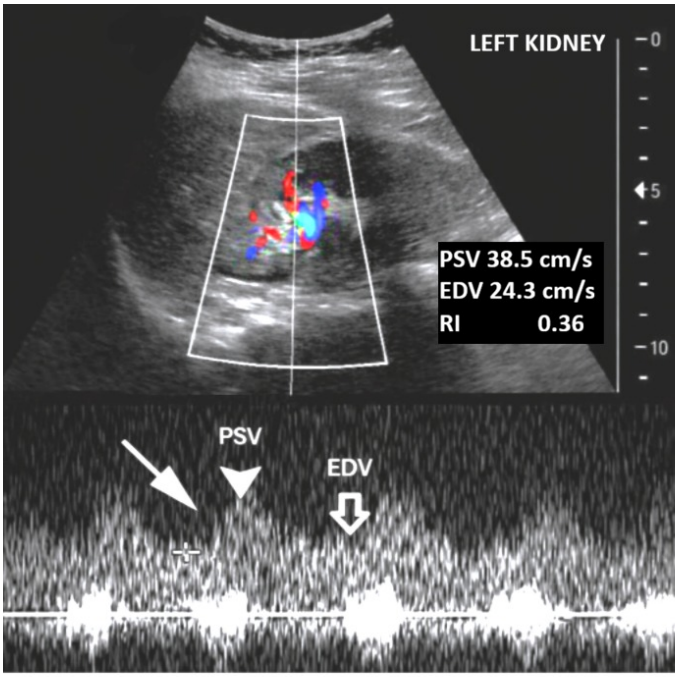

Figure 1: Doppler ultrasound image showing parvus tardus waveform in left superior interlobar artery with RI of 0.36

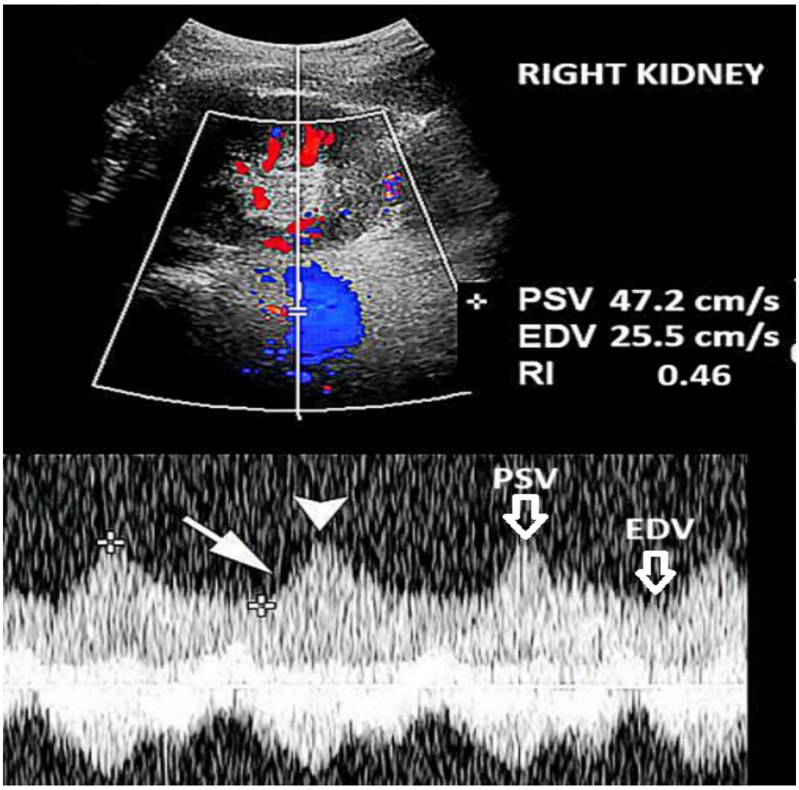

Figure 2: The USG Doppler image shows parvus tardus waveform in right middle interlobar artery and RI value of 0.46.

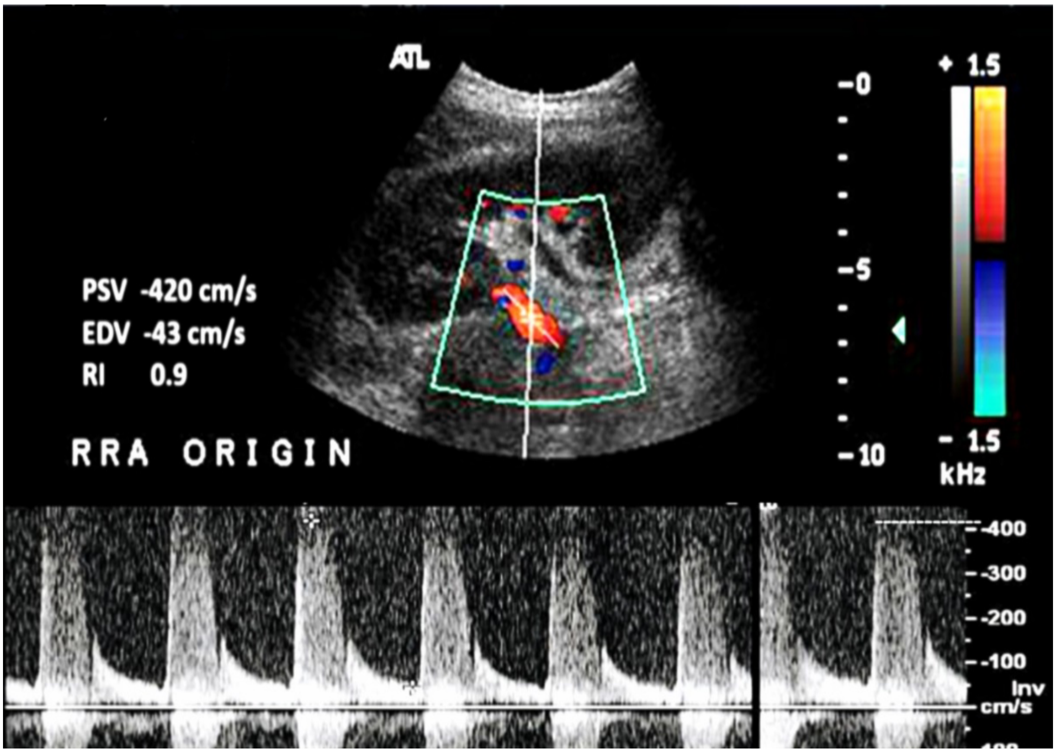

Figure 3: Doppler ultrasound image showing aliasing at right main renal artery origin (PSV 420 cm/s) in a 27-year-old male

Figure 4: Non-contrast MR Angiography showing significant stenosis at right proximal renal artery (approximately 80% luminal narrowing)

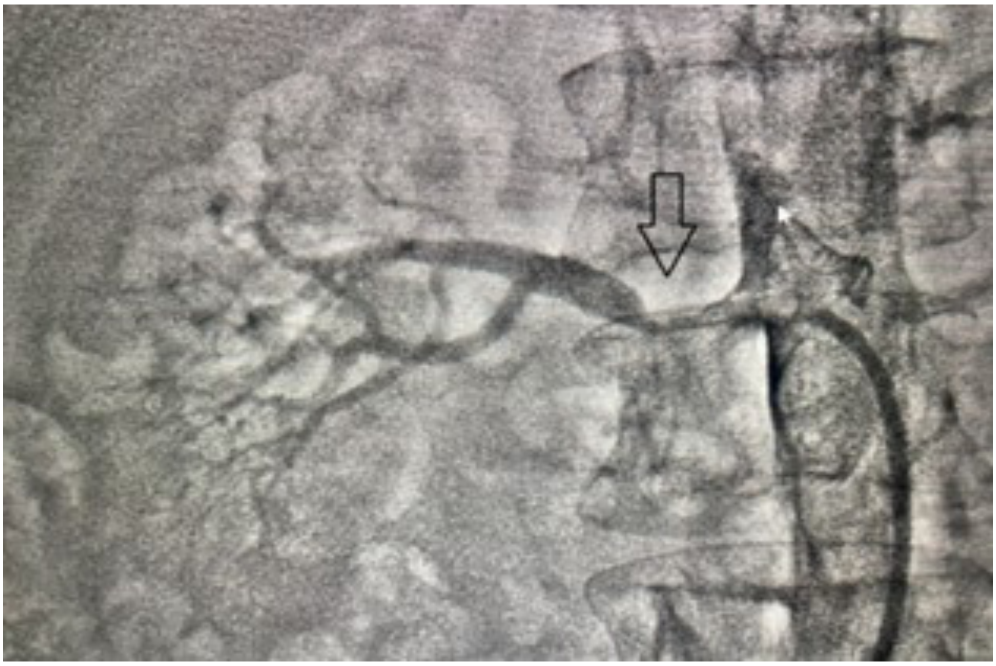

Figure 5: Digital subtraction angiography confirming proximal renal artery stenosis with 75% luminal narrowing

Discussion

This prospective study compared Doppler USG and NC-MRA for RAS detection in 60 patients with suspected renovascular hypertension. Our findings demonstrate that both modalities are valuable non-invasive screening tools, but with important differences in diagnostic performance based on the side evaluated.

Side-to-Side Performance Discrepancy: A striking finding was the marked difference in diagnostic performance between right and left renal arteries. For the right renal artery, Doppler USG sensitivity was only 62.50% compared to 82.76% for the left. This discrepancy likely reflects anatomical challenges: the right renal artery arises from the aorta and passes posterior to the inferior vena cava, often with a more tortuous course, making Doppler interrogation technically difficult. Bowel gas interposition and deeper location may compromise signal acquisition on the right side.[9] NC-MRA showed more consistent performance across both sides (right sensitivity 83.33%, left 82.76%), confirming its advantage in providing complete anatomical assessment regardless of vascular orientation. Saejeung et al.[10] similarly reported that NC-MRA visualized significantly more renal artery segments than color Doppler US ($p<0.0001$) with shorter examination times (21.2 vs 47.5 minutes).

Comparison with Previous Studies: Our Doppler USG results for the left renal artery (sensitivity 82.76%, specificity 100%) compare favorably with published literature. Asif et al.[11] reported sensitivity of 79.4% and specificity of 84.6% in 120 patients using CT angiography as reference. Tassadaq et al.[12] found lower sensitivity (57.1%) and specificity (72.7%), consistent with our right-sided results. The variability across studies underscores the operator-dependent nature of Doppler USG.[13]

For NC-MRA, our findings align with Utsunomiya et al.[8] (sensitivity 78%, specificity 91%) and Sebastia et al.[7] (sensitivity 88.8%, specificity >95%). The slightly lower specificity in our right renal artery (66.67%) may reflect the tendency of MRA to overestimate stenosis severity, a limitation previously noted by Soulez et al.[14]

Lal et al.[15] demonstrated excellent agreement between NC-MRA and contrast-enhanced MRA in 400 renal arteries (κ significant at $p<0.001$), supporting NC-MRA as a viable alternative when gadolinium is contraindicated. This is particularly relevant as 40% of our patients had moderate renal impairment (eGFR <60 mL/min/1.73m²).

Clinical Implications: Our findings support a sequential diagnostic approach. Doppler USG should remain a first-line screening tool, particularly when left-sided disease is suspected or in resource-limited settings. The high PPV (93.75-100%) means a positive Doppler result reliably predicts significant stenosis. However, the low NPV for right renal artery (35.71%) indicates that negative Doppler US on the right does not exclude significant stenosis. NC-MRA should be employed when Doppler results are inconclusive, when right renal artery evaluation is technically challenging, or in patients with high clinical suspicion and negative Doppler findings. The absence of ionizing radiation and contrast agents makes NC-MRA particularly valuable in patients with renal impairment, younger patients, and those requiring serial imaging.

Study Limitations: Limitations include relatively small sample size from a single tertiary care center, potential selection bias, operator-dependent nature of Doppler USG without inter-observer variability assessment, lack of systematic accessory renal artery evaluation, and exclusion of patients with severe renal impairment (creatinine >1.5 mg/dL).

Future Directions: Multicenter studies with standardized protocols are needed to establish robust diagnostic thresholds. Cost-effectiveness analyses comparing sequential vs direct NC-MRA screening strategies would inform evidence-based guidelines. Advances in AI-based image reconstruction and higher field strength MRI may further enhance NC-MRA diagnostic capability.

Conclusion

Non-contrast MR Angiography provides more consistent diagnostic performance across both renal arteries compared to Doppler ultrasonography, with superior sensitivity for right-sided renal artery stenosis where Doppler has significant limitations. Doppler ultrasonography remains valuable for left renal artery evaluation and as a first-line screening tool in resource-limited settings. A sequential approach using Doppler USG initially, followed by NC-MRA for inconclusive or negative high-suspicion cases, particularly for right-sided disease, optimizes non-invasive screening for renal artery stenosis.

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