Section: Radiodiagnosis

Original Research Article

ASSESSMENT OF CENTRAL VEINS IN HEMODIALYSIS PATIENTS USING DOPPLER, MAGNETIC RESONANCE VENOGRAPHY AND DIGITAL SUBTRACTION VENOGRAPHY - A COMPARATIVE STUDY TO DETERMINE THE USEFULNESS OF BEDSIDE DOPPLER IN EXPERT HANDS

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Abstract

Background: CVSD is a major complication in haemodialysis patients, often due to repeated catheterisation. Although DSV is the gold standard, non-invasive alternatives, such as Doppler and MRV, are needed. This study aimed to compare the diagnostic accuracy of these modalities to assess whether expert bedside Doppler can serve as a viable and less invasive alternative. **Materials and Methods:** This prospective observational study included 82 haemodialysis patients from Kanyakumari Govt Medical College and Govt Stanley Hospital, Chennai (2020-2021). Doppler Ultrasonography was used for the initial screening, followed by MRV for suspected stenosis, with DSV as the reference standard. Two radiologists independently assessed the results, and statistical analyses included sensitivity, specificity, PPV, NPV, and Cohen's kappa coefficient. **Result:** MRV showed superior diagnostic accuracy compared with Doppler when validated against DSV. The sensitivity, specificity, PPV, and NPV for MRV were 95.74%, 98.35%, 95.74%, and 98.35%, respectively, whereas Doppler showed values of 88.65%, 95.33%, 88.03%, and 95.59%, respectively. MRV had a stronger agreement with DSV ($\kappa = 0.941$) than with Doppler ($\kappa = 0.838$). Doppler imaging exhibited limitations in assessing the superior vena cava, missing 52.4% of cases, whereas MRV detected 89% of patent veins, aligning closely with the DSV findings. **Conclusion:** CKD is a major health concern in India, and haemodialysis based on CVC increases the risk of CVSD. While MRV is more accurate than Doppler, its cost and limitations make bedside Doppler a reliable alternative in expert hands. This study reinforces the practicality of Doppler ultrasonography as an accessible tool for central vein assessment in haemodialysis patients.

INTRODUCTION

Chronic Kidney Disease (CKD) is a major global health concern, contributing significantly to morbidity and mortality.[1] The prevalence of CKD in India varies across regions, ranging from 1% to 13%, with a recent study by the International Society of Nephrology's Kidney Disease Data Centre reporting an overall prevalence of 17%.[2] In certain states such as Andhra Pradesh, Odisha and Goa, CKD of unknown aetiology (CKDu) has been observed, often manifesting as chronic interstitial nephropathy with an insidious onset and slow progression.[3]

Haemodialysis remains the primary treatment for CKD patients who require renal replacement therapy, necessitating the use of vascular access. Initially, haemodialysis was performed via temporary catheterisation of the subclavian or internal jugular veins before creating an arteriovenous fistula (AVF) or implanting an arteriovenous graft (AVG). Adequate blood flow and proper venous access are crucial for the long-term success of haemodialysis.[4] However, central venous catheterisation (CVC) is associated with significant complications, including haemothorax, pneumothorax, infections, and, most critically, Central Venous Steno-Occlusive Disease (CVSD), which affects 25-40% of haemodialysis patients.[5] CVSD can result in the loss of vascular access, increased venous pressure on dialysis machines leading to dysfunction and arm swelling due to venous hypertension, necessitating prompt diagnosis and management.[6]

The primary cause of CVSD is iatrogenic, often resulting from repeated catheter insertions in the same vein over a prolonged period and recurrent infections at the catheter tip.[7] The accurate diagnosis of central vein stenosis (CVS) is essential for optimal patient management. Various imaging techniques are available for this purpose including Doppler Ultrasonography, Magnetic Resonance Venography (MRV), and Digital Subtraction Venography (DSV). While ultrasonography is a widely used non-invasive technique for detecting thrombosis or stenosis in the internal jugular and subclavian veins, its accuracy in assessing brachiocephalic veins and the superior vena cava (SVC) is limited.[8]

MRV, using contrast and non-contrast techniques, offers superior morphological details, enabling precise assessment of lesion length and severity.[9] Additionally, contrast-enhanced MRV using safer agents like Gadoterate meglumine (Dotarem) minimises the risk of nephrogenic systemic fibrosis (NSF) in patients with renal impairment.[10] DSV, although considered the gold standard for diagnosing CVSD, is invasive and associated with risks such as contrast-induced nephropathy, thrombosis, and hypersensitivity reactions.[11]

Given the limitations of these methods, there is a growing need to explore the role of bedside Doppler ultrasonography, particularly by experts, as a reliable, non-invasive, and accessible alternative for detecting CVSD. Although DSV remains the reference standard, when performed by experienced practitioners, Doppler ultrasonography may provide real-time functional assessments with minimal risk.

Aim

This study aimed to compare the diagnostic accuracy of Doppler Ultrasonography, MRV, and DSV in assessing central veins in haemodialysis patients to determine whether bedside Doppler, in expert hands, can serve as a viable alternative to more invasive and expensive imaging techniques.

MATERIALS AND METHODS

This prospective observational study included 82 patients at Kanyakumari Govt Medical College, Asaripallam and Govt Stanley Hospital, Chennai, who underwent haemodialysis between January 2020 and June 2021 (one year and six months). The Institutional Ethics Committee approved this study before initiation, and informed consent was obtained from all patients.

Inclusion criteria

Patients with all-stage renal disease who required haemodialysis with a central venous catheter were included.

Exclusion criteria

Patients with contraindications for MRI, such as those with implanted electric and electronic devices, heart pacemakers, hearing aids, intracranial metal chips, and metallic bodies in the eye, were excluded.

Methods

Patients undergoing routine vascular access assessment were enrolled and their demographic data, clinical complaints, and signs of vascular dysfunction were recorded. Doppler ultrasonography (Samsung Accuvix XG) was the initial screening tool used to assess vascular patency, stenosis, and thrombosis. The subclavian, brachiocephalic, and SVC veins were examined in the supine position with a 5 MHz probe used for overweight patients or severe oedema cases.

Suspected stenosis was further evaluated using 3D phase-contrast MRV (1.5T Siemens MAGNETOM AMIRA), covering the thoracic inlet to the diaphragm. Image reconstruction included MIP and MPR. Confirmed central venous stenosis or occlusion was assessed using DSV (Siemens Artis Zee Biplane), the gold standard. Contrast-enhanced venography was performed using 50 mL iodinated contrast (Omnipaque 300) with alternative administration via an arteriovenous fistula in difficult cases. Patients were monitored for 24 h post-examination and followed up for three months. Two independent radiologists (with 15 and 10 years of experience) interpreted the results separately and were blinded to the other modalities.

Statistical analysis

The distribution of outcomes for individual veins, including the right IJV, SCV, and BCV and left IJV, SCV, BCV and SVC, was analysed using Doppler ultrasonography, phase-contrast MRV and DSV. The frequencies and percentages of the findings across modalities were tabulated. The diagnostic concordance between Doppler, MRV and DSV was assessed, and the degree of agreement was evaluated using Cohen's kappa coefficient (κ) with a 95% CI. The sensitivity, specificity, PPV, NPV and overall diagnostic accuracy were calculated for Doppler ultrasonography and MRV using DSV as the gold standard. Statistical significance was set at $p < 0.05$. Statistical analyses were performed using the SPSS software version 23.

RESULTS

MRV showed superior diagnostic accuracy compared to Doppler when validated against DSV across all evaluated veins. In the right internal jugular vein, Doppler identified 51 (62.2%) patent veins, while MRV and DSV identified 58.5%, with identical stenosis and occlusion rates. Despite a slightly lower patent detection rate, MRV outperformed Doppler in terms of accuracy. The right subclavian vein showed minor stenosis discrepancies; however, MRV and DSV were in complete agreement.

For the right brachiocephalic vein, Doppler detected 62 (75.6%) patent veins versus 59 (72%) veins by MRV and DSV, although the stenosis and occlusion rates were consistent. In the left internal jugular and left subclavian veins, Doppler overestimates occlusion and patent veins, respectively, whereas MRV aligns better with the DSV. A slight variation in occlusion rates was noted for the left brachiocephalic vein, but the MRV still showed a higher precision.

The most significant discrepancy occurred in the superior vena cava, where Doppler failed to visualise 43 (52.4%) veins, whereas MRV detected 89% patent veins, aligning perfectly with DSV [Table 1].

Table 1: Venous assessment by Doppler, MRV and DSV.

Vein		Doppler	MRV	DSV
Right internal jugular	Patent	51 (62.2%)	48 (58.5%)	48 (58.5%)
	Stenosis	11 (13.4%)	11 (13.4%)	11 (13.4%)
	Occlusion	20 (24.4%)	20 (24.4%)	20 (24.4%)
	Not done	0	3 (3.7%)	3 (3.7%)
Right subclavian	Patent	66 (81.7%)	64 (78%)	64 (78%)
	Stenosis	7 (7.3%)	6 (7.3%)	6 (7.3%)
	Occlusion	9 (11%)	9 (11%)	9 (11%)
	Not done	0	3 (3.7%)	3 (3.7%)
Right brachiocephalic	Patent	62 (75.6%)	59 (72%)	59 (72%)
	Stenosis	11 (13.4%)	11 (13.4%)	11 (13.4%)
	Occlusion	9 (11%)	9 (11%)	9 (11%)
	Not done	0	3 (3.7%)	3 (3.7%)
Left internal jugular	Patent	51 (63.4%)	49 (59.8%)	49 (59.8%)
	Stenosis	21 (25.6%)	21 (25.6%)	21 (25.6%)
	Occlusion	10 (11%)	9 (11%)	9 (11%)
	Not done	0	3 (3.7%)	3 (3.7%)
Left subclavian	Patent	61 (74.4%)	58 (70.7%)	58 (70.7%)
	Stenosis	15 (18.3%)	15 (18.3%)	15 (18.3%)
	Occlusion	6 (7.3%)	6 (7.3%)	6 (7.3%)
	Not done	0	3 (3.7%)	3 (3.7%)
Left brachiocephalic	Patent	62 (75.6%)	59 (72%)	58 (72%)
	Stenosis	14 (17.1%)	14 (17.1%)	14 (17.1%)
	Occlusion	6 (7.3%)	6 (7.3%)	7 (7.3%)
	Not done	0	3 (3.7%)	3 (3.7%)
Superior vena cava	Patent	35 (42.7%)	73 (89%)	73 (89%)
	Stenosis	1 (1.2%)	3 (3.7%)	3 (3.7%)
	Occlusion	3 (3.7%)	3 (3.7%)	3 (3.7%)
	Not done	43 (52.4%)	3 (3.7%)	3 (3.7%)
All	Patent	388 (67.5%)	410 (71.4%)	409 (71.2%)
	Stenosis	80 (13.9%)	81 (14.1%)	81 (14.1%)
	Occlusion	63 (10.9%)	62 (10.8%)	63 (10.9%)
	Not done	43 (7.2%)	21 (3.6%)	21 (3.6%)

MRV consistently showed superior accuracy compared with Doppler when compared with DSV. For the right internal jugular vein, MRV identified steno-occlusive disease in 30 (96.8%) patients compared with 28 (90.3%) patients by Doppler, with MRV showing almost complete agreement with DSV. The right subclavian vein followed a similar pattern, with MRV detecting 14 (93.3%) compared to Doppler 13 (86.7%), further emphasising MRV's diagnostic superiority of MRV.

In the right brachiocephalic vein, MRV identified steno-occlusive disease in 19 (95%) patients compared to 18 (90%) by Doppler, showing a stronger alignment with DSV results. The left internal jugular vein demonstrated the highest reliability for MRV, with perfect 100% agreement with DSV, whereas Doppler identified 28 (93.3%). Similarly, in the left subclavian vein, MRV was detected in 19 (90.5%) patients compared to 17 (81%) patients by Doppler imaging, reaffirming MRV's superior diagnostic accuracy.

For the left brachiocephalic vein, MRV identified 19 (95%) steno-occlusive diseases compared to Doppler 18 (90%), further proving the MRV's higher reliability. The superior vena cava showed that MRV achieved a perfect match with DSV, identifying all four cases (100%) accurately, whereas Doppler detected three cases (75%) [Table 2].

Table 2: Comparison of steno occlusive disease and patency in major veins using Doppler, MRV and DSV

Vein		Doppler and DSV	MRV and DSV
Right internal jugular	Steno occlusive disease	28 (90.3%)	30 (96.8%)
	Patent	3 (9.7%)	1 (3.2%)
Right subclavian	Steno occlusive disease	13 (86.7%)	14 (93.3%)
	Patent	2 (13.3%)	1 (6.7%)
Right brachiocephalic	Steno occlusive disease	18 (90%)	19 (95%)
	Patent	2 (10%)	1 (5%)

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Left internal jugular	Steno occlusive disease	28 (93.3%)	30 (100%)
	Patent	2 (6.7%)	-
Left subclavian	Steno occlusive disease	17 (81%)	19 (90.5%)
	Patent	4 (19%)	2 (9.5%)
Left brachiocephalic	Steno occlusive disease	18 (90%)	19 (95%)
	Patent	2 (10%)	1 (5%)
Superior vena cava	Steno occlusive disease	3 (75%)	4 (100%)
	Patent	1 (25%)	-
All	Steno occlusive disease	125 (88.7%)	135 (95.7%)
	Patent	16 (11.3%)	6 (4.3%)

MRV showed stronger agreement with DSV than Doppler, emphasising its higher diagnostic accuracy. For the right internal jugular vein, MRV had a kappa value of 0.946 compared with Doppler 0.839, both with $p < 0.05$. Similarly, in the right subclavian vein, MRV again showed superior agreement with DSV (K = 0.917) compared to Doppler (K = 0.799), indicating enhanced reliability. In the right brachiocephalic vein, both Doppler (K = 0.866) and MRV (K = 0.933) showed a strong agreement with DSV and MRV showing a higher level of concordance.

For the left internal jugular vein, MRV had the highest agreement with DSV (K = 0.973), significantly outperforming Doppler (K = 0.865), and confirming MRV's superior diagnostic performance. Similarly, in the left subclavian vein, MRV provided significantly better agreement (K = 0.901) with DSV than Doppler (K = 0.768). The left brachiocephalic vein followed the same pattern, where MRV (K = 0.933) showed higher agreement with DSV than Doppler (K = 0.866), emphasising MRV's superiority.

In the superior vena cava, MRV achieved perfect agreement with DSV (K = 1), confirming its exceptional accuracy, whereas Doppler imaging showed lower agreement (K = 0.72) [Table 3].

Table 3: Comparison of Doppler, MRV and DSV for vein assessment

Vein	Comparison	K value	P-value
Right internal jugular	Doppler vs DSV	0.839	<0.05
	MRV vs DSV	0.946	<0.05
Right subclavian	Doppler vs DSV	0.799	<0.05
	MRV vs DSV	0.917	<0.05
Right brachiocephalic	Doppler vs DSV	0.866	<0.05
	MRV vs DSV	0.933	<0.05
Left internal jugular	Doppler vs DSV	0.865	<0.05
	MRV vs DSV	0.973	<0.05
Left subclavian	Doppler vs DSV	0.768	<0.05
	MRV vs DSV	0.901	<0.05
Left brachiocephalic	Doppler vs DSV	0.866	<0.05
	MRV vs DSV	0.933	<0.05
Superior vena cava	Doppler vs DSV	0.72	<0.05
	MRV vs DSV	1	<0.05
All	Doppler vs DSV	0.838	<0.05
	MRV vs DSV	0.941	<0.05

Across all examined veins, MRV performed better than Doppler when compared to DSV. For the right internal jugular vein, MRV showed higher sensitivity (96.77%) than Doppler (90.32%), while both had the same specificity (97.87%). MRV also had a better overall accuracy (97.44%) than Doppler (96.15%). In the right subclavian vein, MRV outperformed Doppler in terms of sensitivity (93.33% vs. 86.67%) and accuracy (97.44% vs. 93.59%), confirming its superior diagnostic capability. Similarly, for the right brachiocephalic vein, MRV demonstrated higher sensitivity (95%) and accuracy (97.44%) than Doppler’s 90% sensitivity and 94.87% accuracy. [Table 4].

Table 4: Comparison of Doppler and MRV with DSV for vein evaluation

Vein		Doppler vs DSV	MRV vs DSV
Right internal jugular	Sensitivity	90.32	96.77
	Specificity	97.87	97.87
	PPV	96.67	96.77
	NPV	95.83	97.87
	Accuracy	96.15	97.44
Right subclavian	Sensitivity	86.67	93.33
	Specificity	95.24	98.41
	PPV	81.25	93.33
	NPV	96.77	98.41
	Accuracy	93.59	97.44
Right brachiocephalic	Sensitivity	90	95
	Specificity	96.55	98.28
	PPV	90	95
	NPV	96.55	98.28

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	Accuracy	94.87	97.44

The left internal jugular vein showed the best performance for MRV, with 100% sensitivity and 98.72% accuracy, compared to Doppler's 93.33% sensitivity and 93.59% accuracy. In the left subclavian vein, MRV had better specificity (98.25% vs. 94.74%) and sensitivity (90.48% vs. 80.95%), making it more reliable. The left brachiocephalic vein, with MRV showing better accuracy (97.44% vs. 94.87%). For the superior vena cava, MRV had a perfect agreement with DSV, achieving 100% accuracy, whereas Doppler had a lower sensitivity (75%) and accuracy (94.59%). Overall, MRV was consistently better than Doppler across all veins, with a sensitivity of 95.74% compared with Doppler at 88.65%. It also had higher specificity (98.35% vs. 95.33%) and better accuracy (97.62% vs. 93.47%) [Table 5].

Table 5: Comparison of Doppler, MRV and DSV for detecting central vein blockages

Vein		Doppler vs DSV	MRV vs DSV
Left internal jugular	Sensitivity	93.33	100
	Specificity	93.75	97.92
	PPV	90.32	96.77
	NPV	95.74	100
	Accuracy	93.59	98.72
Left subclavian	Sensitivity	80.95	90.48
	Specificity	94.74	98.25
	PPV	85	95
	NPV	93.1	96.55
	Accuracy	91.03	96.15
Left brachiocephalic	Sensitivity	90	95
	Specificity	96.55	98.28
	PPV	90	95
	NPV	96.55	98.28
	Accuracy	94.87	97.44
Superior vena cava	Sensitivity	75	100
	Specificity	96.97	100
	PPV	75	100
	NPV	96.97	100
	Accuracy	94.59	100
All	Sensitivity	88.65	95.74
	Specificity	95.33	98.35
	PPV	88.03	95.74
	NPV	95.59	98.35
	Accuracy	93.47	97.62

DISCUSSION

Our study assessed the efficacy of Doppler, MRV, and DSV in diagnosing steno-occlusive disease of the veins. The results showed comparable performances among these imaging modalities, with slight variations in sensitivity and specificity. Specifically, Doppler identified 80 (13.9%) stenosed and 63 (10.9%) occluded veins, while MRV identified 81 (14.1%) stenosed and 62 (10.8%) occluded veins. Alternatively, DSV showed similar findings, with 81 (14.1%) stenosed and 63 (10.9%) occluded veins. Overall, the diagnosis of steno-occlusive disease was consistent across all three modalities, with 142 (28.1%) identified by Doppler and 141 (27.9%) by both MRV and DSV.

The understanding of MRV and DSV was stronger than that of MRV and Doppler, emphasising MRV's superior diagnostic performance in terms of sensitivity, specificity, PPV, NPV, and overall accuracy. This aligned with Kaya et al. and Subramaniam et al., which emphasised the enhanced diagnostic capabilities of MRV over Doppler for vascular conditions.[12,13] MRV's improved sensitivity and specificity in detecting venous abnormalities were also emphasised by Zhuang et al,[14] further supporting its role in providing detailed and accurate anatomical information. However, Doppler remains a valuable and reliable tool for initial assessment, particularly by experts. This is in line with the findings of Richarz et al., who emphasised the importance of Doppler as the first-line imaging modality for dialysis access assessment because of its accessibility, non-invasiveness, and effectiveness.[15] Furthermore, He et al. found comparable results between Doppler ultrasonography and PC-MRI in measuring blood flow in AV fistulas, supporting the reliability of Doppler in assessing vascular conditions. However, in more complex cases or when detailed anatomical visualisation is critical, MRV and DSV may offer reliable results.[16]

In practical applications, our study also emphasised the advantages of PC-MRV as a non-invasive alternative for patients with renal impairment, eliminating the need for contrast agents. While Elkins et al. and Layer et al. noted limitations, such as long scan times and lower image quality in partially occluded segments, our study found that a notably shorter 3D PC-MRV duration (2 min 43 s) enhanced its practicality. This shorter duration addresses some of the challenges identified in earlier studies, improving the technique's feasibility for clinical use.[17,18]

DSV continues to be regarded as the gold standard for venous imaging despite some procedural challenges, such as the complications arising from dye dilution during internal jugular vein cannulation, as noted in our study and similar work by Kroencke et al. While DSV remains the definitive method for assessing venous pathologies, our findings suggest that both MRV and DU can offer reliable alternatives in appropriate clinical contexts, with MRV showing superior accuracy for detailed anatomical evaluations.[9]

Our study's comparison of the sensitivity, specificity, PPV and NPV between Doppler ultrasonography and DSV further supports these conclusions. We found that Doppler demonstrated 88.65% sensitivity, 95.33% specificity, 88.03% PPV and 95.59% NPV, which aligns closely with the results of Passman et al. and Baxter et al. Variations in the accuracy of ultrasonography can be attributed to factors such as operator expertise, patient anatomy, vein location, and degree of stenosis.[19,20]

In particular, the sensitivity for detecting stenosis in the subclavian and brachiocephalic veins was 80.95% and 90%, respectively, which is consistent with the findings of Rad et al.[21] Our study also confirmed that Doppler ultrasonography remains highly reliable for evaluating veins, such as the internal jugular, subclavian and brachiocephalic veins, especially when performed by skilled practitioners. In line with Osman et al,[22] we found that venous abnormalities such as central venous stenosis can occur without prior instrumentation due to factors such as extrinsic compression, anatomical variations, or haemodynamic stress and not just from previous vascular interventions. Although Doppler ultrasonography remains a valuable, non-invasive tool for initial screening, MRV and DSV offer superior accuracy and detailed anatomical information, particularly in complex or challenging cases. These results are consistent with previous studies, such as those by Atwan et al. and Ding et al., which emphasised the utility of MRV and DSV in providing comprehensive vascular assessments.[23,24]

Limitations

We did not account for catheter dwell time or prior procedural history, both of which may influence stenosis development. The dual-center design limits generalizability, as the sample may not reflect the broader population of dialysis patients. Stenosis assessment relied on visual estimation; a method susceptible to subjectivity. Additionally, the pelvic and abdominal veins were not evaluated, and critical regions were omitted for comprehensive vascular analysis. These limitations may affect the reliability and external validity of our findings.

CONCLUSION

CKD is a major health concern in India, with haemodialysis serving as a crucial renal replacement therapy despite transplant limitations. CVC, which is essential for haemodialysis, poses a risk for CVSD. Although DSV remains the gold standard for diagnosis, its invasive nature, contrast-related risks and radiation exposure limit its use. This study highlights that MRV using 3D non-contrast PC sequences is more diagnostically accurate than Doppler imaging for detecting CVSD. However, MRV is costly, artefact-prone and challenging for critically ill non-ambulatory patients. In expert hands, bedside Doppler has proven to be a reliable alternative, with statistical accuracy comparable to that of MRV. Despite Doppler's limitations in imaging the SVC, using an endocavitary probe improves the visualisation of the proximal SVC. Thus, this study reinforces the practicality of bedside Doppler as a valuable and accessible tool for assessing the central veins in haemodialysis patients with CVC.

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