Section: Radiodiagnosis

Original Research Article

THE ROLE OF SHEAR WAVE ELASTOGRAPHY AND RENAL ARTERY DOPPLER IN PATIENTS WITH DIABETIC NEPHROPATHY

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ABSTRACT

Background: Diabetic nephropathy (DN) is the leading cause of end-stage renal disease worldwide, and imaging biomarkers that permit earlier, non-invasive detection are needed. This study evaluated the diagnostic utility of renal shear wave elastography (SWE) and renal artery Doppler ultrasound in patients with diabetic nephropathy and correlated these imaging parameters with clinical and biochemical markers of disease severity. **Materials and Methods:** A cross-sectional study was conducted in the Department of Radiodiagnosis, Government Rajaji Hospital, Madurai. Seventy-six patients with established type 2 diabetes mellitus and diabetic nephropathy underwent grey-scale renal ultrasound, Doppler assessment of the intrarenal resistive index (RI), and shear wave elastography (SWE, in KPa) of both kidneys. Imaging parameters were correlated with protein-creatinine ratio (PCR), estimated glomerular filtration rate (eGFR), and glycated haemoglobin (HbA1c), and diagnostic performance was assessed using receiver operating characteristic (ROC) curve analysis. **Results:** The mean age of participants was 50.5≠9.7 years, and 72.4% were male, with a mean diabetes duration of 9.9≠2.6 years. The mean intrarenal RI was 0.72≠0.03 bilaterally, and mean renal stiffness was 30.6≠7.3 KPa (right) and 30.3≠7.4 KPa (left). Both RI and SWE correlated significantly with PCR, eGFR, and HbA1c ($p<0.05$ for all), with SWE showing consistently stronger correlations than RI (e.g., HbA1c: $r=0.793$ vs $r=0.627$ for the right kidney, $p<0.001$). On ROC analysis using PCR and eGFR as reference standards, SWE showed better discrimination (AUC 0.731–0.785) than RI (AUC 0.568–0.598). Renal stiffness, but not RI, differed significantly between patients stratified by PCR and eGFR severity categories ($p<0.05$). **Conclusion:** Renal SWE correlates more strongly with biochemical markers of diabetic nephropathy severity and provides better diagnostic discrimination than Doppler RI. SWE may serve as a useful non-invasive, radiation-free adjunct imaging biomarker for the assessment of diabetic nephropathy, with the present study contributing normative and cut-off data for a South Indian population using the Esaote MyLabX8 eXP system.

INTRODUCTION

Diabetes mellitus (DM) is one of the most prevalent non-communicable diseases of the modern era, carrying with it a formidable burden of systemic microvascular and macrovascular complications. Among these, diabetic nephropathy (DN) stands as the single most common cause of end-stage renal disease (ESRD) worldwide, accounting for approximately 30–40% of all patients requiring renal replacement therapy.[1]

The diagnosis of DN has historically depended on laboratory parameters—most notably urinary albumin excretion and the albumin-to-creatinine ratio—together with serum creatinine and estimated GFR (eGFR). However, these biochemical markers carry well-recognised limitations. Microalbuminuria is neither sensitive nor specific for DN; it may be transiently elevated by urinary tract infections, vigorous exercise, fever, uncontrolled hypertension, and heart failure, necessitating serial testing to confirm the diagnosis.[2] Furthermore, normoalbuminuric nephropathy—in which eGFR declines without significant albuminuria—has been increasingly recognised, particularly in women, meaning that a substantial proportion of DN patients may be missed by albumin-based screening alone.[3] Renal biopsy, the gold standard for histological

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characterisation of disease, is invasive and carries risks of haemorrhage, arteriovenous fistula formation, and perinephric haematoma, rendering it impractical as a routine or serial diagnostic tool.[4] Together, these limitations create a clinical imperative for reliable, non-invasive, radiation-free imaging techniques capable of detecting and monitoring DN from its earliest stages.

Ultrasonography has long occupied a central role in renal evaluation, but conventional grey-scale ultrasound is of limited value in early DN. Progressive diminution in renal size and increase in cortical echogenicity are recognised features of advanced renal disease, yet these changes become definitively apparent only in stage IV chronic kidney disease (CKD) and correlate more with tubular atrophy and interstitial inflammation than with the interstitial fibrosis that is pathologically dominant in DN.[5] The diagnostic window afforded by grey-scale ultrasound therefore opens too late to influence early management decisions. Two advanced ultrasonographic techniques - renal artery Doppler with resistive index measurement, and shear wave elastography - have emerged as promising non-invasive tools that probe the haemodynamic and biomechanical consequences of DN at stages when biochemical markers may still be within normal limits or only marginally elevated.

Aim

To compare the diagnostic accuracy of renal shear wave elastography and renal artery Doppler ultrasound in early detection and assessing the severity of diabetic nephropathy.

MATERIALS AND METHODS

The study was conducted as a cross sectional study in Department of Radiodiagnosis, Government Rajaji Hospital and Madurai Medical College, Madurai over a period of 12 months after obtaining Institutional Ethical committee clearance. Sample size was 76 patients. Inclusion criteria were diabetes mellitus patients diagnosed with diabetic nephropathy, age group between 18 to 61 years, spot urine protein creatinine ratio>30mg/gm, reduced kidney glomerular filtration rate as assessed by eGFR. Exclusion criteria were age group lesser than 18 and greater than 61 years, patients with severe co-morbid conditions affecting renal function, renal artery stenosis, hydronephrosis, renal stones, polycystic kidney disease, morbid obesity, pregnant women and respiratory problems.

This study was performed using an ultrasound machine (Esaote's MyLabX8 eXP) with a curvilinear probe for colour doppler sonography and shear wave elastography. The patient positioned properly (supine, prone, lateral decubitus) in order to get best view and both kidney size obtained in its maximum length and width. Colour doppler was done first at each renal pole and doppler values viz. PSV, EDV and RI were calculated. Then, shear wave elastography was done at each pole excluding the medullary pyramid to obtain stiffness value in kilopascal (kPa).

RESULTS

Demographics and baseline: Age ranged from 19–61 years, mean±SD 50.5±9.7 years. Men accounted for 72.4% (n=55) and women 27.6% (n=21). Duration of diabetes ranged from 3–16 years, mean 9.9±2.6 years. All 76 participants had increased renal cortical echogenicity; 40.8% had maintained corticomedullary differentiation (CMD) while CMD was lost in 59.2%. PCR ranged 406.9–12023.8 (mean 4511.7±3439.2), with 82.9% having PCR≥500. eGFR ranged 65–101 ml/min/1.73 m2 (mean 83.1±7.8 ml/min/1.73 m2), with 82.9% in the 60–89 range. HbA1c ranged 5.8–10.8% (mean 7.9±0.9%). Mean RI was 0.72±0.03 for both kidneys; mean renal stiffness was 30.6±7.3 kPa (right) and 30.3±7.4 kPa (left). Correlations: RI correlated significantly with PCR, eGFR and HbA1c bilaterally ($p \leq 0.001$ for most). Renal stiffness (KPa) showed consistently stronger correlations than RI with the same parameters. Diagnostic performance: On ROC analysis using PCR as the reference standard, kidney stiffness showed the best discrimination (AUC 0.785), compared to kidney RI (AUC 0.568). Similar findings were observed using eGFR as the reference standard (kidney stiffness AUC 0.785 vs kidney RI AUC 0.568).

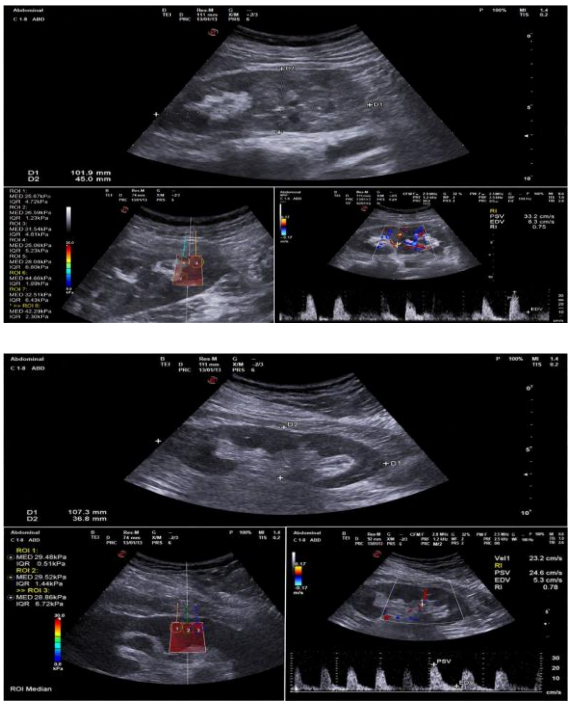

Figure 1: Case 1: Right and left kidney of a 58 year old male with type 2 diabetes mellitus for 10 years and EGFR 79mL/min/1.73m² showing increased renal echogenicity, poor differentiation of CMD, Increased resistive index and stiffness

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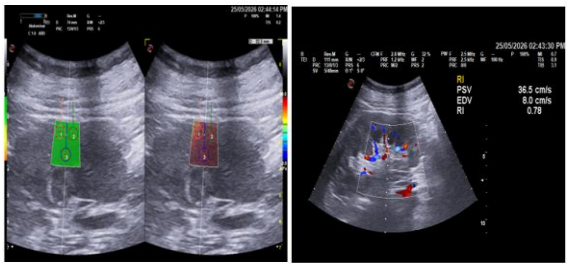

Figure 2: Case 2: A 39-year-old male patient with a history of diabetes for 9 years, and had presented with proteinuria and serum creatinine 1.8 mg/dl. SWE image showing a mean stiffness value of the kidney was 46.12 KPa. Colour duplex image is shows mean RI of 0.78.

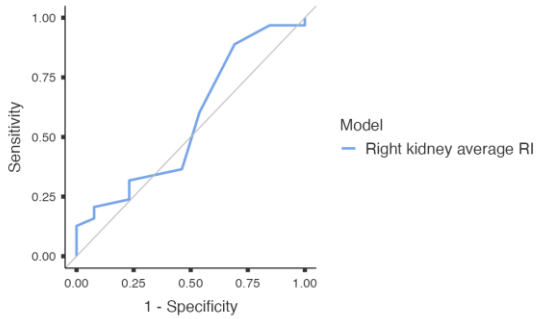

Figure 3: ROC curve of right kidney average resistive index (RI) for prediction of reduced eGFR

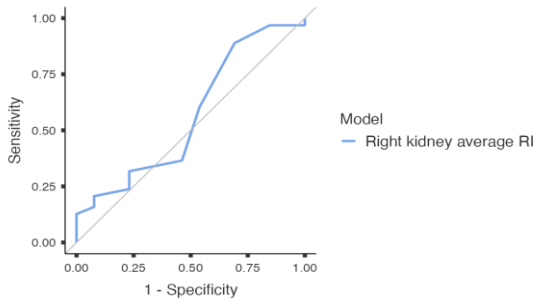

Figure 4: ROC curve of right kidney average stiffness (KPa) for prediction of reduced eGFR

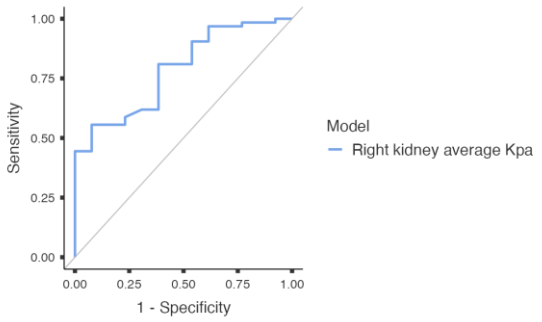

Figure 5: Comparison of RI and KPa values between participants stratified by PCR and eGFR categories

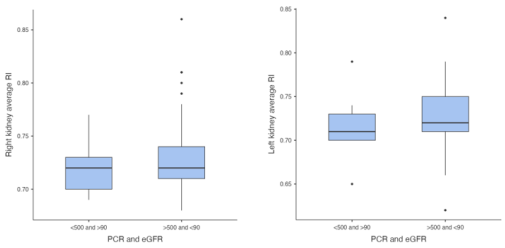

Figure 6: Comparison of average resistive index (RI) between participants stratified by PCR and eGFR categories

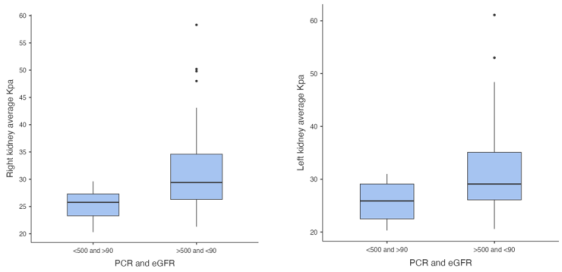

Figure 7: Comparison of average stiffness (KPa) between participants stratified by PCR and eGFR categories

Table 1: Distribution of participants according to categorised PCR and eGFR

Variable	Category	Frequency	Percentage
PCR	</=500	13	17.1
	>500	63	82.9
eGFR	>90	13	17.1
	60-89	63	82.9

Table 2: Diagnostic performance (ROC curve analysis) of RI and KPa using PCR as the reference standard

Variable	Optimal cut-off	AUC	Sensitivity at cut-off	Specificity at cut-off
Right kidney average RI	0.7050	0.568	88.9	30.8
Left kidney average RI	0.7150	0.598	66.7	53.8
Right kidney average KPa	28.7550	0.785	55.6	92.3
Left kidney average KPa	31.100	0.731	44.4	100

Table 3: Comparison of RI and KPa values between participants stratified by PCR and eGFR categories

Variable	PCR <500 and eGFR >90	PCR>500 and eGFR <90	p-value
Right kidney average RI	0.72 (0.70-0.74)	0.72 (0.71-0.74)	0.437
Left kidney average RI	0.71 (0.70-0.74)	0.72 (0.71-0.75)	0.263
Right kidney average KPa	25.8 (22.7-27.9)	29.4 (26.3-34.6)	0.001
Left kidney average KPa	25.9 (22.4-29.5)	29.1 (26.1-35.1)	0.009

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DISCUSSION

Diabetes mellitus and its complications contributes to a disproportionately large share of disease burden in India. With over 77 million individuals diagnosed with DM, India is home to the second largest diabetic population on the planet, and the prevalence of DN among Indian type 2 diabetics has been estimated to range from 5–9% in older community-based studies, with more recent investigations suggesting figures that may exceed 26% depending on the diagnostic criteria and population studied. [6,7]

Diabetic nephropathy is defined by persistent albuminuria exceeding 300 mg per day or 200 µg per minute on at least two occasions three to six months apart, in conjunction with a progressive reduction in the glomerular filtration rate (GFR).[8] The early stage of microalbuminuria, characterised by 30–300 mg of albumin in a 24-hour urine collection, is the most clinically actionable phase, as intervention at this point can meaningfully alter the trajectory of renal decline. This microalbuminuric phase may persist for five to fifteen years before overt proteinuria develops, and during this window, the kidneys undergo progressive histopathological changes including glomerular basement membrane thickening, mesangial expansion, tubular hypertrophy, and incipient interstitial fibrosis—changes that alter both the mechanical stiffness and the haemodynamic properties of the renal parenchyma well before they become apparent on conventional imaging.[8] The present study was undertaken to evaluate the diagnostic utility of renal shear wave elastography (SWE) and renal artery Doppler ultrasound to detect DN at this early stage when biochemical markers may still be within normal limits or only marginally elevated.

Intrarenal resistive index (RI), derived from spectral Doppler waveform analysis of interlobar renal arteries, is defined as the ratio of peak systolic velocity minus end-diastolic velocity to peak systolic velocity. It reflects the downstream vascular resistance within the renal parenchyma and has been shown to correlate with interstitial fibrosis, arteriolar sclerosis, and focal fibrosis—all of which are prominent in DN.[9] Studies have consistently demonstrated that RI is elevated in DN patients compared to healthy controls, increases progressively with advancing CKD stage, and carries independent prognostic significance for renal function deterioration.[10,11]

Shear wave elastography (SWE) is a more recently developed ultrasonographic technique that quantitatively estimates the mechanical stiffness of soft tissues. The technique operates on the principle that focused acoustic radiation force impulses generate transverse shear waves whose propagation velocity through tissue is directly proportional to tissue stiffness; stiffer tissues transmit these waves at higher velocities. The resultant shear wave velocity is converted by the scanner software into an elastic modulus expressed in kilopascal (KPa).[12] In the context of renal disease, SWE measures cortical stiffness, which reflects the cumulative mechanical consequences of fibrosis, hypertrophy, and parenchymal architectural disruption. The characteristic pattern of SWE changes across the stages of DN reflects the complex and evolving histopathological milieu of the disease. In early stages (stages I–II), glomerular and tubular hypertrophy produce an increase in tissue stiffness, yielding elevated SWE values relative to healthy controls. In advanced stages (stages III–V), progressive glomerulosclerosis, tubular atrophy, and end-stage parenchymal contraction reduce tissue stiffness, resulting in a biphasic curve with peak values at stage II and a decline thereafter.[10]

Demographic and Clinical Characteristics of the Study Population: The study cohort comprised 76 patients with a mean age of 50.5 ± 9.7 years, ranging from 19 to 61 years. The duration of diabetes in our participants ranged from 3 to 16 years, with a mean of 9.9 ± 2.6 years. This duration is clinically significant, as the risk of developing nephropathy increases substantially after 5-10 years of diabetes. The median duration of 10 years (IQR 8-12 years) suggests that most of our patients were in the critical window where early detection of nephropathy could meaningfully alter clinical management.

The PCR ranged widely from 406.9 to 12023.8, with a mean of 4511.7 ± 3439.2, and 82.9% of patients had PCR ≥500, indicating significant proteinuria consistent with established nephropathy. The eGFR values ranged from 65 to 101 ml/min/1.73m², with a mean of 83.1 ± 7.8, placing most patients in CKD stage 2 (eGFR 60-89 ml/min). This distribution is clinically informative, as it suggests that our cohort predominantly represents early-to-moderate DN (stages II-III), where intervention can be most impactful and where imaging biomarkers may be expected to demonstrate their greatest utility. The HbA1c values ranged from 5.8 to 10.8%, with a mean of 7.9 ± 0.9%, reflecting generally poor glycaemic control.

Renal Size Parameters and Grey-Scale Ultrasound Findings: All patients in our study demonstrated increased cortical echogenicity on grey-scale ultrasound. The renal dimensions in our cohort showed right kidney length of 10.3 ± 0.7 cm (range 8.2-12.1 cm) and left kidney length of 10.6 ± 0.7 cm (range 8.2-12.5 cm), with corresponding widths of 4.8 ± 0.5 cm and 4.9 ± 0.5 cm respectively. These values are within the normal range for adult kidneys but show a tendency toward the lower end of normal. This reinforces the fact that that size reduction is a late manifestation of DN and that functional and biomechanical changes precede structural atrophy detectable by conventional ultrasound.

Resistive Index Findings and Correlations: The mean intrarenal RI in our study was 0.72 ± 0.03 for both right and left kidneys, with ranges of 0.68-0.86 and 0.62-0.84 respectively. These values are

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significantly elevated compared to the accepted normal range of 0.50-0.70. The correlation analysis revealed that RI showed significant positive correlations with PCR (right kidney: r = 0.366, p = 0.001; left kidney: r = 0.403, p < 0.001), indicating that higher proteinuria is associated with increased intrarenal vascular resistance. There was a negative correlation between RI and eGFR (right kidney: r = -0.451, p < 0.001; left kidney: r = -0.427, p < 0.001).

Shear Wave Elastography Findings and Correlations: The SWE values in our study showed mean cortical stiffness of 30.6 ± 7.3 kPa for the right kidney and 30.3 ± 7.4 kPa for the left kidney, with ranges of 20.3-58.3 kPa and 20.3-61.1 kPa respectively. PCR showed strong positive correlations with both right kidney stiffness (r = 0.565, p < 0.001) and left kidney stiffness (r = 0.407, p < 0.001). These correlations are stronger than those observed for RI, suggesting that SWE is more sensitive to the structural changes associated with proteinuria. The negative correlations between SWE and eGFR (right kidney: r = -0.651, p < 0.001; left kidney: r = -0.529, p < 0.001) were also stronger than those observed for RI. The correlation between SWE and HbA1c (right kidney: r = 0.793, p < 0.001; left kidney: r = 0.658, p < 0.001) was notably strong, reinforcing the relationship between long-term glycaemic control and renal biomechanical properties.

Comparative Diagnostic Performance of RI and SWE: On comparison of imaging parameters between patients with PCR <500/eGFR >90 (less severe disease) and those with PCR >500/eGFR <90 (more severe disease), RI showed no significant difference between these groups (right kidney: p = 0.437; left kidney: p = 0.263), while SWE demonstrated highly significant differences (right kidney: p = 0.001; left kidney: p = 0.009). The relatively poor performance of RI in our ROC analysis is noteworthy. While RI showed significant correlations with biochemical parameters, its discriminatory ability for dichotomised PCR and eGFR categories was limited (AUCs ~0.57-0.60). This differential sensitivity suggests that SWE may be more responsive to the structural changes that distinguish moderate from more severe nephropathy, while RI reflects haemodynamic alterations that may be more consistently elevated across all stages of disease.

Combination of RI and SWE: The combination of RI and SWE in a conjunctive 'AND' model showed increased sensitivity and specificity, when compared to either modality alone.

Proposed Diagnostic Algorithm: In patients with type 2 diabetes, screening SWE could be performed at the time of diagnosis or annually thereafter, with values above the established cut-off (28.8 kPa for the right kidney in our cohort) prompting more intensive monitoring of renal function. Patients with elevated SWE but normal PCR and eGFR may represent the preclinical phase of DN. The combination of SWE with RI could provide additional confirmation, with elevated RI in the presence of elevated SWE strengthening the suspicion of significant nephropathy.

Limitations: Few limitations of this study should be acknowledged. First, the absence of a control group of healthy individuals or diabetic patients without nephropathy limits our ability to establish diagnostic cut-offs with sensitivity and specificity for the detection of DN. Second, the ROC analyses were performed against PCR and eGFR categories rather than against a gold standard such as renal biopsy, which would be the definitive reference standard. However, the invasive nature of renal biopsy makes it impractical for routine use, and the use of established biochemical criteria for DN staging is a reasonable approach in clinical research. Third, the relatively small sample size (76 patients) and the predominance of patients with stage II-III CKD limits the generalisability of our findings to patients with more advanced (stage IV-V) or very early (stage I) disease. Future studies should aim to include larger cohorts with broader stage distribution to fully characterise the biphasic SWE pattern across all stages of DN. Lastly, Technical factors including patient body habitus, depth of the kidney, and respiratory motion can affect SWE measurements, and while we attempted to minimise these sources of variability through careful protocol standardisation, they may have contributed to the range of values observed.

CONCLUSION

This study demonstrates that renal shear wave elastography and Doppler resistive index are significantly altered in patients with diabetic nephropathy and correlate meaningfully with biochemical markers of disease severity including PCR, eGFR, and HbA1c. SWE provides superior diagnostic discrimination compared to RI for categorising disease severity, with stronger correlations with all biochemical parameters and better ROC performance. The combination of SWE and RI offers complementary information that reflects distinct aspects of renal pathology—biomechanical stiffness and haemodynamic resistance—and may enhance the clinical assessment of DN. These findings support the use of SWE as a non-invasive, radiation-free imaging biomarker for the detection and monitoring of diabetic nephropathy, particularly in South Indian populations where machine-specific normative data are essential. The establishment of cut-off values for the Esaote MyLabX8 eXP system contributes to the growing evidence base for renal elastography and provides a foundation for future prospective studies to validate these findings and explore their clinical utility in guiding therapeutic decisions.

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