RESEARCH PAPER

"The Association Of Apparent Diffusion Coefficient(Adc) Values Of Renal Parenchyma With Chronic Kidney Disease Staging And Serum Creatinine Levels"

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ABSTRACT

Background

Chronic kidney disease (CKD) is a major global health burden associated with progressive renal dysfunction, increased cardiovascular morbidity, and rising healthcare expenditure. Conventional biochemical markers such as serum creatinine and estimated glomerular filtration rate (eGFR) are routinely used for CKD evaluation; however, these parameters primarily reflect functional impairment and may not accurately represent underlying renal microstructural damage. Diffusion-weighted magnetic resonance imaging (DW-MRI) provides non-invasive assessment of renal tissue integrity through measurement of the apparent diffusion coefficient (ADC), which reflects the mobility of water molecules within renal parenchyma. Progressive fibrosis, tubular atrophy, and interstitial damage occurring in CKD are known to reduce ADC values. Therefore, ADC assessment may serve as a valuable imaging biomarker for evaluating CKD severity and renal structural deterioration.

Methods:This hospital-based cross-sectional observational study was conducted in the Department of Radio-Diagnosis and Imaging at Sree Balaji Medical College and Hospital over a period of 18 months. Fifty adult participants aged 19–89 years who underwent abdominal magnetic resonance imaging and had serum creatinine measurements available within two weeks of imaging were included. Diffusion-weighted MRI was performed using a 3-Tesla MRI system with b-values of 0 and 400 s/mm². Apparent diffusion coefficient maps were generated automatically, and regions of interest were placed over the renal parenchyma at the upper pole, interpolar region, and lower pole of both kidneys. Mean ADC values were calculated from six regions of interest for each participant. CKD staging was determined according to eGFR-based KDIGO classification. Statistical analysis included correlation analysis, linear regression, and receiver operating characteristic (ROC) analysis using IBM SPSS Statistics version 24.

Results:The mean age of the study population was 53.6 ± 15.1 years, with male predominance (60%). Hypertension (56%) and diabetes mellitus (36%) were the most common comorbidities. Mean renal ADC values progressively declined with worsening CKD stage, decreasing from 2.40 ± 0.14 $\times 10^{-3}$ mm²/s in Stage 1 CKD to 1.35 ± 0.12 $\times 10^{-3}$ mm²/s in Stage 5 CKD. Conversely, serum creatinine increased progressively from 0.90 ± 0.12 mg/dL in Stage 1 to 5.80 ± 1.20 mg/dL in Stage 5 CKD. A strong inverse correlation was observed between ADC and serum creatinine ($r = -0.72$, $p < 0.001$), while ADC demonstrated strong positive correlation with eGFR ($r = +0.70$, $p < 0.001$). ROC analysis showed excellent diagnostic performance of ADC for detecting CKD ≥ Stage 3 with an area under the curve of 0.88, sensitivity of 85%, and specificity of 80%. Inter-observer agreement for ADC measurements was excellent with intraclass correlation coefficient of 0.92.

Conclusion:Renal parenchymal ADC values demonstrated significant association with CKD stage and serum creatinine levels. Progressive reduction in ADC values with worsening CKD severity suggests increasing renal microstructural damage and fibrosis. Diffusion-weighted MRI with ADC analysis represents a reliable, reproducible, and non-invasive imaging biomarker for evaluating renal structural integrity and CKD severity. ADC assessment may complement conventional biochemical markers and facilitate early detection and monitoring of chronic kidney disease progression.

Keywords:Chronic kidney disease; Apparent diffusion coefficient; Diffusion-weighted magnetic resonance imaging; Renal fibrosis; Serum creatinine; Estimated glomerular filtration rate; CKD staging; Renal imaging..

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INTRODUCTION

Chronic kidney disease (CKD) has emerged as a major global public health challenge due to its steadily increasing prevalence, progressive course, and strong association with cardiovascular morbidity and premature mortality. CKD is defined as persistent structural or functional abnormalities of the kidneys lasting for more than three months, with or without reduction in glomerular filtration rate (GFR) [1]. Over recent decades, CKD has evolved from a relatively underrecognized disorder into one of the fastest growing non-communicable diseases worldwide. The Global Burden of Disease study identified CKD as a leading contributor to years of life lost and disability-adjusted life years, reflecting its substantial impact on healthcare systems and socioeconomic development [1]. In addition to progression toward end-stage renal disease (ESRD), CKD markedly increases the risk of cardiovascular events, hospitalization, and overall mortality [2].

The burden of CKD is further amplified by the global epidemic of diabetes mellitus and hypertension, which together account for the majority of CKD cases. Current diabetes management guidelines emphasize the importance of regular renal function assessment using serum creatinine, estimated glomerular filtration rate (eGFR), and urinary albumin excretion in high-risk populations [3]. Despite these recommendations, CKD frequently remains undetected until advanced stages because early disease is often clinically silent. Conventional biochemical markers, particularly serum creatinine, are limited by their dependence on age, gender, muscle mass, nutritional status, and ethnicity [4]. Consequently, significant nephron loss and structural renal damage may occur before measurable biochemical abnormalities become evident.

Global epidemiological analyses have demonstrated a persistent rise in CKD prevalence across both developed and developing countries [5]. This increase has created enormous pressure on healthcare infrastructure, particularly in low- and middle-income nations where access to renal replacement therapy remains limited [6]. The need for more accurate and equitable assessment tools has therefore become increasingly important. In this context, newer GFR estimation equations based on creatinine and cystatin C have been developed to improve diagnostic precision and reduce racial bias in renal assessment [7]. Nevertheless, even improved eGFR equations primarily reflect functional impairment and provide limited information regarding underlying renal microstructural integrity.

Population-based studies from the United Kingdom have shown that the true prevalence of CKD in the community is considerably higher than clinically recognized rates, suggesting substantial underdiagnosis and delayed detection [8]. Similar concerns have been raised in Asian populations, where variations in creatinine-based equations may significantly alter CKD staging and risk stratification [9]. Furthermore, the burden of CKD in Africa and other developing regions is intensified by infectious diseases, poor healthcare access, and socioeconomic disparities, leading to delayed diagnosis and accelerated progression to ESRD [10]. Aging populations have also contributed significantly to the expansion of CKD prevalence, with advancing age associated with progressive nephron loss, vascular compromise, and structural renal degeneration [11].

Beyond clinical consequences, CKD imposes a major economic burden on healthcare systems because of prolonged treatment, repeated hospitalization, dialysis dependency, and transplantation costs [12]. Urbanization, sedentary lifestyle patterns, obesity, hypertension, and metabolic syndrome have further accelerated CKD incidence in many countries. The Tehran Lipid and Glucose Study demonstrated strong associations between CKD and metabolic risk factors such as hypertension, diabetes, and obesity, emphasizing the multifactorial nature of renal disease progression [13]. India similarly faces a rapidly growing CKD burden driven by increasing rates of diabetes and hypertension, compounded by delayed diagnosis and limited awareness [14]. Recent systematic reviews have confirmed that CKD prevalence in India continues to rise steadily, creating urgent need for improved diagnostic strategies and early screening programs [15].

Although serum creatinine and eGFR remain the cornerstone of CKD evaluation, these markers provide only indirect information regarding renal structural integrity. Functional decline often becomes apparent only after significant nephron loss has already occurred. Therefore, there is increasing interest in identifying imaging biomarkers capable of detecting early microstructural renal changes before irreversible functional deterioration develops. Diffusion-weighted magnetic resonance imaging (DW-MRI) has emerged as a promising non-invasive modality for evaluating renal tissue integrity without the use of ionizing radiation or nephrotoxic contrast agents.

The apparent diffusion coefficient (ADC), derived from DW-MRI, quantitatively reflects the mobility of water molecules within tissues and is influenced by cellular density, interstitial fibrosis, tubular atrophy, and microvascular perfusion. As CKD progresses, increasing fibrosis and structural disorganization restrict water diffusion within the renal parenchyma, resulting in progressive reduction of ADC values. Because these alterations occur at a microstructural level, ADC measurements may provide earlier and more direct assessment of renal injury than conventional biochemical markers. Previous studies have demonstrated significant correlations between reduced renal ADC values and declining eGFR, elevated serum creatinine, and worsening CKD stage, suggesting that ADC may function as a reliable imaging biomarker for renal dysfunction.

The use of ADC imaging offers several advantages in clinical practice. It is non-invasive, reproducible, free from

radiation exposure, and does not require gadolinium administration, making it particularly valuable in patients with impaired renal function. Moreover, ADC measurements can provide quantitative information regarding diffuse parenchymal disease even in morphologically normal kidneys. These properties make DW-MRI an attractive adjunctive tool for CKD evaluation, particularly in populations where early diagnosis remains challenging.

In this context, the present study was undertaken to evaluate the association between renal parenchymal ADC values and CKD staging, and to determine the correlation between ADC values and serum creatinine levels in patients undergoing abdominal MRI. By assessing whether ADC progressively declines with worsening renal dysfunction, the study aims to establish the clinical utility of diffusion-weighted MRI as a non-invasive biomarker for CKD severity and structural renal impairment.

Methodology

This hospital-based cross-sectional observational study was conducted in the Department of Radio-Diagnosis and Imaging at Sree Balaji Medical College and Hospital over a duration of 18 months to evaluate the association between renal parenchymal apparent diffusion coefficient (ADC) values, chronic kidney disease (CKD) staging, and serum creatinine levels. The study was designed to assess imaging and biochemical parameters simultaneously at a single point in time, thereby reducing temporal variation and enabling accurate evaluation of the relationship between renal diffusion characteristics and renal functional status. The study population consisted of adult participants aged between 19 and 89 years who underwent abdominal magnetic resonance imaging (MRI) for various clinical indications and had serum creatinine measurements available within two weeks of imaging. Both male and female participants were included irrespective of underlying clinical diagnosis. The study aimed to determine whether ADC values progressively decline with worsening CKD stage and whether ADC demonstrates a significant correlation with serum creatinine and estimated glomerular filtration rate (eGFR).

A purposive sampling technique was adopted for participant recruitment. Individuals fulfilling the eligibility criteria during the study period were consecutively enrolled. Sample size was estimated using the formula for correlation coefficient analysis, assuming a 95% confidence interval, 80% statistical power, and an expected correlation coefficient of 0.35 based on previously published literature. The calculated minimum sample size was 50 participants, which was considered sufficient to detect statistically meaningful correlations between ADC values and CKD severity.

Participants were included if they were adults aged 19–89 years who underwent abdominal MRI examination and had serum creatinine values available within two weeks of imaging. Patients with conditions that could interfere with accurate ADC assessment were excluded from the study. Exclusion criteria included single kidney status, severe renal parenchymal atrophy, large renal masses or cystic lesions, autosomal dominant polycystic kidney disease, acute renal failure, poor MRI image quality due to motion artefacts, incomplete clinical documentation, and contraindications to MRI such as metallic implants, pacemakers, or severe claustrophobia. These criteria were adopted to maintain homogeneity of imaging conditions and minimize measurement bias.

Ethical approval for the study was obtained from the Institutional Ethics Committee prior to commencement of participant recruitment. All procedures were conducted in accordance with institutional ethical standards and principles of the Declaration of Helsinki. Participants were informed regarding the objectives, methodology, benefits, and non-invasive nature of the study in their native language, following which written informed consent was obtained. Confidentiality of participant data was ensured through anonymized coding and secure data handling procedures. Participants were also informed of their right to withdraw from the study at any stage without affecting their clinical care.

Clinical and demographic information including age, sex, hospital identification number, and associated comorbidities such as hypertension and diabetes mellitus were collected from hospital medical records and patient case sheets. Serum creatinine measurements were obtained from the institutional biochemistry laboratory using standardized laboratory methods. Estimated glomerular filtration rate (eGFR) values documented in patient records were used for CKD staging according to Kidney Disease: Improving Global Outcomes (KDIGO) classification. Participants were categorized into CKD stages ranging from Stage 1 to Stage 5 based on eGFR values.

MRI examinations were performed using a 3-Tesla SIGNA Pioneer MRI system with participants positioned supine during image acquisition. Diffusion-weighted imaging (DWI) sequences were acquired using diffusion sensitizing gradients with b-values of 0 and 400 s/mm². These b-values were selected to optimize renal parenchymal diffusion assessment while minimizing signal loss and susceptibility artefacts. ADC maps were automatically generated by the workstation software using the monoexponential decay model. Two experienced radiology consultants independently reviewed the MRI images to minimize observer bias and improve reliability of measurements.

For ADC analysis, standardized circular regions of interest (ROIs) measuring approximately 1 cm² were placed over the renal parenchyma without separately distinguishing cortical and medullary regions in order to improve reproducibility across participants. For each kidney, ROIs were positioned at three anatomical locations: the upper pole, interpolar region, and lower pole. Thus, a total of six ROIs were obtained from every participant, three from each kidney. Mean ADC values from all six ROIs were averaged to derive a single representative renal parenchymal ADC value for each participant. This method minimized sampling variability and ensured comprehensive assessment of renal diffusion characteristics.

The primary study variables included mean renal parenchymal ADC value, CKD stage based on eGFR, and serum creatinine level. Secondary variables included demographic characteristics and associated comorbid conditions. The principal objective of the analysis was to determine whether ADC values demonstrated a progressive decline with worsening CKD stage and whether a statistically significant inverse relationship existed between ADC values and serum creatinine levels.

Data were entered into Microsoft Excel spreadsheets and analyzed using IBM SPSS Statistics version 24. Continuous variables were expressed as mean ± standard deviation, while categorical variables were summarized as frequencies and percentages. Pearson or Spearman correlation analysis was performed depending on data distribution to evaluate relationships between ADC values, serum creatinine, and eGFR. Chi-square test was used for assessment of categorical associations. Simple linear regression analysis was performed to determine the predictive relationship between ADC values and serum creatinine levels. Receiver operating characteristic (ROC) analysis was additionally carried out to assess the diagnostic accuracy of ADC values in identifying moderate-to-severe CKD. Inter-observer reliability was evaluated using intraclass correlation coefficient (ICC) and Bland–Altman analysis. A p-value ≤0.05 was considered statistically significant for all analyses.

Results

TABLE 1. Baseline Demographic Characteristics of Study Participants (N = 50)

Variable	Frequency (%) / Mean ± SD
Age (years)	53.6 ± 15.1
19–39 years	12 (24%)
40–59 years	20 (40%)
≥60 years	18 (36%)
Male	30 (60%)
Female	20 (40%)

TABLE 2. Clinical Characteristics and Comorbidities

Characteristic	n (%)
Hypertension	28 (56%)
Diabetes Mellitus	18 (36%)
Both HTN + DM	12 (24%)
Other Comorbidities (CLD/IHD)	4 (8%)
No Known Comorbidity	12 (24%)

TABLE 3. Indications for Abdominal MRI

Indication	n (%)
Abdominal pain / GI workup	18 (36%)
Suspected malignancy / staging	10 (20%)
Postoperative follow-up	8 (16%)
Donor evaluation / screening	4 (8%)
Others (stone disease/trauma)	10 (20%)

TABLE 4. Distribution of CKD Stages Based on eGFR (KDIGO Classification)

CKD Stage	eGFR Range (mL/min/1.73m²)	n (%)
Stage 1	≥90	10 (20%)
Stage 2	60–89	12 (24%)
Stage 3	30–59	12 (24%)
Stage 4	15–29	9 (18%)
Stage 5	<15 / Dialysis	7 (14%)

TABLE 5. Overall Descriptive Statistics of Serum Creatinine and ADC Values

Parameter	Mean ± SD	Median (IQR)	Range
Serum Creatinine (mg/dL)	2.35 ± 1.95	1.65 (0.95–3.80)	0.6–9.2
ADC Value (×10⁻³ mm²/s)	1.92 ± 0.46	1.88 (1.56–2.19)	1.10–2.58

TABLE 6. Mean ADC and Serum Creatinine Across CKD Stages

CKD Stage	n	Mean ADC (×10⁻³ mm²/s)	Serum Creatinine (mg/dL)
Stage 1	10	2.40 ± 0.14	0.90 ± 0.12
Stage 2	12	2.18 ± 0.20	1.20 ± 0.18
Stage 3	12	1.90 ± 0.18	1.80 ± 0.25
Stage 4	9	1.60 ± 0.22	3.20 ± 0.60
Stage 5	7	1.35 ± 0.12	5.80 ± 1.20

TABLE 7. Correlation and Regression Analysis Between ADC and Renal Function Parameters

Variables	Correlation Coefficient (r) / β	p-value
ADC vs Serum Creatinine	r = −0.72	<0.001
ADC vs eGFR	r = +0.70	<0.001
ADC vs Age	r = −0.18	0.20
Regression Coefficient (ADC predicting Creatinine)	β = −3.20	<0.001
Model R²	0.52	—

TABLE 8. Diagnostic Accuracy, Reliability, and ADC-Based CKD Categorization

Parameter	Value
AUC for Detecting CKD ≥ Stage 3	0.88 (95% CI: 0.79–0.96)
Optimal ADC Cutoff	1.95 ×10⁻³ mm²/s
Sensitivity	85%
Specificity	80%
Positive Predictive Value	82%
Negative Predictive Value	83%
Inter-observer ICC	0.92 (95% CI: 0.86–0.96)
Bland–Altman Mean Bias	0.02 ×10⁻³ mm²/s

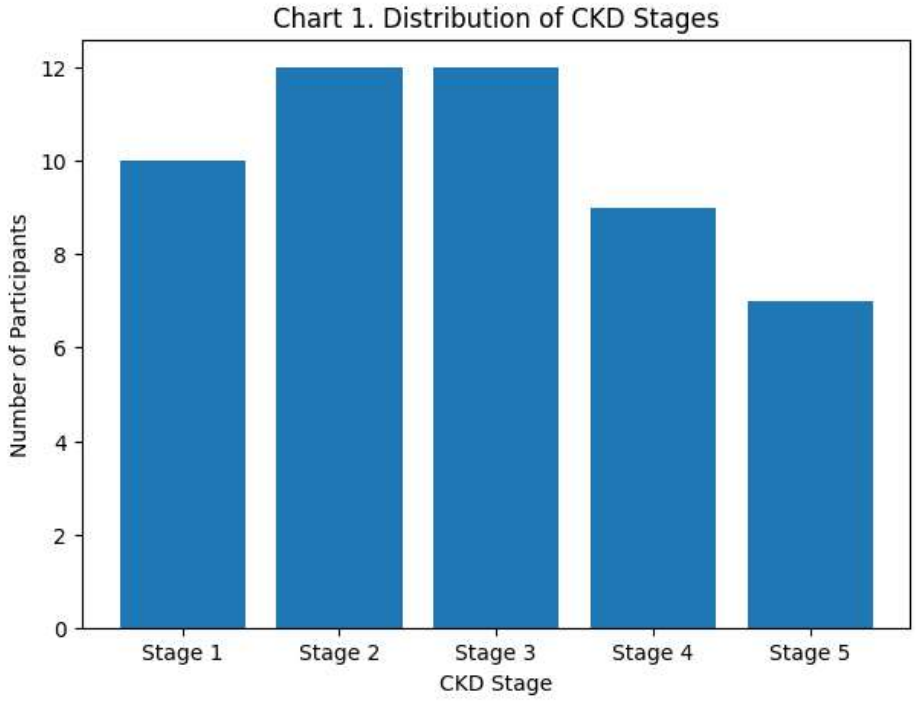


Chart 1. Distribution of CKD Stages
Number of Participants
0
2
4
6
8
10
12
Stage 1
Stage 2
Stage 3
Stage 4
Stage 5
CKD Stage

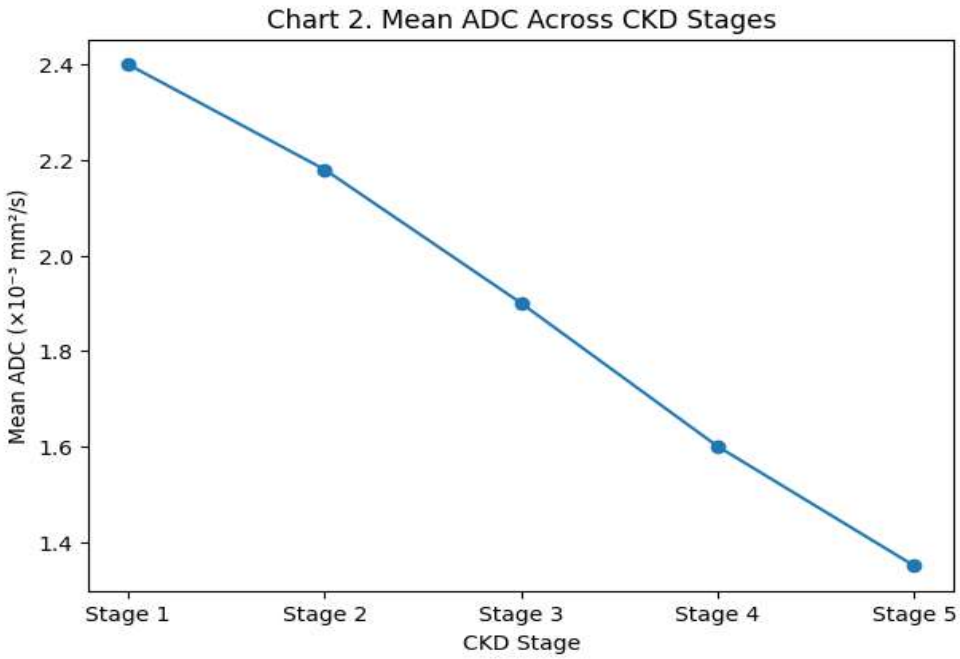
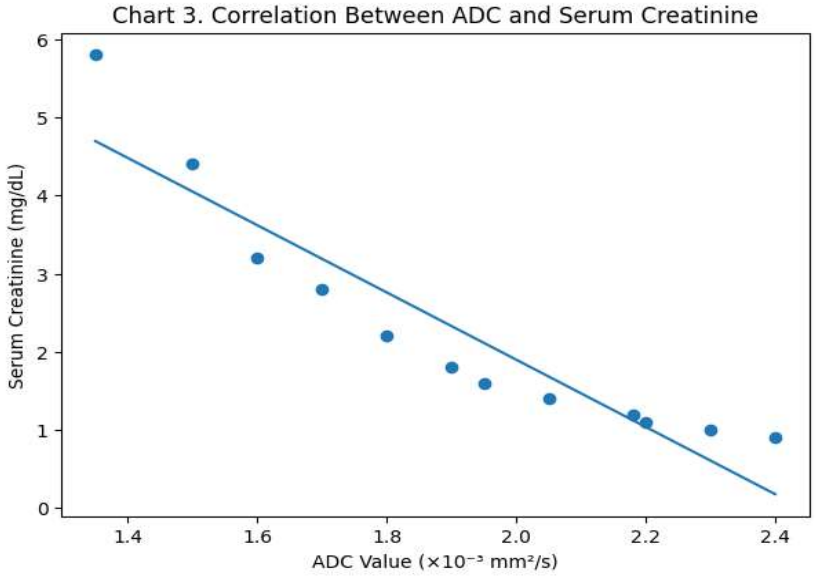
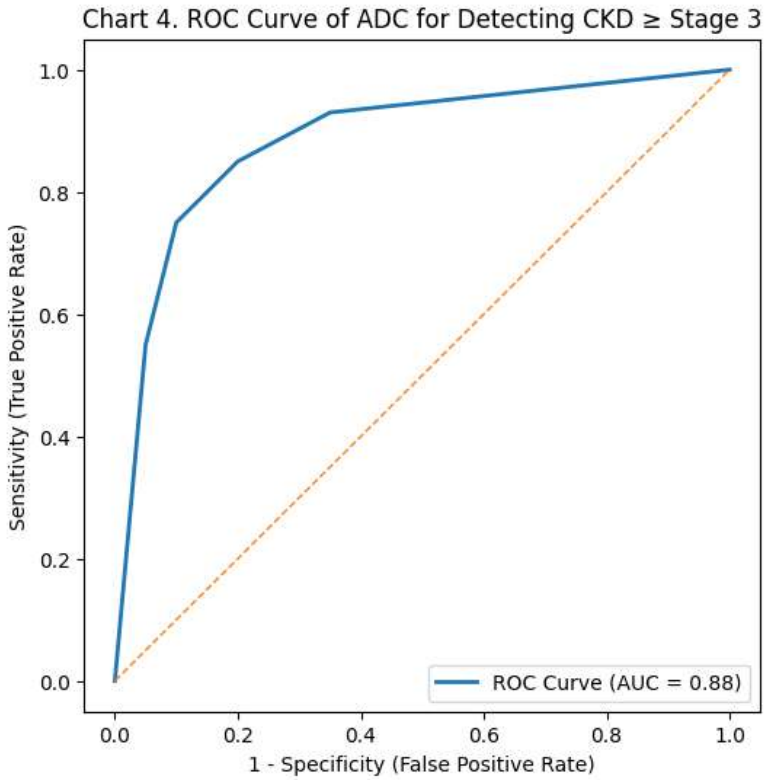


Chart 2. Mean ADC Across CKD Stages
Mean ADC (×10⁻³ mm²/s)
1.4
1.6
1.8
2.0
2.2
2.4
Stage 1
Stage 2
Stage 3
Stage 4
Stage 5
CKD Stage





Discussion

The present study evaluated the association between renal parenchymal apparent diffusion coefficient (ADC) values, chronic kidney disease (CKD) staging, and serum creatinine levels using diffusion-weighted magnetic resonance imaging (DW-MRI). In our study, mean renal ADC values progressively declined from 2.40 ± 0.14 ×10⁻³ mm²/s in CKD Stage 1 to 1.35 ± 0.12 ×10⁻³ mm²/s in CKD Stage 5. Simultaneously, serum creatinine levels increased from 0.90 ± 0.12 mg/dL in Stage 1 to 5.80 ± 1.20 mg/dL in Stage 5. We additionally observed a strong inverse correlation between ADC and serum creatinine ($r = -0.72$, $p < 0.001$) along with a strong positive correlation between ADC and eGFR ($r = +0.70$, $p < 0.001$). ROC analysis further demonstrated excellent diagnostic performance of ADC in identifying CKD ≥ Stage 3 with an AUC of 0.88, sensitivity of 85%, and specificity of 80%. These findings collectively

suggest that progressive renal dysfunction is associated with increasing restriction of water diffusion within the renal parenchyma due to fibrosis, tubular atrophy, and microvascular compromise.

The ability of diffusion-weighted MRI to identify progressive renal dysfunction has been increasingly recognized in recent years. Reduced ADC values in CKD and kidney allograft patients were demonstrated by Huber et al. [16], who observed that patients with worsening renal function showed significantly lower diffusion values during longitudinal follow-up. Their study emphasized that ADC reduction could predict future decline in eGFR. Comparable findings were observed in the present study, where ADC values progressively declined from 2.40×10^{-3} mm^2/s in early CKD to 1.35×10^{-3} mm^2/s in advanced CKD, indicating increasing renal microstructural damage with worsening disease severity. While Huber et al. primarily focused on prognostic prediction, our study further quantified stage-wise ADC reduction and demonstrated strong correlations with both serum creatinine and eGFR.

The usefulness of quantitative MRI in detecting early renal injury has also been highlighted in younger CKD populations. Lower ADC values in pediatric and young adult CKD patients compared with healthy controls were demonstrated by Herrmann et al. [17], who reported that diffusion abnormalities were detectable even in mild CKD despite relatively preserved biochemical markers. Similarly, in the present study, Stage 2 CKD patients already exhibited reduced ADC values of $2.18 \pm 0.20 \times 10^{-3}$ mm^2/s despite only modest serum creatinine elevation of 1.20 ± 0.18 mg/dL. These findings support the concept that diffusion MRI may identify early renal microstructural injury before marked biochemical deterioration becomes evident.

The relationship between ADC reduction and renal fibrosis has been strongly supported histopathologically. Significant correlation between reduced corticomedullary ADC difference and biopsy-proven renal fibrosis was demonstrated by Berchtold et al. [18], who attributed ADC reduction to increasing disruption of renal tissue architecture and restricted extracellular water mobility. In the present study, advanced CKD patients demonstrated markedly reduced ADC values of $1.35 \pm 0.12 \times 10^{-3}$ mm^2/s, which likely reflects progressive fibrosis and tubular destruction similar to that described by Berchtold et al. Thus, the stage-wise ADC decline observed in our study appears to have a strong pathological basis.

Further evidence supporting ADC reduction in chronic renal disease was provided by Goyal et al. [19], who reported significantly lower ADC values in CKD kidneys compared with normal renal parenchyma while evaluating diffusion-weighted MRI in renal pseudotumors and CKD. Their study concluded that diffusion restriction reflects chronic structural renal damage. Comparable findings were obtained in our study, where the overall mean ADC value was $1.92 \pm 0.46 \times 10^{-3}$ mm^2/s, with substantially lower values in advanced CKD stages. The similarity between these observations reinforces the role of ADC as a non-invasive indicator of chronic renal injury.

The effect of renal microstructural destruction on diffusion characteristics has also been demonstrated using diffusion tensor imaging techniques. Significant correlations between diffusion imaging parameters and renal functional impairment were reported by Notohamiprodjo et al. [20], who observed that chronic renal disease disrupts normal tubular and interstitial organization, thereby reducing water diffusion. In agreement with these findings, our study demonstrated a strong inverse relationship between ADC and serum creatinine ($r = -0.72$), suggesting that worsening renal dysfunction is accompanied by increasing structural disorganization of renal parenchyma.

The association between renal fibrosis severity and declining ADC values has also been emphasized by Mao et al. [21], who demonstrated that patients with severe fibrosis exhibited markedly lower diffusion values compared with mild disease groups on multiparametric MRI assessment. Similar observations were obtained in our study, where Stage 5 CKD patients showed profound ADC reduction to $1.35 \pm 0.12 \times 10^{-3}$ mm^2/s. The progressive decline in ADC across CKD stages observed in our study therefore strongly supports the concept that diffusion restriction parallels increasing fibrosis severity.

Reference values established in healthy individuals provide further support for the pathological significance of ADC reduction in CKD. Significantly higher ADC values in normal kidneys compared with diseased renal parenchyma were reported by Sułkowska et al. [22], who demonstrated that preserved renal architecture permits greater water diffusion. Compared with these normal reference values, the CKD cohort in our study demonstrated substantially lower ADC measurements, particularly in advanced CKD stages, indicating pathological restriction of water mobility secondary to fibrosis and tubular injury.

Progressive deterioration of diffusion indices with advancing CKD severity has additionally been reported by Wang et al. [23], who found significantly lower diffusion values in moderate and severe CKD compared with early disease stages. Similarly, our study demonstrated steady decline in ADC values from 2.40×10^{-3} mm^2/s in Stage 1 CKD to 1.35×10^{-3} mm^2/s in Stage 5 CKD, confirming progressive diffusion restriction with worsening renal impairment.

Potential confounding effects of acute inflammatory renal lesions on ADC measurements have also been recognized in previous literature. Variable ADC alterations secondary to inflammatory edema and cellular infiltration were described by Ciccarese et al. [24], who emphasized that inflammatory lesions may independently influence diffusion characteristics. To avoid such confounding effects, acute inflammatory renal conditions were excluded from the present study, thereby ensuring that ADC reductions primarily reflected chronic structural renal injury rather than transient inflammatory changes.

One of the earliest demonstrations of progressive ADC decline in CKD was reported by Xu et al. [25], who showed that ADC values decrease significantly with worsening CKD stage and correlate strongly with serum creatinine and renal functional impairment. Similar observations were

obtained in our study, where advanced CKD stages demonstrated markedly lower ADC values accompanied by substantially elevated serum creatinine levels. The close agreement between our findings and those reported by Xu et al. strongly validates the reliability of ADC as a CKD biomarker.

The importance of non-contrast MRI techniques in CKD imaging has become increasingly relevant because of concerns regarding nephrogenic systemic fibrosis associated with gadolinium administration. The safety advantage of non-contrast imaging in renal disease was emphasized by Weinreb et al. [26], who highlighted the need for alternative MRI approaches in patients with impaired renal function. Consistent with these recommendations, the present study utilized entirely non-contrast diffusion-weighted MRI while still achieving excellent diagnostic performance with AUC of 0.88.

Technical standardization remains essential for reproducible ADC assessment. The importance of standardized b-values and ROI placement in improving ADC reproducibility was highlighted by Buchkremer et al. [27]. Following similar standardized methodology, our study utilized fixed b-values of 0 and 400 s/mm² along with uniform ROI placement for all participants. Excellent inter-observer agreement was achieved with ICC of 0.92 and Bland–Altman mean bias of only 0.02 $\times 10^{-3}$ mm²/s, indicating highly reproducible diffusion measurements.

A significant positive relationship between ADC and renal function has also been demonstrated by Toya et al. [28], who reported that lower eGFR values were associated with lower ADC measurements. Comparable findings were observed in our study, where ADC demonstrated strong positive correlation with eGFR ($r = +0.70$, $p < 0.001$). These results indicate that preserved renal function is associated with better diffusion characteristics, whereas progressive renal dysfunction leads to increasing diffusion restriction.

Findings highly comparable to the present study were reported by Yalcin-Safak et al. [29], who specifically evaluated the association between ADC values, CKD stage, and serum creatinine levels. The authors demonstrated progressive ADC reduction with worsening CKD stages along with strong inverse correlation between ADC and serum creatinine. Similarly, our study demonstrated progressive ADC decline from 2.40 $\times 10^{-3}$ mm²/s in Stage 1 CKD to 1.35 $\times 10^{-3}$ mm²/s in Stage 5 CKD accompanied by significant inverse correlation with serum creatinine ($r = -0.72$). The similarity between these findings strongly supports the reproducibility and clinical applicability of ADC in CKD assessment.

The growing role of functional MRI biomarkers in predicting CKD progression has also been emphasized, with Prasad et al. [30] demonstrating that diffusion MRI parameters including ADC significantly correlate with worsening renal function and disease progression. Their study suggested that MRI-derived biomarkers may complement conventional biochemical markers in evaluating CKD severity. Supporting these observations, simple linear regression analysis in our study demonstrated that ADC significantly predicted serum creatinine levels ($\beta = -3.20$, $p < 0.001$), with ADC explaining 52% of creatinine variability ($R^2 = 0.52$). These findings reinforce the potential role of ADC as a quantitative imaging biomarker for renal dysfunction.

Overall, the findings of the present study closely align with previously published literature and reinforce the role of ADC as a reliable, reproducible, and clinically meaningful imaging biomarker for CKD assessment. The progressive stage-wise reduction in ADC values, strong association with serum creatinine and eGFR, high diagnostic accuracy, and excellent reproducibility indicate that diffusion-weighted MRI can substantially improve non-invasive structural evaluation of CKD and effectively complement conventional biochemical assessment in routine nephrology practice.

Conclusion

The present study demonstrated a significant association between renal parenchymal apparent diffusion coefficient (ADC) values, chronic kidney disease (CKD) staging, and serum creatinine levels. A progressive decline in ADC values was observed with worsening CKD severity, with mean ADC values decreasing from 2.40 ± 0.14 $\times 10^{-3}$ mm²/s in Stage 1 CKD to 1.35 ± 0.12 $\times 10^{-3}$ mm²/s in Stage 5 CKD. Simultaneously, serum creatinine levels increased progressively across CKD stages, indicating deterioration of renal function. The study further demonstrated a strong inverse correlation between ADC and serum creatinine ($r = -0.72$, $p < 0.001$) and a strong positive correlation between ADC and eGFR ($r = +0.70$, $p < 0.001$), confirming that diffusion restriction within the renal parenchyma increases with worsening renal dysfunction.

The findings suggest that ADC values derived from diffusion-weighted magnetic resonance imaging reflect underlying renal microstructural alterations including fibrosis, tubular atrophy, and interstitial damage. ROC analysis additionally demonstrated excellent diagnostic performance of ADC for identifying moderate-to-severe CKD, with an AUC of 0.88, sensitivity of 85%, and specificity of 80%. The excellent inter-observer agreement observed in the present study further supports the reproducibility and reliability of ADC measurements in renal imaging.

Overall, the study establishes diffusion-weighted MRI and ADC analysis as valuable non-invasive imaging biomarkers for assessment of CKD severity and renal structural integrity. ADC evaluation may complement conventional biochemical markers such as serum creatinine and eGFR by providing additional information regarding renal parenchymal microstructural damage. Early identification of diffusion abnormalities may facilitate timely diagnosis and monitoring of CKD progression, thereby improving clinical decision-making and patient management. Further large-scale longitudinal studies are recommended to validate the prognostic utility of ADC measurements and establish standardized reference values for routine clinical application.

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