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Radiological evaluation of kidney morphology in patients with chronic kidney disease: analysing kidney size, echogenicity, corticomedullary differentiation, and their impact on clinical outcomes in a Nigerian population.

***Rafiu MO[1,2], *Akerele NN[1,2], Ahmed SD[1,2], Otaigbe OI[3,4], Erohubie CE[1,2], Emorinken A[2,5], Eluehike SU[6,7], Olugbemide OA [2,8], Akpede N[3,4], Dada SA[9], Akerele JM [10,11], Adetunji AE[12,13], Azubike CO[1,14]**

Rafiu MO and Akerele NN (*) means first co-author.

1. Nephrology Division, Department of Internal Medicine, Irrua Specialist Teaching Hospital, Irrua, Edo State, Nigeria.
2. Department of Medicine, Faculty of Clinical Sciences, College of Medicine, Ambrose Alli University, Ekpoma, Edo State, Nigeria.
3. Public Health Department, Irrua Specialist Teaching Hospital, Irrua, Edo State, Nigeria.
4. Community Medicine Department, Faculty of Clinical Sciences, Ambrose Alli University, Ekpoma, Edo State, Nigeria.
5. Rheumatology Division, Department of Internal Medicine, Irrua Specialist Teaching Hospital, Irrua, Edo State, Nigeria.
6. Radiology Department, Irrua Specialist Teaching Hospital, Irrua, Edo State, Nigeria.
7. Radiology Department, Faculty of Clinical Sciences, Ambrose Alli University, Ekpoma, Edo State, Nigeria.
8. Endocrinology Division, Department of Internal Medicine, Irrua Specialist Teaching Hospital, Irrua, Edo State, Nigeria.
9. Nephrology Unit, Department of Internal Medicine, College of Medicine, Ekiti State University, Ado-Ekiti, Ekiti State, Nigeria.
10. Cardiothoracic Unit, Surgery Department, Irrua Specialist Teaching Hospital, Irrua, Edo State, Nigeria.
11. Surgery Department, Faculty of Clinical Sciences, Ambrose Alli University, Ekpoma, Edo State, Nigeria.
12. Department of Paediatrics, Irrua Specialist Teaching Hospital, Irrua, Edo State, Nigeria.
13. Department of Paediatrics, Faculty of Clinical Sciences, College of Medicine, Ambrose Alli University, Ekpoma, Edo State, Nigeria.
14. Department of Medical Physiology, College of Medicine, University of Benin, Benin, Edo State, Nigeria.

Abstract

Background: Renal ultrasound is an effective, noninvasive method for assessing renal health. It measures parameters like kidney size, echogenicity, and corticomedullary differentiation, which help evaluate renal function and pathology. Despite rising chronic kidney disease (CKD) cases in Nigeria and worldwide, data on ultrasound use in Nigerian patients are limited. This study examines renal features in patients with CKD and their clinical implications. Method: This was a Retrospective Observational study at Irrua Specialist Teaching Hospital (ISTH) carried out from June 2023 - June 2024. All consenting adults with CKD were included. Ultrasound was used to assess kidney size, echogenicity, and corticomedullary differentiation. Data obtained were analysed with Stata 17, with significance set at P<0.05. Result: The average renal lengths measured were 10.08 ± 1.48 cm for the right kidney and 10.40 ± 1.46 cm for the left kidney. Increased renal echogenicity was identified in 58.1% of right kidneys and 59.0% of left kidneys. Loss of corticomedullary differentiation was observed in 34.5% of right kidneys and 34.2% of left kidneys. The presence of reduced kidney size increased cortical echogenicity, and loss of corticomedullary differentiation was significantly associated with mortality. Conclusion: Ultrasound measurements of renal length in our CKD patients were mostly within normal limits, but smaller kidneys, increased cortical echogenicity, and loss of corticomedullary differentiation were significantly associated with higher mortality.

Keywords: kidney length, renal echogenicity, corticomedullary differentiation, CKD.

Introduction

Renal ultrasound imaging is a vital diagnostic modality for assessing kidney health. It plays a crucial role in nephrology, facilitating procedures such as haemodialysis, catheter placement and renal biopsies, while also providing detailed insights into renal morphology.[1] This technique is cost-effective, straightforward, and can be conveniently performed at the patient's bedside, offering clinicians valuable

Corresponding author Dr Mojeed Olaitan Rafiu
Email: raphymoj2012@gmail.com
Phone Number: +2348033566001
ORCID ID: 0000-0001-6289-0967

anatomical information with minimal interobserver variability. The advent of Point-of-Care Ultrasonography (POCUS) further enhances bedside assessment, serving as a complementary tool to physical examination, primarily utilised by nephrologists.[1,2] Accurate measurement of renal size via ultrasound is essential in the evaluation of patients suspected of renal pathology.[3]

Chronic kidney disease (CKD) represents a significant global public health challenge, characterised by rising incidence and prevalence rates, substantial healthcare costs, and often poor patient outcomes.[4,5] CKD involves the progressive destruction of renal tissue, leading to irreversible sclerosis and nephron loss, which impact on renal morphology and can be detected by ultrasonography. According to *Hills et al*. in a comprehensive systematic review and meta-analysis, the worldwide prevalence of CKD was estimated at 13.4% across stages 1 to 5, and 10.6% in stages 3 to 5, with notable variability among studies and high heterogeneity.[6] The prevalence of CKD is notably higher in sub-Saharan Africa compared to North Africa, and it is nearly twice as high in high-risk populations relative to the general population.[7] *Ogundele et al*. reported a CKD prevalence of 15.8% across stages 1 to 5, and 4.6% in stages 3 to 5 among adults residing in Africa.[7] In Nigeria, estimates indicate that CKD affects approximately 8-10% of all medical admissions, with some studies reporting prevalence rates between 19.9% and 27%.[8,9]

Kidney function assessment primarily involves evaluating glomerular performance. The most precise indicator of renal functional status is the quantification of nephron count, representing the total number of nephrons within the kidneys.[10] Research by *Vegar et al*. demonstrated that calculated kidney volume can be effectively utilised in clinical practice for monitoring chronic kidney disease (CKD), especially when combined with other clinical and laboratory parameters.[10] A direct correlation exists between kidney size and its functional capacity. [11] *Sanusi et al.* reported that ultrasonographically determined kidney volume correlates with glomerular filtration rate (GFR), highlighting its potential as a predictive measure of renal function in both healthy individuals and CKD patients. [11]

Renal length, cortical, and parenchymal echogenicity serve as non-invasive diagnostic tools for investigating renal pathologies. Early detection of renal function decline may be more accurately achieved through measurements of renal cortical and parenchymal thicknesses rather than traditional parameters such as serum creatinine levels.[12] Conversely, absolute and relative renal lengths are more effective in predicting the progression to late-stage CKD.[12] Several factors can compromise the reliability of ultrasound screening for CKD, often related to comorbidities like diabetes mellitus, which may lead to a relative increase in renal size and volume.[12] However, the specificity and sensitivity of the renal ultrasound are very high at stages IV and V (late-stage CKD). The assessment of renal echogenicity is typically qualitative, involving comparison of the cortical echotexture to the liver on the right and the spleen on the left.[13] Normally, the renal cortex appears isoechoic or hypoechoic relative to these organs. An increase in cortical echogenicity is frequently observed in CKD and is associated with interstitial fibrosis, tubular atrophy, and glomerulosclerosis.[13] Additionally, CKD—excluding diabetic nephropathy and infiltrative diseases—is generally characterised by reduced kidney size and cortical thickness.[13] There is limited data on the application of ultrasound for assessing renal morphology in CKD patients within Nigeria. This study aims to evaluate the radiological features of renal morphology in CKD patients, focusing on kidney size, echogenicity, and corticomedullary differentiation, alongside their implications for patient outcomes.

Materials and Method

This observational study was conducted at the Nephrology clinic and Radiology suite of Irrua Specialist Teaching Hospital (ISTH) in Irrua, Edo State, Nigeria, spanning from June 1, 2023, to June 30, 2024. A non-randomised sampling approach was employed to recruit adult participants aged 18 years and above diagnosed with CKD, all of whom provided preemptive informed consent prospectively at the nephrology clinics. Inclusion criteria encompassed individuals with comprehensive electronic medical records and documented ultrasound scans from the radiology department. The primary objective was to collect detailed data on CKD patients within the specified timeframe. Each patient recruited was followed up for 1year from the date of recruitment. Diagnosis and staging of CKD was performed by nephrologists following the KDIGO guidelines.[4]

All participants underwent renal imaging performed by experienced consultant radiologists in the radiology department, who were blinded to laboratory test results. Each kidney was examined in both longitudinal and transverse planes to assess renal dimensions, including length and width, measured in centimetres using LOGIQ™ P9, General Electric 2D grey-scale Ultrasound scanner with colour Doppler (LOGIQ™ series, GE HealthCare, United States). Kidney echogenicity adapted

from the methodology described by *Hricak et al.*[14] The grading system is as follows: Grade 0 indicates cortical echogenicity slightly less than that of the liver; Grade 1 signifies cortical echogenicity equivalent to the liver; Grade 2 reflects moderate increase in echogenicity with a corresponding loss of corticomedullary distinction; and Grade 3 denotes markedly increased echogenicity with complete loss of corticomedullary differentiation. Kidney with Grade 0 or 1 echogenicity is reported as normal, while Grade 2 or 3 is reported as increased echogenicity in this study. In adults, the normal kidney length and width are 12cm and 6cm, respectively; however, the length of the kidney can range from 10 – 14cm in males and 9 – 13cm in females.[15,16] The left kidney is usually slightly larger than the right.[16] In this index study, normal kidney size is defined as a kidney length of 9 to 13cm, small kidney is defined as a kidney length of < 9cm, and enlarged kidney is defined as a kidney length of > 14cm.

This study protocol received approval from the ethics and research committee of ISTH, Irrua, under protocol number ISTH/HREC/20241704606.

Statistical analysis

Data analysis was conducted using Stata 17 (StataCorp LLC, TX, USA). Continuous variables were summarised as means and standard deviations, while categorical variables were summarised as frequencies and percentages. The primary outcome variable was patient treatment outcome, which was categorised into four groups: “died”, “on follow-up”, “lost to follow-up”, and “referred”. Associations between radiological features and treatment outcomes were assessed using a chi-square test. A P-value less than 0.05 was considered statistically significant.

Results

Radiological findings are summarised in Table 1. Increased renal echogenicity was observed in 58.1% of right kidneys and 59.0% of left kidneys. Loss of corticomedullary differentiation (CMD) was seen in 34.5% and 34.2% of right and left kidneys, respectively, while CMD was preserved in approximately two-thirds of cases. The average length of the right kidney was 10.08 ± 1.48cm, while the average length of the left kidney was 10.40 ± 1.46 cm.

Table 1: Radiological findings

Variable	Frequency n=339	Percent (%)
Right kidney echogenicity		
Normal	140	41.3
Increased	197	58.1
Empty/NA	2	0.6
Right kidney CMD		
Normal/preserved	220	64.9
Loss	117	34.5
Empty/NA	2	0.6
Right kidney size		
Normal	228	67.7
Small	75	22.3
Enlarged	34	10.1
Right kidney length (Mean ± SD)	10.08 ± 1.48	
Right kidney width (Mean ± SD)	4.45 ± 0.88	
Left kidney echogenicity		
Normal	137	40.4
Increased	200	59.0
Absent/Empty/NA	2	0.6
Left kidney CMD		
Normal/preserved	221	65.2
Loss	116	34.2
Absent/Empty/NA	2	0.6
Left kidney size		
Normal	262	77.7
Small	43	12.8
Enlarged	32	9.5
Left kidney length (Mean ± SD)	10.40 ± 1.46	
Left kidney width (Mean ± SD)	4.80 ± 0.86	

CMD=Corticomedullary differentiation; SD=Standard Deviation. NA=Not Available

Radiological features were found to be significantly associated with treatment outcomes. Approximately 19% of those with increased echogenicity in the right kidneys died compared to only about 4% of those with normal echogenicity. About a quarter of those with loss of corticomedullary differentiation died, while only about 7% of those with normal corticomedullary differentiation died. A greater proportion of deaths was observed in those with reduced kidney sizes (Table 2).

Table 2: Radiological features and treatment outcome

Variable	Died n (%)	On follow-up n (%)	Lost to follow-up	Referred n (%)	χ^2	P
Right kidney echogenicity						
Normal	6 (4.3)	130 (92.9)	2 (1.4)	2 (1.4)	30.72	<0.001
Increased	38 (19.3)	133 (67.5)	11 (5.6)	15 (7.6)		
Right kidney CMD						
Normal/preserved	15 (6.9)	195 (89.0)	6 (2.7)	3 (1.4)	45.32	<0.001
Loss	29 (24.8)	68 (58.1)	7 (6.0)	13 (11.1)		
Right kidney size						
Normal	27 (11.8)	188 (82.5)	6 (2.6)	7 (3.1)	22.49	0.001
Small	15 (20.0)	48 (64.0)	3 (4.0)	9 (12.0)		
Enlarged	2 (5.9)	27 (79.4)	4 (11.8)	1 (2.9)		
Left kidney echogenicity						
Normal	5 (3.7)	127 (92.7)	2 (1.5)	3 (2.2)	29.17	<0.001
Increased	39 (19.5)	136 (68.0)	11 (5.5)	14 (7.0)		
Left kidney CMD						
Normal/preserved	15 (6.8)	196 (88.7)	6 (2.7)	4 (1.8)	44.14	<0.001
Loss	29 (25.0)	67 (57.8)	7 (6.0)	13 (11.2)		
Left kidney size						
Normal	28 (10.7)	216 (82.4)	8 (3.1)	10 (3.8)	26.17	<0.001
Small	13 (30.2)	24 (55.8)	1 (2.3)	5 (11.6)		
Enlarged	3 (9.4)	23 (71.9)	4 (12.5)	2 (6.3)		

CMD=Corticomedullary differentiation; SD=Standard Deviation

Discussion

We looked into the pattern of changes in the morphologies of the kidneys using ultrasonographic assessments and the impacts of these changes on the clinical outcomes of our patients with CKD. We focused on kidney length, cortical echogenicity and corticomedullary differentiation. Although ultrasound assessment has been reported to underestimate kidney size when compared with other radiological modalities, such as magnetic resonance imaging (MRI) and computed tomography (CT), in individuals without kidney disease, renal ultrasound scan is cheaper, safer, more readily available, and accessible; hence, it is considered the modality of choice for initial assessment of CKD.[17] This is particularly the case in resource-poor settings. Our study found that the mean lengths of the right and left kidneys were 10.08 ± 1.48 and 10.40 ± 1.46cm, respectively, which reflected that renal length is mostly preserved in the study population with CKD, and that the left kidney is slightly longer than the right kidney, as also previously reported, though in the healthy population. [16] The finding of normal kidney length in our study population is most likely due to the predominant cause of CKD in this environment, which was reported to be diabetic nephropathy. [18] Diabetic nephropathy is an established cause of CKD with either preserved kidney sizes or enlarged kidneys (relative renomegaly) in the early stage. [19] This is due to glomerular hyperfiltration, increased blood flow, and hypertrophy of the tubules. [18] The observed mean kidney size in this study may also be a reflection that many of the patients recruited were in the early stage of CKD. Despite the mean kidney sizes being found to be in the normal range, more deaths were significantly observed in CKD patients with reduced kidney sizes in this study. This observation is consistent with the findings of *Chen et al*., who specifically investigated the impact of kidney size on mortality in diabetic patients receiving peritoneal dialysis. [20] Our study was, however, not restricted to diabetic patients; there is a paucity of data in Nigeria correlating kidney size or length to outcome in patients with kidney diseases. *van der Sande et al*. investigated the relationship between eGFR (estimated glomerular filtration rate)/length and mortality and found that high eGFR/length conferred an increased risk of all-cause mortality in patients with clinically manifest vascular disease. [21] Contrary to the observation of *Chen et al*., *Wang et al*. concluded that small kidney size on starting haemodialysis was not related to an augmented risk for death in diabetic patients receiving haemodialysis. [22] Although, majority of the CKD patients in ISTH, Irrua had diabetic nephropathy as previously reported, the main renal replacement therapy (RRT) modality used was haemodialysis; our analysis was not restricted to CKD patients on RRT. [18] The difference in observations between these studies on CKD patients may be the disparities in the stages of the kidney disease in the patients evaluated, rather than the modalities of RRT or the cause of CKD. Kidney size correlates with kidney function; hence, the association of small kidney size to mortality in our study was predictable and expected, as it implied that patients with small kidney sizes had more severe or advanced renal diseases. [23] Progressive decrease in kidney size in CKD is due to kidney atrophy

from progressive scarring that affects all the structures of the kidneys, loss of nephrons, and reduced blood supply. [23] CKD is characterised by a vicious cycle of fibrosis activated after the initial renal injury from any cause. Chronic glomerulonephritis is still one of the leading causes of CKD in Nigeria.[18] It is characterised by bilaterally shrunken kidneys, and it has a poor prognosis due to late presentation in resource-poor settings. [24]

The majority of the patients in this study had increased echogenicity, and this was significantly associated with mortality. Chronic kidney disease is one of the causes of an increase in renal cortical echogenicity; some other specific causes include normal variation, renal amyloidosis, sickle cell disease, and HIV (Human Immunodeficiency Virus) nephropathy. [25] Apart from the normal variation of increased renal echogenicity, other causes listed above are also specific causes of CKD. Increased echogenicity of the kidney was reported to be most predictive of kidney dysfunction in CKD, particularly in HIV. [26] This implication of renal echogenicity was also established in the Paediatric population in a study where it was found to have a positive correlation with interstitial infiltration or fibrosis, tubular atrophy, and microalbuminuria, but a negative correlation with eGFR. [27] It was concluded that echogenicity on ultrasound was useful for determining the status of renal pathology and function. [27] *Araújo et al*. also found that the discriminative power of kidney length and cortical thickness for renal dysfunction and histological changes was improved after weighting for cortical echogenicity. [28] The findings in all these previous studies explain the significant association of increased renal cortical echogenicity and mortality in our index study. *Liborio et al*. investigated the capacity of quantitative renal echogenicity to identify irreversible advanced CKD, and concluded that this is correct in patients with glomerular disease and normal kidney size. [29] *Yaprak et al.* also found a positive correlation between eGFR and ultrasonographic CKD score calculated from kidney length, parenchymal thickness, and parenchymal echogenicity. [30] Despite all these reported correlations, however, a significant proportion of the CKD patients in our study still had normal renal echogenicity. It should also be noted that increased renal echogenicity does not always necessarily imply CKD; it can be a normal variation in some people. [25]

We assessed the renal corticomedullary differentiation in this study and also found a significant association between its loss and mortality. Loss of corticomedullary differentiation is an imaging feature where the renal cortex and medulla are not seen as different structures. It is not a reliable indicator of chronicity in kidney diseases except when combined with other parameters like renal size, echogenicity, and peculiar clinical features of the patient. [31] Infection, renal vein thrombosis, renal allograft rejection, and autosomal recessive kidney disease are some of the other conditions that can cause loss of corticomedullary differentiation. [32] Regardless, renal corticomedullary differentiation has been reported to correlate with serum creatinine in CKD, such that with worsening corticomedullary differentiation, serum creatinine has been observed to rise. [33] This implies that loss of corticomedullary differentiation correlates with progressive deterioration in kidney function in patients with CKD, and poor prognosis, hence our observation in the index study.

The limitations of the index study are the relatively short duration of follow-up, and small sample size which may have confounded our observations. We also did not factor in the renal cortical thickness which is also of clinical significance in the evaluation of kidney health.

Conclusion

The mean renal lengths measured by ultrasound in our CKD patients were within normal limits; however, small kidney sizes, increased renal cortical echogenicity, and loss of corticomedullary differentiation were significantly associated with mortality, hence indicated bad prognosis. We recommend that when these ultrasonographic features are observed in CKD patients, the nephrologist should initiate counselling for preemptive kidney transplantation.

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