JHWCR JOURNAL OF HEALTH, WELLNESS AND COMMUNITY RESEARCH 3007-0570

https://doi.org/10.61919/gxx84722

Original Article

Association of Computed Tomography Findings with Severity of Chronic Kidney Disease

Ammar[1], Mahrukh Bhullar[2], Tayyaba M. Aslam[1], Aimen Sohail Butt [1],Rafia Ali[2], Musaab Jamil[1], Hafiz Subhan Ali[1], Hassan Bin Nazar[3]

[1] Medical Imaging Technologist, University Institute of Radiological Sciences & Medical Imaging, The University of Lahore, Lahore, Pakistan
[2] Clinical Demonstrator, Operation Theatre Technologist, Department of Health Professional Technologies, The University of Lahore, Lahore, Pakistan
[3] CT Technologist, District Headquarter Hospital, Kasur, Pakistan

***Corresponding author: Mahrukh Bhullar, mahrukh.bhullar304@gmail.com**

"Cite this Article" **Received**: 05 July 2025; **Accepted**: 29 March 2026; **Published**: 15 April 2026
Author Contributions: Concept, design, data collection, analysis, and drafting: A, MB, TMA, MJ, ASB, HSA, HBN.. **Ethical Approval**: Government College University, Lahore, Pakistan. **Informed Consent**: Written informed consent was obtained from all participants; **Conflict of Interest**: The authors declare no conflict of interest. **Funding**: No external funding; **Data Availability**: Available from the corresponding author on reasonable request; **Acknowledgments**: N/A.

ABSTRACT

Background: Chronic kidney disease is a progressive disorder characterized by structural and functional renal impairment, and early imaging markers that reflect disease severity remain clinically important. Objective: To assess the association of computed tomography-derived renal morphometric parameters, cortical thickness, and cortical density with the severity of chronic kidney disease. Methods: A cross-sectional observational study was conducted on 100 patients with chronic kidney disease who underwent plain and contrast-enhanced renal CT between June 2023 and August 2024. Renal length, width, volume, cortical thickness, and cortical density were measured and compared across CKD stages using the Kruskal-Wallis test with post hoc analysis where appropriate. Results: The study included 54 males and 46 females, with a mean age of 45.88 ± 11.03 years and mean BMI of 22.74 ± 2.58 kg/m². Significant differences were observed across CKD stages for kidney length ($p = 0.000001$), kidney width ($p = 0.003401$), kidney volume ($p < 0.000001$), and cortical density ($p < 0.000001$). Median kidney length declined from 13.80 in Stage I to 7.40 in Stage III, while median kidney volume decreased from 95.00 to 50.50 over the same comparison. Cortical density increased markedly from 410.00 in Stage I to 1626.75 in Stage V. Cortical thickness did not differ significantly across stages ($p = 0.335104$). Conclusion: CT-derived renal morphometric measures and particularly cortical density were significantly associated with CKD severity, whereas cortical thickness was not. These findings suggest that quantitative CT parameters may assist in structural staging of CKD, although further validation with standardized protocols is required. Keywords: chronic kidney disease, computed tomography, cortical density, cortical thickness, renal morphometry, kidney volume

INTRODUCTION

Chronic kidney disease (CKD) represents a progressive and irreversible decline in renal function characterized by structural and functional abnormalities persisting for more than three months, often culminating in end-stage renal disease requiring dialysis or transplantation (1). Globally, CKD imposes a significant healthcare burden due to its increasing prevalence, strong association with cardiovascular morbidity, and substantial economic impact. In developing countries such as Pakistan, the prevalence is further amplified by limited healthcare infrastructure, late diagnosis, and a rising incidence of diabetes mellitus and hypertension, which are the leading etiological factors contributing to nephron loss and progressive renal dysfunction (2).

Early detection of CKD remains clinically challenging due to its largely asymptomatic course in initial stages. Conventional diagnostic approaches, including serum creatinine levels and estimated glomerular filtration rate (eGFR), often fail to detect subtle structural alterations until significant nephron damage has already occurred (3). Imaging modalities, particularly ultrasonography, have traditionally been used to assess renal morphology; however, their sensitivity in detecting early parenchymal changes and subtle cortical alterations is limited (4). Consequently, there is growing interest in advanced imaging techniques that can provide quantitative and reproducible biomarkers reflecting both structural and functional renal changes.

Computed tomography (CT) has emerged as a valuable imaging modality capable of providing high-resolution anatomical details along with quantitative assessment of tissue density. Parameters such as renal cortical thickness and cortical attenuation values measured in Hounsfield units (HU) offer insights into parenchymal integrity, vascular perfusion, and interstitial fibrosis (5).

The renal cortex, which contains the majority of glomeruli and receives approximately 90% of renal blood flow, is particularly sensitive to pathological changes associated with CKD progression (6). Alterations in cortical density during different contrast phases may reflect changes in perfusion, filtration capacity, and interstitial composition, thereby serving as potential imaging biomarkers for disease severity.

Despite these advantages, the clinical application of CT-based quantitative parameters in CKD assessment remains underexplored, particularly in correlating cortical density and morphometric parameters such as renal length, width, and volume across different stages of CKD. Existing literature has primarily focused on ultrasonographic cortical thickness or qualitative CT findings, with limited studies systematically evaluating the association between CT-derived quantitative metrics and CKD staging (7).

Furthermore, variability in imaging protocols and lack of standardized measurement techniques have contributed to inconsistent findings, highlighting the need for more robust and methodologically sound investigations.

Given these gaps, there is a need to evaluate the diagnostic and prognostic utility of CT-derived renal parameters in CKD patients using standardized imaging protocols and appropriate statistical analysis. This study aims to assess the association between renal cortical density, cortical thickness, and morphometric parameters with the severity of CKD, thereby exploring their potential role as imaging biomarkers for disease staging and clinical decision-making. It is hypothesized that CT-derived cortical density and renal morphometric parameters demonstrate significant variation across CKD stages and may serve as reliable indicators of disease severity.

MATERIALS AND METHODS

This study was conducted as a cross-sectional observational analysis to evaluate the association between computed tomography-derived renal parameters and the severity of chronic kidney disease. The study was carried out in the Department of Medical Imaging at a tertiary care hospital over a period extending from June 2023 to August 2024. A total of 100 patients diagnosed with CKD based on established clinical and biochemical criteria, including reduced estimated glomerular filtration rate (eGFR < 60 mL/min/1.73 m^2) persisting for more than three months, were consecutively enrolled.

Participants were included if they were adults aged 18 years or older with confirmed CKD across stages I to V. Patients with a history of renal malignancy, congenital renal anomalies, acute kidney injury, prior renal surgery, or contraindications to contrast media were excluded to avoid confounding structural alterations. Recruitment was performed through outpatient and inpatient nephrology services, and all participants provided informed consent prior to inclusion in the study.

All patients underwent computed tomography scanning using a standardized 64-slice multidetector CT scanner. Imaging was performed in both non-contrast and contrast-enhanced phases following intravenous administration of iodinated contrast material. Scans were acquired during cortical, nephrographic, and excretory phases to ensure comprehensive evaluation of renal parenchymal characteristics. Imaging parameters were standardized across all participants, including tube voltage, current modulation, slice thickness, and acquisition timing, to ensure reproducibility and minimize technical variability.

Renal morphometric parameters, including kidney length, width, and volume, were measured using multiplanar reconstruction techniques. Cortical thickness was measured at standardized anatomical points perpendicular to the renal capsule, avoiding areas of focal scarring or distortion.

Cortical density was quantified in Hounsfield units (HU) by placing region-of-interest (ROI) measurements within the renal cortex during the cortical phase, ensuring exclusion of medullary tissue, vessels, and cystic areas. Measurements were obtained bilaterally, and mean values were calculated to improve reliability.

The primary outcome variables included renal cortical density, cortical thickness, and kidney dimensions (length, width, and volume), while the primary independent variable was CKD stage categorized according to established clinical staging criteria. Demographic variables such as age, gender, and body mass index (BMI) were also recorded and analyzed as potential confounders.

To minimize measurement bias, all imaging assessments were performed by experienced radiologists who were blinded to the clinical stage of CKD. Standardized measurement protocols were followed, and repeated measurements were conducted in a subset of cases to ensure intra-observer consistency. Potential confounding variables were addressed through stratified analysis and appropriate statistical adjustments.

Sample size was determined based on feasibility and the ability to detect statistically significant differences across CKD stages with adequate power. Statistical analysis was performed using SPSS software (version XX). Continuous variables were expressed as mean ± standard deviation or median with interquartile range, depending on data distribution.

The Kruskal–Wallis test was used to compare renal parameters across CKD stages, followed by post-hoc pairwise comparisons using the Conover method. Correlation analysis was conducted using Pearson or Spearman coefficients as appropriate. A p-value of less than 0.05 was considered statistically significant, and where applicable, confidence intervals were calculated to quantify the precision of estimates.

Ethical approval for the study was obtained from the institutional review board, and all procedures were conducted in accordance with the principles outlined in the Declaration of Helsinki. Data integrity was ensured through standardized data collection forms, double-entry verification, and secure storage of patient information. The study methodology was designed to ensure reproducibility by adhering to consistent imaging protocols, clearly defined measurement techniques, and transparent statistical analysis procedures.

RESULTS

A total of 100 patients with chronic kidney disease were included in the analysis. Of these, 54 were male and 46 were female. The overall age ranged from 26 to 78 years, with a mean age of 45.88 years, median 45.00 years, and standard deviation of 11.03 years.

Body mass index ranged from 18.0 to 29.0 kg/m^2, with a mean of 22.74 kg/m^2, median 23.00 kg/m^2, and standard deviation of 2.58 kg/m^2. Across CKD stages, statistically significant differences were observed for average kidney length, average kidney width, average kidney volume, and average cortical density, whereas average kidney cortical thickness did not differ significantly between stages.

The study included 100 patients with CKD, comprising 54.0% males and 46.0% females, with a mean age of 45.88 ± 11.03 years and mean BMI of 22.74 ± 2.58 kg/m^2. Renal morphometric analysis showed that average kidney length differed significantly across CKD stages (Ht = 34.6885, p = 0.000001), with the highest median value observed in Stage I at 13.80 and the lowest in Stage III at 7.40, indicating a marked reduction in length with advancing disease, particularly between early and mid-stage CKD. Average kidney width also differed significantly (Ht = 15.7317, p = 0.003401), with median values of 5.95 in Stage I, 6.73 in Stage II, 5.75 in Stage III, 6.58 in Stage IV, and 6.95 in Stage V, suggesting nonuniform dimensional changes across disease stages.

Table 1. Baseline Demographic Characteristics of the Study Population

Variable	n	Minimum	Maximum	Mean	Median	SD
Age (years)	100	26.00	78.00	45.88	45.00	11.03
BMI (kg/m²)	100	18.00	29.00	22.74	23.00	2.58

Table 2. Gender Distribution of the Study Population

Gender	Frequency	Percentage
Female	46	46.0
Male	54	54.0
Total	100	100.0

Table 3. Average Kidney Length Across CKD Stages

CKD Stage	n	Minimum	25th Percentile	Median	75th Percentile	Maximum	Average Rank	Overall p-value
I	21	5.90	12.09	13.80	15.00	18.00	71.14	<0.001
II	36	6.30	10.50	11.80	12.95	16.00	59.93	<0.001
III	31	6.05	6.68	7.40	8.09	14.50	27.47	<0.001
IV	4	6.05	8.25	10.48	11.15	11.80	38.50	<0.001
V	8	7.70	9.13	10.93	11.30	13.80	49.13	<0.001

Kruskal–Wallis test: Ht = 34.6885, df = 4, p = 0.000001 Post hoc (Conover): Significant differences were reported between Stage I vs III, IV, and V; Stage II vs III; Stage III vs I, II, and V; Stage IV vs I; and Stage V vs I and III.

Table 4. Average Kidney Width Across CKD Stages

CKD Stage	n	Minimum	25th Percentile	Median	75th Percentile	Maximum	Average Rank	Overall p-value
I	21	5.00	5.60	5.95	6.55	7.55	45.62	0.003
II	36	4.90	5.73	6.73	10.15	12.05	59.22	0.003
III	31	5.10	5.41	5.75	6.35	10.75	36.76	0.003
IV	4	5.85	6.18	6.58	7.05	7.45	61.25	0.003
V	8	6.45	6.63	6.95	7.23	8.80	71.94	0.003

Kruskal–Wallis test: Ht = 15.7317, df = 4, p = 0.003401 Post hoc (Conover): Significant differences were reported between Stage I vs V, Stage II vs III, and Stage III vs II and V.

Table 5. Average Kidney Volume Across CKD Stages

CKD Stage	n	Minimum	25th Percentile	Median	75th Percentile	Maximum	Average Rank	Overall p-value
I	21	37.00	84.25	95.00	110.25	133.50	62.17	<0.001
II	36	41.50	78.25	90.75	130.25	197.50	63.90	<0.001
III	31	41.50	46.63	50.50	63.75	90.50	24.47	<0.001
IV	4	47.00	60.00	78.00	91.50	100.00	44.88	<0.001
V	8	70.00	81.00	91.00	110.50	118.50	63.25	<0.001

Kruskal–Wallis test: Ht = 37.7395, df = 4, p < 0.000001 Post hoc (Conover): Significant differences were reported between Stage III vs I, II, and V.

Table 6. Average Kidney Cortical Thickness Across CKD Stages

CKD Stage	n	Minimum	25th Percentile	Median	75th Percentile	Maximum	Average Rank	Overall p-value
I	21	3.85	4.89	5.25	5.53	5.90	50.57	0.335
II	36	4.15	5.03	5.25	5.38	6.20	43.72	0.335
III	31	4.55	5.16	5.30	5.45	5.55	55.26	0.335
IV	4	4.70	5.00	5.30	5.33	5.35	47.50	0.335
V	8	4.90	5.20	5.40	5.55	5.70	63.87	0.335

Kruskal–Wallis test: Ht = 4.5633, df = 4, p = 0.335104 No statistically significant difference in cortical thickness was identified across CKD stages.

Table 7. Average Cortical Density Across CKD Stages

CKD Stage	n	Minimum	25th Percentile	Median	75th Percentile	Maximum	Average Rank	Overall p-value
I	21	31.50	43.13	410.00	673.75	881.00	25.19	<0.001
II	36	87.00	172.50	417.75	745.00	1054.00	32.15	<0.001
III	31	840.00	1027.50	1125.00	1169.63	1350.00	71.92	<0.001
IV	4	1421.50	1519.25	1631.25	1681.50	1717.50	94.75	<0.001
V	8	1551.00	1608.75	1626.75	1635.00	1875.00	94.37	<0.001

Kruskal–Wallis test: Ht = 74.8913, df = 4, p < 0.000001 Post hoc (Conover): Significant differences were reported between Stage I vs III, IV, and V; Stage II vs III, IV, and V; Stage III vs I, II, IV, and V; Stage IV vs I, II, and III; and Stage V vs I, II, and III.

Kidney volume demonstrated one of the clearest stage-wise differences (Ht = 37.7395, p < 0.000001), with Stage III showing the lowest median volume at 50.50 compared with 95.00 in Stage I, 90.75 in Stage II, and 91.00 in Stage V. In contrast, cortical thickness remained relatively stable, with median values ranging only from 5.25 to 5.40 across all stages and no statistically significant difference (Ht = 4.5633, p = 0.335104). The strongest association with CKD severity was observed for cortical density, which increased sharply from a median of 410.00 in Stage I and 417.75 in Stage II to 1125.00 in Stage III, 1631.25 in Stage IV, and 1626.75 in Stage V (Ht = 74.8913, p < 0.000001), indicating that cortical density may have greater discriminatory value across CKD stages than cortical thickness.

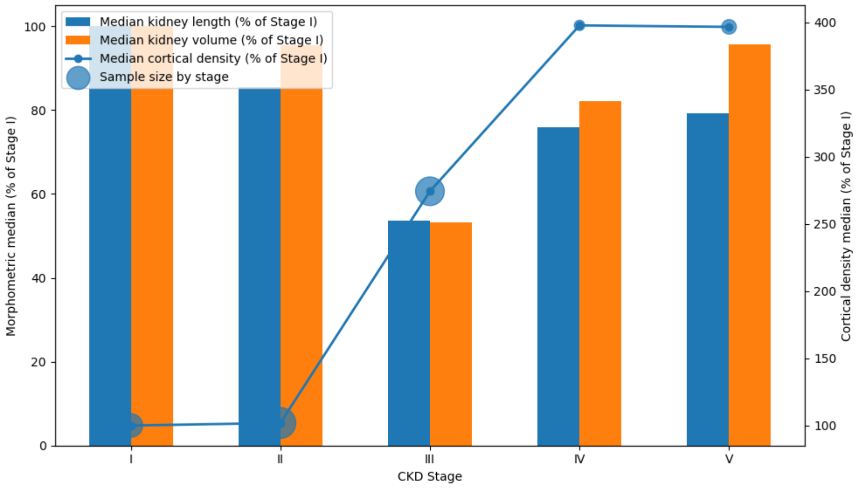

Figure 1 Stage-wise Divergence of Renal Morphometry and Cortical Density in Chronic Kidney Disease

Relative to Stage I, median kidney length declined from 100.0% to 85.5% in Stage II and reached its lowest level at 53.6% in Stage III before partially recovering to 75.9% in Stage IV and 79.2% in Stage V. Median kidney volume showed a similar but less pronounced pattern, falling from 100.0% in Stage I to 95.5% in Stage II and 53.2% in Stage III, then rising to 82.1% in Stage IV and 95.8% in Stage V. In contrast, median cortical density increased sharply, from 100.0% in Stage I to 101.9% in Stage II, 274.4% in Stage III, 397.9% in Stage IV, and 396.8% in Stage V. This divergence indicates that the most marked morphometric contraction occurred at Stage III, while cortical density demonstrated a steep escalation from Stage III onward, suggesting that density-based CT changes may discriminate CKD severity more strongly than cortical thickness or raw dimensional measures alone. Bubble size reflects stage sample size and shows that these trends were driven mainly by Stages II and III, whereas Stage IV estimates should be interpreted cautiously because only four patients were included.

DISCUSSION

The present study demonstrated that several CT-derived renal parameters varied significantly across CKD stages, with the most prominent differences observed in kidney length, kidney width, kidney volume, and cortical density, whereas cortical thickness did not show a statistically significant stage-wise difference. Among the morphometric variables, median kidney length declined from 13.80 in Stage I to 7.40 in Stage III, while median kidney volume decreased from 95.00 in Stage I to 50.50 in Stage III, indicating a substantial reduction in renal size with disease progression. These findings are consistent with the established concept that progressive nephron loss, interstitial fibrosis, tubular atrophy, and parenchymal scarring contribute to a reduction in renal dimensions as renal impairment advances (8,9). The significant reduction in kidney length across stages, particularly between Stages I and III, supports the utility of renal size as a surrogate structural marker of chronic parenchymal damage, although the partial increase in later-stage medians in the present dataset suggests that dimensional change in CKD may not always follow a perfectly linear pattern and may be influenced by underlying etiology, edema, compensatory remodeling, or sample heterogeneity.

Renal cortical thickness has traditionally been considered an imaging correlate of nephron mass and residual renal function, especially on ultrasonography. Previous studies have reported that cortical thickness may outperform total renal length in reflecting functional impairment because it more directly represents preserved cortical parenchyma (10–12). In the present analysis, however, cortical thickness remained relatively stable across CKD stages, with medians ranging from 5.25 to 5.40 and an overall p-value of 0.335104. This lack of statistical significance suggests that cortical thickness alone may have limited discriminatory value for stage-wise CKD stratification in this sample. One possible explanation is that cortical thinning may occur gradually and with substantial overlap between stages, reducing its sensitivity in cross-sectional comparisons. In addition, variations in measurement plane, corticomedullary boundary definition, and focal parenchymal irregularity may reduce precision when subtle cortical differences are being assessed. Therefore, although cortical thickness remains clinically relevant, the current findings suggest that it should not be interpreted in isolation when evaluating CKD severity.

In contrast, cortical density showed the strongest association with CKD stage, rising markedly from median values of 410.00 and 417.75 in Stages I and II to 1125.00 in Stage III and more than 1600 in Stages IV and V. Statistically, this was the most robust parameter in the dataset, with a Kruskal-Wallis p-value below 0.000001 and multiple significant pairwise differences across early, intermediate, and advanced stages. This pattern suggests that CT-based cortical attenuation may capture parenchymal alterations that are less readily appreciated through gross morphometric measurements. Previous CT-based work has shown that renal parenchymal attenuation and enhancement behavior may reflect perfusion characteristics, cortical blood flow, and the degree of tissue remodeling or fibrosis, thereby offering a quantitative index of renal injury severity (13,14). Because the renal cortex receives the majority of renal blood flow and contains most glomeruli, changes in cortical enhancement and density may plausibly parallel deterioration in filtration dynamics and microvascular integrity. On that basis, the present findings support the potential role of cortical density as a more sensitive CT-derived marker of CKD severity than cortical thickness, although the reported magnitude of the density values should be rechecked against the raw imaging data before final publication to exclude unit or transcription errors.

The behavior of kidney width and volume in this study also deserves consideration. Median kidney width was lowest in Stage III at 5.75 and highest in Stage V at 6.95, while kidney volume similarly dropped most in Stage III before rising again in later stages. Although the overall differences were statistically significant, this non-monotonic pattern indicates that renal morphometry in CKD may be influenced by more than stage alone. Etiological differences such as diabetic kidney disease, obstructive nephropathy, inflammatory changes, or volume-related parenchymal expansion may produce variable structural appearances despite comparable biochemical severity (15). In this context, reliance on a single linear model of size reduction may oversimplify disease behavior. Rather, the combination of declining length, altered volume distribution, and markedly rising cortical density may provide a more informative multidimensional picture of CKD-related structural change than any individual variable considered alone.

From a clinical perspective, these findings suggest that CT can contribute more than descriptive anatomical assessment in CKD. Quantitative extraction of renal morphometric and density-based markers may assist in disease stratification, support the interpretation of equivocal clinical findings, and potentially improve the radiologic characterization of chronic renal injury. This is particularly relevant when conventional laboratory markers do not fully reflect the extent of structural damage or when cross-sectional imaging is already being performed for another clinical indication. However, CT-based assessment must also be interpreted cautiously in view of contrast exposure, radiation burden, and variability in acquisition protocols. The literature has emphasized that contrast-enhanced CT in patients with impaired renal function requires careful risk-benefit evaluation, particularly in those with severely reduced eGFR, although more recent work suggests that the actual risk of contrast-associated injury may be lower than historically assumed when appropriate precautions are used (16,17). Accordingly, any proposed use of CT-derived biomarkers in CKD should be positioned within a selective and clinically justified imaging framework rather than as a routine screening tool.

The present study has several limitations that should be acknowledged. First, the cross-sectional design precludes causal inference and limits interpretation to association rather than prediction of CKD progression. Second, the distribution across CKD stages was uneven, with only four patients in Stage IV and eight in Stage V, which reduces the stability and generalizability of estimates for advanced disease. Third, the absence of multivariable adjustment means that potential confounders such as diabetes duration, hypertension severity, hydration status, and CKD etiology could not be fully accounted for. Fourth, the study relied on imaging-derived measurements without reporting interobserver variability, which is important for assessing reproducibility. Finally, although cortical density emerged as the strongest differentiating parameter, the absolute values reported appear unusually high for standard attenuation measurements and should therefore be validated against the original scanner output and region-of-interest methodology before definitive interpretation. Despite these limitations, the study provides useful preliminary evidence that CT-derived cortical density and renal morphometric variables may reflect CKD severity and may warrant further evaluation in larger, methodologically standardized cohorts.

Future studies should adopt longitudinal designs, include balanced stage-wise sampling, integrate biochemical and radiologic endpoints, and report reproducibility measures for ROI placement and morphometric analysis. Standardized CT acquisition parameters and clearly defined measurement protocols will be necessary to determine whether cortical density can be translated into a robust imaging biomarker for clinical use. Comparative studies against ultrasonographic cortical thickness, MRI-based fibrosis markers, and functional renal outcomes would further clarify where CT-derived measurements add the greatest diagnostic value. If validated, these quantitative parameters may help bridge the gap between structural imaging and functional disease assessment in chronic kidney disease.

CONCLUSION

CT-derived renal parameters demonstrated meaningful associations with CKD severity in this study, with kidney length, kidney width, kidney volume, and especially cortical density showing significant stage-wise differences, whereas cortical thickness did not vary significantly across stages. The marked increase in cortical density alongside reductions in renal length and volume suggests that CT may provide quantitative structural information relevant to disease stratification beyond routine morphologic assessment. Although these findings support the potential value of cortical density and renal morphometry as imaging markers of CKD severity, further studies with larger samples, standardized measurement protocols, and validated attenuation data are required before these parameters can be recommended for broader clinical application.

REFERENCES

1. Hori S, Takata T, Sugihara T, Ida A, Ogawa M, Mae Y, et al. Predictive value of cortical thickness measured by ultrasonography for renal impairment: a longitudinal study in chronic kidney disease. J Clin Med. 2018;7(12):527.

2. Yamashita SR, Atzingen ACV, Iared W, Bezerra ASDA, Ammirati AL, Canziani MEF, et al. Value of renal cortical thickness as a predictor of renal function impairment in chronic renal disease patients. Radiol Bras. 2015;48:12-16.

3. Korkmaz M, Aras B, Güneyli S, Yılmaz M. Clinical significance of renal cortical thickness in patients with chronic kidney disease. Ultrasonography. 2018;37(1):50-4.

4. Beland MD, Walle NL, Machan JT, Cronan JJ. Renal cortical thickness measured at ultrasound: is it better than renal length as an indicator of renal function in chronic kidney disease? AJR Am J Roentgenol. 2010;195(2):W146-51.

5. Higgins CB, Higgins BA. MRI and CT of the cardiovascular system. Philadelphia: Lippincott Williams & Wilkins; 2010.

6. Kidney Disease: Improving Global Outcomes. Clinical practice guideline for the evaluation and management of chronic kidney disease. Kidney Int Suppl. 2013;3(1):1-150.
7. Webb WR, Brant WE, Major NM. Fundamentals of body CT. Philadelphia: Elsevier Health Sciences; 2014.
8. Brown PA, Akbari A, Molnar AO, Taran S, Bissonnette J, Sood M, et al. Factors associated with unplanned dialysis starts in patients followed by nephrologists: a retrospective cohort study. PLoS One. 2015;10(6):e0130080.
9. Saade C, Deeb IA, Mohamad M, Al-Mohiy H, El-Merhi F. Contrast medium administration and image acquisition parameters in renal CT angiography: what radiologists need to know. Diagn Interv Radiol. 2016;22(2):116-23.
10. Cohen EP, Olson JD, Tooze JA, Bourland JD, Dugan GO, Cline JM. Detection and quantification of renal fibrosis by computerized tomography. PLoS One. 2020;15(2):e0228626.
11. Kaufman DP, Basit H, Knohl SJ. Physiology, glomerular filtration rate. Treasure Island (FL): StatPearls Publishing; 2018.
12. Schrauben SJ, Jepson C, Hsu JY, Wilson FP, Zhang X, Lash JP, et al. Insulin resistance and chronic kidney disease progression, cardiovascular events, and death: findings from the chronic renal insufficiency cohort study. BMC Nephrol. 2019;20:1-11.
13. Hajjari J, Janus SE, Albar Z, Al-Kindi SG. Myocardial injury and the risk of stroke in patients with chronic kidney disease (from the chronic renal insufficiency cohort study). Angiology. 2022;73(4):312-7.
14. Zelnick LR, Shlipak MG, Soliman EZ, Anderson A, Christenson R, Lash J, et al. Prediction of incident atrial fibrillation in chronic kidney disease: the chronic renal insufficiency cohort study. Clin J Am Soc Nephrol. 2021;16(7):1015-24.
15. Knutson KL, Lash J, Ricardo AC, Herdegen J, Thornton JD, Rahman M, et al. Habitual sleep and kidney function in chronic kidney disease: the chronic renal insufficiency cohort study. J Sleep Res. 2018;27(2):283-91.
16. Dorans KS, He H, Chen J, Dobre M, Go AS, Hamm LL, et al. Change in ankle-brachial index and mortality among individuals with chronic kidney disease: findings from the chronic renal insufficiency cohort study. Nephrol Dial Transplant. 2021;36(12):2224-31.
17. Janus SE, Hajjari J, Al-Kindi S. High-sensitivity troponin and the risk of atrial fibrillation in chronic kidney disease: results from the chronic renal insufficiency cohort study. Heart Rhythm. 2020;17(2):190-4.
18. Wang Z, Xu X, Liu Y, Gao Y, Kang F, Liu B, Wang J. Assessment of the aging of the brown adipose tissue by 18F-FDG PET/CT imaging in the progeria mouse model Lmna−/−. Contrast Media Mol Imaging. 2018;2018:8327089.
19. Grunwald JE, Pistilli M, Ying GS, Daniel E, Maguire M, Xie D, et al. Association between progression of retinopathy and concurrent progression of kidney disease: findings from the chronic renal insufficiency cohort study. JAMA Ophthalmol. 2019;137(7):767-74.
20. Nagai K, Yamagata K, Iseki K, Moriyama T, Tsuruya K, Fujimoto S, et al. Antihypertensive treatment and risk of cardiovascular mortality in patients with chronic kidney disease diagnosed based on the presence of proteinuria and renal function: a large longitudinal study in Japan. PLoS One. 2019;14(12):e0225812.

21. Giglio J, Kamimura MA, Souza NC, Bichels AV, Cordeiro AC, Pinho N, et al. Muscle mass assessment by computed tomography in chronic kidney disease patients: agreement with surrogate methods. Eur J Clin Nutr. 2019;73(1):46-53.

22. Agarwal R, Rossignol P, Romero A, Garza D, Mayo MR, Warren S, et al. Patiromer versus placebo to enable spironolactone use in patients with resistant hypertension and chronic kidney disease (AMBER): a phase 2, randomised, double-blind, placebo-controlled trial. Lancet. 2019;394(10208):1540-50.

23. Sharma AK, Toussaint ND, Elder GJ, Masterson R, Holt SG, Robertson PL, et al. Magnetic resonance imaging based assessment of bone microstructure as a non-invasive alternative to histomorphometry in patients with chronic kidney disease. Bone. 2018;114:14-21.