Journal of Cardiovascular Disease Research

ISSN: 0975-3583, 0976-2833 VOL14, ISSUE 07, 2023

Intra-Renal Arterial Resistance and its Association with Different Stages of Chronic Kidney Disease; A Cross Sectional Study

Dr. Neethu Nandan M.[1], Dr. Anjali Dathan [2], Dr. Sinni K.V. [3], Dr. M.N. Brahmadathan[4]

[1]Postgraduate Student, Department of Radiodiagnosis, Government Medical College, Thrissur, Kerala, India.
[2]Associate Professor and HOD, Department of Radiodiagnosis, Government Medical college (IIMS), Palakkad, Kerala, India.
[3]Associate Professor, Department of Radiodiagnosis, Government Medical college, Thrissur, Kerala, India.
[4]Former Professor and HOD, Department of Radiodiagnosis, Government Medical College, Thrissur, Kerala, India.

Corresponding Author:Dr. Anjali Dathan,

Article History: **Received:** 12.05.2023 **Revised:**15.06.2023 **Accepted:** 25.07.2023

ABSTRACT

Background

This study was conducted to analyze the association between intrarenal arterial resistive index (RI) measured using renal duplex ultrasonography and different stages of chronic kidney disease (CKD), thereby assessing its ability to predict the severity of CKD.

Methods

This was a hospital-based cross sectional analysis conducted among 100 patients (age >18 years) diagnosed to have CKD at the National Kidney Foundation, Government Medical College, Thrissur, from August 2017 to June 2019 after obtaining clearance from the institutional ethics committee and written informed consent from the study participants.

Results

The mean RI measured was 0.53, 0.56, 0.66, 0.74 and 0.91 from stage 1 to stage 5 respectively. A positive correlation was found between rising RI and the progression of CKD stages, and the association was found to be statistically significant ($p<0.001$).

Conclusion

RI can be used as a valuable sonological marker in predicting the severity of CKD, thereby helping in the early detection of high-risk patients.

Keywords: Intra-Renal Arterial Resistance, Association, Different Stages of Chronic Kidney Disease.

INTRODUCTION

Chronic kidney disease (CKD) is a worldwide public health problem, both in terms of the number of patients and the cost of treatment involved. Globally, CKD is the 12th cause of death and the 17th cause of disability respectively. The approximate prevalence of CKD in India is 800 per million and the incidence of end stage renal disease is 150-200 per million populations.[1] CKD is defined as kidney damage >3 months, as defined by structural or functional abnormalities of the kidney with or without decreasing GFR, manifested by either pathological abnormalities or markers of kidney damage including abnormalities in the composition of blood or urine or abnormalities in the imaging tests. 2. GFR <60 mL/min/1.73 m^2 for >3 months with or without kidney damage.[2] Diabetes and hypertension cause up to two-thirds of CKD[3] Less common causes include glomerulonephritis, nephrolithiasis, and polycystic kidney disease. In a small proportion of cases, progressive kidney damage leads to end-stage renal disease (ESRD). ESRD patients require dialysis or kidney transplantation to survive. The rate of CKD progression varies between patients depending on disease etiology and pathology.[4,5] Ultrasound is the ideal imaging modality in CKD because of its non-invasiveness and because it provides easy accessibility and visualization of the kidneys. It can be done

ISSN: 0975-3583, 0976-2833 VOL14, ISSUE 07, 2023

at the bedside to provide clinicians with important anatomical details of the kidney with low interobserver variability.[6] The safety of the diagnostic procedure using ultrasound is well established. Sonography identifies the renal length, thickness, and echogenicity of renal parenchyma apart from its importance in detailing a dilated collecting system.[7] These details assist in identifying the extent of the renal parenchymal damage[8], the possibility of its reversibility and the decision to perform a renal biopsy.[9] According to a study, abnormal sonographic findings were seen in 67% of cases of CKD.[10]Renal doppler ultrasonography can detect not only renal macro abnormalities but also changes in the renal vasculature and blood flow. The RI (Resistive Index) is commonly used as an index of intra renal arterial resistance. Progressive chronic renal failure is believed to results in a reduction in the number and area of post glomerular capillaries. Renal scarring ultimately leads to a reduction in the intrarenal vessel area which in turn may be responsible for an increased intra renal vascular resistance. RI increases in various kidney diseases[11-19] and previous studies have shown the association of RI with renal function and patient prognosis.[20-26] The relationship between renal histological changes in CKD and RI has been investigated previously. Glomerulosclerosis,[27] tubulointerstitial damage[28] and vascular lesions have been reported to correlate with an increase in RI. The serum creatinine level is an endogenous marker that is commonly used to estimate GFR and accordingly the stage of CKD. eGFR derived from the formula such as the MDRD (Modification of Diet in Renal Disease) equation is superior to serum creatinine alone in the diagnosis of CKD.[29] By calculating eGFR the reserved renal function and in turn the severity of the patient can be evaluated.[30]

There are studies showing changes in renal echogenicity with different stages of CKD, but there is a scarcity of literature regarding the variation of RI in different stages of CKD. Our study was conducted to find out if there is a significant link between the resistive index in renal duplex ultrasonography and different stages of CKD and if this parameter can be used to measure the severity of CKD.

Aims and Objectives

To analyze the association between intrarenal arterial resistive index (RI) measured using renal duplex ultrasonography and different stages of chronic kidney disease (CKD), thereby assessing its ability to predict the severity of CKD.

METHODS

This was a hospital-based cross sectional analysis study conducted among 100 patients (age >18 years) diagnosed to have CKD at the National Kidney Foundation, Government Medical College, Thrissur, from August 2017 to June 2019 after obtaining clearance from the institutional ethics committee and written informed consent from the study participants.

Inclusion Criteria

The ethical committee of our institution approved this cross-sectional study. According to the National Kidney Foundation's standards, 100 people over the age of 18 who were clinically diagnosed with CKD (calculated by using the Cockcroft-Gault equation) between August 2017 and June 2019 at Government Medical College, Thrissur, were included in the study.

Exclusion Criteria

Patients with hepatic illness diagnosed by ultrasonography, those receiving hemodialysis, peritoneal dialysis, renal transplant patients, patients with renal tumours (both primary and secondary), and patients with hepatic disease. The detailed medical history of patients, including their age, duration of diabetes mellitus if diabetic, duration of hypertension if hypertensive, other causes of chronic renal failure, and treatment history. The most recent serum creatinine values were noted.

Statistical Methods

Data was entered in MS Excel and analyzed using SPSS software. Results were presented as tables.

RESULTS

ISSN: 0975-3583, 0976-2833 VOL14, ISSUE 07, 2023

H/O	No. of Cases	%
DM	43	43.0
HT	26	26.0
DM, HT	18	18.0
None	13	13.0
Total	**100**	**100.0**

Table 1: Medical History

The most commonly known cause of CKD in these patients was diabetes mellitus, which was seen in 43 cases (43%) followed by hypertension in 26 cases (26%), and diabetes and hypertension together in 18% of the cases. No provisional cause was made in 13% of the cases.

CKD Stage	Mean RI	SD	Min	Max	Anova F	P-Value
1	0.53	0.05	0.48	0.68	246.24	< 0.001, HS
2	0.56	0.06	0.48	0.69		
3	0.66	0.04	0.5	0.7		
4	0.74	0.04	0.64	0.79		
5	0.91	0.03	0.86	0.96		
Total	**0.68**	**0.14**	**0.48**	**0.96**		

One Way ANOVA

Stage Compared	Mean Diff.	P-Value
1-2	0.03	0.45, ns
1-3	0.13	0.00**
1-4	0.20	0.00**
1-5	*0.38*	0.00**
2-3	*0.10*	0.00**
2-4	*0.18*	0.00**
2-5	*0.35*	0.00**
3-4	*0.08*	0.00**
3-5	*0.25*	0.00**
4-5	*0.17*	0.00**

Post-hoc Tukey's Test

Table 2: Resistive Index in Relation to CKD and Stage Wise Comparison

The mean RI values were 0.53 for stage 1 CKD, 0.56 for stage 2, 0.66 for stage 3, 0.74 for stage 4 and 0.91 for stage 5. A statistically significant positive correlation was seen between the CKD stages and the resistive index. As the CKD stage advanced there was an increase in the resistive index(p=<0.001). Between CKD stages 1 and 2, no significant change in RI was observed(p=0.45).

CKD Stage	Mean Length (cm)	SD	Min	Max	Anova F	P-Value
1	9.59	0.69	8.3	11	87.48	< 0.001, HS
2	9.41	0.63	8.3	11		
3	8.81	0.62	7.4	9.7		
4	8.86	0.67	7.4	7.3		
5	6.26	0.58	5.2	7.3		
Total	**8.54**	**1.36**	**5.2**	**11**		

One Way ANOVA

Stages Compared	Mean Diff.	P-Value
1-2	0.03	0.91, ns
1-3	0.13	0.002*
1-4	0.20	0.00**
1-5	*0.38*	0.00**

ISSN: 0975-3583, 0976-2833 VOL14, ISSUE 07, 2023

2-3	*0.10*	0.03**
2-4	*0.18*	0.005**
2-5	*0.35*	0.00**
3-4	*0.08*	0.94. ns
3-5	*0.25*	0.00**
4-5	*0.17*	0.00**
Post-hoc Tukey's Test		

Table 3: Renal length in Relation to CKD Stages and Stage Wise Comparison

The mean renal lengths were 9.59cm for stage 1 CKD, 9.4 cm for stage 2,8.8cm for stage 3,8.6cm for stage 4 and 6.26cm for stage 5. The average kidney length measured in the present study was 8.5cm (range = 5.2cm to 11cm; SD=1.36 cm). The kidneys were small in all patients with stage 5 CKD. A statistically significant positive correlation was observed between CKD stage and mean renal length($p<0.001$). As the stage increased, there was a reduction in renal length. The size of the kidney was significantly reduced in patients with stage 5 CKD compared with other stages. However, no statistically significant reduction in renal length occurred as the CKD stage advanced from stage 1 to stage 2 and stage 3 to stage 4.

CKD Stage	**Mean PT (mm)**	**SD**	**Min**	**Max**	**Anova F**	**P-Value**
1	16.99	0.81	15.0	18.0	12.06	< 0.001, HS
2	16.56	1.07	14.0	18.0		
3	15.15	1.04	13.0	16.0		
4	14.91	2.02	10.0	18.0		
Total	15.90	1.57	10.0	18.0		
One Way ANOVA						
Stages Compared		**Mean Diff.**			**P-Value**	
1-2		0.43			0.73, ns	
1-3		1.84			0.00**	
1-4		2.08			0.00**	
2-3		*1.41*			0.007**	
2-4		*1.65*			0.002**	
3-4		*0.25*			0.94. ns	
Post-hoc Tukey's Test						

Table 4: Parenchymal Thickness Interrelation to CKD Stages and Stage Wise Comparisons

The mean parenchymal thickness obtained in the present study was 15.9mm (range=10mm to 18mm, SD=1.57mm). A statistically significant positive correlation was observed between CKD stage and parenchymal thickness ($p=<0.001$). As the stage of CKD advanced, there was a decrease in the parenchymal thickness. However, no statistically significant reduction in parenchymal thickness occurred as the CKD stage advanced from stage 1 to stage 2 and stage 3 to stage 4.

CKD Stage	**Mean CT (mm)**	**SD**	**Min**	**Max**	**Anova F**	**P-Value**
1	6.92	0.69	6.0	8.0	6.73	< 0.001, HS
2	7.44	0.94	6.0	9.0		
3	6.65	1.02	5.0	8.7		
4	6.17	0.96	4.0	8.0		
Total	6.79	1.00	4.0	9.0		
One Way ANOVA						
Stages Compared		**Mean Diff.**			**P-Value**	
1-2		0.43			0.28, ns	
1-3		1.84			0.78, ns	
1-4		2.08			0.05*	
2-3		1.41			0.04*	

ISSN: 0975-3583, 0976-2833 VOL14, ISSUE 07, 2023

2-4	1.65	0.00**
3-4	0.25	0.36, ns
Post-hoc Tukey's Test		

Table 5: Cortical Thickness in Relation to CKD Stages and Stage Wise Comparisons

The mean cortical thickness obtained in the present study was 6.79mm (range: 4mm to 9mm, SD=1mm). A statistically significant positive correlation was observed between CKD stage and cortical thickness (p=<0.001). As the stage of CKD advanced, there was a decrease in cortical thickness. However, no statistically significant reduction in parenchymal thickness occurred as the CKD stage advanced from stage 1 to stage 2 and stage 3 to stage 4.

DISCUSSION

The burden of CKD has dramatically increased and is consuming the resources of both developed and developing economies. For this reason, efforts to reduce the cost of managing this disease are always appreciated.

In the present study, we evaluated the correlation between various ultrasonographic indices such as renal echogenicity, renal length, renal parenchymal thickness, cortical thickness and resistive index with various stages of CKD.

RI in CKD patients is considered as a marker of renal dysfunction. It has been reported that RI can be a useful predictor of the progression of renal dysfunction.[31,32] RI can be increased by extrinsic factors such as kidney compression, breath holding during the Valsalva maneuver and extreme bradycardia. RI values are also correlated with extrarenal markers of vascular stiffness, indicating that RI might not be an ideal test for renal disease.[33] Nevertheless, RI can provide diagnostic information for several renal diseases. A RI value exceeding 0.80 is associated with a reduced likelihood of improved renal function after the correlation of renal artery stenosis.[34]A RI value exceeding 0.80 is also associated with poor allograft survival after renal transplantation.[35] RI increases in diabetic nephropathy when the kidneys start to shrink and microalbuminuria occurs.[36] RI decreases with the use of RAS inhibitors in diabetic nephropathy and hypertensive nephrosclerosis, explaining why these drugs are Reno protective. In the present study, we demonstrated that the progression of CKD could be predicted by an RI value. A study done by Parolin et al. showed that an RI of 0.70 or higher is predictive of an unfavorable outcome in patients with CKD. A clinical study done by Hanamura et al. showed that CKD patients with a high normal range RI (0.65-0.70) were at risk for an adverse prognosis.[37] The mean RI measured in the present study was 0.68 (range: 0.48-0.96, SD = 0.14). This study showed a statistically significant increase in RI as the CKD stage advanced (p-value<.001, HS). This finding is consistent with those of Hanamura et al. who found that RI was the best marker of CKD stage among the ultrasonographic indices and showed that RI increases with CKD stage.

Patients with end-stage kidney disease may have bilateral shrunken kidneys, but at early stages of CKD the kidney length may be within the normal range. Renal length is measured as the longest diameter obtained on a posterior oblique image with a lower limit of normality generally indicated as 9cm. According to Fiorini and Barizzi, renal length under 8cm is definitely reduced and should be attributed to CKD, whereas length between 8 and 9 cm should always correlate to the patient's phenotype particularly height.[38] The mean renal length measured in the present study was 8.54cm. Patients with stage 5 CKD had small kidneys with a mean length of 6.26+- 0.58. In the remaining stages the kidneys were of normal size. This correlated well with the finding of Yamashita et al. in which the average renal length was 9.5cm in CKD patients (range;6.99 cm to 13cm). Renal length has traditionally been considered a surrogate marker of renal function. A statistically significant reduction in renal length occurred as the stage of CKD increased. This finding contradicts those of Sidappa et al. and Moccise et al. which showed no significant correlation between renal length and serum creatinine.[39,40]Additionally, a study by Hanamura et al. showed that there is no established normal range of cortical thickness. A normal range of 8 to 11.5 mm was reported in a small study of transplant donors by Raj et al.[41] However, El-Reshaid et al. stated that cortical thickness values up to 6mm are also considered normal.[42] The mean cortical thickness in our study group was found to be 6.79mm (range: 6mm to 8mm). Cortical thickness could not be assessed in stage 5 CKD patients as the renal pyramids could not be identified in USG. In a study conducted by Beland et al.[43] it was

ISSN: 0975-3583, 0976-2833 VOL14, ISSUE 07, 2023

reported that cortical thickness measured using US was related to eGFR. Those authors measured the RCT and the length of the kidneys in 25 patients with CKD and found that the RCT was more significantly related to eGFR than was the renal length.

Normal parenchymal thickness ranges from 1.5 - 2 cm. The mean parenchymal thickness obtained in the present study was 15.9mm (range: 1cm to 2.35cm; SD=0.3 cm). The average parenchymal thickness was normal in 75% of the cases. In 18% of the cases it was reduced, and in 7% of the cases, it could not be assessed as the cortico-medullary differentiation was lost. These findings correlated well with those of Moghazi et al. who found the mean parenchymal thickness to be 1.71 cm (range: 0.7 cm to 3.3 cm).

Raised renal cortical echogenicity was reported in patients with CKD in this study. Similar echogenicity changes were observed in both kidneys in all cases. Paivansalo et al. also reported that an echogenic cortex was the most common abnormality detected in CKD patients. In the present study, echogenicity was further graded according to the classification proposed by Sidappa et al. 11 cases had grade 0 echogenicity, 25 cases had grade 1 echogenicity, 27 cases had grade 2 echogenicity, 21 cases had grade 3 echogenicity and 16 cases had grade 4 echogenicity. Thus, grade 2 echogenicity had the maximum number of cases. These findings are slightly different from those of Sidappa et al., who found grade 1 echogenicity to be the largest group with 48.3% of the cases in it. Also, corticomedullary differentiation was maintained in 63% of the cases, poorly maintained in 21% of the cases and lost in 16% of the cases. This finding closely resembles the study done by Arvinder Singh et al., who had 77% of cases with maintained corticomedullary differentiation, 16% of cases with poorly maintained corticomedullary differentiation and 7% of cases where the corticomedullary differentiation was lost.

CONCLUSION

RI can be used as a valuable sonological marker in predicting the severity of CKD, thereby helping in the early detection of high-risk patients.

REFERENCES

1. Agarwal SK, Srivastava RK. Chronic kidney disease in India: challenges and solutions. Nephron ClinPract 2009;111(3):197-203.
2. Levey AS, Coresh J, Balk E, et al. National kidney foundation practice guidelines for chronic kidney disease: evaluation, classification, and stratification. Ann Intern Med 2003;139(2):137-47.
3. Emamian SA, Nielsen MB, Pedersen JF. Intraobserver and interobserver variations in sonographic measurements of kidney size in adult volunteers a comparison of linear measurements and volumetric estimates. ActaRadiol 1995;36(4):399-401
4. Hergesell O, Felten H, Andrassy K, et al. Safety of ultrasound-guided percutaneous renal biopsy-retrospective analysis of 1,090 consecutive cases. Nephrol Dial Transplant 1998;13(4):975-77.
5. Rifkin MD, Needleman L, Pasto ME. Evaluation of renal transplant rejection by Duplex Doppler examination: value of the resistive index.Am J Roentgenol1987;148(4):759-62.
6. Platt JF, Rubin JM, Ellis JH, DiPietro MA. Duplex Doppler US of the kidney: differentiation of obstructive from nonobstructive dilatation.Radiology1989;171(2):515-7.
7. PatriquinHB,O'Regan S, Robitaille P,Paltiel H. Hemolytic-uremic syndrome: intrarenal arterial Doppler patterns as a useful guide to therapy.Radiology 1989;172(3):625-8.
8. Platt JF, Rubin JM, Ellis JH. Lupus nephritis: predictive value of conventional and Doppler US and comparison with serologic and biopsy parameters. Radiology 1997;203(1):82-6.
9. Aikimbaev KS, Canataroglu A, Özbek S, Usal A. Renal vascular resistance in progressive systemic sclerosis: evaluation with duplex Doppler ultrasound. Angiology 2001;52(10):697-701.
10. Ishimura E, Nishizawa Y, Kawagishi T, Okuno Y, Kogawa K, Fukumoto S, et al. Intrarenal hemodynamic abnormalities in diabetic nephropathy measured by duplex Doppler sonography. Kidney International 1997;51(6):1920-7.
11. Soldo D, Brkljacic B, Bozikov V, Drinkovic I, Hauser M. Diabetic nephropathy: comparison of conventional and duplex Doppler ultrasonographic findings. ActaRadiologica 1997;38(2):296-302.

ISSN: 0975-3583, 0976-2833 VOL14, ISSUE 07, 2023

12. Hamano K, Nitta A, Ohtake T, Kobayashi S. Associations of renal vascular resistance with albuminuria and other macroangiopathy in type 2 diabetic patients. Diabetes Care 2008;31(9):1853-7.
13. Boddi M, Cecioni I, Poggesi L, Fiorentino F, Olianti K, Berardino S, et al. Renal resistive index early detects chronic tubulointerstitial nephropathy in normo-and hypertensive patients. American Journal of Nephrology 2006;26(1):16-21.
14. Platt JF, Ellis JH, Rubin JM, DiPietro MA, Sedman AB. Intrarenal arterial Doppler sonography in patients with nonobstructive renal disease: correlation of resistive index with biopsy findings. AJR. American Journal of Roentgenology 1990;154(6):1223-7.
15. Petersen LJ, Petersen JR, Talleruphuus U, Ladefoged SD, Mehlsen J, Jensen HA. The pulsatility index and the resistive index in renal arteries. Associations with long-term progression in chronic renal failure. Nephrology, dialysis, transplantation: official publication of the European Dialysis and Transplant Association-European Renal Association 1997;12(7):1376-80.
16. Splendiani G, Parolini C, Fortunato L, Sturniolo A, Costanzi S. Resistive index in chronic nephropathies: predictive value of renal outcome. Clinical Nephrolog. 2002;57(1):45-50.
17. Radermacher J, Ellis S, Haller H. Renal resistance index and progression of renal disease. Hypertension 2002;39(2):699-703.
18. Ikee R, Kobayashi S, Hemmi N, Imakiire T, Kikuchi Y, Moriya H, et al. Correlation between the resistive index by Doppler ultrasound and kidney function and histology. American Journal of Kidney Diseases 2005;46(4):603-9.
19. Parolini C, Noce A, Staffolani E, GiarrizzoGF, Costanzi S, Splendiani G. Renal resistive index and long-term outcome in chronic nephropathies. Radiology 2009;252(3):888-96.
20. Sugiura T, Wada A. Resistive index predicts renal prognosis in chronic kidney disease. Nephrology Dialysis Transplantation 2009;24(9):2780-5.
21. Sugiura T, Wada A. Resistive index predicts renal prognosis in chronic kidney disease: results of a 4-year follow-up. Clinical and Experimental Nephrology 2011;15(1):114-20.
22. MostbeckGH, Kain R, Mallek R, Derfler K, Walter R, Havelec L, et al. Duplex Doppler sonography in renal parenchymal disease. Histopathologic correlation. Journal of Ultrasound in Medicine 1991;10(4):189-94.
23. Sugiura T, Nakamori A, Wada A, Fukuhara Y. Evaluation of tubulointerstitial injury by Doppler ultrasonography in glomerular diseases. Clinical Nephrology 2004;61(2):119-26.
24. Levey AS, Bosch JP, Lewis JB, Greene T, Rogers N, Roth D. Modification of Diet in Renal Disease Study Group*. A more accurate method to estimate glomerular filtration rate from serum creatinine: a new prediction equation. Annals of Internal Medicine 1999;130(6):461-70.
25. National Kidney Foundation. “K/DOQI clinical practice guidelines for chronic kidney disease: evaluation,classification, and stratification. American Journal of Kidney Diseases
26. Bigé N, LévyPP, Callard P, FaintuchJM, Chigot V, Jousselin V, et al. Renal arterial resistive index is associated with severe histological changes and poor renal outcome during chronic kidney disease.BMC Nephrol 2012;13:139.
27. Winther SO,Theisson HC,Poulsen LN,Chehri M,AgerskoVH,Tepel M. The renal arterial resistive index and stage of chronic kidney disease in patients with renal allograft. PLOS One 2012;7(12):1-6.
28. Gulek B, Soker G, Erken E, Adam FU, Varan HI, Ada S, et al. The Usefulness of Renal Doppler Parameters in Chronic Kidney Disease: Is There a Cut-Off Value to Estimate End Stage Kidney Disease? Open Journal of Radiology 2016;6(1):18-23.
29. Kim JH, Lee SM, Son YK, Kim SE, An WS. Resistive index as a predictor of renal progression in patients with moderate renal dysfunction regardless of angiotensin converting enzyme inhibitor or angiotensin receptor antagonist medication. Kidney Res ClinPract2017;36(1):58-67.
30. Hanamura K, Tojo A, Kinugasa S, Asaba K, Fujita T. The resistive index is a marker of renal function, pathology, prognosis, and responsiveness to steroid therapy in chronic kidney disease patients. Int J Nephrol 2012;2012:139565.
31. Rosenfield AT, Siegel NJ. Renal parenchymal disease: histopathologic-sonographic correlation. Am J Roentgenol 1981;137:793-8.

ISSN: 0975-3583, 0976-2833 VOL14, ISSUE 07, 2023

32. Rosenfield AT, Taylor KJ, Crade M, DeGraaf CS. Anatomy and pathology of the kidney by gray scale ultrasound. Radiology 1978;128(3):737-44.
33. Levey AS, Becker C, Inker LA. Glomerular filtration rate and albuminuria for detection and staging of acute and chronic kidney disease in adults: a systematic review. JAMA 2015;313(8):837-46.
34. Chen RA, Scott S, MatternWD, Mohini R, Nissenson AR. The case for disease management in chronic kidney disease. Dis Manag2006;9:86-92.
35. Levey AS, Coresh J. Chronic kidney disease. Lancet 2012;379(9811):165-80.
36. Haynes R, Staplin N, Emberson J, Herrington WG, Tomson C, Agodoa L, et al. Evaluating the contribution of the cause of kidney disease to prognosis in CKD: results from the Study of Heart and Renal Protection (SHARP). American Journal of Kidney Diseases 2014;64(1):40-8.
37. Radermacher J. Resistive index: an ideal test for renovascular disease or ischemic nephropathy? Nature ClinPract 2006;2(5):232-3.
38. Radermacher J, Chavan A, Bleck J, Vitzthum A, Stoess B, Gebel MJ, et al. Use of Doppler ultrasonography to predict the outcome of therapy for renal-artery stenosis. New England Journal of Medicine 2001;344(6):410-7.
39. Radermacher J, Mengel M, Ellis S, Stuht S, Hiss M, Schwarz A, et al. The renal arterial resistance index and renal allograft survival. New England Journal of Medicine 2003;349(2):115-24.
40. Marzano MA, Pompili M, Rapaccini GL, Covino M, Cotroneo P, Manto A, et al. Early renal involvement in diabetes mellitus: comparison of renal Doppler US and radioisotope evaluation of glomerular hyperfiltration. Radiology 1998;209(3):813-7.
41. Beland MD, Walle NL, Machan JT, CronanJJ. 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):W146-9.
42. Standring S, Gray HA. Gray's anatomy: the anatomical basis of clinical practice. 40th edn. Edinburgh, Scotland: Churchill Livingstone 2008.
43. Urban BA, Ratner LE, Fishman EK. Three-dimensional volume-rendered CT angiography of the renal arteries and veins: normal anatomy, variants, and clinical applications. RadioGraphics 2001;21(2):373-86.