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Evaluation of renal vasculature and its variants by CT angiography

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ABSTRACT

Background: Kidneys are a pair of retroperitoneal organs supplied by a single renal artery and vein. However, the classic illustration of the renal vasculature, formed by one renal artery and one renal vein, occurs in ≤25% of cases. MDCT angiography is presently the most preferred investigation for assessing prospective renal donors. **Aims and Objectives:** This study aims to familiarize urologists with the variations found in the renal vascular system, emphasizing prevalence, the adequate, appropriate terms, and the clinical and surgical implications involved. **Materials and Methods:** A cross-sectional study in 50 patients clinically indicated to undergo CT Renal angiographic study over 2 years is included in the study. This study was carried out to look for any anatomical variants in renal vasculature. CT examination was performed on a multidetector 16 slice CT Siemens scanner in the department of radiodiagnosis. Once conventional CT is done, the data obtained can produce 3D post-processing images that simulate conventional angiograms. **Results:** Out of 50 patients, single renal arteries are present in 27, and multiple renal arteries are present in 23 patients. Out of 27 patients with single renal arteries, 22.2 % has perihilar arterial branching. The most common variant was accessory renal arteries, which are found in 56% of individuals, followed by aberrant renal arteries found in 30% of individuals. Double renal arteries are found in 8.7% and triple renal arteries in 4.3% of cases. Out of 50 patients, 48 patients have a single renal vein, whereas two patients have supernumerary veins. The present study found right renal vein duplication in only 2% of patients. **Conclusion:** Renal arteries and veins show numerous variations in their origin sites, numbers, course, and division patterns. These variants exist in the population with high prevalence and are thus crucial in preoperative and intra-operative analysis for better prognosis and reduced complications. Preoperative CT evaluation of renal vasculature using MDCT angiography helps depict the presence or absence of renal arterial and venous variants.

Key words: Circumaortic; CT angiography; Renal artery; Renal vein

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INTRODUCTION

Kidneys are a pair of retroperitoneal organs supplied by a single renal artery and vein. However, the classic illustration of the renal vasculature, formed by one renal artery and one renal vein, occurs in ≤25% of cases.[1] The increased use of laparoscopic nephrectomy and nephron-sparing surgeries has propelled the necessity for a more comprehensive radiological evaluation of the renal vascular anatomy.[2] Conventional angiography was once considered to be the gold standard for the analysis of renal vasculature. The development of spiral CT has provided the radiologist with unparalleled capabilities to acquire high-quality image data.[3]

The renal arterial and venous anatomy show many variations. The urologists need to have a substantial preoperative understanding of the renal vascular anatomy for choosing the proper kidney and surgical planning when performing laparoscopic donor nephrectomy.[4,5] Depiction of the renal vascular variants on the preoperative imaging facilitates the dissection of these vessels, and it also helps prevent vascular injuries. In renal neoplasm,

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planning nephron-sparing surgery also requires precise localization of the renal lesion and its relationship to the renal vasculature.[6]

Multidetector CT (MDCT) angiography is a fast, definitive, and non-invasive modality for comprehensive renal vasculature evaluation. MDCT angiography is presently the most preferred investigation for assessing prospective renal donors, and it has replaced conventional angiography in many institutions. MDCT angiography can accurately depict the renal arterial and venous anatomy, the vascular lumina, and the vessel walls, including the smaller tributaries such as gonadal, lumbar, and adrenal veins.[7,8] Furthermore, CTA has the advantage of allowing a better evaluation of the renal collecting system to identify hydronephrosis and of the kidneys themselves to identify congenital disorders such as horseshoe kidney, tumours, parenchymal atrophy, and duplication of the renal pelvis.[9]

Digital image processing and manipulation in diagnostic workstations provided with programs and monitors dedicated to this purpose are indispensable for CT Angiographic studies. These studies allow two-dimensional and three-dimensional (3D) multiple image reconstructions to be performed based on raw data drawn out from the original axial images. The maximum intensity projection (MIP), multiplanar reconstruction (MPR), and volume rendering (VR) techniques are extensively used.

A limitation of this technique is the excess of structures combined to the image as the slab encloses more sections, which visually confuses the examiner. The VR method applies opacity values ranging from 0% (transparent) to 100% (opaque) between different sections in any plane in an artificial line of sight projection. By bringing together these values with luminous effects, the VR 3D image generated recreates the depth's perspective more steadily than MIP. [10]

All patients undergoing renal angiography are evaluated for anatomical variants in both renal arteries and veins in the present study. This study aims to familiarize urologists with the variations found in the renal vascular system, emphasizing prevalence, the adequate, appropriate terms, and the clinical and surgical implications involved.

Aims and objectives

This study evaluates the anatomy and variants in the renal vascular system by CT angiography and provides a road map to urologists with anatomical variants before treatment.

MATERIALS AND METHODS

A cross-sectional study in 50 patients clinically indicated to undergo CT Renal angiographic study over 2 years is included in the study. The study was carried out to look for any anatomical variants in renal vasculature. Initially, plain CT is done, followed by a renal angiographic study, and findings were documented. Exclusion criteria are People with low eGFR (<45), that is, CKD stage 3 or more, Pregnant women and who previously had allergic reactions to contrast.

CT examination was performed on a multidetector 16 slice CT Siemens scanner in the department of Radiodiagnosis. Once conventional CT is done, the data obtained can produce 3D post-processing images that simulate conventional angiograms. Commonly used techniques include VR, MIP and surface rendering. Of all the reconstruction techniques available for performing CT angiography, VR has emerged as the post-processing technique of choice. In VR, the entire CT data set is used to create the angiogram, and the data from each voxel are summed along a line from the viewer's eye through the data set. For CT angiography, VR is commonly performed with a level transfer function or window that results in high-density materials appearing bright and opaque, whereas less-dense structures appear dim and translucent. The resultant image provides a single, comprehensive vascular map of both the arteries and veins.

RESULTS

Out of 50 patients, there are 21 females and 29 males. The age of the patients ranged from 11 to 78 years. The mean age of the patients was 42.2 years. The youngest patient among males was 11 years old and among females was 19-years-old. The oldest patient among males was 78 years old and among females was 70years old.

Out of 50 patients, single renal arteries are present in 27, and multiple renal arteries are present in 23 patients. Out of 27 patients with single renal arteries, 22.2 % has perihilar arterial branching (Figure 1). The most common variant was accessory renal arteries, which are found in 56% of individuals, followed by aberrant renal arteries found in 30% of individuals (Figure 2). Double renal arteries are found in 8.7% and triple renal arteries in 4.3% of cases (Figure 3). In total multiple renal arteries are found in 46% of cases, mostly found in the age groups of 30 to 59 years (Table 1-3) (Figure 4).

Out of 50 patients, 48 patients have a single renal vein, whereas two patients have supernumerary veins. The present study found right renal vein duplication in only 2% of patients (Figure 5). This study also found circumaortic left renal vein in 6% and retro aortic left renal vein in 4% of the patients studied (Table 4,5) (Figure 6,7).

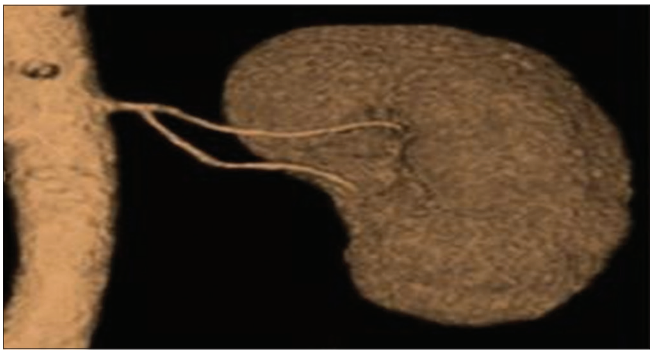

Figure 1: Image showing perihilar arterial branching in the left kidney

Figure 2: MIP image shows an accessory right renal artery arising from the anterior aspect of the abdominal aorta

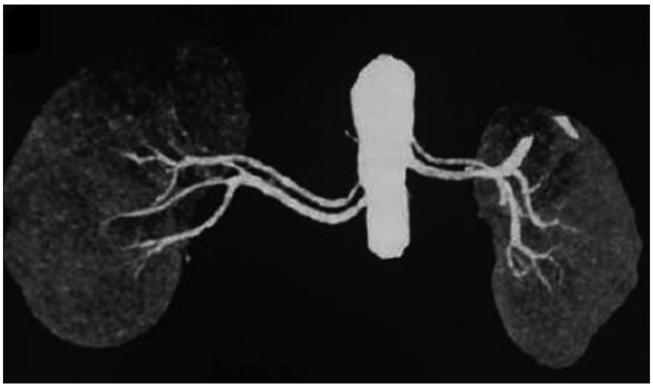

Figure 3: A three dimensional reconstructed image showing bilateral renal artery duplication

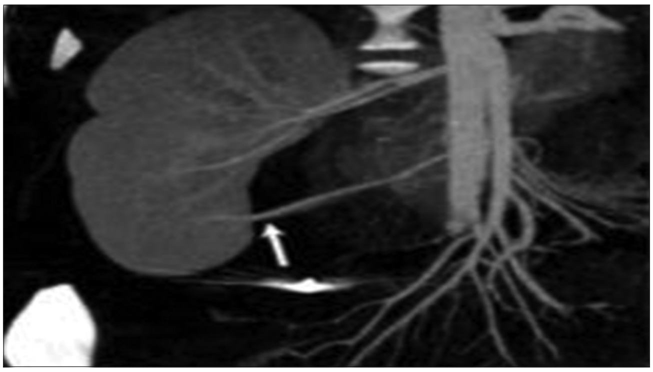

Figure 4: MIP image illustrating a right inferior polar accessory artery arising from the anterior aspect of the aorta

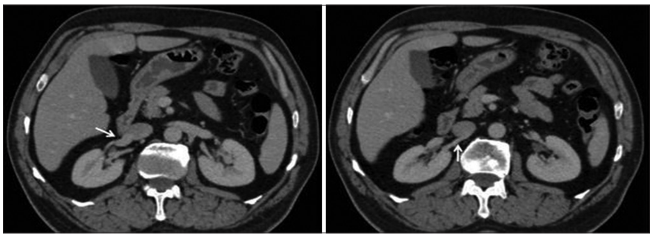

Figure 5: Axial MDCT images show double right renal vein (arrows)

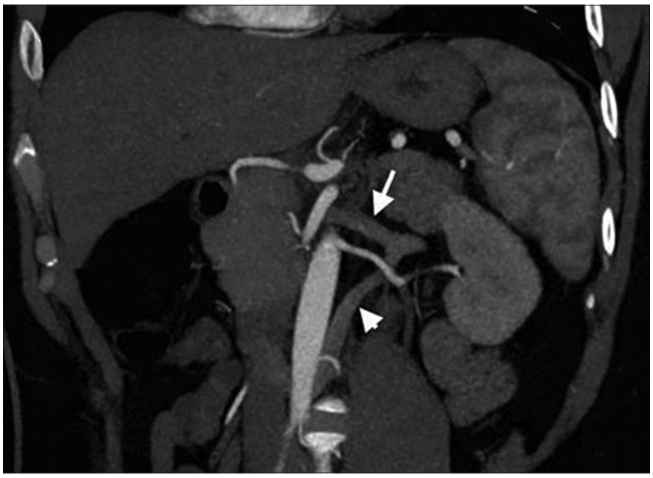

Figure 6: Maximum intensity projection CTA image demonstrates a circumaortic left renal vein; the branch anterior to the abdominal aorta (arrow) is draining into the proximal portion of the inferior vena cava, whereas the branch posterior to the abdominal aorta (arrowhead) is draining to the distal portion of the IVC

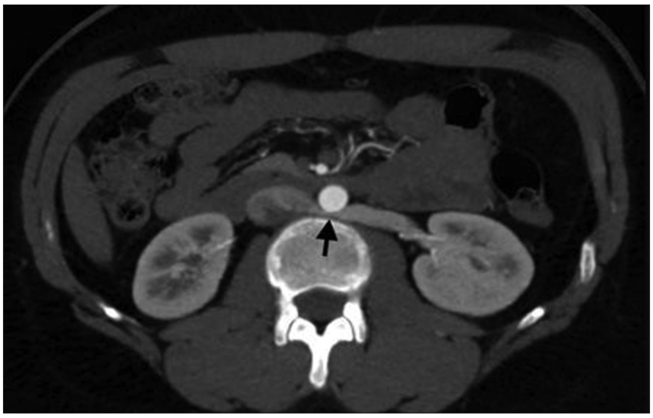

Figure 7: MIP CTA image demonstrates retroaortic left renal vein (arrow)

Table 1: Distribution of patients according to number of renal arteries on each side

Age Groups	Single renal artery	Multiple renal arteries	Total	P value
11–19	1	2	3	0.94
20–29	5	3	8	
30–39	6	6	12	
40–49	7	6	13	
50–59	4	3	7	
60–69	4	2	6	
70–79	0	1	1	
Total	27	23	50	

Table 2: Distribution of patients according to renal artery variants

Age groups	Double renal arteries	Triple renal arteries	Quadruple renal arteries	Accessory/ Hilar artery	Aberrant/ polarartery
11–19	0	0	0	2	1
20–29	0	0	0	1	2
30–39	1	1	0	3	1
40–49	0	0	0	3	1
50–59	0	0	0	3	2
60–69	1	0	0	1	0
70–79	0	0	0	0	0
Total	2	1	0	13	7

Table 3: Percentage of variants in multiple renal arteries

Multiple renal arteries	Frequency	Percentage
Double renal arteries	2	8.7
Triple renal arteries	1	4.35
Quadruple renal arteries	0	0
Accessory/hilar Arteries		
Right	6	26.09
Left	7	30.43
Aberrant/polar Arteries		
Right	3	13.04
Left	4	17.39
Total	23	100.0

Table 4: Distribution of patients according renal vein variants

Age groups	Single renal vein	Super numerary veins	P value
11–19	3	0	0.71
20–29	8	0	
30–39	12	0	
40–49	12	1	
50–59	6	1	
60–69	6	0	
70–79	1	0	
Total	48	2	

Table 5: Distribution of patients according renal vein variants

Age groups	Single renal vein	Super numerary veins	P value
11–19	3	0	0.71
20–29	8	0	
30–39	12	0	
40–49	12	1	
50–59	6	1	
60–69	6	0	
70–79	1	0	
Total	48	2	

DISCUSSION

Pre-operative evaluation of renal vascular variations is essential for procedures such as vascular intervention for renal artery stenosis, laparoscopic donor or partial nephrectomy, or endovascular management for an abdominal aortic aneurysm to improve outcomes and minimize postoperative complications as quoted by Khamanarong et al.[11]

Conventionally, invasive conventional arteriography and venography were used to evaluate renal vascular variations. In studies done by Ratner et al. and Wiberg et al.[12,13] documented renal vascular variants have been mostly cadaveric or postoperative renal donor studies. Recently, MDCT angiography has allowed preoperative assessment of the renal arteries and veins non-invasively and more quickly. Conventional angiography is the gold standard imaging technique for the evaluation of renal vessels. However, nowadays, MDCT angiography is increasingly being used as an initial choice of technique to demonstrate renal vascular anatomy as it is less invasive and readily available. MDCT angiography enables precise visualization of the normal and variant anatomy of the renal vasculature, which helps in preparing the vascular roadmap before any surgical intervention, especially while choosing the donors for renal transplant. MDCT has an accuracy of 95–100%. Systematic analysis of CT angiography images was performed, and we were able to identify various parameters which have significant implications and are relevant for surgical planning. Therefore, the present study aimed to demonstrate the different variations occurring in the vascular anatomy of the kidneys along with their patterns and prevalence in the population using CT angiography. The majority of these variants were compared with previous studies, thus making the study more comprehensive and better understanding of this subject.

Age and sex distribution

There was no significant relationship between age, sex, and renal vascular variants. Out of 50 patients studied, most were males (58%), and most of them were in the age groups of 30-59 years (82%). Females accounted for (42%), and most of them were in the age groups of 20-49 years(71%). The age of the patients ranged from 11 to 78 years. The mean age of the patients was 42.2 years. The youngest patient among males was 11-years-old and among females was 19 years old. The oldest patient among males was 78-years-old and among females was 70 years old.

RENAL VASCULAR VARIANTS

Renal arteries

Accessory renal arteries are the most common, clinically important renal vascular variant. It is seen in up to one-third of patients. In a Spring et al.[14] study, multiple renal arteries are unilateral or bilateral. The accessory renal arteries usually arise from the aorta or iliac arteries anywhere from T11 to L4. In rare scenarios, they can arise from the lower thoracic aorta or lumbar or mesenteric arteries, according to Kinnison et al.[15] Usually, the accessory renal arteries course into the renal hilum to supply the upper or lower renal poles. Accessory arteries to the poles are usually smaller in size than hilar renal arteries, which are typically equal in caliber to a single renal artery. Another common variant that needs to be checked in patients evaluated for donor nephrectomy is perihilar arterial branching. In a study done by Johnson et al.[16], VR images, MIP images, SSD images, and MPR images have all demonstrated a high sensitivity (approaching 100%) in detecting accessory arteries. Images must be acquired during the arterial phase to obtain such good results. Smith and Fishman,[17] showed that the use of 3D VR CT angiography enabled correct visualization of renal artery anatomy in 41 of 42 patients undergoing preoperative evaluation for laparoscopic nephrectomy. Rubin et al.[18] showed 3D CT angiography to be 100% sensitive in identifying accessory renal arteries. Platt et al., found that 3D CT angiography was comparable with conventional angiography in predicting vascular variant anatomy in 154 patients.[19] Arterial branching pattern variations, including perihilar branching, are also well identified with 3D CT angiography. In interpreting 3D images, caution must be taken not to mistake normal overlapping vessels for accessory renal arteries near the renal hilum. The perihilar branching pattern of the renal artery is essential for surgeons to know before kidney transplantation. Morphologically, the arterial branching patterns were classified into ladder (with sequential branching points) and fork (with a common branching point) types.

The later was either duplicated or triplicated. The perihilar morphology of the main renal artery was then categorized according to its primary and secondary divisions and their patterns. Single, duplication, triplication, and quadruplication of the arteries were defined by Wiberg et al as arteries having separate origins from the abdominal aorta.[13] That study, involving 800 kidneys, showed that the most common variant was a duplication of renal arteries (23%). Triplication and quadruplication were observed in four (2%) and one (0.5%) kidneys. In the present study of 50 individuals, the most common variant was accessory renal arteries, which are found in 56% of individuals, followed by aberrant renal arteries found in 30% of individuals. Double renal arteries are found in 8.7% and triple renal arteries in 4.3% of cases. In total multiple renal arteries are found in 46% of cases, mostly found in the age groups of 30 - 59 years. The rest of the 54% has a single renal artery.

The laterality of the occurring variation is essential for surgeons and interventionists. Variations are more commonly noted in the left renal artery than in the right; therefore, the left kidney is usually not the first choice for a donor's kidney. According to Pozniak et al., if bifurcation occurs within 1.5 cm of the renal arterial ostium in the abdominal aorta, it is called perihilar bifurcation.[20] We observed perihilar bifurcation in 6 (22.2%) of kidneys. These results are comparable to Budhiraja et al., who observed perihilar bifurcation in 11 (11.66%) kidneys.[21] In the present study, the laterality of perihilar bifurcation was present with equal prevalence in the left and right kidneys. Of the six instances of perihilar bifurcation observed, three were on the left, and three were on the right renal arteries. Multiple perihilar branches of renal arteries correspond to segmental arteries. Therefore, the risks of intraoperative hemorrhage during renal transplantation, segmental ischemia in postoperative status, and hypertension due to loss of parenchyma increase with perihilar bifurcations.

The previous study on the accessory renal artery and earlier division of renal artery was conducted by Gümüş et al., They reported earlier division in 27% and accessory renal artery in 27%.[22] In a study done by Munnusamy et al., the earlier division was seen in 12%, and the accessory renal artery was seen in 38% of individuals.[23] This increased incidence of accessory renal arteries in this study compared to previous studies may be due to regional differences in individuals as this study was conducted on the Chennai population. In this study, they analyzed 100 renal angiograms of which the accessory renal arteries were found in 38 individuals (38%), out of 38% variations, 13% were on the right side, and 13% were on the left side. Accessory renal artery on both right and left side was present in 12% of individuals. A similar study on the arterial pattern was also done by Satyapal et al., where they analyzed 130 renal angiograms on donors.[24] They found 23.2% of first (single accessory renal artery) and second (double accessory renal artery) additional arteries on both sides, and the frequency of such incidence was more on the left side 32% than right side 23.3%, and on both sides, it was 10.2%, for first additional arteries only. Zağyapan et al analyzed angiographic images of 150 individuals with 42% of multiple renal arteries, which correlates with this current study.[25] The incidence of accessory renal arteries is equal on both sides. Furthermore, there was not much significant difference in its bilateral incidence. Multiple renal arteries did not significantly affect complications such as intra-operative blood loss in donor, 1-year graft survival, and creatinine clearance in recipients provided the appropriate anatomy of multiple renal arteries is known to the surgeons operating in that area.

Ligation of both bifurcated branches is of imperative importance for the donor's kidney, as failure to do so may lead to continuous hemorrhage in the donor. During perihilar bifurcation, the superior branch may have to travel vertically to supply the upper pole, and the vertical course gains importance here. Beyer and Daily showed that such vertically directed upper polar arteries might lead to upper pole infarction.[26]

Renal veins

Multiple renal veins is the most common venous variant and are seen in approximately 15% to 30% of patients, according to the study done by Kinnison et al S.[15] according to the study done by Beckmann and Abrams it occurs in up to 30% of individuals on the right side, and sometimes a single vein may divide before joining the inferior vena cava.[27] According to a study done by Doppman, the most common variant of the left renal venous system is the circumaortic renal vein, which is seen in up to 17% of patients.[28] The left renal vein bifurcates into ventral and dorsal branches that encircles the abdominal aorta in this variant. The circumaortic vein has two common variants. One renal vein at the renal hilum subsequently divides before entering the inferior vena cava. This is the most common variant. In the less common variant, two veins originate from the renal hilum separately. In the presence of a circumaortic renal vein, the adrenal vein will join the preaortic limb, and the gonadal vein will join the retro aortic limb. A less common venous anomaly seen in 3% of patients is the completely retro aortic, renal vein. Here, the single left renal vein will course posterior to the aorta and drains into the inferior vena cava. Alternatively, it can also drain into the iliac vein. As newer laparoscopic techniques are now routinely employed for donor nephrectomy, accurate depiction of venous anomalies is crucial in the preoperative evaluation of these patients. Unlike conventional surgery, laparoscopic nephrectomy is carried out with a limited view of the venous vascular anatomy. Hence, all of the venous anomalies listed above constitute a potential surgical nightmare if they are not documented in advance. Hence CT angiography can provide this complete evaluation with an accuracy comparable to conventional angiography, according to Smith and Fishman.[17] According to Urban et al., supernumerary renal veins are the most common venous variant, observed in approximately 15-30% of patients.[29] The right renal vein is a short, stout vein draining into the IVC. Owing to its short course, the length of ligation is an essential factor in renal transplant outcome. According to Beckmann and Abrams, right renal vein variations are noted in about 30% of patients.[27] In contrast, Pozniak et al., found a right renal vein variations in only 13.2% of patients, including multiple renal veins with different ostia.[20] In contrast, the present study found right renal vein duplication in only 2% of patients.

The left renal vein has a long, complex course and the variations noted are unique. Multiplicity is a scarce variation in the left renal vein. Circumaortic and retro aortic left renal veins are the most common variations. Circumaortic left renal vein occurs when ventral and dorsal parts of the left renal vein encircle the abdominal aorta before entering the IVC. Circumaortic left renal vein has two main subtypes: in one, the single left renal vein bifurcates into two branches which encircle the abdominal aorta before entering the IVC; in the other, two different left renal veins arise from the hilum of the left kidney and course anterior and posterior to the abdominal aorta before entering the IVC. Retroaortic vein occurs when the single left renal vein courses posterior to the abdominal aorta, between the aorta and the vertebral body, before entering the IVC. Pozniak et al., found a circumaortic left renal vein in 8.3% and retro aortic left renal vein in 2.9% of the patients studied.[20] Beckmann and Abrams found a circumaortic left renal vein in 17% and retro aortic left renal vein in 3% of the patients studied.[27] The current study results followed a similar trend, with circumaortic left renal vein in 6% and retro aortic left renal vein in 4% of the patients studied. Pandya et al.,evaluated renal venous variants and found that duplication was the most common variant observed and that circumaortic venous variation of the left renal vein was more common than retro-aortic.[30] Although venous variations are important, the present study also evaluated common arterial variations, giving surgeons and interventionists a complete picture of the renal vasculature.

These findings are of great clinical significance because of a syndrome known as "nutcracker syndrome," which is caused by the anatomic compression of the left renal vein between the superior mesenteric artery and the aorta or, if the left renal vein has a retro aortic or circumaortic variation, between the aorta and an underlying vertebral body. According to Ribeiro et al., a Nutcracker syndrome refers to the cascade of symptoms developing due to increased venous pressure in the left renal vein due to obstruction of its venous outflow into the inferior vena cava.[31] This finally results in the development of intra- and extra-renal hypertensive valveless venous collateral vessels.

We studied variations in the renal vasculature using MDCT angiographic images. Our observations confirm the prevalence of variants in the renal vasculature, as reported in the literature. We have also described the clinical and surgical significance of each variant.

Henceforth the study on anatomical variations in vascularization of the kidney is critical to transplant surgeons involving in donor nephrectomies. The surgeon can explore and treat renal trauma, renal transplantation, renal vascular embolization, angioplasty, and radical renal surgeries with this knowledge.

Limitations of the study

The study included MDCT angiographic images of 50 patients. Although almost most of the variants were documented in this study, the sample size is smaller than that of the previous studies, such as that of Wiberg et al. A continuation of this study to include a larger population would increase the power of the results. Fine arterial or venous networks could have been missed as it was beyond the capability of CT examination; however, the knowledge on these vascular channels is not of clinical importance. The various definitions used for describing the variations are not standard for every institution and surgeon as they largely depend on the surgeons available. Importance of knowing these variations and accurate radiological reporting cannot be underestimated to avoid life-threatening complications.

CONCLUSION

Renal arteries and veins show numerous variations in their origin sites, numbers, course, and division patterns. These variants exist in the population with high prevalence and are thus crucial in preoperative and intra-operative analysis for better prognosis and reduced complications. Venous variation asserts its importance by revealing conditions such as nutcracker syndrome in otherwise healthy patients.

Pre-operative CT evaluation of renal vasculature using MDCT angiography helps depict the presence or absence of renal arterial and venous variants. It helps detect abnormalities of the renal parenchyma and collecting system, renal calculi, and other renal and extra-renal abnormalities that help in further planning.

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