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ORIGINAL ARTICLE

Computed Tomography Angiographic Appearance of Normal Anatomy and Spectrum of Common Variants of the Renal Vasculature

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ABSTRACT

Introduction: *Variations in the anatomy of the renal vasculature are common. Conventional angiography has long been regarded as the gold standard imaging modality for evaluation of these vessels. Recent advances in multidetector computed tomography (MDCT) angiography have greatly improved evaluation of the renal arteries and veins. The present study aimed to investigate the variants occurring in the renal vasculature and to evaluate the prevalence of these variants.*

Methods: *We analysed MDCT angiographic images of 100 patients who came to our department for contrast-enhanced computed tomography of the abdomen. We analysed the images using various techniques, including maximum intensity projection, multiplanar reconstruction, and volume rendering.*

Results: *Among the MDCT angiographic images studied, 66% of patients showed some variation in renal vasculature. The most common variant was duplication of the renal artery, seen in 16.5% of the kidneys. The circumaortic (6%) and retroaortic (2%) veins were the most common variants of the left renal vein, whereas duplication (4%) was the most common variant of the right renal vein.*

Conclusion: *Variations in the renal vasculature occur with high incidence. Awareness of these variations is necessary for preoperative and intra-operative analysis for better prognosis and fewer complications after surgery.*

Key Words: *Anatomy; Computed tomography angiography; Renal artery; Renal veins*

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中文摘要

腎血管系統的正常解剖學電腦斷層血管造影表現和常見變異譜

M Vashishta、K Udhaya Kumar、A Ramalingam、BR Nagaraj

引言：腎血管系統解剖結構的變化很常見。常規血管造影一直被視為評估這些血管的黃金標準成像模式。多排螺旋電腦斷層血管造影的最新進展大大改善對腎動脈和靜脈的評估。本研究旨在檢視腎血管系統中發生的變異並評估這些變異的發生率。

方法：分析來自我科的100名患者的多排螺旋電腦斷層血管造影圖像，用於腹部對比增強電腦斷層掃描。我們使用各種技術，包括最大密度投影、多層面重建和體積成像來分析圖像。

結果：在眾多排螺旋電腦斷層血管造影圖像中，66%顯示腎血管系統出現變異。最常見變異是重複腎動脈，發生率為16.5%。環主動脈靜脈（6%）和主動脈後靜脈（2%）是左腎靜脈最常見變異，而重複靜脈（4%）是右腎靜脈最常見的變異。

結論：腎血管系統中變異的發生率高。提高對這種變異的意識對術前及術中分析是必要的意識，有助更佳預後及減少術後併發症。

INTRODUCTION

Advances in surgical and diagnostic techniques have led to procedures such as renal transplant, nephrectomy, and renal artery embolisation being conducted very frequently. For patients with complete renal failure, transplant increases the patient life expectancy by many years. Technology in the fields of ex vivo preservation and microvasculature has eradicated the majority of allografting-related complications. Postoperative complications after kidney transplant are commonly related to the vascular supply of the donor organ; therefore, knowledge of the variations in the vasculature of the donor kidney can improve prognosis.

Factors affecting donor and recipient kidneys, such as minimum ischaemia time, can be improved by preoperative knowledge of the kidney arterial system. Such knowledge results in a lower incidence of delayed graft function, which is a significant negative prognostic factor for graft survival.[1]

Hunter[2] reported in the 18th century that no evidence of intrarenal interarterial anastomosis arose, thereby ruling out the chance of intraparenchymal collateral formation in case of renal arterial supply reduction. Hegedüs[3] reported, in his study of 138 kidneys, that 120 kidneys were supplied by single renal arteries, 15 by two renal arteries, and three had triple arterial supply.

Traditionally, the only way to reveal the renal vasculature preoperatively was through catheter angiography. However, because this is an invasive procedure, its popularity remains limited. Recent advances in multidetector computed tomography (MDCT) angiography, high-resolution CT, multiple interpretation techniques like multiplanar imaging, maximum intensity projection, three-dimensional rendering and volume rendering have gained widespread popularity in preoperative evaluation of the variations in the arteries and veins in the patient in question, thus, giving a personalised mapping of the anatomy non-invasively.

The present study therefore aimed to demonstrate the different variations occurring in the vascular anatomy of the kidneys along with their patterns and prevalence in the population. The prevalence of these variants was compared with previous studies[4] thus making the study more comprehensive and to achieve a better understanding in this subject.

METHODS

This study was conducted at the Mahatma Gandhi Medical College and Research Institute Hospital, a rural tertiary care hospital in India. The Institutional Medical Ethics Committee approved this study. We retrospectively analysed MDCT images of 100 patients who were referred to our department for contrast-enhanced computed tomography of the abdomen from December 2014 to August 2016. Male and female patients of any age were included in the study. Distorted images, images with high artefact levels, or patients with a history of renal vascular surgery were excluded.

Imaging Technique

After confirming that the renal functional test values were within normal limits, 1 L of 1% v/v mannitol solution was administered orally for 45 minutes as a neutral intraluminal contrast. This distended the collapsed loops for better visualisation of the bowel wall. A plain scan of the abdomen was taken pre-contrast from the base of the lungs cranially to the symphysis pubis. For contrast administration, the right antecubital vein was cannulated using an 18G cannula and connected to the injector. Non-ionic water-soluble iodinated low-osmolality contrast iohexol (Magnapaque; Magnus Health Management Pvt Ltd, Mumbai, India) containing 350 mg/mL iodine was used. For abdomen contrast studies 1.5 mL/kg contrast solution was administered and arterial opacification phase and venous opacification phase CT images were taken of the whole abdomen. Images were acquired using an Optima CT660 128-slice CT system (GE Healthcare, Chicago [IL], US) with tube potential 120 kv, helical scan with Rot value 0.6 sec/helix and 39.4 mm/rot scan. Renal arteries and veins were examined using multiple reconstruction techniques, such as multiplanar imaging, maximum intensity projection, and volume rendering.

Statistical Analysis

All data were entered into a data collection proforma sheet and were entered into Excel 2011 (Microsoft Corp. Redmond [WA], US). The data were manually analysed for the presence of variants in the renal vasculature and their frequency of occurrence was noted. The frequency of occurrence of any variant was documented and calculated as a percentage (%) of the total number of patients included. Data from the present study were also compared with previous studies.

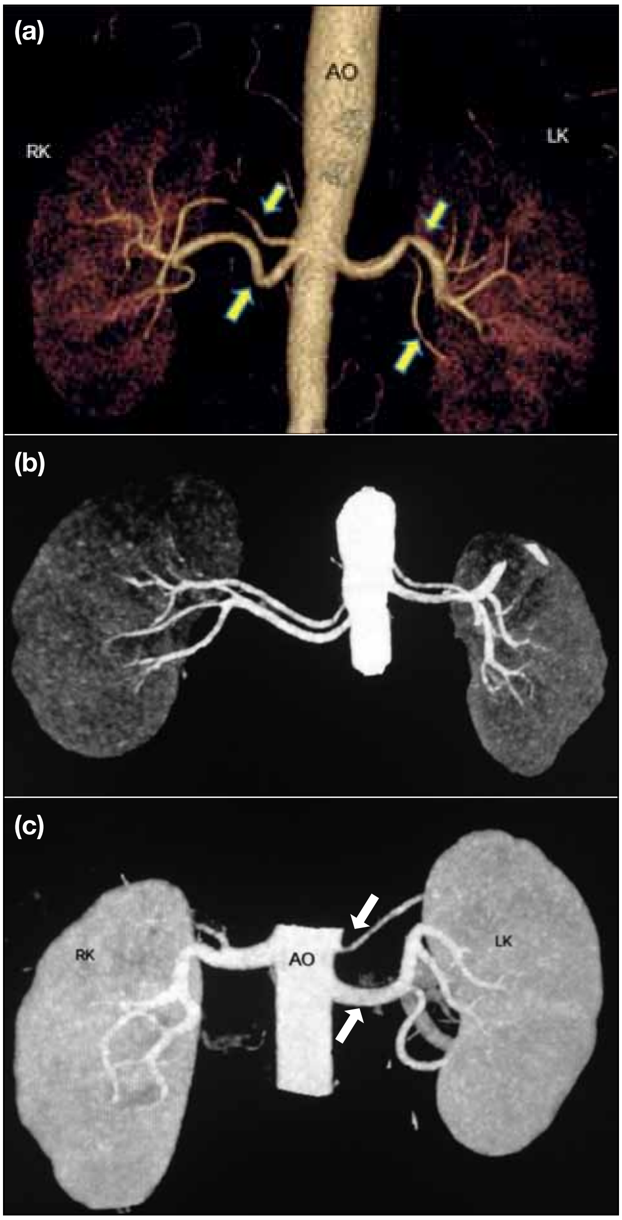

Figure 1. Renal artery duplication. (a) Volume rendering reconstructed image showing bilateral renal artery duplication. (b) Three-dimensional reconstructed image showing bilateral renal artery duplication. (c) Three-dimensional reconstructed image showing left renal artery duplication.
Abbreviations: AO = aorta; LK = left kidney; RK = right kidney.

RESULTS

Of 100 patients studied, the majority (89%) were male, and most (68%) were in the 31 to 60 years age-group. The patients had mean age 53 (range, 18-78) years.

Arterial Variations

Duplication of renal arteries (Figure 1) was the most common variant seen in 16.5% of the kidneys (Table). Triplication (Figure 2) was rare and quadruplication (Figure 3) was extremely rare. Presence or absence of prehilar bifurcation (Figure 4) was decided according to definitions described in previous studies.[5] In our study we also observed inferior phrenic arteries arising from the renal arteries. This has not been widely reported in previous studies of renal arteries. Inferior phrenic arteries originated from the right artery more commonly than from the left artery (Table).

Table. Renal arterial variants in our study.

	Left (n = 100)	Right (n = 100)	Overall (n = 200)
Single renal artery	77%	85%	162 (81%)
Duplication of renal artery	19%	14%	33 (16.5%)
Triplication of renal artery	3%	1%	4 (2%)
Quadruplication of renal artery	1%	-	1 (0.5%)
Prehilar bifurcation of renal artery	11%	12%	23 (11.5%)
Inferior phrenic artery originating from renal artery	2%	11%	13 (6.5%)

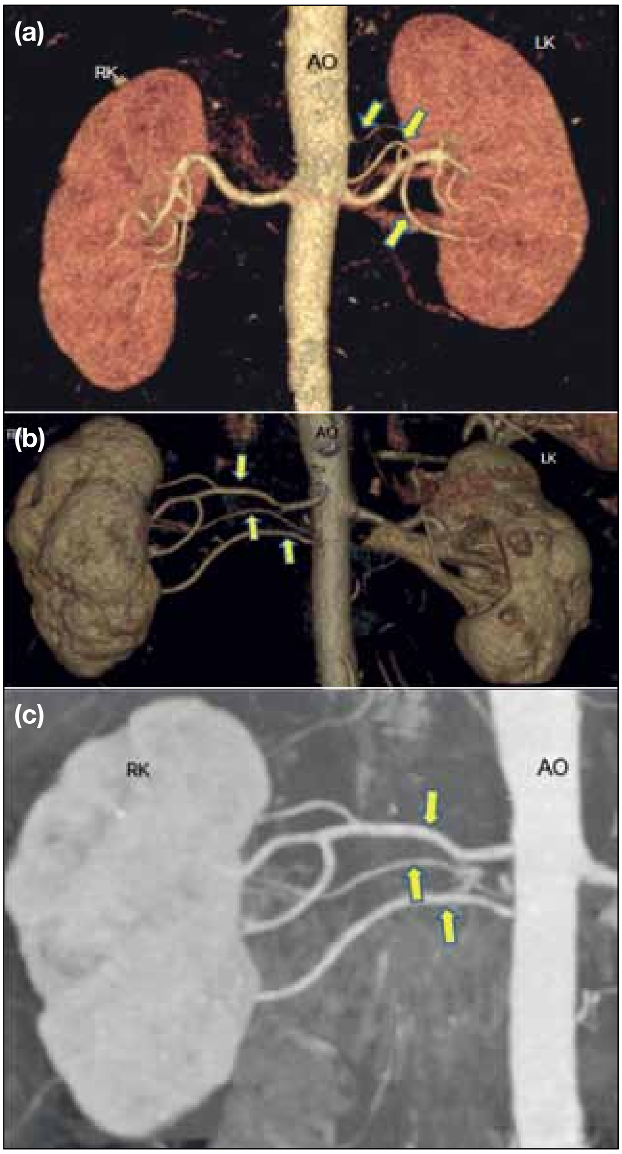

Figure 2. Renal artery triplication. (a) Volume rendering reconstructed image showing left renal artery triplication. (b) Volume rendering reconstructed image showing right renal artery triplication. (c) Three-dimensional reconstructed image showing right renal artery triplication.
Abbreviations: AO = aorta; LK = left kidney; RK = right kidney.

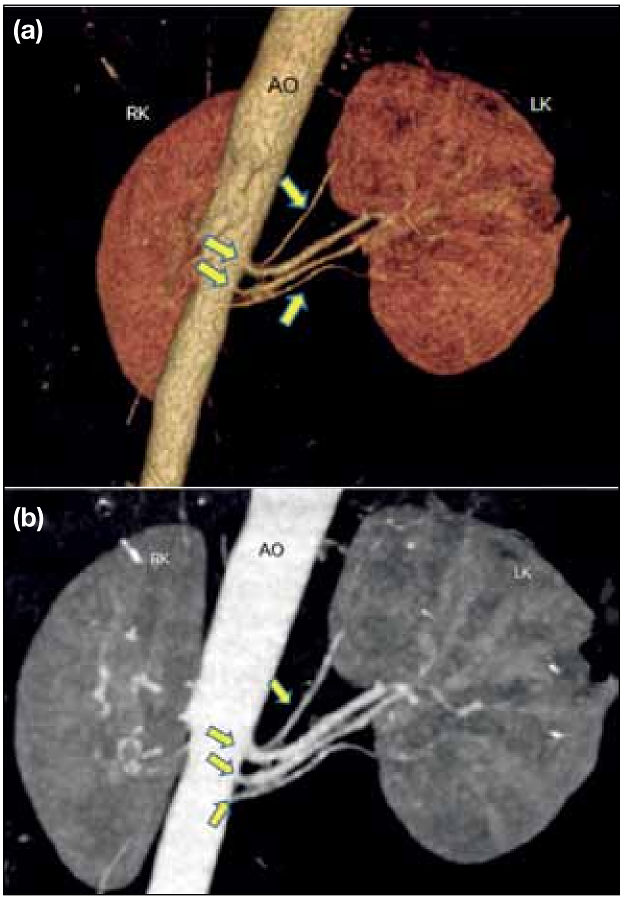

Figure 3. Renal artery quadruplication. (a) Volume rendering reconstructed image showing left renal artery quadruplication. (b) Three-dimensional reconstructed image showing left renal artery quadruplication.
Abbreviations: AO = aorta; LK = left kidney; RK = right kidney.

Venous Variations

Right and left renal vein variants are different in morphology and occurrence; thus, we studied left and right renal vein variants separately. Duplication of the right renal vein was noted in 4% of patients (Figure 5). Circumaortic and retroaortic veins are the most common types of variations on the left renal vein according to Urban et al.[11] In the present study, we observed that 6% of patients had circumaortic left renal vein (Figure 6) and 2% of patients had retroaortic left renal vein (Figure 7).

DISCUSSION

Knowledge of the vascular anatomy of the kidneys has been a topic of interest for the surgeons and concerned interventionists since the beginning of kidney-related procedures in the 18th century. Preoperative evaluation of variations in the renal vasculature is crucial for procedures such as laparoscopic donor or partial nephrectomy, vascular intervention for renal artery stenosis, or open surgical or endovascular management for abdominal aortic aneurysm,[6] to improve outcomes and minimise postoperative complications.

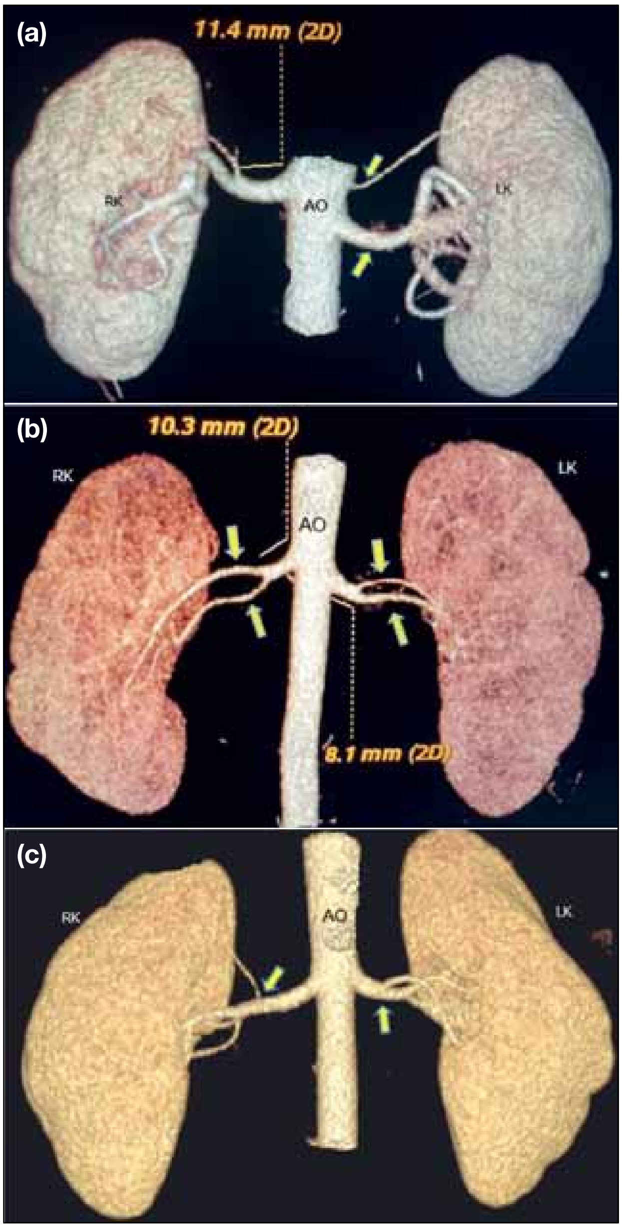

Figure 4. Prehilar bifurcation. (b) Volume rendering image showing two left renal arteries with right renal artery prehilar bifurcation. (b and c) Volume rendering reconstructed images showing bilateral prehilar bifurcation.

Abbreviations: 2D = two-dimensional; AO = aorta; LK = left kidney; RK = right kidney.

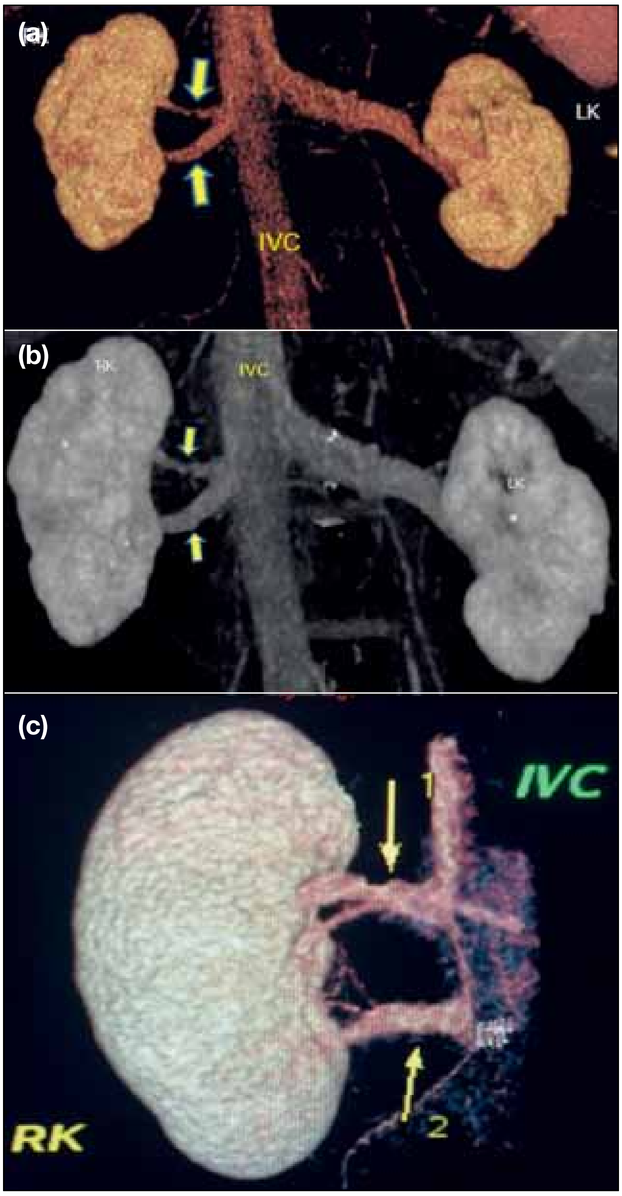

Figure 5. Right renal vein duplication. (a) Volume rendering reconstructed image showing right renal vein duplication. (b and c) Three-dimensional reconstructed images showing right renal vein duplication.

Abbreviations: IVC = inferior vena cava; LK = left kidney; RK = right kidney.

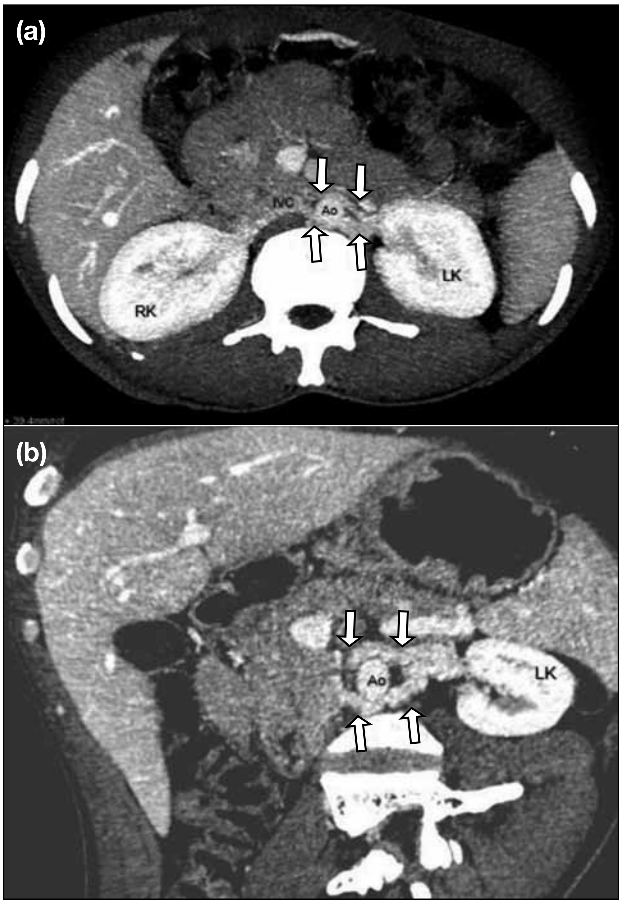

Figure 6. Circumaortic left renal vein. (a) Maximum intensity projection axial multidetector computed tomography image showing circumaortic left renal vein. (b) Maximum intensity projection multioblique reconstructed multidetector computed tomography image showing circumaortic left renal vein.
Abbreviations: Ao = aorta; IVC = inferior vena cava; LK = left kidney; RK = right kidney.

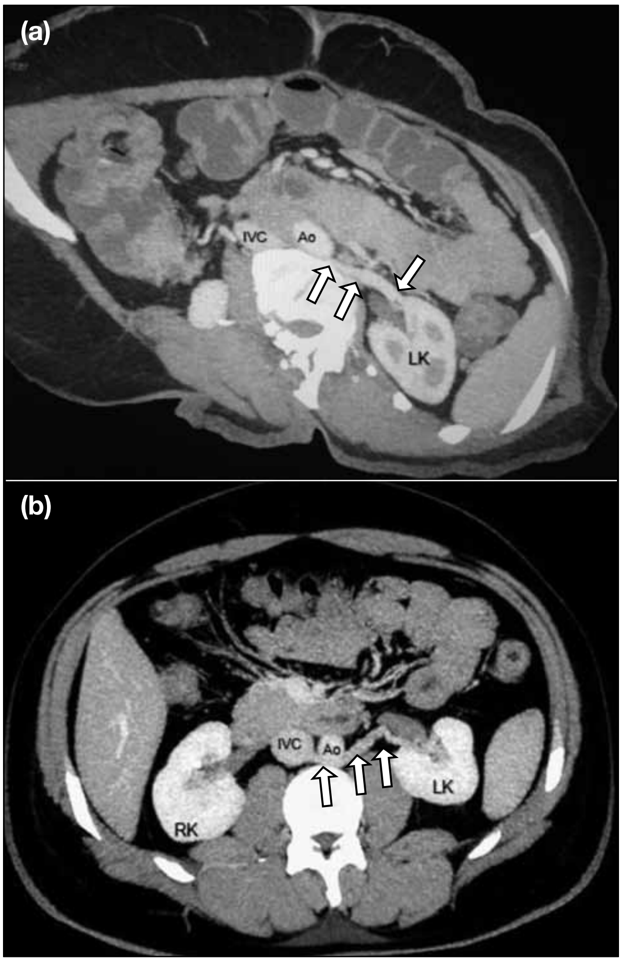

Figure 7. Retroaortic left renal vein. (a) Multiplanar reconstruction image showing retroaortic left renal vein. (b) Maximum intensity projection axial multidetector computed tomography image showing retroaortic left renal vein.
Abbreviations: Ao = aorta; IVC = inferior vena cava; LK = left kidney; RK = right kidney.

Traditionally, invasive conventional arteriography and venography was used to evaluate renal vascular variations. Previous studies documenting renal vascular variants have been mostly cadaveric or postoperative renal donor studies.[1,7] Recently, MDCT angiography has allowed preoperative assessment of the renal arteries and veins non-invasively and more quickly.

Single, duplication, triplication and quadruplication of the arteries were defined by Pollak et al[7] as arteries having separate origins from the abdominal aorta. That study,[7] involving 800 kidneys, showed that the most common variant was duplication of renal arteries (23%), which is in accordance with the present study (16.5%). Triplication and quadruplication were observed in four (2%) and one (0.5%) kidneys, respectively, in the present study, compared with 32 (4%) and eight (1%) kidneys, respectively, in Pollak et al.[7] The laterality of the occurring variation is important for surgeons and interventionists. Variations are more commonly noted in left renal artery[7] than in the right; therefore, the left kidney is usually not the first choice for donor kidney.

According to Pozniak et al,[5] if bifurcation takes place within 1.5 cm of the renal arterial ostium in the abdominal aorta, it is called prehilar bifurcation. We observed prehilar bifurcation in 23 (11.5%) of kidneys. These results are comparable to Budhiraja et al[8] who observed prehilar bifurcation in 11 (11.66%) of kidneys. The laterality of prehilar bifurcation was present with equal prevalence in the left and right kidneys. Of the 23 instances of prehilar bifurcation observed, 11 were on left and 12 were on right renal arteries.

Multiple prehilar branches of renal arteries correspond to segmental arteries. Therefore, the risks of intra-operative haemorrhage during renal transplantation, segmental ischemia in postoperative status, and hypertension due to loss of parenchyma increase with prehilar bifurcations. Ligation of both bifurcated branches is of imperative importance for the donor kidney, as failure to do so may lead to continuous haemorrhage in the donor. During prehilar bifurcation the superior branch may have to travel vertically to supply the upper pole, and the vertical course gains importance here. Beyer and Daily[9] showed that such vertically directed upper polar arteries may lead to upper pole infarction.

Venous variations are less common than arterial variation, but are equally important to the surgeon and the interventionist. According to Urban et al,[10] supernumerary renal veins are the most common venous variant, observed in approximately 15% to 30% of patients.

The right renal vein is a short stout vein draining into the IVC. Owing to its short course, the length of ligation is an important factor in renal transplant outcome.

According to Beckmann and Abrams,[11] the right renal vein variations are noted in about 30% of patients, whereas Pozniak et al[5] showed right renal vein variations in only 13.2% of patients, including mainly multiple renal veins with different ostia. In contrast, the present study found right renal vein duplication in only 4% of patients.

The left renal vein has a long complex course and the variations noted are unique. Multiplicity is a very rare variation in the left renal vein. Circumaortic and retroaortic 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.[10] 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.[10]

Pozniak et al[5] found circumaortic left renal vein in 8.3% and retroaortic left renal vein in 2.9% of the patients studied. Beckmann and Abrams[11] found circumaortic left renal vein in 17% and retroaortic left renal vein in 3% of the patients studied. The results of the present study follow a similar trend, with circumaortic left renal vein in 6% and retroaortic left renal vein in 2% of the patients studied.

Pandya et al[4] evaluated renal venous variants, and also 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. Although venous variations are important, the present study also evaluated common arterial variations, giving surgeons and interventionists a more complete picture of the renal vasculature.

These findings are of great clinical significance because of a syndrome known as "nutcracker syndrome,"[12] 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 retroaortic or circumaortic variation, between the aorta and an underlying vertebral body.[13-15] Nutcracker syndrome refers to the cascade of symptoms developing due to increased venous pressure in the left renal vein as a result of obstruction of its venous outflow into the inferior vena cava.[16,17] This finally results in the development of intra- and extra-renal hypertensive valveless venous collateral vessels.[18,19]

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.

Limitations

The study included MDCT angiographic images of 100 patients. Although almost all types of variants were documented in this study, the sample size is smaller than that of previous studies, such as that of Pollak et al.[7] A continuation of this study to include a larger population would increase the power of the results.

CONCLUSIONS

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 important 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.

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