CT Angiography for Living Kidney Donors: Accuracy, Cause of Misinterpretation and Prevalence of Variation

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Objective: To determine the accuracy of the use of multi-detector row CT (MDCT) to predict vascular anatomy in living kidney donors and to reveal the prevalence of vascular variations in a Korean population.

Materials and Methods: A total of 153 living kidney donors that had undergone preoperative CT and nephrectomy, either with open or laparoscopic surgery, were selected retrospectively. The initial CT results were compared with the surgical findings and repeated review sessions of CT scans were performed to determine the causes of mismatches in discordant cases.

Results: The accuracy of CT angiography was 95% to predict the number of renal vessels. Four arteries and two veins were missed during the initial CT interpretation due to perception errors (for two arteries and two veins) and technical limitations (two arteries). The prevalence of multiple renal arteries and veins, early branching of a renal artery and late confluence of a renal vein were 31%, 5%, 12%, 17%, respectively. The circumaortic renal vein and the bilateral inferior vena cava were found in two cases each (1.3%). One case (0.7%) each of a retroaortic renal vein and a supradiaphragmatic originated renal artery were found.

Conclusion: MDCT provides a reliable method to evaluate the vascular anatomy and variations of living kidney donors.

Index terms:
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Living renal donor
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Renal transplantation is associated with better survival and quality of life in end-stage renal disease patients than performing dialysis, and living donor renal transplantation has been shown to offer better graft survival than cadaver donor renal transplantation. However, adequate preoperative living kidney donor evaluation is mandatory to reduce the possible occurrence of surgical complications that can threaten the graft, and sometimes the survival of the recipient (1).

The usefulness of single section helical computed tomography (CT) for the preoperative evaluation of living kidney donors has been well established (2–4). Several investigators have also described the use of multi-detector row CT (MDCT) for the preoperative evaluation of living kidney donors (5, 6).

The study presented here is the largest to date in terms of the number of cases among studies that have examined the accuracy of MDCT that is reconstructed at a 1.00–1.25 mm slice thickness to predict renal vascular anatomy in living renal donors. We also evaluated the cause of misinterpretations by CT. In addition, the prevalence of renal vessel variations in a Korean population was determined.

MATERIALS AND METHODS

Kidney Donors

One hundred and eighty three donor candidates underwent an MDCT evaluation at Seoul National University Hospital (Seoul, Korea) between January 2002 and December 2005. One hundred and sixty five kidneys were eventually donated. Properly documented surgical reports were available for 153 donor nephrectomies, including 136 open nephrectomies and 17 laparoscopic nephrectomies. Properly documented surgical reports were defined as reports that contained information about the selected side for donation, the number of renal vessels and major variations that required a longer ischemic time or additional procedures in surgery. The finally selected 153 donors (mean age, 38 years; age range, 19−61 years) consisted of 74 male donors (mean age, 36 years; age range, 20−61 years) and 79 female donors (mean age, 39 years; age range 19−58 years).

Informed consent was obtained before MDCT/iodinated contrast material examinations were performed. The ethical committee at our hospital approved this retrospective study.

MDCT Scanning and Image Post-Processing

A four-channel MDCT unit (MX-8000; Marconi Medical Systems, Cleveland, OH), an eight channel MDCT unit (GE Hispeed Ultra; GE Medical Systems, Milwaukee, WI) and a sixteen channel MDCT unit (Sensation 16; Siemens, Enlangen, Germany) were used for the CT examinations in 67, 58 and 28 cases, respectively.

MDCT scans were obtained with patients in the supine position; where the feet entered the gantry first. An 18-gauge venous line was placed, usually in an antecubital fossa vein, and a total of 150 mL of nonionic contrast material containing iopromide (Ultravist 370; Schering, Berlin, Germany) was injected at 4 mL/sec using a power injector (Envision CT; Medrad, Indianola, PA) in the same manner for all three MDCT scanners. Just after the contrast injection, a total of 40 ml normal saline was injected at 2 ml/sec to allow the residual contrast material in the veins to be pushed into the arterial system to increase the efficiency of contrast enhancement.

Pre-contrast CT covering both kidneys, including arterial phase and venous phase scans covering from the diaphragmatic dome to iliac crest level, were obtained. Bolus triggering methods were routinely used to ensure appropriate scan timing. The arterial phase scan started when the triggering level of the mid descending thoracic aorta reached 100 Hounsfield units (HU), and the venous phase scan followed the arterial scan. The acquisition parameters used for the CT examinations were 120 kVp for all CT scanners, 250 effective mAs for the 4-channel and 200 mAs for 8 and 16 channel units, and a 0.5 sec rotation time for all three units. Detector collimations were 4 $\times$ 1 mm, 8 $\times$ 1.25 mm, 16 $\times$ 0.75 mm, respectively for the three units, and the reconstruction parameters were a 1 mm slice thickness for the 4 and 16-channel units, and a 1.25 mm slice thickness for the 8-channel unit. A 1 mm reconstruction increment was used for all three units.

Thin-section axial images were transferred to a workstation installed with a PC-based three-dimensional (3D) program (Rapidia, INFINITT, Seoul, Korea). Individual volume data were loaded into the 3D program, and the data were reformed into routine 3D images, which included maximum intensity projection (MIP), multiplanar-reconstruction (MPR), and volume-rendered images by an experienced technician. The routine MIP images and volume rendered images were reconstructed to cover both kidneys to the upper pelvis in an exact coronal plane and oblique coronal plane adjusted to be parallel with both renal hilum. Curved MPR was performed by setting the curve axis along both main renal arteries. The radiologist performed additional reconstructions, if special focused images were needed after a review of the axial CT scans.

Image Analysis

Image Analysis for the Accuracy of MDCT

Initial interpretations of all CT images, including thin section axial images and 3D reformatted images, were performed retrospectively by an experienced cardiovascular radiologist unaware of the surgical results. The numbers and major variations of the renal arteries and veins were evaluated. Initial interpretations were compared with the surgical findings (the reference standard) and the accuracy of CT for the evaluation of renal vascular anatomy, particularly in terms of the numbers of arteries and veins, was determined. The accuracies of CT evaluations were derived from the donor side kidneys only, for which the surgical findings confirmed the anatomies.

A secondary image interpretation session was conducted after matching the CT and surgical findings. The radiologist who interpreted the CT images during the initial CT analysis also reviewed the CT images that showed a mismatch between the CT and surgical findings, but without knowledge of the surgical findings, to determine whether vessels were missed because of technical limitations or because of interpretation errors.

After matching the secondary image interpretations with the surgical findings, the remaining mismatched cases were finally reviewed with knowledge of the surgical findings, by the same radiologist.

Prevalence of Vascular Variations of the Renal Vessels

The prevalence of vascular variations was calculated using surgical and CT findings in the donated side kidneys, whereas the prevalence of vascular variations in the non-donated side kidneys was evaluated using CT alone. The prevalence of multiple renal arteries and veins, early renal artery branching, and late confluence of the renal vein were recorded. Other anatomical variations of the renal vein and artery, such as a circumaortic renal vein, bilateral inferior vena cava (IVC) or a retroaortic renal vein, or of an unusual course or origin of the renal artery, were also recorded.

More than two renal arteries that arose from the aorta with multiple ostia, regardless of the size, were defined as multiple renal arteries. More than two renal veins that drained into the vena cava with multiple ostia, again regardless of the size, were defined as multiple renal veins. An early branching renal artery was defined as a first renal artery branch that arose within 1.5 cm of the ostium of the renal artery. A late confluence of the renal vein was defined as a final confluence point within 1.5 cm from the left lateral border of the aorta for the left kidney. A late confluence of the renal vein for the right kidney was not evaluated as the right kidney had a short renal vein and in almost all cases, confluence occurred within 1.5 cm from the IVC.

RESULTS

Surgical Findings of the Donated Kidneys

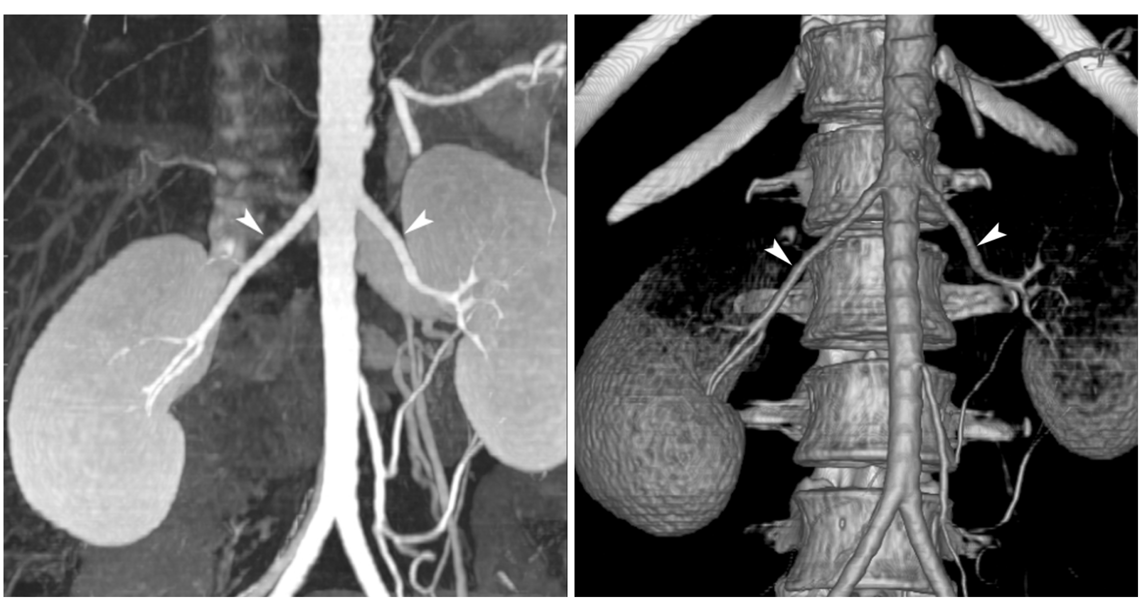
The left kidney was selected in 145 candidates and the right kidney in eight candidates. Among the donated kidneys, a single renal artery was present in 100 left kidneys and in six right kidneys (69.3%, a total of 106 kidneys out of 153 kidneys). Forty-seven kidneys had multiple arteries, i.e., 40 left and two right kidneys had two renal arteries (27.5%, a total of 42 kidneys out of 153 kidneys), three left kidneys had three renal arteries (2%, three kidneys out of 153 kidneys) and two left kidneys had four renal arteries (1.3%, two kidneys out of 153 kidneys).

A single renal vein was present in 139 left kidneys and in seven right kidneys (95%, a total of 146 kidneys out of 153 kidneys). Seven kidneys had two renal veins (4.6%, one right kidney and six left kidneys out of 153 kidneys).

The Accuracy of MDCT with Respect to the Number of Renal Arteries and Veins

It was found that the MDCT anatomy exactly matched the surgical findings for 146 donors (95.4%, 146 donors out of 153 donors). The accuracy for the prediction of the renal artery number in the initial CT interpretation was 96% (147 donors out of 153 donors) and the accuracy for the prediction of the renal vein number was 99% (151 donors out of 153 donors).

The accuracies of CT for predicting the existence of renal



A B

Fig. 1. 31-year-old female, left kidney donor.
A, B. Maximum intensity projection image and 3D volume rendered image show bilateral single renal arteries (arrowheads). Two left renal arteries were found during donor nephrectomy. However, retrospective review with knowledge of surgical results revealed only one visible renal artery.

vessels based on the number of renal arteries and veins were 98% (203 arteries out of 207 arteries) and 99% (158 veins out of 160 veins), respectively. There were two false positive cases.

Four arteries and two veins of five donors were missed during the initial CT interpretation. On a second-look of the CT scans (without knowledge of the surgical results), one missed artery and one missed vein on the initial interpretation were detected retrospectively. The sizes of retrospectively detected artery and vein were 2.7 mm and 2.4 mm, respectively. The accuracies of the second-look interpretation session were 25% (one artery out of four arteries) and 50% (one vein out of two veins), respectively.

Final reading sessions (with knowledge of the surgical findings) revealed that one artery and one vein with a size of 1.3 mm and 2 mm at a peripheral vessel location, respectively, were also missed on both the initial and second-look interpretation sessions. The accuracies of the final reading session were 33% (one artery out of three arteries) and 100% (one vein out of one vein), respectively. However, two missed arteries were not detected even after repeated careful re-evaluations of the CT images, with knowledge of surgical information (Fig. 1).

Prevalence of Variations of the Renal Vessels

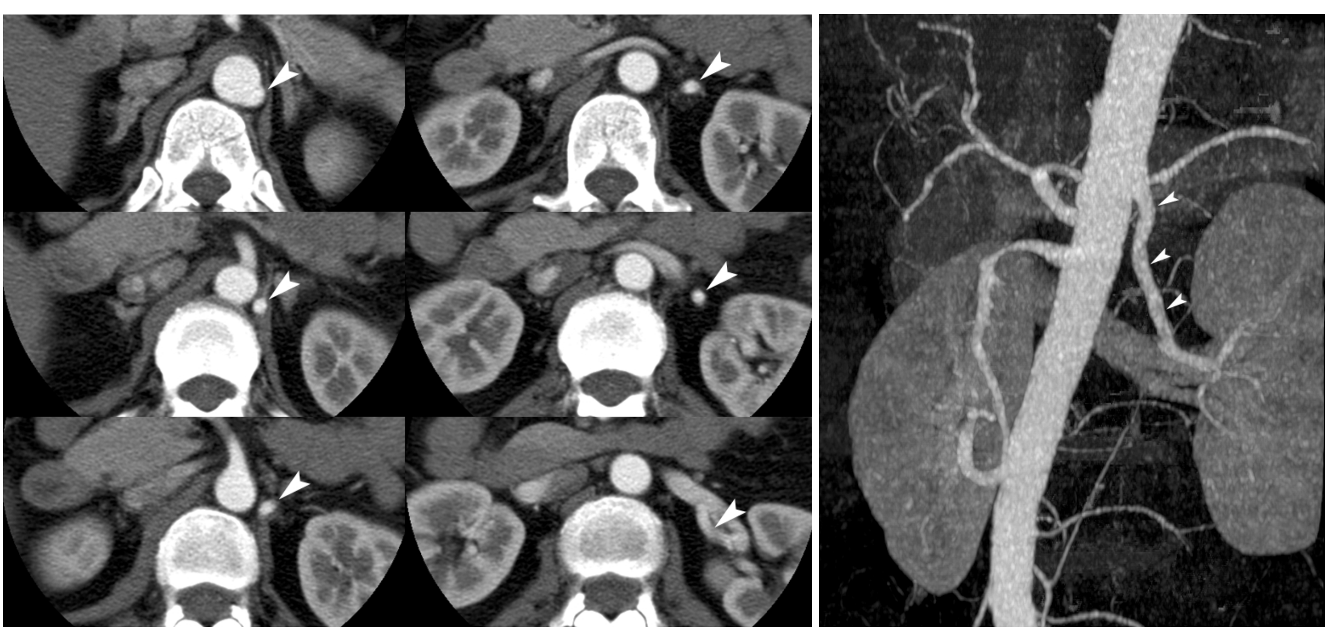
The prevalence of vascular variations was calculated from the surgical findings of the donated kidneys and the CT findings of non-donated kidneys. Forn a total of 306 kidneys from 153 kidney donors, a single renal artery was detected in 220 kidneys (71.8%, 220 kidneys out of 306 kidneys) and a single renal vein was detected in 258 kidneys (84.3%, 258 kidneys out of 306 kidneys). Two renal arteries were found in 76 kidneys (24.8%, 76 kidneys out of 306 kidneys), three renal arteries in eight kidneys (2.6%, eight kidneys out of 306 kidneys) and four renal arteries in two kidneys (0.6%, two kidneys out of 306 kidneys). In addition, two renal veins were found in 40 kidneys (13.0%, 40 kidneys out of 306 kidneys) and three renal veins in eight kidneys (2.6%, eight kidneys out of 306 kidneys).

Thirty-seven kidneys had an early branching renal artery, and 33 kidneys had a late confluence of renal vein. Two kidneys had circumaortic renal veins. Two donor candidates had a bilateral IVC, and one donor had a retroaortic renal vein. In addition, there was one precaval right renal artery and one left renal artery with a supradiaphragmatic origin (Fig. 2). The summarized results of the renal vascular variations are shown in the Table 1.

DISCUSSION

Accuracy of MDCT

This study aimed to evaluate the accuracy of renal CT angiography obtained by the use of MDCT for the prediction of renal vascular anatomy and its variations in living



A B

Fig. 2. 49-year-old female, left kidney donor.
A, B. Contrast-enhanced arterial phase axial CT scan images and maximum intensity projection image showing left renal artery with supradiaphragmatic origin (arrowheads in **A, B**), which is known as rare variation. In this case, left renal artery length was sufficient for donor nephrectomy.

kidney donors. We also evaluated the cause of misinterpretations by CT, because the accuracy of CT might be increased by reducing the causes of misinterpretation.

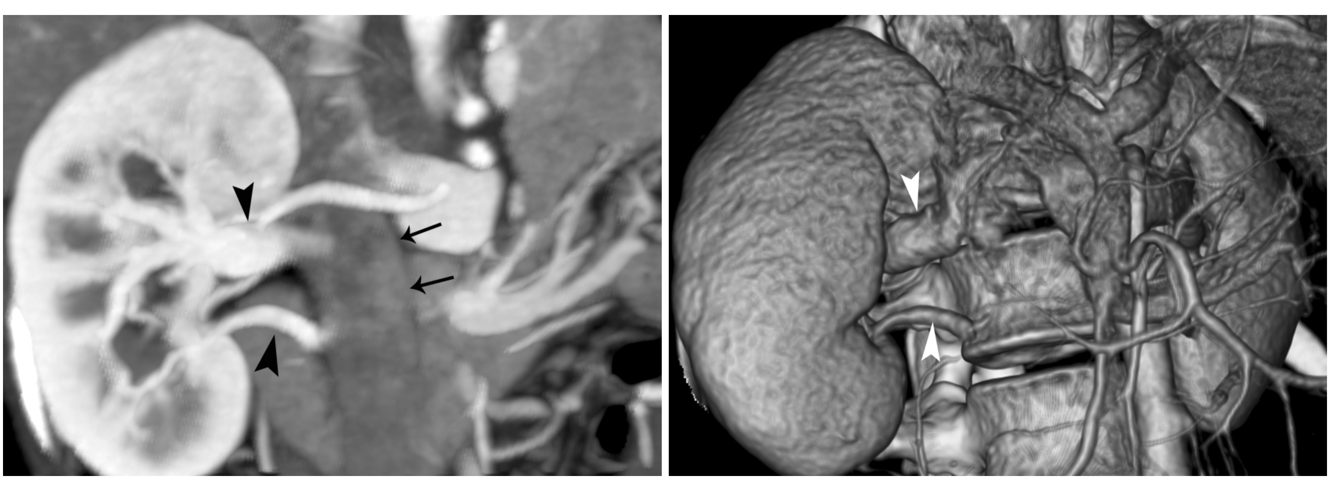
In our study, CT angiographic anatomies with respect to the renal arteries and veins precisely matched the surgical findings for 146 of 153 donors, an accuracy of 95% with respect to the kidney donor. The accuracy for predicting only the number of renal arteries was 96%, and the accuracy for predicting renal veins was 99%. Results of this study correspond well with those of earlier studies that have reported that MDCT showed high sensitivity in the assessment of renal vasculatures (7−10).

Out of four renal arteries that were not detected on the initial interpretation of the CT scans, two of these arteries were also not observed on retrospective reviews with knowledge of the surgical findings, and were thus attributed to technical limitations. Villablaca et al. (11) have reported that MDCT can be a reliable tool for quantification of a vessel with a size over 7 mm, and the range of size for a renal accessory renal artery was described as 0.2−3.0 cm by Satyapal et al. (12). Therefore, the majority of the accessory renal arteries should be well demonstrated with MDCT. However, in our study, repeated evaluation of the CT images could not depict the missed arteries. This could not be confirmed, but it could be presumed that the accessory renal artery mentioned on the surgical report was not detectable in the repeated evaluations of the CT due to artifacts such as a motion artifact or a stair-step artifact. It was also emphasized that adequate contrast enhancement is also critical for detecting small arteries by

Table 1. Incidence of Major Vascular Variation in Renal Donors

	Donated Kidney* (n = 153)		Both Kidneys** (n = 306)	
	N	Percentage (%)	N	Percentage (%)
Artery				
Accessory renal artery	47	30.7	86	28.1
Early branching of renal artery	18	11.8	37	12.1
Supradiaphragmatic origin of renal artery	1	0.7	1	0.3
Precaval renal artery	0	0	1	0.3
Vein				
Accessory renal vein	7	4.6	48	15.7
Late confluence of renal vein	27	17.6	33	10.8
Retroaortic renal vein	1	0.7	1	0.3
Circumaortic renal vein	2	1.3	2	0.7
Bilateral Inferior Vena Cava	2	1.3	2	0.7

Note.—N = Number of Patients, * data from surgical reports, ** data from CT findings



A B

Fig. 3. 23-year-old female, right kidney donor. One right renal vein was detected at initial CT interpretation, but two right renal veins were found during donor nephrectomy.
A, B. Maximum intensity projection image and 3D volume rendered image show two right renal veins. Retrospective review without knowledge of surgical results revealed accessory renal vein (arrowheads in **A, B**) confluence at lower level of inferior vena cava (arrows in **A**).

Claves et al. (13). Therefore, an acceptable quality of the CT scan and optimal scan timing for adequate contrast enhancement could reduce the technical limitations of MDCT.

Two renal arteries and two renal veins were retrospectively detected. These cases were attributed to an interpretational limitation. The sizes of the missed arteries and veins ranged between 1.3–2.7 mm, and most of the vessels were not difficult to find in repeated interpretation session. If the missed arteries and veins were detected during the initial interpretation, the accuracy of CT could have been increased. In addition, MDCT has been shown to be reliable even when images are interpreted by multiple readers with varied levels of expertise, as reported in a study by Sahani et al. (8). Therefore, when the images are obtained in adequate scan protocols and with adequate contrast enhancement (14), human errors can be decreased by careful image interpretations (Fig. 3).

There were two false positive arteries found in our initial interpretation session. One of them was a 1.2 mm sized accessory renal artery that arose from the upper abdominal aorta, so it could be missed in the limited operative field. However, CT well-demonstrated the accessory artery penetrating the renal cortex and supplying the upper pole of the kidney, thus the CT finding could be more reliable than the surgical record, which is based on a narrow field of vision. The other accessory renal artery was 3.2 mm in diameter, and arose from the upper renal hilum and supplied the lower pole of the left kidney. It was nearly the same size as the main renal artery, but it was not described in the surgical report. We included these two cases in the calculation of accuracy, but they were excluded from the missed cases.

Variations of the Renal Vessels

The prevalence of the supernumerary renal artery was 28% in the present study, which is similar to that found in previous studies (23–40%) (6, 14–16). In addition, the prevalence of an early branching renal artery was reported as 10–12% (4, 6), which also concurs with the 12% of our study. An early branching renal artery is considered technically in the same manner as a double renal artery from a surgical perspective, as it requires a longer ischemic time. Furthermore, in our study, two rare renal artery variations were observed, i.e., a precaval right renal artery and a left renal artery with a supradiaphragmatic origin.

The prevalence of a supernumerary renal vein has been reported to be in the range from 9–28% (2, 6, 14, 15). Forty-eight kidneys (15.6%) had multiple renal veins in our study, which is concurrent with previous studies.

Thirty-three kidneys (10.8%) showed late renal vein confluence. This variation has been described in a few previous studies, e.g. 16% in a study by Kim et al. (7). Other renal vein variations are less common in the Korean population than in other populations. Two kidneys (1.4%) had a circumaortic left renal vein, which has been previously reported to occur at an incidence of 3–17% (5, 17). Two donor candidates (0.7%) had a bilateral IVC, and only one donor (0.3%) had a retroaortic left renal vein, which is substantially smaller than the 3% reported in previous studies (2, 5, 14).

There are some limitations in this study. First, the size and location of the renal artery or renal vein are not all described in the surgical reports. Thus, we cannot know the size of a vessel that was unable to be seen on CT, and a focused evaluation of CT scans for the described locations was not possible. Second, the prevalence of renal vascular anatomy was only confirmed in the donated kidney. As the complexity of renal vascular anatomy influences the decision of the donor site, the incidence of complex vascular variations could be only presumed from the CT findings.

CT can demonstrate both venous and arterial anatomy, which is its major advantage as compared with conventional angiography. Moreover, the depiction of tributaries, such as the ascending lumbar and adrenal veins, is only possible by CT. Pre-operative knowledge of the venous anatomy can help reduce the number of surgical complications and shorten the ischemic time.

MDCT offers rapid data acquisition and narrow collimation, which allows greater anatomical coverage and higher longitudinal spatial resolution. MDCT also provides thinner and more accurate anatomical information than conventional CT. In our study, only two renal arteries remained undetected after the initial and retrospective reviews. Thus, the accuracy of CT in terms of revealing surgical results before or after surgery, reached almost 99%, and its technical limitations may be considerably reduced in the future.

In conclusion, MDCT can provide a highly accurate assessment of the renal vascular anatomy in living kidney donors.

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