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ORIGINAL ARTICLE

Preoperative evaluation of living kidney donors using multirow detector computed tomography: comparison with digital subtraction angiography and intraoperative findings

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Summary

To assess the accuracy of multirow detector computed tomography (MDCT) for the evaluation of renal anatomy for preoperative donor assessment in living related kidney transplantation. MDCT-scans (4- and 16-slice-CT) of 51 consecutive living kidney donors (age, 51.6 ± 9.7 years; range, 28–68 years) were analysed by three blinded observers and compared with digital subtraction angiography (DSA) and surgery. Contrast-enhanced MDCT was performed with 1 mm slice thickness reconstruction interval during arterial and venous phases. Supernumerary renal arteries, veins, early branching of vessels and abnormalities of the ureters were documented. The overall accuracy of computed tomography angiography (CTA) for detection and classification of surgically relevant arterial variants was 97% (99/102). The interpretation of 16-channel MDCT images was correct in all cases (accuracy, 100%), while the four-channel CTA had three incorrect results regarding the differentiation of early branching vessels from double renal arteries (accuracy, 93%). The overall accuracy of DSA was 91%. Renal vein abnormalities were correctly diagnosed with MDCT in 100% compared with 89% correct findings with DSA. There were three kidneys with incomplete ureter duplication, detected both with MDCT and DSA. MDCT demonstrated superior accuracy compared with non-selective DSA for the preoperative assessment of renal anatomy in living kidney donors; and for the distinction of supernumerary arteries versus early branching patterns, 16-channel CTA data were better than those of the four-channel system.

Introduction

There has been a substantial increase of patients with end-stage renal disease waiting for kidney transplantation over the last 10 years. However, only a minority of patients receive transplants as a consequence of limited availability of cadaveric organs [1–5].

Living donor renal transplantation has been shown as safe surgical procedure with an excellent graft survival. The procedure also offers the opportunity to overcome the relative organ shortage. While approximately 15–20% of renal allografts are performed as living donor transplantations in Europe, this procedure represents the majority of renal transplants currently performed in US (54% of all kidney transplantations in 2003) [6,7].

Preoperative assessment of renal anatomy is crucial during donor work-up. Supernumerary arteries and early branching are of particular importance in addition to renal function for the decision on the site of nephrectomy. Ideally, preoperative imaging should also give sufficient information on variants of renal veins and ureters [8–10].

Digital subtraction angiography (DSA) is denoted as the gold standard for the assessment of renal anatomy. For a precise evaluation on supernumerary arteries, however, a selective procedure is frequently required bearing the risk of local endothelial damage. Computed tomography angiography (CTA) with its more recent and rapid technical development is proven to be a powerful tool to visualize the vasculature of various anatomic regions. Particularly, multirow detector scanners with their increased speed and decreased slice thickness are shown suitable for renal vessel visualization. With the more recent introduction of 16-channel computed tomography (CT), a further improvement of diagnostic accuracy can be expected [10–15].

The purpose of our study, therefore, was to evaluate the accuracy of multirow detector computed tomography (MDCT) with four- and 16-channel scanners for the preoperative assessment of renal anatomy in comparison with DSA in living kidney donors.

Materials and methods

Patients

Between January 2001 and November 2004, 51 consecutive living kidney donors (mean age, 51.6 (±9.7) years; range, 28–68 years; male, $n = 20$; female, $n = 31$) were evaluated by both DSA and MDCT and underwent a subsequent unilateral nephrectomy in our institution. Written informed consent was obtained from all patients.

Multirow detector computed tomography

Computed tomography data were obtained with a four-channel (Somatom Plus 4; Siemens, Erlangen, Germany) or a 16-channel (Lightspeed 16/Pro 16; GE Medical Systems, Milwaukee, WI, USA) multidetector CT scanner. After a nonenhanced scan, a contrast-enhanced CTA of renal arteries was performed followed by a venous contrast phase of the entire abdomen [volume, 100-ml iopromide (iodine concentration, 370 mg/ml); Ultravist 370®, Schering, Berlin, Germany]. The contrast material was intravenously injected through an 18-G catheter in an antecubital vein using a power injector (contrast material flow, 4 ml/s) followed by a 40-ml saline flush (flow, 4 ml/s). For the arterial phase the CT scan was started, using a bolus tracking system with the aorta as the region of interest on the first position of the scan field. The scan parameters of the four-channel CT (120 kV, 200–300 mA, rotation time 0.5 s, collimation 4×1 mm, table feed 4–6 mm/gantry rotation) resulted in average scan duration of 25 s for 30-cm scan length. The scan duration of the 16-channel CT (120 kV, 280 mA, 0.5 s, detector collimation 16×1.25 mm, table feed of 13.75 mm/gantry rotation) was 11 s for 30-cm scan lengths. Venous phase scanning was initiated 40 s after the beginning of the first scan.

For CT analysis, a workstation (Advantage Windows 4.1; GE Medical Systems) was utilized providing interactive reconstruction modes including multiplanar reconstruction (coronal, sagital and oblique planes), curved reformatting, maximum intensity projections (MIP) and colour encoded volume rendering technique (VRT) with optimized presettings for CT-angiography of the renal arteries.

Digital subtraction angiography

Digital subtraction angiography was performed through a femoral artery access with a 5-F sheath in Seldinger technique. For overview and non-selective angiography a flush aortogram from the diaphragm to the aortic bifurcation was performed; briefly, a catheter (5F omni-flush catheter; AngioDynamics, New York, NY, USA) was positioned in the abdominal aorta just above the expected origin of the renal arteries, and after administration of 20 ml iodinated contrast material [iopromide (iodine concentration, 300 mg/ml); Imeron 300®, Altana, Konstanz, Germany] with a power injector at a flow rate of 15 ml/s, images during arterial, parenchymal, venous and excretory phases were obtained. For selective DSA, a 5F cobra catheter (Terumo, Leuven, Belgium) was selectively positioned in the main renal arteries followed by arterial and parenchymal phase images (manual injection; 5 ml). Whenever there was direct or indirect (incomplete kidney silhouette) suspicion of a supernumerary renal artery, accessory vessels were selectively catheterized and visualized with additional contrast material injections ($n = 18$).

Image analysis

The review of CT images regarding anatomic variants of renal arteries was performed by three independent observers with different levels of clinical experience blinded for the results of DSA and intraoperative findings.

Moreover, CT image quality was assessed for the presence of artifacts (breathing, moving of the patient) and inadequate scan phases (contrast material in renal veins overlying the arteries; scan preceding the contrast bolus with insufficient contrast of the renal arteries) and rated accordingly as (i) good, (ii) sufficient or (iii) non-diagnostic. DSA examinations were performed and reviewed by an experienced interventional radiologist.

Radiological examinations were finally compared with findings recorded during surgery. Surgically relevant anomalies of the renal arteries were classified as early branching (branching of the main renal artery <20 mm from its origin of the aorta, and presence of supernumerary renal arteries. In addition, supernumerary renal veins (classified in number of supernumerary veins) and ureteral abnormalities were recorded.

Statistical analysis

Statistical analysis was performed with the help of SPSS Version 10.0.7 (SPSS Inc., Chicago, IL, USA). For assessing interobserver variability kappa statistics was used. The final MDCT consensus of the three observers, and the DSA results were additionally compared with the intraoperative findings of 51 kidneys. Calculation of sensitivity, specificity and accuracy for detection of surgically relevant anomalies of the renal vessels were calculated and stratified for selective and non-selective DSA and compared with the results of four- and 16-channel MDCT examinations for all 102 kidneys evaluated.

Results

Our observation period was paralleled by the advancements in CT scanning; thus, 30 patients underwent 16-channel MDCT and 21 were evaluated by four-channel MDCT. Selective DSA was performed in the presence of indirect or direct signs for supernumerary arteries ($n = 18$); 33 patients had nonselective DSA. Among 18 patients who underwent selective DSA, 10 had 4-channel MDCT and eight had 16-channel MDCT. In the group of patients with non-selective DSA ($n = 33$), 11 had four-channel MDCT and 22 had 16-channel MDCT.

Image quality

Image quality had increased with the implementation of 16-channel MDCT. While quality was considered as excellent in 93% ($n = 28$) following 16-channel MDCT 47% of individuals demonstrated excellent images with four-channel system. The remaining images were considered sufficient (7%, $n = 2$ and 53%, $n = 21$ for 16- and four-channel MDCT respectively).

Renal arteries

Thirty-six of 102 kidneys (35%) showed surgically relevant anatomic variants of renal arteries (Fig. 1). Among those, eight early branching arteries (Fig. 2), 24 kidneys with one and four with two supernumerary arteries arising from the aorta were observed (Figs 3 and 4). Detection and classification of surgically relevant variants of renal arteries by DSA and MDCT are summarized in Tables 1–3.

The detection of an early arterial branching pattern with DSA resulted in a sensitivity and specificity of 75% and 98% respectively (accuracy, 96%; false positive, $n = 2$; false negative, $n = 2$). Regarding the visualization of the correct number of supernumerary arteries, the sensitivity was 75% and the specificity was 99% (accuracy, 92%). The overall accuracy of DSA for the exact classification of the arterial anatomy, regarding the total number of accessory vessels or the presence of an early branching renal artery, was 91% (selective DSA, 97%; nonselective DSA, 88%). Table 3 demonstrates that nonselective DSA falsely classified the anatomic situation in eight kidneys. Selective

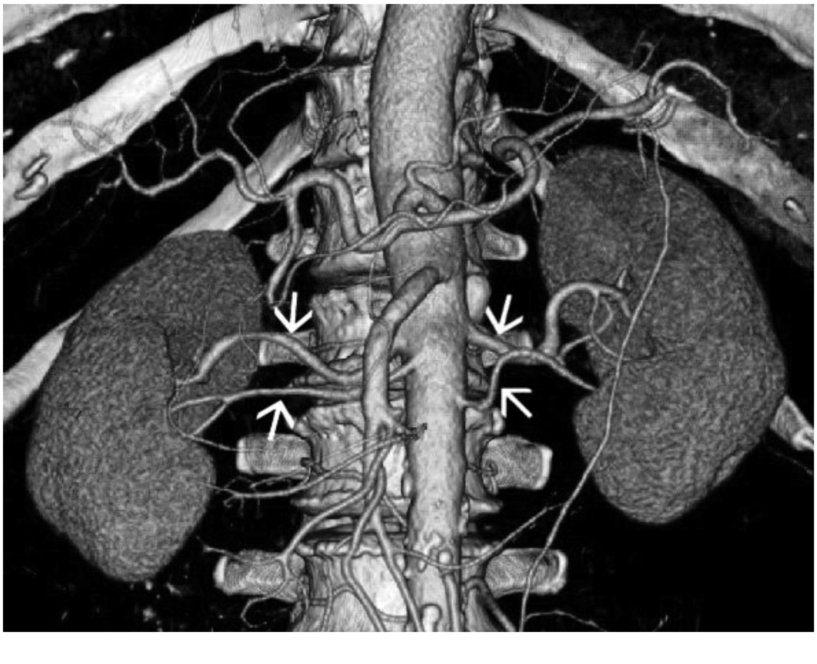

Figure 1 Computed tomography angiography (16-channel CT) of a living kidney donor whose right kidney was procured. Anterior reconstruction obtained with volume rendering technique demonstrates two renal arteries (arrows) for both right and left kidney.

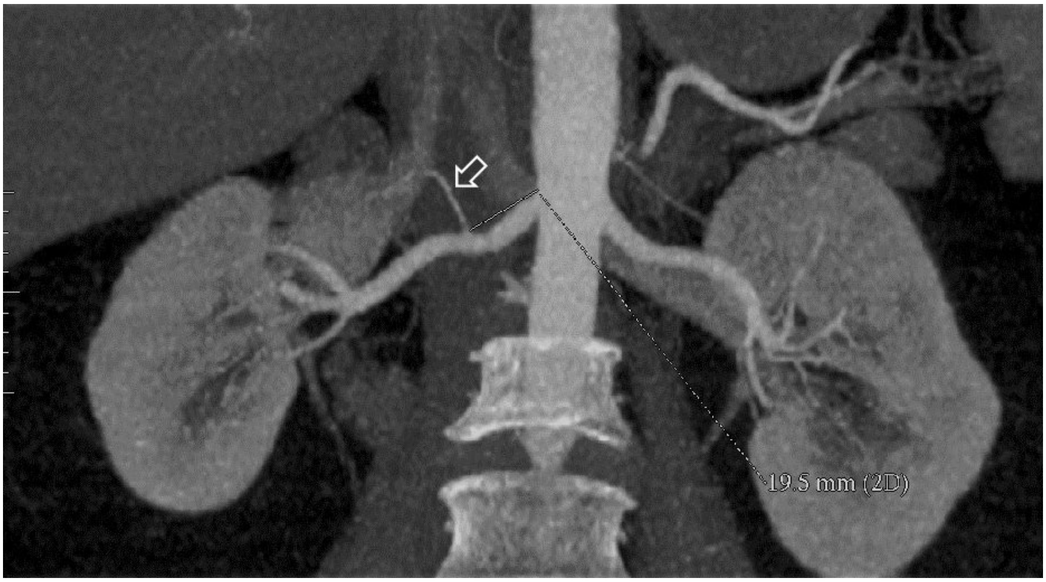

Figure 2 Computed tomography angiographic image (16-channel multirow detector CT) in a living kidney donor who donated his right kidney. Maximum intensity projection reconstruction demonstrates an early branching of a small calibre artery to the right upper kidney pole (arrow); 2D-measurement of the distance from the aorta to the branching point revealed a distance of approximately 19 mm.

DSA was incorrect in one case: here DSA detected two renal arteries in a graft which was found to have three arteries on CTA and intraoperatively.

Clinical experience did reflect the accuracy of MDCT evaluations to some extent with reduced kappa values for the least experienced radiologist. Using MDCT, the accuracies for observer 1, 2 and 3 were 89% (kappa, 0.789), 96% (kappa, 0.925) and 95% (kappa, 0.906) respectively, and with the consensus reading of all three reviewers the accuracy was 97% (kappa, 0.944). Interobserver agreement of CT readers revealed kappa values between 0.866 and 0.944. The accuracy of consensus reading for the subgroup of patients who had their examination with the 4-channel system was 93% (kappa, 0.841), and for patients with the 16-channel-MDCT it was 100% (kappa, 1.000).

Renal veins

With MDCT, accessory or branching renal veins were seen in 20% of kidneys (left, $n = 8$; right, $n = 12$) including two patients with circumaortic veins of the left kidney and three patients with three renal veins of the right kidney. When correlated with the intraoperative findings, MDCT enabled a correct diagnosis in all cases. The kappa values for interobserver agreement were 0.905–1.000 (observer 2 and 3 had concordant results).

DSA detected anatomic variants of the renal veins with a sensitivity of 45% (9/20), a specificity of 100% (82/82), and an accuracy of 89% (91/102). Both circumaortic veins were not visualized by DSA, but clearly demonstrated with MDCT. Of 11 false-negative findings with DSA, nine were on the right and two on the left side; the accuracy for selective DSA and nonselective DSA was 86% and 91% respectively.

Ureter

Both, MDCT and DSA showed incomplete ureter duplications in three of 102 kidneys (3%). All CT observers correctly identified those kidneys with ureter variants with a complete interobserver agreement (kappa = 1.000).

Discussion

The visualization of renal vessels in addition to a precise medical work-up is crucial during the evaluation of potential living kidney donors. Both functional results and anatomic technical considerations contribute to the decision to accept the donor and on the site of nephrectomy. In this study, we analysed MDCT with 4- and 16 channel-technique and found both systems highly accurate for donor vessel analysis. The overall accuracy for depicting surgically relevant arterial and venous variants was 97% and 100% respectively, which compared similarly or superior with more recent studies that used 2- and 4-channel multirow detector technology [11,12,16]. Moreover, it must be emphasized that in this study MDCT was as accurate as selective DSA (accuracy, 97%) and superior to nonselective catheter angiography (accuracy, 88%) for the determination of arterial anatomy.

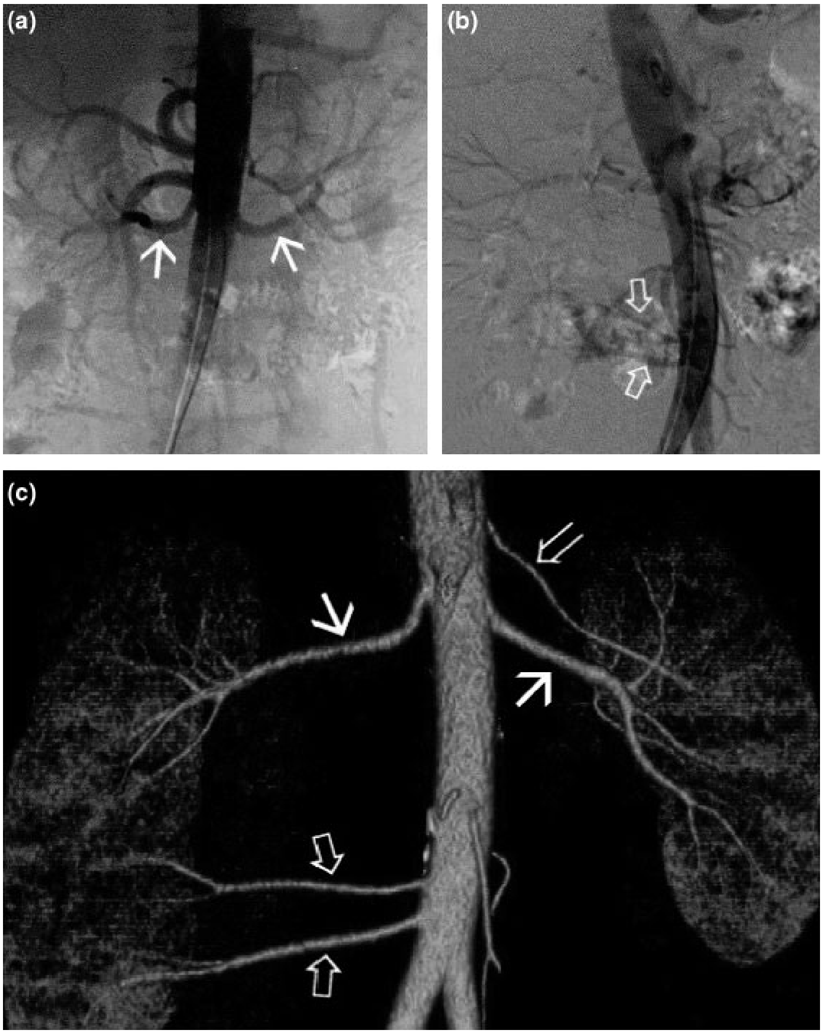

Figure 3 Nonselective digital subtraction angiography and computed tomography angiography in a living kidney donor who donated his left kidney. Difficult delineation of renal arteries on flush aortogram [early (a) and late (b) arterial phases] of DSA with substantial overlap of lumbar and mesenteric arteries. CT-angiography (c) (16-channel multirow detector CT) with anterior volume rendering clearly demonstrates the renal arteries (arrows) with two supernumerary arteries for the right kidney (closed arrows), and one supernumerary artery for the left kidney (open arrow).

As shown herein, we observed no significant differences when comparing 4- and 16- channel systems for the detection of the presence of surgically relevant anatomic variants. However, the ability of MDCT to display early renal artery branching (i.e. <20 mm from the origin of the aorta) had improved with the 16-channel-system (accuracy, 100%) compared with the 4-channel CT with a false assignment in three of 42 patients (accuracy 93%). The overall DSA accuracy for the detection of early branching was 96%, which was in accordance or superior to previously reported studies. However, it must be noted that with the sole assessment of flush angiograms the sensitivity for the detection of early arterial branchings or supernumerary arteries was only 50% and 75% for nonselective and selective DSA respectively [17,18].

It has been hypothesized that an increase in row numbers and higher MDCT speed will be associated with a superior visualization of renal arteries, because longer data acquisition has been shown to be more prone to breathing artifacts; moreover, the fast perfusion of healthy kidneys with early enhancement of renal veins may result in difficulties to differentiate small renal arteries from veins [9]. In our study, the duration for a 30-cm *z*-axis scan was 11 s for the 16-channel and 25 s for the 4-channel system; and in this study, we consistently more often observed motion artefacts and renal vein enhancement during arterial phase acquisition with 4-channel MDCT scans than with the 16-channel device (57% vs. 7% of scans).

In contrast, with the increased speed of modern MDCT systems, scan timing has been shown to be of utmost importance and variations in circulation time may result in poor contrast enhancement with nondiagnostic images. To overcome the risk of inadequate timing with scans preceding the contrast material bolus, we used a bolus-tracking technique that allowed for adequate definition of the contrast material timing in this study [19–21].

There has been some controversial discussion regarding the best reconstruction method for evaluating CT data in

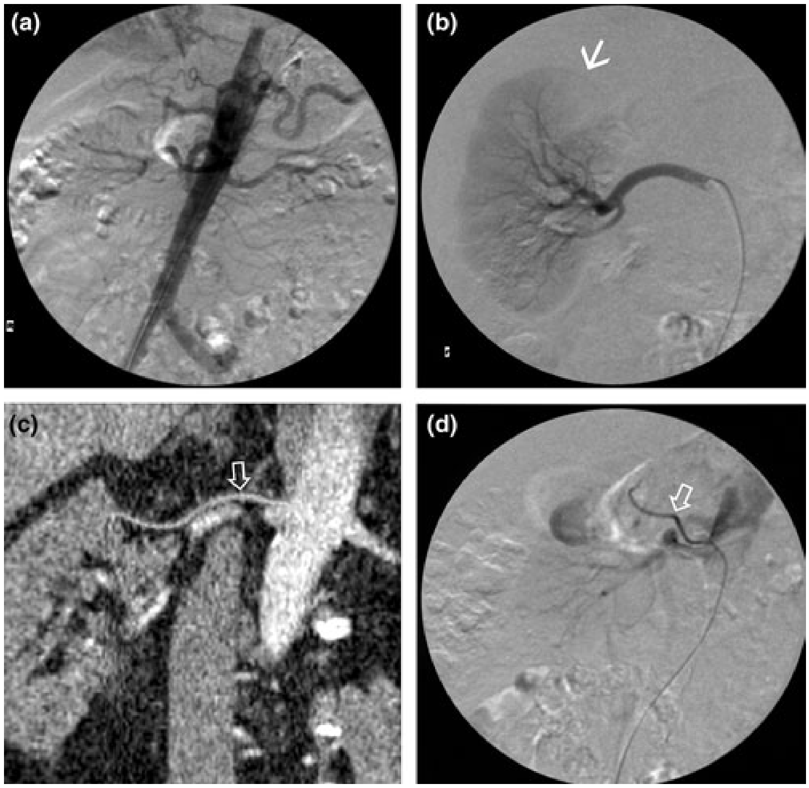

Figure 4 Nonselective digital subtraction angiography and computed tomography angiography in a living renal donor who donated his left kidney. Flush-angiogram (a) demonstrates singular renal arteries bilaterally. However, selective injection into the main right renal artery (b) shows a noncontrasted portion at the right upper pole, suggesting the presence of a supernumerary vessel. Curved reformatted image of a 16-channel multirow detector CT (c) scan clearly visualizes a small supernumerary upper pole artery, which was also found upon selective catheterization (d).

Table 1. Evaluation of renal vessels in living donor kidney transplantation: accuracy of MDCT and DSA.

	Early branching artery*			Supernumerary arteries†			
Modality	Sensitivity (%)	Specificity (%)	Accuracy (%)	Sensitivity (%)	Specificity (%)	Accuracy (%)	Overall accuracy‡ (%)
DSA	75 (6/8)	98 (92/94)	96 (98/102)	75 (21/28)	99 (73/74)	92 (94/102)	91 (93/102)
Selective	100 (4/4)	100 (32/32)	100 (36/36)	92 (11/12)	100 (24/24)	97 (35/36)	97 (35/36)
Nonselective	50 (2/4)	97 (60/62)	94 (62/66)	63 (10/16)	98 (49/50)	89 (59/66)	88 (58/66)
MDCT	100 (8/8)	98 (92/94)	98 (100/102)	93 (26/28)	100 (74/74)	98 (100/102)	97 (99/102)
16-channel	100 (6/6)	100 (54/54)	100 (60/60)	100 (18/18)	100 (42/42)	100 (60/60)	100 (60/60)
four-channel	100 (2/2)	95 (38/40)	95 (40/42)	80 (8/10)	100 (32/32)	95 (40/42)	93 (39/42)

MDCT, multirow detector computed tomography; DSA, digital subtraction angiography.
Numbers in parentheses are data from which percentage was calculated.
*Early branching was defined as vessel division from the main renal artery within 20 mm from the aorta.
†Correct number of supernumerary arteries.
‡Correct detection and classification of surgically relevant anatomic variants of renal arteries.

the setting of donor work-up [22]. For arterial assessment we preferred to view CT images first with a scroll modus in axial and coronal reconstructions (slice thickness, 1 mm). This approach was particularly helpful to distinguish early branching arteries from supernumerary vessels. Reconstruction tools like VRT and MIP facilitated an additional excellent vascular overview and were helpful for the presentation of findings.

Concerning supernumerary or branching renal veins, the assessment was mainly based on late venous phases. In situations which remained difficult to read, the arterial phase with nonenhanced or little enhanced venous vessels could be used for verification of diagnoses, or when present, the early and faint enhancement of veins or a contrast jet in the nonenhanced vena cava on the arterial scan phase was helpful to detect and differentiate small supernumerary veins from arteries.

Our data demonstrated that selective DSA was superior to nonselective DSA as missing parenchymal contrast upon selective catheterization was indicative for

Table 2. Detection and classification of surgically relevant anatomic variants of renal arteries by consensus reading of CTA acquired by four- and 16-channel MDCT.

	Gold standard				
CTA	1	Early branching	2	3	Total
1	*65*		1*		66
Early branching	1*	*8*	1*		10
2			*22*		22
3				*4*	4
Total	66	8	24	4	102

CTA, computed tomography angiography; MDCT, multirow detector computed tomography.
Values in italics indicate correct classification of arterial anatomy.
*Kidneys wrongly classified with four-channel MDCT.

Table 3. Detection and classification of surgically relevant anatomic variants of renal arteries by consensus reading of DSA in selective and nonselective technique.

	Gold standard				
DSA	1	Early branching	2	3	Total
1	*66*	1†	2†		69
Early branching		*6*	2†		8
2		1†	*19*	1*; 1†	22
3			1†	*2*	3
Total	66	8	24	4	102

DSA, digital subtraction angiography.
Values in italics correct classification of arterial anatomy.
*Kidneys wrongly classified with selective DSA.
†Kidneys wrongly classified with nonselective DSA.

supernumerary vessels. On the contrary, selective catheter placement in the renal arteries comprises an increased risk for intima injury, dissection and subsequent stenosis of the vessel. Nevertheless, with the use of MDCT the potential donor risks and risks for the explanted organs are being reduced to possible complications associated with the administration of iodinated contrast material. Patient comfort represents an additional concern when applying DSA.

Digital subtraction angiography either performed selectively or nonselectively was not reliable for the visualization of renal veins and demonstrated a low sensitivity; in contrast, MDCT visualized renal veins with high accuracy. Although some surgeons consider the presence of accessory veins of minor importance for their surgical strategy and management, a reliable visualization and knowledge of renal vein anatomy may still be considered as helpful.

For the visualization of ureter anomalies, CT and DSA seem to be equally suited. Although in our MDCT protocol we did not include a separate excretion phase, all observers correctly identified those patients with abnormal collecting systems or ureters. However, an additional delayed anteroposterior topogram during the MDCT evaluation may provide valuable information in specific cases [9].

With all of its advantages as a noninvasive approach, radiation exposure of healthy kidney donors must be considered when using CT angiography, although, the total radiation dose for a triple-phase CT was shown to be less than that with the combination of angiography and excretory urography [12,23]. Nevertheless, it must be emphasized that with MR-angiography (MRA) another competing noninvasive radiation exposure-free approach for renal donors is available, and successful MRA of kidney vessels in the setting of donor evaluation has been reported. Some restrictions in previous MR studies, however, have included the variable ability to detect small accessory renal vessels (<2 mm) with MRA. In contrast, it must be noted that all accessory vessels were adequately detected with the 16-channel MDCT in our study. Thus, further studies are warranted to substantiate the capacity of more recent MR advances with faster sequences and improved resolution for the visualization of small accessory vessels [8,24,25].

In conclusion, MDCT and in particular the most recently available 16-channel scanner represent a highly accurate approach for the anatomic evaluation of renal vessels and ureters with favourable patient comfort in living kidney donors.

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