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Perihilar branching patterns of renal artery and extrarenal length of arterial branches and tumour-feeding arteries on multidetector CT angiography

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Objective: The purpose of our study was to assess the extrarenal length of renal arterial branches and tumour-feeding arteries on multidetector CT (MDCT) angiography, in addition to the perihilar branching patterns, with relevance to segmental artery clamping.

Methods: MDCT angiograms of 64 patients with renal masses <4 cm were retrospectively reviewed by 2 radiologists. The perihilar branching patterns of the single main renal artery were assessed according to the number of pre-segmental and segmental arteries. The extrarenal lengths of segmental plus pre-segmental arteries and the tumour-feeding arteries, measured on volume-rendered images, were compared according to the vascular segmentation and the tumour location, respectively.

Results: In the 116 kidneys, 1 pre-segmental plus 5 segmental arteries ($n=48$) was the most common branching pattern. The mean extrarenal length of the inferior segmental plus pre-segmental arteries (33.05 mm) and the posterior segmental plus pre-segmental arteries (32.30 mm) was longer than any of the other segmental plus pre-segmental arteries (apical, 23.87 mm; superior, 26.80 mm; middle, 29.23 mm) ($p<0.05$). The mean extrarenal length of the lower pole tumour-feeding arteries (35.94 mm) was longer than those of the upper and mid-pole tumour-feeding arteries (24.95 mm, 29.62 mm), with significant difference between the lower and the upper pole tumour-feeding arteries ($p<0.05$).

Conclusion: Tumours in the lower pole, supplied by the inferior or posterior segmental

artery, may be more amenable to segmental artery clamping.

Advances in knowledge: MDCT angiography with volume rendering can demonstrate the

extrarenal length of tumour-feeding arteries and may help in determining the accessibility for segmental artery clamping.

Nephron-sparing surgery is standard management in selected patients with renal tumours <4 cm [1]. With advanced surgical techniques, laparoscopic partial nephrectomy has become an accepted alternative for patients with renal tumours [2–6]. Clamping of the main renal artery is a commonly used technique to decrease intraoperative haemorrhage in partial nephrectomy, and renal hilar control provides improved visibility for tumour resection and repair of the renal collecting system [7, 8]. However, this technique causes warm ischaemic injury, affecting renal function after partial nephrectomy. Further, a warm ischaemia time of longer than 20 min can result in significant renal functional loss [7–9].

Graves [10] presented the first detailed description of renal vascular segmentation in 1954 and depicted four renal segments, namely, apical, upper, middle and posterior, supplied by their own segmental arteries with no collateral arterial supply between these segments. However, renal vascular variances have not been well described. Further, the extrarenal division and branching pattern of the renal artery were also disregarded. Renal vascular segmentation suggests that the selective clamping of a segmental renal artery can offer an improved surgical field and decrease the risk of warm ischaemic injury to the whole kidney. Shao et al [8] reported that segmental artery clamping minimised intraoperative warm ischaemic injury and improved post-operative renal function compared with main renal artery clamping.

Multidetector CT (MDCT) angiography is commonly used to evaluate the renal vascular anatomy and vascular disorders [11]. MDCT angiography is also an excellent tool to display wide variations in the renal vascular system, including tumour-related changes for planning kidney surgery [12].

To our knowledge, there have been no reports describing perihilar branching patterns of the renal artery nor any measuring the length of segmental renal arteries

on CT angiography. The aim of this study was to assess the perihilar branching patterns of the renal artery and the extrarenal length of arterial branches and tumour-feeding arteries on MDCT angiography with relevance to segmental artery clamping during nephron-sparing surgery.

METHODS AND MATERIALS

Patients

Our institutional review board approved this retrospective study. Between March 2007 and February 2011, 380 consecutive patients underwent abdominal MDCT angiography at our institution and a total of 98 patients with a renal mass based on the abdominal CT scan were referred for pre-operative CT angiography. This retrospective study included 64 patients (46 male, 18 female; mean age, 56 years) with renal masses <4 cm in diameter from the total 98 patients undergoing CT angiography. Among the 64 patients with renal tumours, the diagnosis in 61 patients was confirmed by pathological examination; the diagnosis in 53 patients was renal cell carcinoma, the diagnoses in 7 patients were angiomyolipoma, chronic inflammation, oncocytoma and atypical carcinoid, and the remaining patient showed no pathological diagnosis. The other three patients were lost to follow-up or observed without surgical treatment.

MDCT scanning technique and three-dimensional post processing

All patients underwent CT angiography using a 64-detector-row scanner (Brilliance 64; Philips Medical Systems, Cleveland, OH). The scanning parameters for CT angiography were 120 kV, 250 mAs with dose modulation (D-Dom; Philips Medical Systems), 64×0.625 mm collimation and a rotation time of 0.75 s. The region from the diaphragmatic dome to the iliac crest level was scanned. Scanning was initiated 7 s after a threshold attenuation of 150 HU was reached in the descending aorta at the level of the renal arteries by the use of bolus-tracking software (Bolus Pro Extra; Philips Medical Systems). For each patient, 130 ml of non-ionic contrast

material (iomeprol, Iomeron® 400; Bracco Diagnostics, Milan, Italy) was administered monophasically at a rate of 5.0 ml s^{-1} through an 18- or 20-gauge angiographic catheter inserted into an antecubital vein.

All thin-section CT data were transferred to a dedicated workstation installed with a three-dimensional (3D) program (Rapidia; Infinitt, Seoul, Republic of Korea). 3D post-processing techniques consisted of maximum intensity projection (MIP), multiplanar reconstruction (MPR) and volume rendering. Reviewers were allowed to rotate the 3D volume-rendered data set in any direction and to plot the path of the tortuous vessel in 3D space by using the program. The actual length was measured from the origin to the end by tracing along each route of the vessel in 3D space (Figure 1).

Image interpretation and analysis

All MDCT angiography source data were retrospectively reviewed in consensus by two observers (a radiologist with 14 years of experience in body imaging and a fourth-year radiology resident). MDCT axial source images were used to evaluate the renal vascular anatomy. The perihilar branching patterns and the number of the main renal arteries and the presence of an accessory artery were assessed on both sides. According to the study of Weld et al [7], the pre-segmental artery was defined as a branch of the main renal artery that divided into two or more segmental arteries and the segmental artery was defined as a branch that enters the renal parenchyma. The main renal artery was defined as an artery running from the ostium to the first branching point. We divided the individual cases with a single main renal artery into three types according to the number of the pre-segmental artery (Type I, no pre-segmental artery; Type II, one pre-segmental artery; Type III, two pre-segmental arteries), and each type was subgrouped according to the number of the segmental artery (a, three segmental arteries; b, four segmental arteries; c, five segmental arteries). The location of renal tumours was divided into three regions (upper, middle, lower poles) on the basis of the relative position of tumours to renal polar lines. The polar line is designated as the plane of the kidney above or below which the medial lip of the parenchyma is interrupted by the renal sinus fat, vessels or the collecting system [13].

3D volume-rendered images were used to measure the extrarenal length of segmental plus pre-segmental arteries

Figure 1. Multidetector CT angiogram of a 47-year-old female with renal cell carcinoma in the right kidney. (a) Curved multiplanar reconstruction image shows the pre-segmental (curved arrow) and left inferior segmental arteries (arrows) to the normal left kidney. (b) Three-dimensional volume-rendered image shows the length measurement (36.09 mm) of the pre-segmental (curved arrow) plus inferior segmental arteries (arrows) following the route from the first branch of the main renal artery to the distal part of inferior segmental artery reaching the renal capsule.

(a)

(b)

(Figure 1) and each tumour-feeding artery according to the tumour location (Figure 2). The extrarenal length of segmental plus pre-segmental arteries was measured

Figure 2. Multidetector CT angiogram of a 68-year-old male with renal cell carcinoma in the right kidney. (a) Coronal reconstruction image shows the inferior segmental artery (arrows) supplying the renal cell carcinoma (arrowheads) in the lower pole of the right kidney. (b) Three-dimensional volume-rendered image shows the extrarenal length measurement (41.27 mm) of the pre-segmental (curved arrow) plus inferior segmental arteries (arrows) supplying the renal cell carcinoma (arrowheads).

(a)

(b)

by following the route from the first branching point of the main renal artery to the distal point of the segmental artery reaching the renal capsule in 3D space.

Statistical analysis

Statistical analyses were performed with SPSS® v. 13.0 for Windows software package (SPSS Inc., Chicago, IL).

All data are presented as the mean $\pm$ standard deviation. Differences were compared with analysis of covariance among the mean extrarenal length of segmental plus pre-segmental arteries according to the vascular segmentation. Analysis of variance and the Games–Howell test were used to compare the differences in the mean extrarenal length of tumour-feeding arteries according to the tumour location. The results were considered as significant when the p -value was <0.05 .

RESULTS

Of the 128 kidneys, 116 (91%) had a single main renal artery and 12 (9%) had multiple main renal arteries, 11 had two main arteries and 1 had four main arteries. Of the 128 kidneys, 113 (88.3%) had no polar arteries, 12 (9.4%) had inferior polar arteries and 3 (2.3%) had superior polar arteries. According to the number of pre-segmental arteries, the branching pattern of the

Figure 3. Perihilar branching pattern of the renal artery (white, main renal artery; grey, pre-segmental artery; black, only segmental artery). The branching patterns of the renal artery were classified into three groups according to the number of the pre-segmental artery (Type I, no pre-segmental artery; Type II, one pre-segmental artery; Type III, two pre-segmental arteries). In each type, the branching patterns were subgrouped according to the number of the segmental artery (a, three segmental arteries; b, four segmental arteries; c, five segmental arteries).

single main renal artery was classified as Type I (segmental arteries without pre-segmental artery) in 22 cases, Type II (segmental arteries plus one pre-segmental artery) in 70 cases and Type III (segmental arteries plus two pre-segmental arteries) in 24 cases (Figure 3). Of the Type I, 3 (2.6%) had 3 segmental arteries originating from the main renal artery, 12 (10.3%) had 4 segmental arteries and 7 (6%) had 5 segmental arteries. Of the Type II, 4 (3.4%) had 3 segmental arteries originating from the main renal artery, 18 (15.5%) had 4 segmental arteries and 48 (41.4%) had 5 segmental arteries. Of the Type III, 4 (3.4%) had 4 segmental arteries originating from the main renal artery and 20 (17.2%) had 5 segmental arteries.

The mean values for the extrarenal lengths of each segmental plus pre-segmental artery are shown in Table 1. The extrarenal lengths of the inferior segmental plus pre-segmental arteries and the posterior segmental plus pre-segmental arteries were significantly longer than any of the other segmental plus pre-segmental arteries, respectively ($p < 0.01$, $p < 0.05$). The average length of the inferior segmental plus pre-segmental arteries was the longest, but there was no significant difference between the length of the inferior segmental and the posterior segmental plus pre-segmental arteries (Table 2, Figure 4).

The 66 renal masses with 72 tumour-feeding arteries were presented in 65 kidneys. One patient had bilateral renal masses, one patient had two masses in a unilateral kidney and six patients had two tumour-feeding arteries. Of the 72 tumour-feeding arteries, according to the tumour location, 19 were upper pole tumour-feeding arteries, 21 were mid-pole tumour-feeding arteries and 32 were lower pole tumour-feeding arteries. The mean lengths of the tumour-feeding arteries according to the tumour location are shown in Table 3.

The comparison of the extrarenal length of tumour-feeding arteries according to the tumour location revealed that the mean extrarenal length of lower pole tumour-feeding arteries was longer than those of upper and mid-pole tumour-feeding arteries. However, there exists only a significant difference between the extrarenal lengths of lower and upper pole tumour-feeding arteries ($p < 0.012$) (Table 4, Figure 5).

DISCUSSION

Contemporary nephron-sparing surgery typically involves hilar clamping, which creates the desired bloodless operating field, allowing precise tumour excision and renal reconstruction [14]. However, main renal arterial occlusion may result in warm ischaemic injury that has the potential to cause post-operative renal dysfunction. Compared with clamping the main renal artery, clamping the segmental artery has reduced warm ischaemic injury and maintained the blood flow to the whole kidney in clinical practice [15].

The length of the artery has been a significant factor in determining accessibility to vascular clamping [7]. In the study by Nohara et al [15], an atrophic partial nephrectomy with selective renal segmental artery clamping was not very difficult to perform when the length of the tumour-feeding artery on angiograms was >10 mm. Nevertheless, they measured the length of the tumour-feeding artery on a two-dimensional (2D) conventional angiogram, which did not reflect the true length of the arteries in the operating field [15]. With 73 fixed cadaveric kidneys, Weld et al [7] reported that the average extrarenal length of the segmental plus pre-segmental arteries that were accessible to segmental arterial clamping was 31 mm. In our study, the mean extrarenal length of the inferior segmental plus pre-segmental arteries, posterior segmental plus pre-segmental arteries and lower pole tumour-feeding arteries

Table 1. Mean extrarenal length of segmental plus pre-segmental arteries

Artery	Mean (mm)	Standard error	95% confidence interval (mm)	
			Lower bound	Upper bound
Apical	23.87	0.88	22.13	25.61
Superior	26.80	0.91	25.01	28.60
Middle	29.23	0.96	27.33	31.13
Inferior	33.05	1.08	30.91	35.18
Posterior	32.30	1.19	29.94	34.66

Table 2. Pairwise comparisons of the extrarenal length of segmental plus pre-segmental arteries

Artery		Mean difference (mm)	Standard error	Significance	95% confidence interval for difference (mm)	
					Lower bound	Upper bound
Apical	Superior	-2.94	0.86	0.009	-5.41	-0.46
	Middle	-5.36	1.04	0.000	-8.35	-2.38
	Inferior	-9.18	1.14	0.000	-12.44	-5.92
	Posterior	-8.43	1.11	0.000	-11.61	-5.25
Superior	Apical	2.94	0.86	0.009	0.46	5.41
	Middle	-2.43	0.72	0.010	-4.48	-0.38
	Inferior	-6.25	0.96	0.000	-9.00	-3.49
	Posterior	-5.50	0.89	0.000	-8.04	-2.95
Middle	Apical	5.36	1.04	0.000	2.38	8.35
	Superior	2.43	0.72	0.010	0.38	4.48
	Inferior	-3.82	0.68	0.000	-5.78	-1.86
	Posterior	-3.07	1.01	0.030	-5.97	-0.17
Inferior	Apical	9.18	1.14	0.000	5.92	12.44
	Superior	6.25	0.96	0.000	3.49	9.00
	Middle	3.82	0.68	0.000	1.86	5.78
	Posterior	0.75	1.18	1.000	-2.65	4.15
Posterior	Apical	8.43	1.11	0.000	5.25	11.61
	Superior	5.50	0.89	0.000	2.95	8.04
	Middle	3.07	1.01	0.030	0.17	5.97
	Inferior	-0.75	1.18	1.000	-4.15	2.65

was >31 mm. Given that Ng et al [16] recently developed a technique for anatomical vascular microdissection of renal artery branches for laparoscopic partial nephrectomy, it could be possible to clamp the shorter tumour-feeding arteries during laparoscopic surgery.

The perihilar branching pattern of the main renal artery shows high individual variability in clinical practice. Despite great variances in the extrarenal division of the main renal artery, we divided individual cases into predictable patterns according to the number of pre-segmental and segmental arteries in the majority of kidneys. According to the study by Weld et al [7], the most frequent perihilar branching pattern consisted of only segmental arteries without any pre-segmental artery, whereas, in our study, the most common perihilar branching pattern was one pre-segmental plus segmental arteries. Our classification provides the basic

perihilar branching patterns that allow easy recognition of the renal hilar vasculature.

MDCT angiography offers an accurate, safe and rapid visualisation of the vascular structure. Very high sensitivity and accuracy are possible pre-operatively for a range of laparoscopically relevant renal arterial and venous variants by using MDCT angiography and 3D reviewing on a dedicated workstation [17]. Approximately 20% of patients have multiple renal arteries, and many surgeons find pre-operative CT or MR angiograms to be valuable, particularly when partial nephrectomy or laparoscopic approaches are planned [18].

In our institution, pre-operative MDCT angiography with 3D reconstruction has been routinely performed since 2007 to provide surgeons with the relationship of the tumour to the collecting system, adjacent normal

Figure 4. Box and whisker plots of the extrarenal length of segmental plus pre-segmental arteries. A, apical segmental artery; I, inferior segmental artery; M, middle segmental artery; O, outliers; P, posterior segmental artery; S, superior segmental artery. Centre line, median; top of box, 75th percentile; bottom of box, 25th percentile; whiskers, data within 1.5 interquartile ranges; ★, significant difference ($p < 0.05$) between the extrarenal lengths for each segmental plus pre-segmental artery.

parenchyma and vascular supply for laparoscopic radical or partial nephrectomy. However, we did not measure the extrarenal length of the renal arteries because our urologists usually performed hilar clamping for laparoscopic partial nephrectomy throughout the study. Investigators employing segmental artery clamping for laparoscopic partial nephrectomy also performed CT angiography with 3D reconstruction to delineate the renal vascular segmentation [8, 19]. However, no prospective study has been performed to evaluate the feasibility of segmental artery clamping according to the extrarenal length of tumour-feeding arteries.

Commonly available post-processing techniques include MIP, MPR and volume rendering. Even though

each of these techniques has its advantages and disadvantages for depiction of the renal artery anatomy, a volume-rendering technique can show the whole renal vasculature and provide a simple and comprehensive overview to the interpreter and referring physicians [20]. With MIP, the voxels whose value is the highest along the ray are represented and the display is a 2D representation that does not show the actual 3D relationships of the vessels [12, 21]. Owing to the projective nature of the MIP image, measurements are not reliable [22]. MPR is obtained from native slice images displayed in a different plane [21] and is used to show tortuous structures such as vessels. However, manual definition of curved planes is usually highly prone to error and often difficult to measure exactly [23]. The volume-rendering technique, which accurately

Table 3. Mean extrarenal length of tumour-feeding arteries according to the tumour location

Location	Mean (mm)	Standard error	95% confidence interval (mm)	
			Lower bound	Upper bound
Upper	24.95	3.37	18.23	31.66
Middle	29.62	3.20	23.23	36.01
Lower	35.94	2.59	30.76	41.11

Table 4. Multiple comparisons of the extrarenal length of tumour-feeding arteries according to the tumour location

Location (mm)		Mean difference (mm)	Standard error	Significance	95% confidence interval	
					Lower bound	Upper bound
Upper	Middle	-4.67	3.79	0.442	-13.95	4.61
	Lower	-10.99	3.69	0.012	-19.90	-2.08
Middle	Upper	4.67	3.79	0.442	-4.61	13.95
	Lower	-6.32	4.39	0.329	-16.93	4.29
Lower	Upper	10.99	3.69	0.012	2.08	19.90
	Middle	6.32	4.39	0.329	-4.29	16.93

visualises 3D relationships including crossing vessels and overlapping anatomy [21], could make it possible to measure the extrarenal length of renal arterial branches reaching the renal capsule in our study. The accuracy of volume-rendered images depends on the parameter settings including the window width, window level, brightness and opacity adjusted by the user [24].

In addition to information about primary tumours, renal vascular variations including renal artery variations, accessory renal artery and a perihilar branching pattern are also demonstrated on CT angiography [20].

Thus, it is important that CT angiography with a volume-rendering technique accurately depicts the renal vascular anatomy and the tumour-feeding artery before surgery to safely facilitate the laparoscopic partial nephrectomy. However, the patients in our study were exposed to high doses of radiation because they underwent CT angiography in a short time after conventional CT examinations. Accordingly, the optimisation of scanning protocols is required to minimise the radiation dose without compromising the image quality. Cho et al [25] recently found that an 80-kVp protocol using a moderate concentration contrast medium could provide improved image quality compared with a

Figure 5. Box and whisker plots of the extrarenal length of tumour-feeding arteries according to the tumour location. Centre line, median; top of box, 75th percentile; bottom of box, 25th percentile; whiskers, data within 1.5 interquartile ranges; O, outliers; ★, significant difference ($p < 0.05$) between the extrarenal lengths of lower and upper pole tumour-feeding arteries.

120-kVp protocol using a high-concentration contrast medium for CT angiography of the renal arteries.

There are several limitations to our study. First, because segmental artery clamping was attempted in a few patients, surgical correlation was not available in our study. To confirm the results of this study, further studies are needed with surgical correlation to evaluate the optimal extrarenal length of renal arterial branches, measured on pre-operative MDCT angiography, for segmental artery clamping. We believe that MDCT angiography with 3D data can provide more accurate assessment of the extrarenal length of the renal arteries than surgery because the operative field is narrow, especially in the laparoscopic surgery. Second, there may have been selection bias in this study because of the retrospective nature. Third, even though a volume-rendering technique is more susceptible to interobserver variability and is dependent on the user's level of experience in optimising rendering parameters [21], neither a separate independent review of the data nor

an interobserver agreement analysis was performed in our study.

CONCLUSION

MDCT angiography with volume-rendering reconstruction provides clear visualisation of the extrarenal length and perihilar branching patterns of renal arteries. Tumours in the lower pole, supplied by inferior or posterior segmental arteries longer than the other segmental arteries, may be more amenable to segmental artery clamping during laparoscopic partial nephrectomy.

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