Triple-bolus MDCT evaluation of renal vascular anatomy in potential laparoscopic living kidney donors

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Purpose

Renal transplantation is the preferred treatment of choice for end-stage renal disease. Living related kidney donation is an important source of renal grafts due to insufficient supply of cadaveric kidneys and to longer life of living related kidney grafts (1, 2). Nowadays, laparoscopic nephrectomy is the preferred surgery technique compared with the open approach, because it offers several advantages such as a reduction of postoperative pain, shorter recovery time, better cosmetic results and reduced postoperative morbidity and mortality rate (3, 4). However, visual field is limited during laparoscopic nephrectomy, therefore accurate preoperative assessment of the urinary system including renal vascular anatomy and its variations has key importance.

Multidetector spiral computed tomography (MDCT) enables complete evaluation of the urinary tract including urolithiasis, focal or diffuse renal parenchymal lesions, urinary tract anomalies and vascular variations (5). However, multiphase MDCT protocols associated with high ionizing radiation dose depending on the number of acquired series. Previous studies have assessed the feasibility of reducing the number of acquired phases, which is especially important in the case of donor candidates who are healthy and mostly young individuals. Kawamoto et al reported accurate depiction of renal venous anatomy on arterial phase (6). Caoili et al reported a radiation dose reduction by omitting the non-contrast phase or replacing the excretory phase with a localizer radiograph or with an abdominal radiograph (7). Sahani et al suggested that CTA of renal donors performed with lower kilovoltage (100 kVp) provides diagnostically acceptable images with significant radiation dose reduction (8).

Triple-bolus MDCT urographic technique is a recently introduced alternative to reduce ionizing radiation dose, in which three separate contrast material injections followed by single scanning results in a combined vascular, parenchymal and excretory phases (9, 10). Recently feasibility and good sensitivity of split-bolus protocol with significant reduction of ionizing radiation dose have been published in potential laparoscopic living kidney donors (11, 12).

The objective of our study was twofold: 1) to evaluate the urinary system in potential laparoscopic living kidney donors by a dose reduction protocol that uses combined arterial-venous-excretory phase MDCT scanning achieved by triple-bolus iv. contrast injection; 2) to assess the sensitivity, specificity and interobserver variability of triple-bolus MDCT for renal vascular anatomy and its variations.

Methods and Materials
The local institutional review board approved the study protocol; patient informed consent was not required for this retrospective study.

**Donor candidates:** Our patient population included 91 consecutive potential laparoscopic living kidney donors (49±13 years, 30 male, 61 female), who underwent preoperative MDCTA examination as part of their clinical work-up between November 2010 and November 2012. Donor nephrectomy had been performed on 49 patients. On the basis of preoperative imaging findings, the left kidney was harvested in 42 cases, and the right kidney was harvested in 7 cases. The surgical findings used as reference standards were compared with findings on MDCT.

**MDCT scanning protocol:** MDCT imaging was performed with a 16-slice CT unit (Philips Brilliance). All patients were given cca. 500 ml of water orally starting 30-60 min before imaging. Iv. 20 mg buscopan with saline infusion was administered before MDCT examination. Acquisition and reconstruction parameters of nonenhanced and triple-bolus phase are shown in Table 1. Nonenhanced and triple-bolus CT acquisition extended from above the diaphragm to below the pubic symphysis. A triple-bolus contrast administration protocol was used to enable simultaneous acquisition of arterial, nephrographic and excretory phases. 40 ml of non-ionic contrast medium was administered intravenously at a rate of 2 ml/s via a cannula placed in the antecubital fossa. After 435 s, another 50 ml of contrast medium was given at 1.5 ml/s. After 53 s, 60 ml of contrast medium at 3 ml/s was given. Imaging commenced at 646 s after the initial contrast medium bolus (10).

**Image evaluation:** Two independent radiologists from a pool of six radiologists with 5-12 years' experience in genitourinary CT imaging reviewed MDCT images. Both readers were blinded to patient surgical findings. Axial and multiplanar reformatted images, maximum intensity projections and volume rendering images were reviewed.

The presence of kidney stones, morphology of the kidney, and any extrarenal abnormalities were recorded. Renal vascular anatomy was described in details. For each artery, the presence of any supernumerary artery, stenosis or of an early arterial branching was noted. The distance of each proximal branch from the aorta was recorded, and early arterial branching was defined as branching within 20 mm of the aorta on the left side and behind the inferior vena cava on the right. Renal venous anatomy was evaluated for the presence of supernumerary veins, retroaortic veins, circumaortic veins and prominent lumbar veins. Prominent lumbar vein was defined left lumbar vein with a diameter larger than 5 mm draining into the left renal vein. The number of ureters associated with each kidney was also recorded.

**Radiation dose analysis:** Dose parameters displayed on the CT user-interface were recorded in all patients. Dose-length product (DLP) was annotated for all acquisition phases. Total DLP, which corresponds to the sum of the DLP of each acquisition phase,
was calculated for each examination. Effective dose (ED) of each examination was later estimated by multiplying the total DLP by the conversion factor for abdomen (0,015 mSv/(mGy*cm)) (13).

**Statistical analysis:** Radiation dose data are expressed as mean ± 1 SD. The sensitivity and specificity of triple-bolus MDCT were calculated on a per kidney basis for presence or absence of supernumerary renal arteries and veins, early branching of the renal artery, venous anomalies and prominent lumbar veins for both Reader 1 and Reader 2. Interobserver variability for renal vascular variations was calculated using k-statistics. Statistical analysis was performed by statistical software (SPSS Statistics, 20.0).

**Results**

All triple-bolus MDCT examinations were technically adequate.

**Radiation dose:** The dose-length product (DLP) of the complete MDCT protocol was 1185±183 mGy*cm. DLP of the nonenhanced phase was 313±125 mGy*cm, while that of the triple bolus phase was 872±84 mGy*cm. The effective dose (ED) of the complete MDCT protocol was 17.8±2.7 mSv. ED of the nonenhanced phase was 4.7±1.9 mSv, while that of the triple bolus phase was 13.1±1.3 mSv. The nonenhanced acquisition accounted 26% of the total radiation dose. Radiation doses are summarized in Table 2.

**Vascular variations:** On the basis of preoperative imaging findings, the left kidney was selected in 42 cases (86%), and the right kidney was selected in 7 cases (14%) for donation. In 4 donors, in whom the right kidney was harvested, left-sided retroaortic/circumaortic venous anomaly, while in 3 donors two or three left-sided accessory arteries were detected on preoperative imaging.

On the basis of 91 donor candidates' imaging findings, 42 accessory renal arteries and 12 early arterial branching were identified. As venous variations, 42 accessory renal veins, 14 venous anomalies and 25 prominent lumbar veins were identified. Vascular variation findings are summarized in Table 3. Sensitivity and specificity for renal vascular variations was 79% and 100%, respectively, for Reader 1, and 94%, and 100%, respectively, for Reader 2.

**Interobserver agreement:** Interobserver agreement was calculated for 48 kidneys of 24 donors. One of the reviewers reported false negative accessory arteries and veins in 4 and 5 cases, respectively, resulting in an acceptable degree of interobserver agreement (Cohen’s #: 0.73 and 0.70, respectively). All of these undetected accessory arteries and veins had a diameter of 1 mm to 3 mm.
Images for this section:
Figure 1: Reformatted triple-bolus MDCT image demonstrating left accessory renal artery in a young female donor.
Figure 2: Reformatted and volume rendering triple-bolus MDCT images demonstrating circumaortic left renal vein in a young female donor.
Figure 3: Reformatted triple-bolus MDCT image demonstrating two right renal veins in a middle-aged female donor.
Figure 4: Volume rendering triple-bolus MDCT image demonstrating left renal hilar components including renal artery, retroaortic renal vein, adrenal vein, pyelon and ureter.
Table 1: Acquisition and reconstruction parameters of nonenhanced and triple-bolus MDCT phases

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Nonenhanced acquisition</th>
<th>Triple-bolus acquisition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tube current (mA·s)</td>
<td>100</td>
<td>250</td>
</tr>
<tr>
<td>Tube voltage (kVp)</td>
<td>120</td>
<td>120</td>
</tr>
<tr>
<td>Collimation (mm)</td>
<td>16 x 1.5</td>
<td>16 x 0.75</td>
</tr>
<tr>
<td>Pitch</td>
<td>0.938</td>
<td>0.938</td>
</tr>
<tr>
<td>Rotatory time (s)</td>
<td>0.75</td>
<td>0.75</td>
</tr>
<tr>
<td>Reconstructed section width (mm)</td>
<td>2.5 mm</td>
<td>1 mm</td>
</tr>
</tbody>
</table>

Table 2: Radiation doses of nonenhanced and triple-bolus acquisitions in 91 potential laparoscopic living kidney donors.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Nonenhanced acquisition</th>
<th>Triple-bolus acquisition</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dose–length product (mGy·cm)</td>
<td>313 ± 125</td>
<td>872 ± 84</td>
<td>1185 ± 183</td>
</tr>
<tr>
<td>Effective dose (mSv)</td>
<td>4.7 ± 1.9</td>
<td>13.1 ± 1.3</td>
<td>17.8 ± 2.7</td>
</tr>
<tr>
<td>number of variations (%)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>--------------------------</td>
<td>------------</td>
<td></td>
<td></td>
</tr>
<tr>
<td>arterial variation</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>accessory artery</td>
<td>42 (23 %)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>early arterial branching</td>
<td>12 (7 %)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>venous variation</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>accessory vein</td>
<td>42 (23 %)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>retroaortic or circumaortic vein</td>
<td>14 (8 %)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>prominent lumbar vein draining into the left renal vein</td>
<td>25 (14 %)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 3: Renal vascular findings of triple bolus MDCT in 182 kidneys of 91 potential laparoscopic living kidney donors.
Conclusion

A detailed preoperative anatomic evaluation of kidney donor candidates is crucial before laparoscopic nephrectomy, especially because renal vascular variations are common. Nowadays, multidetector computer tomography serves as a first-choice imaging technique for potential kidney donors, due to its availability, high spatial resolution, post-processing capabilities and fast acquisition time. As an important disadvantage, however, multiphase MDCT is associated with high ionizing radiation dose, which is of concern in young and healthy kidney donor candidates.

To lower radiation risk in potential kidney donors, a recently introduced MDCT protocol - which includes a low-dose nonenhanced phase and a triple-bolus MDCT scanning - has been our clinical standard for imaging since 2010. Based on 91 MDCT studies, this protocol delivered approximately 18 mSv of ionizing radiation dose, out of which triple-bolus scanning delivered approximately 13 mSv. Our previously used conventional multiphase MDCT urography protocol for donor candidates delivered approximately 30 mSv of ionizing radiation dose, therefore, the use of triple-bolus protocol results in a 40% dose reduction. Moreover, in our earlier multiphase MDCT urography protocol excretory phase was replaced by an excretory topogram, which is clearly inferior to triple-bolus imaging, which allows 3D visualization of the contrast-filled urinary tract.

In our study we found supernumerary arteries and/or veins in half of the donor candidates (43/91), which is comparable with earlier findings (14). Interobserver disagreement in the interpretation of triple-bolus MDCT images was related to vessels with a diameter equal or less than 3 mm. However, such small-caliber vessels are generally considered surgically irrelevant, and may be sacrificed at surgery if they are deemed by the surgeon to supply a small, clinically insignificant capsular or polar vascular territory when clamped.

According to our results, the triple-bolus MDCT examination provides accurate evaluation of renal vascular anatomy with reduced radiation exposure in healthy potential kidney donors.

References


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Images for this section: