Use of Spiral Computed Tomography for Pre-operative Evaluation of Living Donors of Renal Transplantation

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As the technique of organ transplantation progressed in recent thirty years, renal transplantation grew magnificantly, and the need for living donors progressed, too. In the past, angiography was used for the pre-operative imaging evaluation. Because of the fast progress of computed tomography, not only shortened the scan time but resolution improved a lot, it has become the most powerful tool for evaluating the normal anatomy and pathological condition of kidneys. In this study, we use spiral computed tomography for pre-operative evaluation of renal living donors, expecting it can replace angiography, which is more invasive, and establishes a better protocol in the evaluation of living donors in renal transplantation.

From January, 2005 to December, 2005, we had 22 people referred from clinical doctors for pre-operative evaluation of living donors of renal transplantation. The protocol of computed tomography (CT) was as followings: phase I, precontrast; phase II, arterial phase focusing on renal arteries; phase III, nephrographic phase; phase IV excretory phase. The raw axial helical images were reconstructed at 3D workstation for coronal multiplanar reconstruction (MPR). The operative findings were correlated with the findings of the preoperative CT images.

CT angiography is highly accurate in renal vascular evaluation. Renal artery is most clearly seen in phase II and renal vein in phase III. By four phases protocol, the information of morphology of renal vessels and collecting system were completely compatible with operative findings. Other pathology including renal stone (5/22, 22.7%), renal cyst, pheochromocytoma of adrenal gland and pelvic teratoma were also detected.

CT angiography may replace the more invasive traditional angiography to become the first line pre-operative imaging modality in living donors of renal transplantation.

As the technique of organ transplantation progressed in recent thirty years, renal transplantation grew magnificantly. Because of the shortness of the cadaver supply of renal transplantation, the need for living donors increases. Pre-operative evaluation aims on vascular structures which affect the operation and also minimize the operative complication rate. Multiple renal arteries is the most common variation of renal arteries, with its prevalence about 30% [1, 2]; other common variance include polar artery, supplementary artery, extrahilar branching, etc. Besides, minor branches of renal artery also include inferior adrenal artery, ureteral artery, and capsular arteries, etc., which are small but may cause bleeding complication during operation. Therefore, it is important to achieve accurate evaluation pre-operatively. In venous system, the length, numbers, branches and variance, such as multiplicity, circumferential or retro-aortic location, are important parameters for deciding which side to be the donor side. In the past, angiography is main imaging modality for pre-operative evaluation of renal transplantation; it clearly demonstrates renal arteries and its branches, but the disadvantage is
time consuming and invasive. Computed tomography angiography is first reported in literature in 1991 [3]. The fast scanning with appropriate intravenous (IV) contrast administration and image reconstruction via computer can provide images of renal vessels. According to the experience from other country, CT angiography and traditional angiography both has its advantages and disadvantages, and different protocol of computed tomography brings different results. Overall, traditional angiography has better resolution on detail variance of vessels and intra-renal arteries; CT angiography is better in demonstrating venous system.

The controversial issue is about minor branches of renal arteries: some studies show that the sensitivity of computed tomography is about 70% [4], while other studies show that CT angiography is better than traditional angiography [5]. CT angiography is also much superior to traditional angiography in detecting other underlying renal disease, such as calculus or neogrowth. Furthermore, post-IV contrast administration can provide CT urography evaluation aiming on collecting system. Overall, computed tomography with IV contrast administration is a valuable imaging modality for evaluation of living donors of renal transplantation non-invasively. It is highly accurate for diagnosis and may replace traditional angiography.

MATERIAL AND METHODS

A. Basic theory and hypothesis

In recent twenty years, the technique of computed tomography proceeded rapidly. The new multidetector raw spiral computed tomography (MDCT) not only accelerates scanning rate, but also gains better resolution, which has become powerful equipment for evaluating anatomic structure and pathologic condition of kidneys [3-5]. The fast scanning with intravenous contrast medium administration provides computed tomographic angiography (CTA) for evaluation of abdominal vasculature, including renal arteries. Axial cross section can clearly demonstrate the location of kidney, structure of renal parenchyma, and adjacent organs around kidneys. Besides, delayed images with curved multiplanar reformation (curved MPR) become so-called computed tomographic urography (CTU) images, demonstrating the entire collecting system via three-dimensional space configuration. Between 1999 and 2000, forty patients with urogenital disease underwent intravenous contrast enhanced computed tomography. The preliminary result showed computed tomographic urography is capable of providing more advantages in diagnosing urogenital disease in our hospital [6].

In the past, living donor of renal transplantation should receive angiography and intravenous urography (IVU) before operation to evaluate renal vasculature and to exclude underlying pathology (ex. renal lithiasis and neoplasm). We intend to use computed tomography instead of the more invasive angiography for pre-operative imaging evaluation of living donor of renal transplantation, and designing the best standard protocol.

B. Methods

The objects of this study evaluated first by clinical physician to be the candidate of living donors of renal transplantation, and were referred to our department to receive the computed tomography scan. Pregnancy, history of allergy and contraindication for intravenous administration of iodine curtailed contrast medium were excluded. All patients received non-ionic contrast medium. Informed consent were obtained from all objects. This study is a prospective study with the agreement of the clinical ethic institution in our hospital.

A computed tomography scanner SOMATOM SENSATION 16 (Simens Co., Erlangen, Germany) and a compatible work station Leonardo VB30B (Simens Co., Erlangen, Germany) were used in this study.

Phase I: non-contrast, 5mm in thickness, pitch 1.5 focus on kidney.

Phase II: intravenous contrast medium administration in 2ml/sec, totally 100ml non-ionic contrast medium (Iopamiro), 20 seconds after intravenous contrast medium administration and scanning with 5mm thickness, pitch 1.5 focus on kidney (arterial phase).

Phase III: 90 seconds after intravenous contrast medium administration, scanning with 5mm thickness, pitch 1.5 focus on kidney (nephrographic phase).

Phase IV: 15 minutes after intravenous contrast medium administration, 5mm in thickness, pitch 1.5, scanning from kidney to pubic symphysis (excretory phase).

Computed tomographic urography: using compatible work station, coronal view reconstruction (multiplanar reformation).

Twenty-two cases were collected in one year.
CT evaluation of living donors for renal transplantation

The images were interpreted by two uroradiologists. The results were announced to urologists and general surgeons who were in charge of the renal transplantation. The operative findings were correlated with the preoperative images.

C. Analysis of data

Data analysis and statistics: We recorded the clinical information, image findings and operative findings of every patient.

The clinical information included: age, gender.

The image findings included:

1. Artery: Number of bilateral main renal arteries, variance (such as malposition, polar artery, supplementary artery, extrahilar branching), pathology (such as stenosis, occlusion or aneurysm); and if any minor branches (adrenal artery, capsular artery, ureteral artery).
2. Vein: Number of bilateral main renal veins, variance (such as circumferential, accessory tributaries), pathology (such as stenosis, occlusion, or thrombus).
3. Collecting system: Dilatation or congenital anomaly.
4. Other pathology: Renal lithiasis, neoplasm (including benign and malignant).

The image findings were correlated with the operative findings. The diagnostic sensitivity and specificity were assessed.

RESULTS

From January, 2005 to December, 2005, twenty-two patients (13 men and 9 women) were referred by clinical physician for evaluation of living donors of renal transplantation. The age ranged from 29 to 68-year-old with mean age of 45.9-year-old. In our study (Table 1), renal artery could be clearly demonstrated in phase II (arterial phase). Most of the patients had single renal artery on both sides, only one patient was noted to have three renal arteries on the right side (1/22, 4.5%) and three patients were noted to have two renal arteries on the left side (3/22, 13.6%). The most common congenital anomaly of renal artery was extrahilar branching (Fig. 1), 11 patients on the right side (11/22, 50%), one of them showed early branching type (less than 1.5 cm from the renal artery orifice by definition); another 11 patients on the left side (11/22, 50%), 5 of them were also early branching type. Other congenital anomaly included polar artery (right 2/22, 9.0%; left 6/22, 27.3%), accessory artery (Fig. 2) (left 1/22, 4.5%),

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<td>Early branching</td>
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<td>Accessory artery</td>
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Figure 1. Coronary reconstruction of arterial phase images demonstrates extrahilar branching of the right renal artery (arrow), and right renal stones are also noted.

Figure 2. Coronary reconstruction of arterial phase images demonstrates tortuous accessory artery of the left renal artery (arrows) directly arising from abdominal aorta.
and most of them directly originated from abdominal aorta. About one-third of cases showed minor branches from renal artery, among them adrenal artery was the most common (right 8/22, 36.4%; left 6/22, 27.3%), followed by ureteral artery (right 2/22, 9%; left 1/22, 4.5%) and capsular artery (left 1/22, 4.5%).

In our study (Table 2), most cases had single renal vein drainage into inferior vena cava, bilaterally, except for one patient with two right side renal veins (1/22, 4.5%) and one patient with two left side renal veins (1/22, 4.5%). More variation were noted in right renal vein. Except for multiplicity mentioned as above, trifurcation (1/22, 4.5%), bifurcation (1/22, 4.5%) and accessory tributary (2/22, 9.0%) were also noted. Less variance were noted in left renal vein, only two cases of renal vein bifurcation noted at the left side of aorta and one case of accessory tributary were noted. Renal vein was not seen in phase II (arterial phase), instead they were most clearly demonstrated in phase III (nephrogenic phase). As arterial enhancement was not totally diminished in phase III, we correlated coronary reconstruction images with arterial phase images to be acquainted with the venous system. Tributary of left renal vein were more commonly seen than in right side, mainly gonadal vein and first lumbar vein. We could identify left gonadal vein in over half of all cases (12/22, 54.5%), and two of them even had two gonadal veins. One gonadal vein was directly drained into the lower polar vein of kidney (Fig. 3). In our study, quite a number of gonadal veins (5/22, 22.7%) were not

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<th>Findings</th>
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<td>Multiple renal vein</td>
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<td>Extrahilar confluence</td>
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<td>Gonadal vein</td>
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<td>Lumbar vein</td>
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*: two renal veins
**: two of the 12 donors have two gonadal veins

Figure 3. Two sequential images of coronary reconstruction of nephrographic phase show left gonadal vein (arrow) draining into tortuous lower polar vein of the left kidney (circle).

Figure 4. Four sequential images of coronary reconstruction of arterial phase show the tortuous left renal artery (thick arrows) wraps the first left lumbar vein (thin arrows) which drains into the left renal vein.
completely seen in the phase III. The location of first lumbar vein draining into renal vein varied, which could be posterior to gonadal vein, same drainage site, cephalad to renal vein, or might be caudal to renal vein. In one case, three renal arteries noted on left side, and the lumbar vein was enwrapped by the most inferior one (Fig. 4). Pre-operative computed tomography scan provided this information and possible complication could thus be avoided.

In the renal collecting system, congenital anomaly included extrarenal pelvis (1/22, 4.5%), and incomplete duplication of collecting system (1/22, 4.5%). Five patients had renal stone (5/22, 22.7%), but no related hydronephrosis presented. Four patients had small renal cysts, and no other conspicuous pathology of parenchyma were noted. A neoplasm was noted in left adrenal gland accidentally, which was proved to be pheochromocytoma pathologically. Another case showed neoplasm with fat and calcification content in the pelvic cavity accidentally, which turned out to be ovarian teratoma after surgical excision.

Twenty-two patients received left side nephroureterectomy and the operative findings all correlated well with pre-operative information.

**DISCUSSION**

As the techniques of organ transplantation mature, numbers of renal transplantation grow, and the necessity of living donors increases, too. In the past, pre-operative evaluation is focused on vascular anomaly and angiography was the standard imaging modality. Progression of computed tomography techniques had resulted in reduction of scan time and improving image resolution which became so-called computed tomographic angiography images after co-ordination with image reformation technique. The advantages of computed tomography include non-invasiveness, accurate evaluation of renal parenchyma, collecting system, and other intra-peritoneal and retro-peritoneal diseases. However, whether it can replace traditional angiography to be the standard pre-operative image for evaluation of the vascular morphology, variation and minor branches is still debated.

Between 70% and 75% of population may be expected to have one renal artery on each side, while the remainder may be expected to have two or more renal arteries on each side [7,8]. Pollack et al. [8] found that 23% had double renal arteries, 4% had triple arteries, and 1% had quadruple arteries. Multiple renal arteries occur on the left side in 26%-32% of people and on the right side in 23%-29% [8,9]. Bilateral multiple renal arteries occur in 15% [8]. It is important to detect any extrahilar branching that occurs within 2cm of the origin of the renal artery from the abdominal aorta, because most urologists require at least a 2-cm length of renal artery before hilar branching, to ensure adequate control and anastomosis.

In this study, we noticed that using 16-slice multidetector computed tomography with 20 seconds delay of scanning after contrast medium injection, could come up with axial raw images of arterial phase. After utilizing three-dimensional image reformation technique (mainly coronal section), the accuracy of evaluating renal artery could be 100% and nearly 100% on the polar artery and accessory artery. Quite a number of patients demonstrate minor arteries including ureteral artery and capsular artery. Therefore, we thought information from computed tomographic angiography for artery is capable of meeting the clinical demand of pre-operative evaluation. Since left renal vein is longer, left side kidney is usually the candidate of donation. According to this study, although extrahilar branching noted equally on both sides, early branching was more commonly seen in left side than in right side, and polar artery directly originated from abdominal aorta was more commonly seen on left side; which were valuable information for urologists pre-operatively.

From the urologist’s point of view, knowledge of the venous anatomy prior to nephroureterectomy is important to avoid vascular injuries and bleeding. The appropriate venous structures, including renal veins, adrenal veins, gonadal veins, and lumbar veins, must be identified and localized. 92% of population have one renal vein on each side [8]. Duplicated renal veins are more commonly seen on the right side. The left renal vein variants include circumaortic renal vein and retroaortic renal vein. The left adrenal vein and gonadal vein drain into the left renal vein in nearly all people; the right gonadal vein drains into the right renal vein in 7%; the right adrenal vein drains into the right renal vein in 31% [10]. Multiple (usually two) left gonadal veins occur in about 15% of population [10]. There is great variation in the number and location of the lumbar veins. Lumbar veins drain into the left renal vein in 75% of population and 3% to the right renal vein in [10].

Tributary of left renal vein is more compli-
cated than right side, which includes multiplicity of gonadal vein and first lumbar vein. The pattern of lumbar veins and the relationship between vein and artery are valuable information that draw attention. According to this study, the convergence location of first lumbar vein and renal vein had much variance and might have complicated relationship with artery, which boosted the difficulty of operation. Aware of such relation may help pre-operative planning and diminishes possible operative complication.

In designing the protocol, we delay scanning time 90 seconds based on the previous experience in computed tomography of abdomen. The results showed good opacification of renal veins in most cases. While tributary were not well opacified in some other cases. Good opacification of gonadal vein noted in some cases with large diameter, which might be related to venous valvular incompetence with regurgitation. We think 16-slice multidetector computed tomography have rapid scanning time as compared with previous 4-slice computed tomography. Since the tributary of renal vein is the target of evaluation, we suggest the time of delay scanning should be longer than 90 seconds, may be around 100 seconds, to bring the tributary totally opacified, capable for evaluation.

In this study, many candidates for donating kidney have renal stones, and non-contrast computed tomography have high sensitivity for lithiasis. Kidneys with stones are a contraindication for donating kidney is still debated [4]. But it may means the donor may have some kind of metabolic diseases which needs to have further evaluation and close observation even with aggressive treatment post-operatively.

CONCLUSION AND Recommendation

According this study, we have some conclusions as followed:

1. Since left renal vein is longer, left kidney is more suitable to be the donor. While left renal artery has more anomalies. Furthermore, the drainage system of the renal vein and tributary are more complicated.

2. Many candidates for donating kidney have renal stones.

3. Computed tomography not only provides information about renal parenchyma, collecting system and other abdominal disease, but also affords high accuracy in renal vascular evaluation. It may replace the more invasive angiography and become first line pre-operative evaluation imaging modality.

About computed tomography, we have some suggestions as followed:

1. Complete pre-operative computed tomography evaluation should include the following four phases: phase I pre-contrast, phase II arterial phase, phase III nephrographic phase and phase IV excretory phase.

2. Since the rapid scanning time of multidetector computed tomography, it is necessary to delay scanning time after intravenous contrast administration. We suggest a delay of 100 seconds after intravenous contrast medium administration to guarantee total opacification of the tributary of renal vein.

ACKNOWLEDGEMENT

The study is in part supported by research grant from Taipei Veterans General Hospital 94-276.

REFERENCES


以四相電腦斷層攝影做為腎臟活體移植捐贈者之評估

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近三十年來隨著移植技術之成熟，腎臟移植的數量大幅成長，活體腎臟捐贈的需求也隨之上升。對捐贈者術前評估主要是針對血管構造，導引手術之方向，減少手術併發症，並排除預備捐贈之腎臟潛在之病變（例如結石與腫瘤）。傳統上術前評估皆採用血管攝影檢查為主要檢查工具。近年來電腦斷層技術快速成長，不但掃描速度增加，解析度也大為提高，已成為評估腎臟正常解剖構造與病理的有力工具。本研究前瞻性的以電腦斷層攝影評估活體腎臟捐贈者，希望評估以電腦斷層攝影取代過去較具侵入性的血管攝影檢查，成為活體腎臟移植捐贈者術前評估工具的可能性，並設計出最佳標準化之檢查方式。

於 2005 年 1 月至 12 月期間，共有 22 人次經臨床醫師轉介接受檢查，做為活體腎臟捐贈之術前評估。電腦斷層攝影的流程包括 phase I 不施打對比劑（precontrast），phase II 腎動脈相（arterial phase），phase III 腎實質相（nephrographic phase）與 phase IV 分泌相（excretory phase）。所得之原始軸狀影像相容之 3D 工作站，重組冠狀切面（MPR）。所得結果並與手術發現作對照。

22 位病患開刀之結果發現術前評估所提供之資訊，包括腎動脈、靜脈之數目與變異，以及集尿系統之型態，皆與手術結果符合。此外，電腦斷層攝影並偵測其餘的病變包括腎結石（5/22，22.7％），腎囊腫（renal cyst），腎上腺之嗜铬細胞瘤（pheochromocytoma），以及骨盆腔之畸胎瘤。電腦斷層血管攝影不僅提供關於腎實質、集尿系統與其他腹腔疾病之資訊，在血管的評估準確率亦相當高。