Presurgical Evaluation of Potential Kidney Transplant Donors with Multidetector CT

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Learning objectives

• Briefly review renal vasculature anatomy and anatomic variants.

• Discuss multidetector CT angiography protocol, as well as postprocessing techniques that best evaluate the kidneys and allow accurate presurgical evaluation (with special focus on multiplanar reformation, maximum intensity projection (MIP) and volume rendering technique (VRT)).

• Specify important information that should be included in the radiologist’s report.

• Discuss relevant common and uncommon CT findings that affect the possibility of organ donation and influence surgical planning.
Background

End-stage renal disease (ESRD) is the final stage of chronic kidney disease, when complete or almost complete failure of the kidneys occur. The most common causes of ESRD in developed countries are diabetes and high blood pressure.

The possible treatment for this condition is dialysis or kidney transplantation.

Kidney transplantation is the treatment of choice for ESRD. When compared with dialysis, it reduces mortality risk and improves life quality for these patients.

However, donated organs are not enough to meet the ever-increasing demand, and transplantation lists keep growing. This has led to an increase in the number of living-related donors.

Therefore, a rigorous presurgical evaluation of the potential kidney transplant donors is essential to assess the feasibility of kidney transplantation, this way improving the success of surgical procedure.

Multidetector computed tomography (MDCT) angiography is the screening modality of choice for preoperative evaluation of potential renal transplant donors.

It has replaced conventional angiography at many institutions, for it is fast, less expensive, less invasive, better tolerated by patients and provides accurate information regarding renal vascular anatomy and nonrenal intraabdominal organs. CT angiography has very high sensitivity in identification of renal vascular anatomy, as well as anatomic variants of the renal vasculature, including extrahilar branching of the main renal artery, multiple renal vessels and supplementary or capsular arteries. This preoperative information is extremely valuable since knowing the location of anomalous minor vessels allows more careful dissection in proximity to the vessels, this way minimizing surgical complications.

Some of the essential information provided by MDCT angiography is listed below.

- Assessment of the feasibility of kidney transplantation
- Identification of coexisting illnesses that may affect the graft's survival
- Evaluation of vascular and extravascular systems, allowing to determine whether kidney transplantation is possible, whether presurgical procedures are necessary (like an aortofemoral bypass for example), and which is the best surgical technique for each candidate.
- Evaluation of peripheral vascular disease, specially in the presence of risk factors such as smoking, diabetes and cardiovascular pathology. This
evaluation provides information about arterial caliber and the presence of calcifications, that will help planning the surgical procedure

- Detection of unrelated findings that may have surgical impact, including mesenteric calcifications, angiomyolipomas, renal cysts, malignant renal lesions, benign liver lesions, parenchymal scarring, duplicated inferior vena cava, abdominal aortic aneurysm, horseshoe kidney and ureteropelvic junction obstruction
- Providing the transplant surgeon with essential information required for adequate management, namely information about the precise anatomy of renal vasculature, this way minimizing the risks and complications associated with the surgical procedure.

MDCT is preferred over MR imaging because it is a faster acquisition technique and because images have high spatial resolution and are less prone to artifacts.

Besides, in patients who still have residual renal function, the risk of nephrogenic systemic fibrosis must not be neglected.
Findings and procedure details

**MDCT angiography technique**

MDCT allows fast and noninvasive exploration of both vascular and extravascular systems.

The patient is positioned in the table in supine position, with arms above head.

Image acquisition should include the space between the diaphragm and the origin of common femoral arteries.

Oral administration of contrast is not used because a positive contrast material interferes with volume rendering and MIP (maximum intensity projection) images.

An unenhanced scan is usually performed first (Fig. 1, 2). The main purpose of unenhanced imaging is to determine the presence of parietal vascular calcifications, but this acquisition also serves as a baseline for evaluation of the enhancement pattern of lesions.

Administration of intravenous contrast depends on the patient's funcional status.

In nondialysis patients and patients receiving peritoneal dialysis, intravenous contrast may damage the remainder renal function, and only unenhanced images should be obtained.

In these cases, magnetic ressonance is not a good alternative because of risk of nephrogenic systemic fibrosis and because this technique has significant limitations the evaluation of vascular calcifications.

Therefore, angiographic CT evaluation is limited in nondialysis patients and patients receiving peritoneal dialysis.

In these cases, and specially if aortoiliac disease is clinically suspected, unenhanced CT can be supplemented with Doppler imaging.

In hemodialysis patients there is no such limitation, and enhanced images may be obtained.
Combination of unenhanced with enhanced evaluation is extremely important because small calcifications can be underestimated in arterial phase imaging.

In our institution, enhanced scanning is performed with a bolus-tracking technique and automated scan-triggering software, after administration of 100mL of nonionic iodinated contrast at 4 mL/sec, immediately followed by 30mL of sodium chloride.

Arterial phase imaging is then performed, in order to obtain optimum opacification of the aorta, renal arteries and iliofemoral axis (Fig. 3, 4).

The main purpose of arterial phase images is determination of luminal vascular disease. It allows depiction not only of arterial anatomy, but of venous anatomy as well, because arteries and veins show different enhancement.

Arterial phase imaging also provides adequate support for acquisition of 3D images.

A third, parenchymal-phase sequence, from diaphragm to iliac crests, is then acquired (Fig. 5, 6).

This phase is particularly important when unenhanced or arterial phase imaging shows suspicious lesions but results are not conclusive (for example, a suspected malignant renal lesion).

An excretory abdominal topogram is also obtained after a 5-minute delay to evaluate the renal collecting system and ureters (Fig. 7).

Prospectively, arterial sequences are reconstructed every 5mm and 1mm, and reconstructed images are then transferred to a workstation and 3D postprocessing techniques, such as multiplanar reformation, MIP, and volume rendering are obtained.

Axial images can be reformatted and oriented in several planes in order to accurately demonstrate renal vasculature. Measurements of vessel length and distances to important branches can be easily obtained and recorded on these images.

They also represent the data set from which the 3D volume-rendering and MIP images of the renal arteries and veins images are obtained.

MIP images allow detection of small branch vessels in a fast way than volume-rendered images (Fig. 8, 9, 10, 11), but this technique has limitations:
• luminal narrowing can be overestimated due to vascular calcifications, and that is why comparison of MIP images with axial images is important to differentiate wall calcifications from true lumen and, this way, determine accurate degree of stenosis
• sometimes editing of bone is required to allow visualization of vascular map.

In nondialysis patients (unenhanced CT only), MIP images can be used to obtain a vascular map when severe arterial wall calcifications are present.

Volume rendering images (Fig. 12, 13, 14) allow better study of vascular anatomy and vascular complications:

• Allows better demonstration of a vascular map, sometimes with no or minimal bone editing
• Vessel lumen and wall calcifications are usually well defined, and this way the degree of stenosis can be accurately measured.
• Color display may improve understanding of the 3D relationships of different anatomic structures.

**Renal vascular anatomy**

A detailed knowledge of the anatomy and variational pattern in blood supply to the kidney is tremendously important for evaluation of renal transplant donors.

**Renal Artery Anatomy**

The majority of people typically have one single renal artery on each side, in most cases arising at the level of the upper margin of the second lumbar vertebral body. The left renal artery is shorter and follows a nearly horizontal course, while the right renal artery follows an oblique descendent course because the right kidney is inferiorly positioned.

The renal arteries give rise to one or more small inferior adrenal arteries branches, to ureteric arteries and to small vessels to the perirenal fat and renal fascia.

Reaching the hilum, the renal arteries divides into four or five segmental branches to the parenchyma.

Anatomical variants in renal arteries accounts for about 30% of its existence.

They include:
• Multiple renal arteries - often associated with malpositioned or malrotated kidneys, although they might happen in normally positioned kidneys (Fig. 15)

• Polar arteries - arteries that branch from the main renal artery near its origin or from a hilar artery and pierce the substance of the kidney directly into the parenchyma (not passing through the hilum) at the level of the upper or lower pole. In some cases, the polar arteries may arise directly from the aorta (Fig. 16, 17).

• Accessory arteries - additional arteries whose origin is separated from the main renal arteries and pass along with normal renal arteries through the renal hilum rather than directly into the parenchyma. In infrequent cases, accessory arteries may also arise from iliac, superior and inferior mesenteric, celiac, middle colic, lumbar, and middle colic, lumbar, and middle sacral arteries. Small accessory renal arteries are best depicted in 1mm axial images and curved coronal reformation.

• Extrahilar branching (Fig. 18, 19, 20) is a variant in which the main renal artery branches before reaching the renal hilum, and if this happens within 1.5cm of the origin of the renal artery, it is called an early branching. These early branches are important in planning the surgery because a minimum distance of 1-1.5cm is needed to obtain correct anastomosis. These extrahilar and early branches may enter the renal hilum (being hilar vessels) or they may penetrate the renal parenchyma directly (in this case being polar arteries).

Renal vein anatomy

The majority of people typically have one single renal vein on each side.

Double and triple veins may be seen in the right kidney in about 15% of donors.

The left renal vein averages 8.5 cm in length and generally follows a transverse course anterior to the aorta. The left renal vein usually has several major extrarenal tributaries (the adrenal vein, the left testicular/ovarian vein, and sometimes lumbar, ascending lumbar and hemiazygos veins).

Right renal vein is shorter than the left one, and that is why the left kidney is preferred for donation. In most cases, the right renal vein has no venous tributaries.

Renal venous variations are less frequently observed than arterial ones, and are usually caused by anomalies related to the development of inferior vena cava.

The most common variants of the left renal vein, seen in about 5-7% of individuals, are circumaortic and retroaortic veins.

Renal assessment with MDCT angiography
The radiologist’s report on a living donor must include information regarding:

- the location and length of both kidneys
- the number, course and length of main renal arteries and veins, as well as renal arterial variants and venous tributaries.

In a kidney with two arteries, the length of the arteries before the segmentary bifurcation and the distance between the two arteries should be measured. 3D volume-rendered images should be obtained.

More than two arteries within a kidney contraindicates donation.

Donation is only possible if one of the three arteries is a small superior polar artery less than 2 mm in diameter. This vessel an be sacrificed, for the small volume infarcted parenchyma does not substantially affect graft function.

- the real orthogonal diameter of all renal arteries. Artery diameters should be at least 3mm in order to allow an adequate graft anastomosis and reduce the risk of thrombosis. Artery measurements to determine are: the distance between the right/left arterial origin and the first segmentary bifurcation, and the distance between the right inferior vena cava margin and the first segmentary bifurcation,
- Vein measurements to determine are: the distance between the segmentary confluence of the right renal vein and the inferior vena cava, the distance between the segmentary confluence of the left renal vein and the inferior vena cava and the distance between the confluence of the left renal vein and the left margin of the aorta
- the presence of intra or extrahilar arterial segmental bifurcation
- the presence and diameter of polar arteries. This information is important because small polar arteries (<2mm) may be cut or suffer thrombosis during surgery without significant parenchymal infarction. Besides, if small polar arteries are not reported, they may be accidentally sectioned during surgical procedure, causing uncontrolled arterial bleeding and renal infarct. If an inferior polar artery is cut, graft pyeloureteral necrosis may occur, for these vessels frequently suply the upper urinary tract

Other MDCT angiography findings should be mentioned in the report.

**MDCT angiography findings**

**Renal artery disease:**
Atherosclerosis of renal arteries generally occurs at the origin or proximal segment of the renal artery.

It is more common in older patients and is associated with cardiovascular disease risk factors.

It is important to distinguish calcified from soft plaques because calcified ones prevent the vessel from closing adequately, and when the vessel is clamped they may cause laceration of the intima of the renal artery or even the aorta, leading to uncontrolled bleeding.

If a unilateral atherosclerotic plaque is found, transplantation can be performed, with endarterectomy or resection of the affected segment during surgery (Fig. 24, 25).

Bilateral atherosclerotic renal artery disease rules out donation.

Fibromuscular dysplasia is another possible finding in MDCT angiography of renal donors, affecting mainly the mid and distal segments or the main renal artery and segmentary arteries, and typically appearing as a "string-of-beads" appearance, focal stenosis, and aneurysms.

Unilateral fibromuscular dysplasia does not exclude donation, for the affected vascular segment may be replaced with a graft.

Bilateral fibromuscular dysplasia does excludes donation.

Renal calculi:

MDCT is a highly sensitive technique in detecting small renal calculi in asymptomatic patients and nephrocalcinosis, specially through unenhanced scanning.

The presence of calculi suggests that donor may have a metabolic abnormality predisposing to the formation of additional calculi, increasing the risk for renal failure in case of organ donation.

If a single calculus larger than 5 mm or multiple calculi are found on unenhanced images, contrast-enhanced scanning will not be performed, the study will end and patient will be excluded from organ donation.
In our institution, if a single calculus smaller than 5 mm is found on unenhanced images, we proceed to enhanced scanning, specially if it is located in the lower inferior pole and there is no history of lithiasis or metabolic disease (Fig. 26).

If no calculi are found on unenhanced images, the patient will proceed with donation.

Perirenal fat:

By the time of transplantation, perirenal fat is also completely removed.

Men tend to have more perirenal fat than women, as well as overweight individuals.

Large amounts of perirenal fat tend to obscure anatomic landmarks and complicates the surgical procedure, leading to an increase in surgical complexity and time.

The radiologist's report should include measurement of the perirenal fat.

Renal masses:

Renal masses are best depicted on nephrographic phase images.

Simple renal cysts, even if large, do not exclude organ donation (Fig. 27, 28).

Small angiomyolipomas (<5 mm) do not exclude donation either because they are slow growing lesions, with no associated morbidity. Larger angiomyolipomas (> 5 mm) can be locally excised.

Patients with ESRD who have been efficaciously treated for renal cancer are possible candidates for renal transplantation, as long as minimum waiting time before renal transplantation is respected.

In case of large (>5 cm) symptomatic lesions, a waiting time of 5 years is recommended between cancer treatment and renal transplantation, and in case of smaller renal cancers the waiting time should be at least 2 years.

Renal cell carcinoma is associated with very small risk of recurrence or metastization to the contralateral kidney and other organs. So once the lesion is locally excised and the recipient is informed of the risks and consents to the procedure, donation may be performed.
Upper urinary tract evaluation:

Delayed topograms acquired in the excretory phase allow depiction of the pelvicaliceal system and ureters, this way allowing detection of several upper urinary tract anomalies, some of which may directly preclude organ donation. These include, for example, transitional cell tumors, severe hydronephrosis, unilateral agenesis, cortical atrophy, polycystic disease, horseshoe kidney, papillary necrosis and medullary sponge kidney.

Other anomalies, however, don't necessarily exclude the surgical procedure. One example is partial/complete ureteral duplication, a quite common condition in the general population (affects around 1%). Nephrographic reformatted images of the kidneys, specially in the coronal plane, provide accurate anatomical information that allow the surgeon to make a thorough planning of the procedure and minimize the risk of separating the ureters during organ removal.
Fig. 1: Axial unenhanced CT scan as a first step of the protocol for evaluation of a potential kidney transplant donor.

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Fig. 2: Unenhanced CT scan, coronal reconstruction, as a first step of the protocol for evaluation of a potential kidney transplant donor. No renal calculi detected.

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Fig. 3: Axial contrast-enhanced CT scan (arterial phase) as part of the protocol for evaluation of a potential kidney transplant donor.

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**Fig. 4:** Enhanced (arterial phase) CT scan, coronal reconstruction, as part of the protocol for evaluation of a potential kidney transplant donor.

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Fig. 5: Axial contrast-enhanced CT scan (parenchymal phase) as part of the protocol for evaluation of a potential kidney transplant donor.

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Fig. 6: Enhanced (parenchymal phase) CT scan, coronal reconstruction, as part of the protocol for evaluation of a potential kidney transplant donor.

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Fig. 7: MIP coronal reconstruction - Excretory abdominal topogram obtained after a 5-minute delay to evaluate the renal collecting system.

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Fig. 8: Postprocessing, MIP axial reconstruction, showing one renal artery on each side.

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Fig. 9: Postprocessing, MIP coronal reconstruction, showing one real artery on each side.

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**Fig. 10:** Postprocessing, MIP coronal reconstruction, oriented for right kidney for arterial vasculature evaluation.

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**Fig. 11:** Postprocessing, MIP coronal reconstruction, oriented for left kidney for arterial vasculature evaluation.

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**Fig. 12**: Postprocessing, VRT coronal reconstruction, showing one single renal artery on each side.

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**Fig. 13**: Postprocessing VRT coronal reconstruction, oriented for right kidney for arterial vasculature evaluation, showing a single right renal artery.

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Fig. 14: Postprocessing, VRT coronal reconstruction, oriented for left kidney for arterial vasculature evaluation, showing a main renal artery and a superior polar accessory artery originating from the aorta.

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**Fig. 15:** Postprocessing, MIP coronal reconstruction, showing two left renal arteries, one with a larger caliber and extra-hilar branching, irrigating the upper 2/3 of the kidney, and a second renal artery with lesser caliber, originated from the aorta (28mm below the origin of the first renal artery), irrigating the lower 1/3 of the kidney.

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**Fig. 16:** Postprocessing, MIP coronal reconstruction, showing inferior polar artery of the right kidney, originating from the aorta.

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**Fig. 17:** Postprocessing, MIP coronal reconstruction, showing superior polar artery of the left kidney, originating from the aorta.

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Fig. 18: Postprocessing, MIP axial reconstruction, showing extra-hilar branching of the left renal artery, at a distance of 22mm from its aortic origin.

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**Fig. 19:** Postprocessing, VRT coronal reconstruction, showing extra-hilar branching of the right renal artery.

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Fig. 20: Postprocessing, VRT coronal reconstruction, showing extra-hilar branching of both right and left renal arteries.

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**Fig. 21:** Enhanced CT sagittal reconstruction with measurement of kidney length.

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Fig. 22: Postprocessing, MIP coronal reconstruction, showing measurement of the right renal artery before segmentary bifurcation (18.8mm).

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Fig. 23: Postprocessing, MIP coronal reconstruction, showing measurement of the distance between two left renal arteries (approximately 30mm).

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Fig. 24: Postprocessing, MIP coronal reconstruction, showing the presence of scattered calcifications of the aorta and iliac arteries. There is also a single small calcification in the proximal segment of the right renal artery.

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Fig. 25: Postprocessing, VRT coronal reconstruction of, showing the presence of scattered calcifications of the aorta and iliac arteries. There is also a single small calcification in the proximal segment of the right renal artery (same patient as in image 24).

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Fig. 26: Unenhanced CT scan, coronal reconstruction, showing a single calculus smaller than 5 mm in the lower inferior pole.

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Fig. 27: Enhanced CT scan, sagittal reconstruction, showing a small simple cyst in the upper pole of the left kidney.

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Fig. 28: Enhanced CT scan, sagittal reconstruction, showing several parapelvic cysts in the left kidney.

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Conclusion

Precise presurgical evaluation of potential kidney donors is essential for successful renal transplantation.

MDCT angiography is the primary imaging modality to perform this evaluation, and has replaced conventional angiography at many institutions.

This technique provides a wide range of information about vascular and extravascular systems, and has proven to be exceptionally accurate in demonstrating renal anatomy in the presurgical evaluation of these patients.
References


