Computed Tomography Renal Angiography in Living Donors and its Correlation with Surgery

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Abstract
Objective: *To determine the accuracy of computed tomography renal angiography (CTRA) in the evaluation of the arterial renal system and its anatomical variations in living kidney donors, and the correlation of CTRA findings with those observed during kidney harvesting.*
Materials and methods: *Patients who had undergone laparoscopic nephrectomy as living kidney donors and their CTRA performed in our institution between 2014 and 2016 were retrospectively evaluated. Results are presented using statistical descriptive analysis. The following were assessed in the CTRA report: number of main renal arteries, presence and number of polar arteries, and renal artery diameter abnormalities.*
Results: *Twenty-one patients who had undergone laparoscopic nephrectomy as living donors were included: 10 female and 11 male donors (age range 23 - 61 years). Renal harvesting included left kidney in all cases. Out of 21 patients evaluated, 15 had no anatomical variations or arterial renal dilations on CTRA (one main renal artery, without polar arteries). The same findings were confirmed during surgery. In one case CTRA showed a double renal artery, which was also found during kidney harvesting; and in three cases CTRA identified a single polar artery, a finding that was confirmed by surgery. In these 19 cases, a correlation was shown between CTRA and surgery, with 90.4% accuracy. In the remaining 2 cases, there were discrepancies.*
Conclusion: *Detailed knowledge of the renal arterial anatomy is necessary for the surgical planning of laparoscopic nephrectomy in living renal donors. CTRA is the method of choice for this evaluation, showing a good correlation between CTRA findings and surgery.*

Keywords: *Kidney transplantation; Living renal donor; Computed tomography angiography; Renal artery*

Introduction

At present, renal transplantation is the treatment of choice in patients with end-stage chronic renal failure, improving the quality of life of these patients, who require ongoing dialysis. In recent years, because of the shortage of cadaveric kidney donors and the long waiting times for an organ, the percentage of living donor renal transplantation has increased[1]. The evaluation of living donors is essential to reduce potential surgical complications that may compromise the graft, and for surgical planning. Thus, detailed knowledge of the renal arterial and venous anatomy is essential for harvesting kidneys from living donors[2]. Computed tomography renal angiography (CTRA) is the method of choice for the evaluation of the living renal donors' kidney prior to laparoscopic nephrectomy[3].
The aim of this study is to determine the accuracy of CTRA in the evaluation of the arterial renal system in the living donor.

Material and methods

Renal donors
Patients undergoing laparoscopic nephrectomy as living renal donors and their respective CTRA reports, performed between February 2014 and April 2016 at our institution, were retrospectively evaluated. Results were summarized by descriptive statistics.

Imaging protocol and analysis
All CTRAs were performed at our institution using a 16-detector TOSHIBA Activion multislice computed tomography scanner (Minato, Tokyo, Japan) with intravenous administration of 125 ml of nonionic iodinated contrast (Optiray 320 prefilled syringes) by an injection pump into the antecubital vein at 3.5 – 4 ml/sec. Unenhanced arterial phase images were obtained (20-30 seconds) by using the sure-start system, with scanning starting when the contrast level of the

aorta reached 180 Hounsfield units (HU) at the origin of renal arteries, including acquisitions from the diaphragm to the pelvis. CTRA reports were randomly performed by two specialized physicians, who used a Vitrea workstation for image post-processing and subsequent reporting.
The study was approved by the institutional review board. No informed consent was requested from the donor because this was a retrospective study. CTRA images review included: the number of main renal arteries, defined as those entering the renal hilum; presence and number of polar arteries, defined as those that attain the kidney poles; and/or abnormalities of the renal artery diameter (fig. 1).
When there was no correlation with surgery, a repeat review of the CTRA scans was performed to identify causes or sources of error. Anatomical variants of renal veins or of the urinary excretory tract were not considered for this study.

Results

Twenty-one patients undergoing laparoscopic nephrectomy as living donors were included: 10 women and 11 men, with an age range between 23 and 61 years old.
In all cases (table 1), the left kidney was harvested. Out of 21 patients evaluated, 15 had no anatomic variants or diameter abnormalities on CTRA scan reviews; i.e., a single main renal artery was identified, with no polar arteries. The same findings were confirmed during renal surgery (figs. 2 and 3).
In one case, the CTRA scan showed a double main renal artery and this finding was confirmed by surgery (figs. 4 and 5); in other three cases, CTRA identified a single polar artery (the three of them in the inferior pole), a finding that was confirmed during surgery (fig. 6). Therefore, in these 19 cases, an exact correlation has been demonstrated between CTRA and

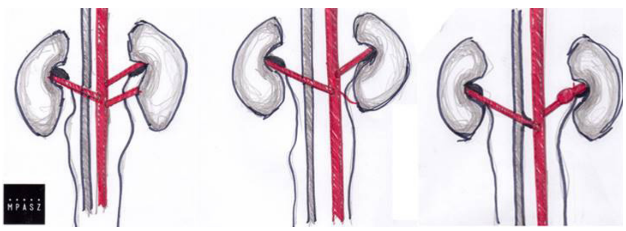

Figure 1. Drawing showing the findings used for CTRA scan reviews: number of renal arteries, presence or absence of polar arteries and arterial diameter abnormalities.

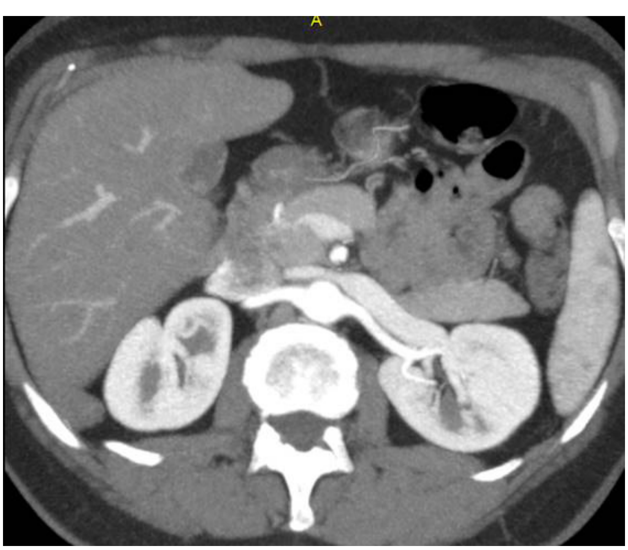

Figure 2. Axial computed tomography renal angiography (CTRA) images in a living donor with Maximum Intensity Projection (MIP), with no anatomical variants. The scan shows a single main renal artery, with no polar arteries or diameter abnormalities.

Figure 3. CTRA with 3D reconstruction shows no anatomical variants, with a main renal artery and no presence of polar arteries.

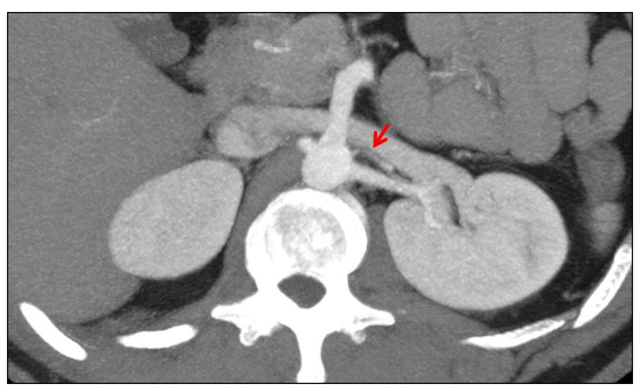

Figure 4. Axial CTRA with MIP in a living donor shows two renal arteries entering the renal hilum, with that anteriorly located being of small diameter (arrow).

Table 1: Detailed report of each case included in this study.

Case	Gender	CTRA report on the LK	SURGERY (LK: left kidney)	Comments
1	F	1 main renal artery 1 small superior accessory renal artery	Harvesting of LK with a single renal artery	Discrepant case depicted in figure 9. Persistent presence of accessory renal artery on imaging, not identified during surgery
2	F	No variants	Harvesting of LK with no anatomical variants	
3	M	No variants	Harvesting of LK with no anatomical variants	
4	F	No variants	Harvesting of LK with no anatomical variants	
5	F	No variants	Harvesting of LK with no anatomical variants	
6	F	No variants	Harvesting of LK with no anatomical variants	
7	F	No variants	Harvesting of LK with no anatomical variants	
8	M	No variants	Harvesting of LK with no anatomical variants	
9	M	No variants	Harvesting of LK with no anatomical variants	
10	M	No variants	Harvesting of LK with no anatomical variants	
11	M	No variants	Harvesting of LK with no anatomical variants	
12	F	No variants	Harvesting of LK with no anatomical variants	
13	F	No variants	Harvesting of LK with 2 arteries (1 superior polar artery and 1 main artery)	Discrepant case depicted in figure 8. The 1-mm diameter superior polar artery was detectable in a repeat review of CTRA scans
14	M	Double renal artery	Harvesting of LK with 2 renal arteries	
15	M	1 renal artery and 1 inferior polar artery	Harvesting of LK with 2 arteries (1 main and 1 polar artery)	
16	M	1 renal artery and 1 inferior polar artery	Harvesting of LK with 2 arteries (1 main and 1 polar artery)	
17	F	No variants	Harvesting of LK with no anatomical variants	
18	M	No variants	Harvesting of LK with no anatomical variants	
19	M	No variants	Harvesting of LK with no anatomical variants	
20	F	No variants	Harvesting of LK with no anatomical variants	
21	M	1 renal artery and 1 inferior polar artery	Harvesting of LK with 2 arteries (1 main and 1 polar artery)	

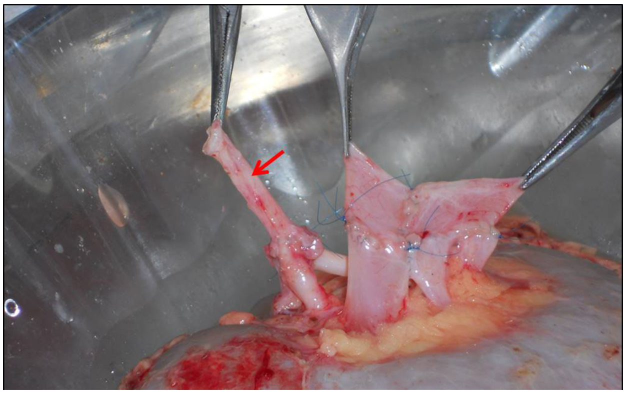

Figure 5. Image of kidney harvesting; double-barrel anastomosis (arrow) was performed between the two arteries visualized in figure 4.

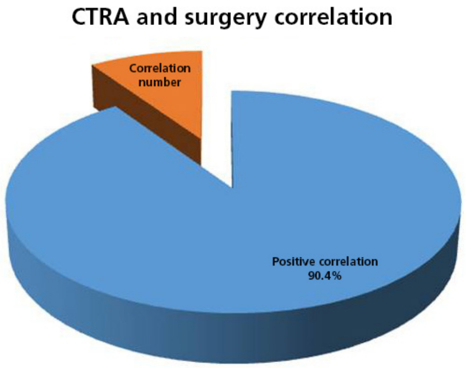

Figure 7 Pie chart showing the correlation between the CTRA report and surgery

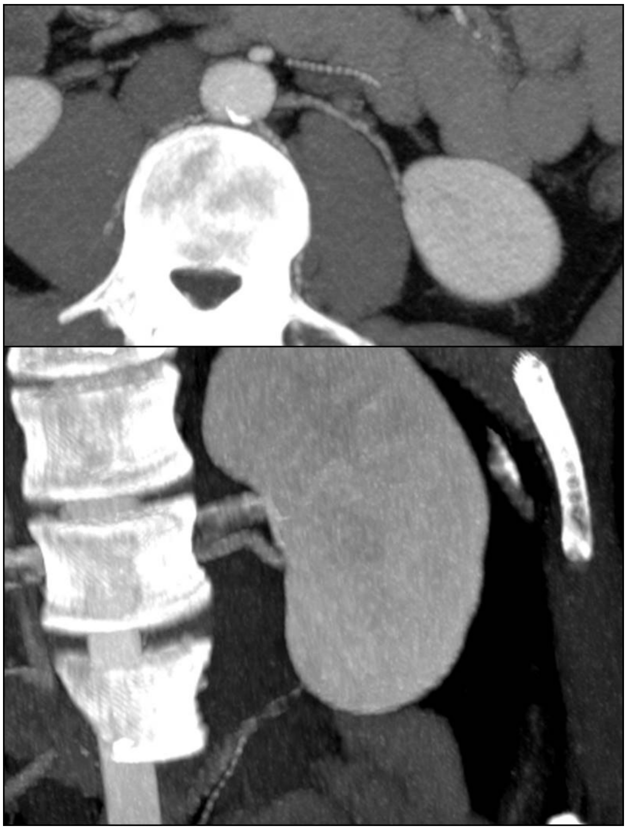

Figure 6. Axial and coronal CTRA, both with MIP, show the presence of a left inferior polar artery.

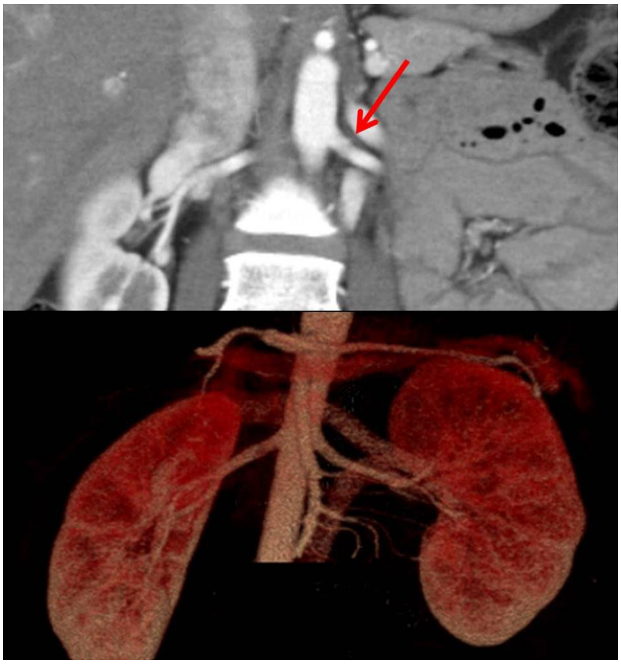

Figure 8. One of the discordant cases of the study. In this case, the polar artery was not visualized in the first review of the scan, being reported during surgery. After a detailed review of the scan (post-surgery stage), this artery could be detected arising perpendicularly to the renal artery (arrow); this position and the small diameter of the artery may have been the reason why we failed to detect it in the first review. It fails to be visualized in 3D reconstruction.

surgery findings. Based on these results, we obtained 90.4% accuracy when comparing CTRA with surgery (fig. 7).
In the two remaining cases, a discrepancy was found between CTRA and surgery. In one of them, the presence of a polar artery that had not been visualized on the CTRA scan was noted during surgery. However, this polar artery could be identified in a repeat review of the CTRA scan. The reason for this false negative result is thought to be the small diameter of the artery (1.5 mm) and the fact that it arises perpendicularly to the main renal artery, which hindered initial visualization (fig. 8).
In the other case of discrepant results, both reviews of the

CTRA scan (initial the preoperative review and the repeat review of the scan after surgery) showed the presence of an accessory renal artery of 1 mm in diameter, arising from the aorta above the main renal artery (fig. 9). During surgery, the search for this artery was disregarded because of its small diameter, the fact that it did not affect subsequent perfusion of the organ and the impossibility of using this artery to perform an effective anastomosis.

Discussion

Living donor kidney transplantation, as opposed to cadaveric donation, is currently considered the best option for the recipient and survival of the graft[3].

The first successful living donor kidney transplantation was performed in 1954 in Boston, between monozygotic 23-year-old twins. However, in 1952, living donor transplantation had already been performed in Paris, but the recipient died 21 days later as a result of fatal rejection. Since then, the importance of histocompatibility between donor and recipient for successful transplantation has been recognized[4]. In addition to compatibility, the evaluation of the potential donor should be free of contraindications for surgery, including, but not limited to, blood hypertension, diabetes and associated malignancies. Each site presents its own preoperative evaluation of the living donor, with general tests and other tests focused on a detailed assessment of the renal system, to define the renal vascular architecture and screen for anatomic abnormalities that may be overlooked[5].

Figure 9. The other discordant case of the study. The presence of a 1-mmm-diameter accessory renal artery (double renal artery) arising from the aorta above the main renal artery was reported (arrow). During surgery, the search for this artery was disregarded because of its small diameter.

Furthermore, a radiologic preoperative evaluation of the living donor's renal system is performed to select and analyze which kidney will be used for transplantation. This information is extremely useful for surgery planning and helps to prevent potential complications at the time of surgery[5].

With the introduction of laparoscopic nephrectomy (LN) in 1995 by Ratner *et al*[6], as a minimally invasive alternative to open nephrectomy, the role of preoperative radiologic evaluation has expanded. Because of the limited field of view available with laparoscopic technique, and the blinded dissection of the upper pole of the kidney, preoperative imaging is required to define the arterial and venous anatomy, the collecting system and renal parenchyma to avoid complications, bleeding and potential injury to the donated organ[7].

The evaluation of the renal arterial anatomy prior to LN helps determine the number and location of the main arteries, the pattern of accessory arterial branches and the presence of intrinsic renal artery disease[7]. Historically, the anatomic evaluation of the renal system was performed using conventional renal angiography, combined with excretory urography, for donor evaluation. Later on, the use of ultrasound provided data about actual size, the presence of masses or abnormalities in other associated intraabdominal organs.

In 1998, multislice computed tomography (CT) was introduced, in its modalities of CT angiography and CT urography, being subsequently followed by magnetic resonance imaging in its different modalities, all these being methods that improved the evaluation of kidney donors, minimizing invasive tests, morbidity and costs for these healthy individuals[5,8].

Undoubtedly, it was multislice computed tomography, in its CTRA modality, the imaging method that changed the way of evaluation of living kidney donors, providing valuable information both on vasculature and the rest of the renal system. Thus, it has become possible to rule out associated pathologies including, but not limited to, the presence of renal masses, calcifications, lithiasis and excretory system abnormalities with the use of a single imaging method, as compared to the limited data provided by other imaging techniques[9,10].

In most individuals (70-75%), the kidneys are supplied by a pair of renal arteries, one on each side, arising from the abdominal aorta below the origin of the superior mesenteric artery, at the level of the L2 vertebral body. Each renal artery is divided into an anterior and a posterior branch at the hilium of the kidneys, and these branches further divide into segmental and then lobar arteries[2]. Notwithstanding this anatomic detail, abnormalities in renal arterial vascular patterns are one of the most common variations in renal morphology[11]. According to various studies[11-13], the average occurrence of accessory or polar renal arteries is approximately 30%. In agreement with these authors, in our experience we have not found anatomic variants in 71% of cases (15 patients out of 21) and the presence of any abnormality in the remaining 29%.

These vascular variations will remain undiscovered unless surgical procedures or radiological interventions are performed or, as in the case of our study, a CTRA is performed[11]. Thus, detailed evaluation of the arterial system prior to a surgical procedure such as laparoscopic nephrectomy is essential.

At present, computed tomography renal angiography is the method of choice for the evaluation of renal vascular anatomy. The relevant data to be recorded in the angiographic report for surgical planning includes: number of main renal arteries, presence of accessory arteries, abnormalities in the caliber and early or late branching of the arteries[14]. Our study is based on these premises, except for the early or late branching of the arteries, which had not been recorded in some of our reports.

Several authors have evaluated the sensitivity of CTRA[1,9,15-18]; though with small differences, in most cases the sensitivity has been shown to be above 90%. Our study demonstrated 90.4% accuracy for the evaluation of the arterial renal system and its variants.

According to Pozniak et al15, CTRA has 100% sensitivity in identifying accessory renal arteries and 93% sensitivity in identifying prehilar arterial branches, thus demonstrating that CTRA is currently the best method for the evaluation of the vascular territory. In our study, sensitivity was not separately calculated for main and/or accessory branches.

In order to achieve such precision and optimal results, it is important to accurately follow the CT protocol, which includes the preparation and positioning of the patient, adequate management of the intravenous contrast, respecting the different phases of image acquisition, and the stage of image interpretation[2]. Even if each institution has its own CTRA protocol, variations in technique are minimal and are mainly related to the model of CT scanner used and the number of detectors. Our protocol includes a first unenhanced phase to evaluate mainly renal morphology and to detect the presence of lithiasis, followed by a second acquisition in arterial phase 20-30 seconds after the intravenous injection of contrast material for vascular assessment. This protocol is similar to most protocols mentioned in the literature[1,2,18].

In image post-processing at the workstation, images are reconstructed by multiplanar reformation, volume rendering and maximum intensity projection (MIP) to optimize the angiographic effect. Notwithstanding the image post-processing possibilities, the analysis of vascular anatomy should always include first a detailed evaluation of axial raw images, and then be followed by 3D evaluation[1,19].

As regards the CTRA false-negative findings in our study, in one of the cases a 1.5-mm-diameter polar artery was overlooked in the first review of the images, but after surgery, when the presence of such artery was reported, a thorough repeat review of the CTRA scan was performed by the same reporting specialist, and this artery could be visualized. Satyapal *et al*[12] described a range of diameter for an accessory renal artery between 0.2 and 3 mm. As our false-negative finding was within this range, we think that it was not only the size of the artery what hindered visualization in the first review of the scan, but also the course followed by this accessory artery, which arose perpendicularly to the main artery, thus impairing visualization in the first review of axial images. Misinterpretation may also be related to technical artifacts such as motion or poor acquisition in the contrast-enhanced phase[18]. If this polar renal artery had been detected in the first review of images, the sensitivity of the CTRA in our study would have been higher (>95%).

Regarding the other case of discrepancy, the CTRA scan showed an accessory renal artery of 1 mm in diameter arising from the aorta above the left renal artery. During surgery, the search for this artery was disregarded because of its small diameter, the fact that it did not affect subsequent perfusion of the organ and the impossibility of using this artery to perform an effective anastomosis. This accessory renal artery was visualized again in the repeat review of the CTRA scan, and therefore we have decided not to consider this finding as false-positive.

The selection of the kidney to be removed is related to anatomical and functional aspects, and the best kidney for the donor is chosen[20]. Even if there have been reports of right kidney harvesting, in these cases surgical resection has been limited because of the small lateral distance from the inferior vena cava. This is the reason why in most cases left nephrectomy is preferred, as the anatomic features of the vessels, such as the longer renal artery and veins allow for an easier surgical procedure with less complications[5,8]. In all our cases, the left kidney was harvested.

Recently, attempts have been made to introduce magnetic resonance angiography (MRA), as this procedure does not use ionizing radiation and, if intravenous contrast is used, the contrast material has less potential adverse reactions than other contrast agents used for conventional angiography and CTRA. A limitation of MRA is that it cannot be performed in patients with pacemakers, metallic prosthesis and implants and there may be difficulties for performing the scan in patients with claustrophobia. Furthermore, duration of the exam is longer and blood vessels are not always visualized at the same level of detail. Diagnosis of small-diameter arteries and differentiation of arteries and veins may be difficult. In addition, the use of MRA is limited because of high costs and limited scanner availability at the various sites[21,22].

Our hospital is a transplantation site for CUCAIBA (Centro Unico Coordinador de Ablación e Implante de la Provincia de Buenos Aires, Single Coordinating Center for Surgical Removal and Implants of Buenos Aires Province). For this reason, we present a large number of organ transplantation from related living donors in a relatively short time of study; however, the small number of patients is a limitation of our study. We think that the analysis of a larger number of cases would confirm the statistical findings reported and would further support CTRA as the method of choice for the evaluation of living donors.

An additional relative limitation of our study is the experience of the specialist physicians in CTRA reporting. Over the years and as more scans were reviewed, the specialists had gained more detailed knowledge by the end of this scientific study.

In order to optimize CTRA efficiency, radiologists should be familiarized with the anatomic renal aspects, have knowledge of technical parameters and be aware of any advances and potential difficulties (including, but not limited to, technical failures or misinterpretation of images) that may occur in relation to this method. It is also important to identify variants not only in renal anatomy but also extrarrenal abnormalities, as these data are crucial at the time of performing laparoscopic nephrectomy in living donors.

Conclusion

Detailed knowledge of the arterial system is necessary for surgical planning and performing laparoscopic nephrectomy in living kidney donors. Computed tomography renal angiography is currently the method of choice for this evaluation, showing a good correlation between imaging findings and those reported by the surgeon during kidney harvesting.

Ethical responsibilities

Protection of human subjects and animals. The authors declare that no experiments were performed on humans or animals for this investigation.

Confidentiality of data. The authors declare that they have followed the protocols of their work center on the publication of patient data.

Right to privacy and informed consent. The authors declare that no patient data appear in this article.

Conflicts of interest

The authors declare no conflicts of interest, except for Dr. Mariano who declares a possible conflict of interest as member of the Editorial Board of Revista Argentina de Radiología.

References

1. Jee Won Chai JW, Lee W, Yu Yin H, Jun Jae H, Wook Chung J, Hoe Kim H, et al. CT Angiography for Living Kidney Donors: Accuracy, Cause of Misinterpretation and Prevalence of Variation. Korean J Radiol. 2008;9:333---9.
2. Arévalo Pérez J, Gragera Torres F, Marín Toribio A, Koren Fernández L, Hayoun C, Daimiel Naranjo I, Angio CT. assessment of anatomical variants in renal vasculature: its importance in the living donor. Insights Imaging. 2013;4:199---211.
3. Sebastià C, Peri L, Salvador R, Bu˜nesch L, Revuelta I, Alcaraz A, Nicolau C. Multidetector CT of Living Renal Donors: Lessons Learned from Surgeons. Radiographics. 2010;30:1875---90.
4. Altes Ineva MP, Alonso Paz P, Abadia H, Izquierdo Reyes L, Oppenheimer F, Alvarez-Vijande R. Evolución del trasplante renal de donante vivo: datos históricos, estadísticos, nacionales y propios. Arch. Esp. Urol. 2005;5:497---501.
5. Arroyo C, Gabilondo F, Gabilondo B. El estudio del donador vivo para trasplante renal. Rev Invest Clin. 2005;57:195---205.
6. Ratner LE, Cisek L, Moore R, Cigarroa F, Kaufman H, Kavoussi LR. Laparoscopic live donor nephrectomy. Transplantation. 1995;60:1047---9.
7. Smith PA, Ratner LE, Lynch FC, Corl FM, Fishman EK. Role of CT angiography in the preoperative evaluation for laparoscopic nephrectomy. Radiographics. 1998;18:589---601.
8. Rydberg J, Kopecky KK, Tann M, Persohn SA, Leapman SB, Filo RS, et al. Evaluation of Prospective Living Renal Donors for Laparoscopic Nephrectomy with Multisection CT: The Marriage of Minimally Invasive Imaging with Minimally Invasive Surgery. RadioGraphics. 2001;21:223---36.
9. Ramírez-Bollas J, Hernández-Domínguez M, Arenas-Osuna J, Romero-Huesca A, Albores-Zú˜niga O. Reporte preliminar. Utilidad de la angiotomografía renal en el protocolo del donador renal. Cir Ciruj. 2003;71:379---82.
10. Stoisa D, Galiano FE, Quaranta A, Villavicencio RL. Estudio vascular renal por TC multidetector de 64 canales. Rev Argent Radiol. 2009;73:45---50.
11. Mehta G, Arole V. Accessory Renal Arteries: A Cadaveric Study. IJBAR. 2014;5:204---6.
12. Satyapal KS, Haffejee AA, Singh B, Ramsaroop L, Robbs JV, Kalideen JM. Additional renal arteries: incidence and morphometry. Surg Radiol Anat. 2001;23:33---8.
13. Dhar P, Lal K. Main and Accessory Renal Arteries-a Morphological study. Ital J Anat Embryol. 2005;110:101---10.
14. de la Torre P, Catalá V. Ri˜nón y vías urinarias patología vascular y tumoral, trasplante renal. En: Stoopen M, García Mónaco R, editores. Retroperitoneo y páncreas. Avances en Diagnóstico por Imágenes Colegio Interamericano de Radiología. Buenos Aires: Ediciones Journal; 2011. p. 97---117.
15. Pozniak MA, Balison DJ, Lee FT Jr, Tambeaux RH, Uehling DT, Moon TD. CT angiography of potential renal transplant donors. Radiographics. 1998;18:565---87.
16. Platt J, Ellis J, Korobkin M, Reige K. Helical CT evaluation of potential kidney donors: findings in 154 subjects. Am J Roentgenol. 1997;169:1325---30.
17. Smith PA, Ratner LE, Lynch FC, Corl FM, Fishman EK. Role of CT angiography in preoperative evaluation for laparoscopic nephrectomy. Radiographics. 1998;18:589---601.
18. Kawamoto S, Montgomery RA, Lawler LP, Horton KM, Fisherman EK. Multi-detector row CT evaluation of living renal donors prior to laparoscopic nephrectomy. Radiographics. 2004;24:453---66.
19. Ramesh Babu CS, Gupta OP. MDCT angiographic evaluation of multiple renal arteries --- a case report. Int J Anat Var. 2012;5:137---40.
20. Ratner LE, Kavoussi LR, Chavin KD, Montgomery R. Laparoscopic live donor nephrectomy: technical considerations and allograft vascular length. Transplantation. 1998;65:1657---8.
21. Ros Mendoza LH, Mayayo E, Solsona I, Ros P. Resonancia magnética renal. Arch. Esp. Urol. 2001;54:555---82.
22. Capalastegui A, Astigarraga E, Larena JA:. Aplicación de la resonancia magnética en el diagnóstico de la patología vascular arterial: angio-resonancia. Gac Med Bilbao. 2005;102:81---8.