Elmokadem *et al. Egypt J Radiol Nucl Med* (2024) 55:135
https://doi.org/10.1186/s43055-024-01307-x

Egyptian Journal of Radiology and Nuclear Medicine

RESEARCH

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# Inter-observer and inter-modality concordance of non-contrast MR angiography and CT angiography for preoperative assessment of potential renal donors

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## Abstract

**Background** Magnetic resonance angiography (MRA) is rapidly being employed as an effective substitute for CTA, particularly in situations of poor kidney function. We aimed to examine the inter-observer and inter-modality reliability of non-contrast MR angiography (NC-MRA) and CTA as a non-invasive tool for assessing the anatomical findings of potential living kidney donors.

**Results** All potential donors were referred from specialized kidney transplantation center and underwent NC-MRA of the renal arteries using a respiratory-triggered magnetization prepared 3D balanced steady-state free precession (b-SSFP) with inversion recovery pulses and fat saturation (Inhance 3D Inflow Inversion Recovery (IFIR)). Two experienced radiologists reviewed NC-MRA images and were asked to evaluate both renal arteries anatomy and their branching pattern, presence of accessory or aberrant renal arteries, and identify any anatomical variant. Lin's correlation test was performed to test MRA readings by each of the two observers against CTA findings which considered as the gold standard for assessment of renal arteries. Additionally, observers were asked to assess the image quality. The study included 60 potential kidney donors (43 males and 17 females) with mean age ± SD of 31.3 ± 5.6 years. Excellent to very good inter-observer agreement was found between both observers in the assessment of renal arteries by NC-MRA. There was perfect concordance between MRA and CTA findings in detecting early arterial division, caliber, and length of left extra-parenchymal segmental branches. Moderate concordance was found in the assessment of the supplied segments of extra-parenchymal segmental renal arterial branches and substantial concordance between both MRA observers' findings in the remaining variables of the study. There was excellent agreement between both observers in the assessment of image quality parameters.

**Conclusions** NC-MRA for the renal arteries is an effective alternative for CTA without the risks of radiation or contrast media.

**Keywords** MR angiography, Kidney transplantation, Contrast media, Donor selection

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## Background

Renal transplantation is often the preferred treatment to improve and prolong the lives of those with end-stage kidney disease. As it provides a significant reduction in morbidity and pain, laparoscopic donor nephrectomy is considered now the technique of choice, and due to the limited field of view in such technique, good preoperative imaging evaluation is essential for proper surgical planning, to evaluate the renal anatomy and anomalies [1, 2]. The gold standard imaging modality of the renal arteries is digital subtraction angiography, as it has the advantage of being diagnostic and sometimes therapeutic in cases of stenosis [3]. However, main drawbacks of this technique are being invasive method using ionizing radiation and iodinated contrast agents which are potentially nephrotoxic [2]. The use of multidetector computed tomography (CT), having higher temporal and spatial resolution, allowed the acquisition of high-quality images, producing results compared to those of digital subtraction angiography in the assessment of renal vasculature and its variants. However, CT angiography (CTA) also uses iodinated contrast agents and ionizing radiation [4, 5].

Magnetic resonance angiography (MRA) has been increasingly used as a good alternative to CTA especially in cases suffering from insufficient kidney function, with recent advances in software settings, and improved sequence performance which allowed high-quality non-invasive renal vasculature to be studied without exposing patients to iodinated contrast agents or ionizing radiation [6–8]. Numerous causes have been reported why non-contrast MRA might be a possible alternative to contrast-enhanced MRA and CTA. The first reason is to avoid possible nephrotoxicity or nephrogenic systemic fibrosis (NSF) secondary to iodinated or gadolinium-based contrast agents, especially in patients with Stage 4 or 5 chronic kidney diseases (CKD). Furthermore, there are many concerns about gadolinium deposition in the basal ganglia after repeated administration of gadolinium chelates [10]. Lastly, contraindication to the use of contrast agents (such as allergy) is of concern. Because all of these concerns, newer non-contrast renal MR angiography techniques become an attractive solution to replace CTA and CE-MRA in assessment of renal vascular anatomy, variants and it shows promising results [11–13]. Therefore, this study aims to assess the inter-observer and inter-modality reliability of NC-MR angiography as a non-invasive method for evaluation of the anatomical findings of potential living kidney donors in comparison with CTA findings.

## Methods

### Study population

This IRB-approved study included 60 potential kidney donors. All potential donors underwent MR angiography of the renal arteries without usage of contrast agent or any chemical materials. The results were compared to CTA results that are done as a routine investigation pre-operatively. All the candidates were informed about the examination time, the value of remaining motionless during examination, and knocking sound of MRI machine. CTA was performed before MRA and the interval between two studies ranged from 0 to 2 days.

### CTA protocol

All subjects were assessed using a 128-slice MDCT scanner (Revolution EVO, GE Healthcare 128 detectors, Milwaukee, WI, USA). The scan composed of arterial, venous, and delayed (excretory) phases. After initial scout topography was obtained, non-ionic iodinated contrast agent (Omnipaque, 350 mgI/ml) was injected through a 16–18-gauge cannula at a flow rate of 5 ml/s. Arterial phase was initiated based on automatic bolus tracking (Smart Prep, GE Healthcare). Scanning starts 5 seconds after reaching a threshold of 150 HU in the area of the abdominal aorta. The scanned area extended from diaphragm to symphysis pubis. The main acquisition parameters for arterial phase were: the section thickness of 1.25 mm, intersection spacing of 1.25 mm, tube voltage of 120 kv, tube current range 250– 500 mAs, with 0.5-s gantry rotation time.

### MRA protocol

Potential donors fasted for 2–4 h prior to the study in order to reduce fluid secretions within bowel loops and peristalsis. The subjects were positioned on the moveable examination table (feet first). Straps and bolsters may be used to help them to stay still and maintain the correct position during imaging. MRI examinations were performed on a 1.5-Tesla closed MRI unit (Signa Explorer, GE Medical Systems, Milwaukee, USA). Sixteen-channel circular, polarized, phased array body coil is positioned anteriorly and posteriorly over the abdomen; respiratory triggered bellows were applied. Subjects were instructed to breath regularly at normal amplitude during data acquisition. The examination included [1] multi-planner T2-weighted fast field echo (FFE) localizer to locate the region of interest starting from diaphragm to iliac bones with slice thickness 9 mm, [2]. Then NC-MRA was performed using respiratory-triggered magnetization prepared 3D balanced steady-state free precession (3D b-SSFP) with inversion recovery pulses and fat saturation (Inhance 3D Inflow Inversion Recovery (IFIR); GE health care). The scanning parameter was TE = 2.7 ms; TR = 5.4 ms; FOV = 110 mm; slice thickness = 0.2 mm; spacing = 0; flip angle = 90°; matrix = 256 × 256. Average scan time was 3.06 min.

### Image processing

The imaging data obtained after the scanning were reviewed on workstation with 2D and 3D capability and multiple editing options (Advantage Workstation 4.7, GE Healthcare). Image reconstruction and post-processing of the NC-MRA source images was performed by two radiologists using maximum intensity projection (MIP) and volume rendering (VR) techniques to produce a coronal image of the entire renal arterial vasculature. The MIP and VR images were magnified and projected at the appropriate viewing angle duo to the small caliber of the renal arteries and their segmental branches.

### Image analysis and interpretation

Two independent radiologists with 13 and 8 years of experience evaluated randomly distributed non-contrast MRA images and comparing its results with CTA results. Both observers were asked to assess the following: (i) renal arteries anatomy, branching pattern and early arterial division, (ii) presence of supernumerary arteries (accessory or aberrant renal arteries), (iii) extra-parenchymal segmental branches, and (iv) identification of different vascular anatomical variants. The accessory arteries defined as vessels that enter the kidney together with the main renal artery from the hilum, whereas the aberrant arteries enter the kidney straight from the capsule outside the hilum. They were asked to measure the caliber and length of main renal arteries, supernumerary arteries, and extra-parenchymal segmental branches. The caliber of renal arteries was measured from source images in cross-sectional planes within fixed distance 10 mm from the aorta, expect of one case with very short main renal artery. The length of renal arteries was measured from coronal reconstructed 3D images with manual 3D cursor in workstation measurement tools, compatible with renal arteries tortuosity. Additionally, both observers were asked to grade the image quality based on sharpness, presence of artifacts, and diagnostic acceptability following grading in (Table 1).

### Statistical analysis

Data were analyzed using IBM-SPSS (IBM Corp. Released 2017. IBM SPSS Statistics for Windows, Version 25.0. Armonk, NY: IBM Corp.) and MedCalc Statistical Software version 18.9.1 (MedCalc Software bvba, Ostend, Belgium; http://www.medcalc.org; 2018). The diagnostic accuracy of NC MRA for determining renal arteries anatomy and variants was correlated with the gold standard CT angiography to calculate the sensitivity and specificity of NC MRA as a single preoperative method for assessment of renal vascular anatomy of living kidney donors and mapping for operation. Quantitative data were expressed as mean ± standard deviation (SD). Non- quantitative data were expressed as frequency [N] and percentage [%]. Inter-observer agreement and inter-modality concordance for nominal data were assessed by Cohen's kappa (poor < 0.20; fair = 0.21–0.40; moderate = 0.41–0.60; good = 0.61–0.80; very good = 0.81-0.099; perfect = 1.00). Inter-observer agreement and inter-modality concordance for ordinal data were assessed by weighted kappa and scale using interclass correlation and Lin's concordance coefficient (poor < 0.90; moderate = 0.90–0.95; substantial = 0.95–0.99; perfect > 0.99).

## Results

### Study population and CTA findings

This study included 60 potential kidney donors, 43 males (71.7%) and 17 females (28.3%), with mean age ± SD of 31.3 ± 5.6 years. According to CTA findings, the mean caliber of right renal arteries ± SD = 5.50 ± 1.01 mm, and the mean caliber of left renal arteries ± SD = 5.55 ± 0.9 mm. The median (IQR) distance to the bifurcation of right renal arteries is 32 (25–41) mm, and the median (IQR) distance to the bifurcation of left renal arteries is 28 (23–32) mm. CTA readings recorded early arterial division within 20 mm distance from the aorta in 15 subjects: eight on the right and seven on the left. The typical bifurcation renal arteries branching pattern was recorded in 56 subjects, and a trifurcation branching pattern in 4 subjects, with three on the right side and one on the left side. All supernumerary (aberrant and accessory) renal arteries arose from the abdominal aorta. Aberrant renal arteries were reported in 14 subjects (Fig. 1), and accessory renal arteries in 6 subjects (Fig. 2). CTA data showed seven proximal extra-parenchymal segmental renal branches in 6 subjects (Figs. 2 and 3). CTA characteristics of the supernumerary and

**Table 1** Qualitative grading score of renal MRA images

| Qualitative grading score | Image quality | | |
|---|---|---|---|
| | **Sharpness** | **Artifacts** | **Diagnostic acceptability** |
| 1 | Blurry | Present and affect interpretation | Unacceptable |
| 2 | Poorer than average | Present but not affect interpretation | Suboptimal |
| 3 | Average | Absent | Average |
| 4 | Better than average | Not applicable | Above average |
| 5 | Sharpest | | Superior |

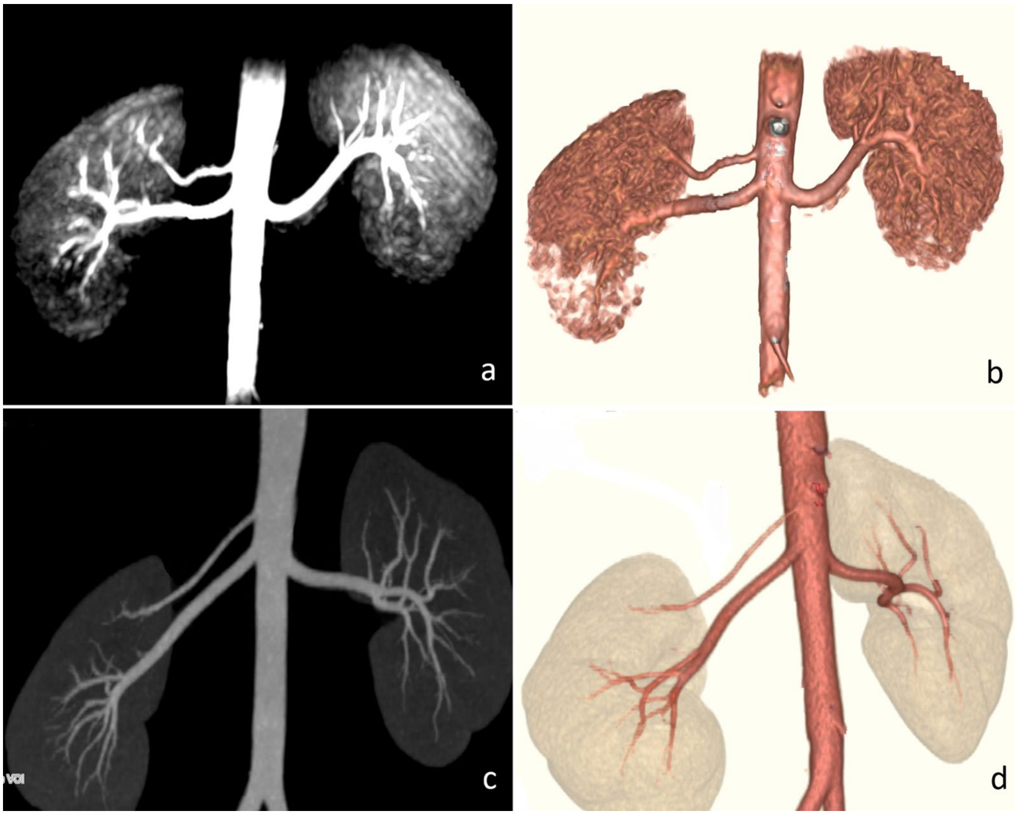


**Fig. 1** Right aberrant renal artery in a 37-year-old male potential renal donor. **a**, **b** Coronal MIP and VR-processed NC-MRA images. **c**, **d** Coronal MIP and VR-processed CTA images

extra-parenchymal segmental renal branches are demonstrated in Table 2.

Renal arterial anatomical variants were reported in 5 subjects as follows: left testicular artery arising from the left renal segmental branch, right adrenal and phrenic arteries arising from the right renal artery, left intra-renal aneurysm, right phrenic artery arising from the right renal artery and right pre-caval accessory renal artery. Both observers failed to detect the left testicular artery (Fig. 4) and succeeded in detecting the other anatomical variants in NC-MRA.

### Quantitative variables assessment and correlations (Table 3)

There was a perfect concordance between findings reported by MRA (observer 2) and CTA findings in detecting the caliber and length of left extra-parenchymal segmental branches. MRA (observer 1) findings had perfect concordance with CTA findings in measuring the length of the right aberrant arteries and the length of the left extra-parenchymal segmental branches. There was moderate concordance between both MRA observers' findings in assessing the supplied segments of extra-parenchymal segmental renal arterial branches. There was poor concordance in the assessment of extra-parenchymal segmental renal branch, number, side, and right branches caliber and length between two observers, which did not achieve statistical significance because of the very small sample size. According to both MRA observers, there were two extra-parenchymal segmental renal arterial branches on the right side, while CTA readings revealed three branches. There was substantial concordance between both MRA observers' findings in the remaining quantitative variables of the study. There was almost perfect agreement between MRA observers and CTA readings in measuring accessory renal arteries and left extra-parenchymal segmental branch length. There was good agreement in assessing the right extra-parenchymal segmental branches caliber and length between two MRA observers and CTA readings. All other remaining quantitative variables showed a very good agreement between the two MRA observers and each MRA observer and CTA readings.

### Non-quantitative variables assessment and correlations (Table 4)

There was a very good agreement in assessing early arterial division and extra-parenchymal segmental branches

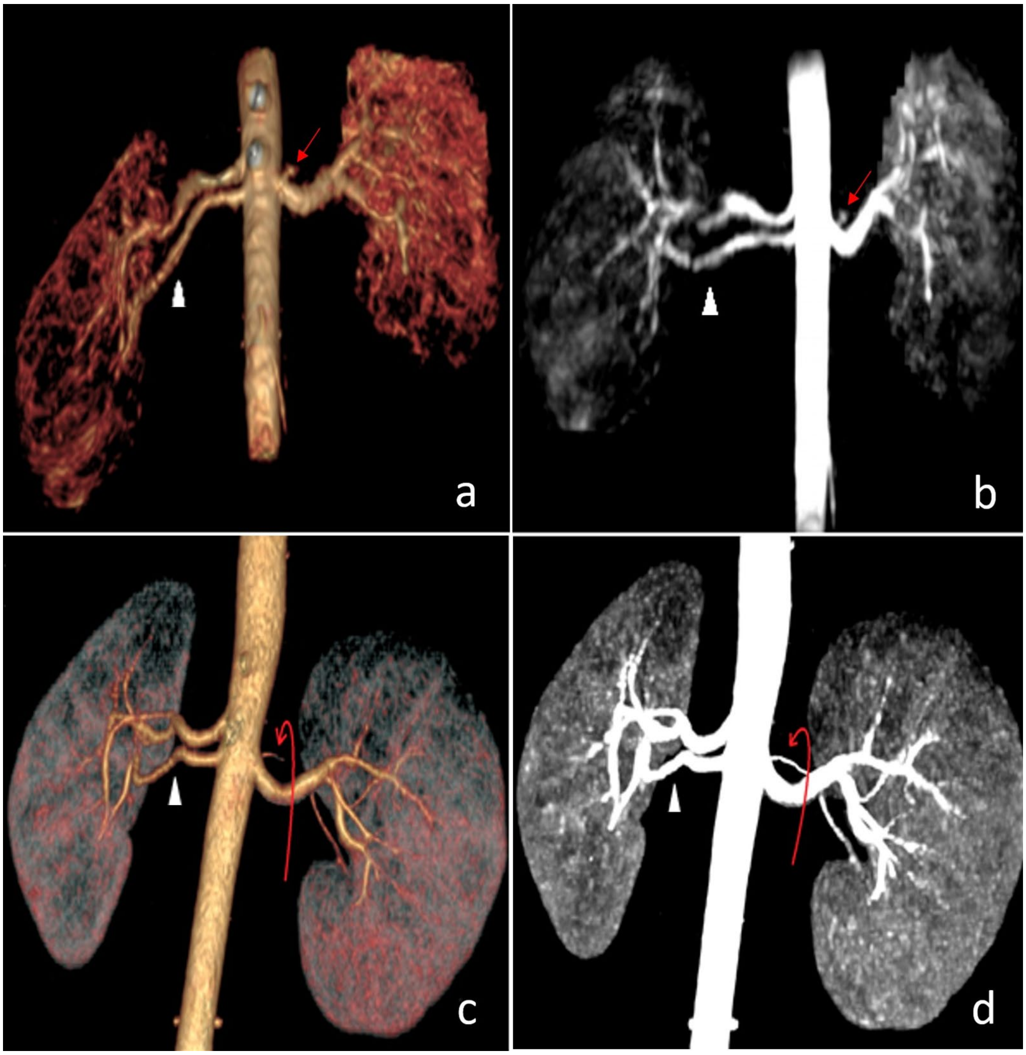


**Fig. 2** Right accessory renal artery (arrow heads) and early division on left side into inferior segmental branch (red curved arrows) in a 23-year-old male potential renal donor. **a**, **b** Coronal MIP and VR-processed NC-MRA images. **c**, **d** Coronal MIP and VR-processed CTA images

number between MRA observers vs. CTA readings and a good agreement in the assessment of extra-parenchymal segmental branches (side and supplied segment) between both MRA observers vs. CTA findings and in the evaluation of other anatomical variants between both MRA observers vs. CTA findings. For other nominal variables, a perfect agreement was found between both MRA observers, each observer, and CTA findings.

### Qualitative assessment of MRA images

There was excellent agreement between both observers in the assessment of image quality parameters. There was one (1.7%) case with poorer sharpness than average, according to (observer 1) scoring, and two (3.3%) cases, according to (observer 2) (Table 5a). Regarding imaging artifacts, both observers listed only one case (1.7%) with imaging artifacts that affected image quality & interpretation (Table 5b). *According to both observers, two (3.3%) cases had suboptimal diagnostic acceptability* (Table 5c).

### Sensitivity and specificity

In the comparison of non-contrast MR renal angiography anatomical findings in our study with the reference standard CT renal angiography, the sensitivity and specificity were calculated as the following: early division (93.3% and 100%), extra-parenchymal segmental branch (85.7% and 100%), and for other anatomical variants (83.3% and 100%).

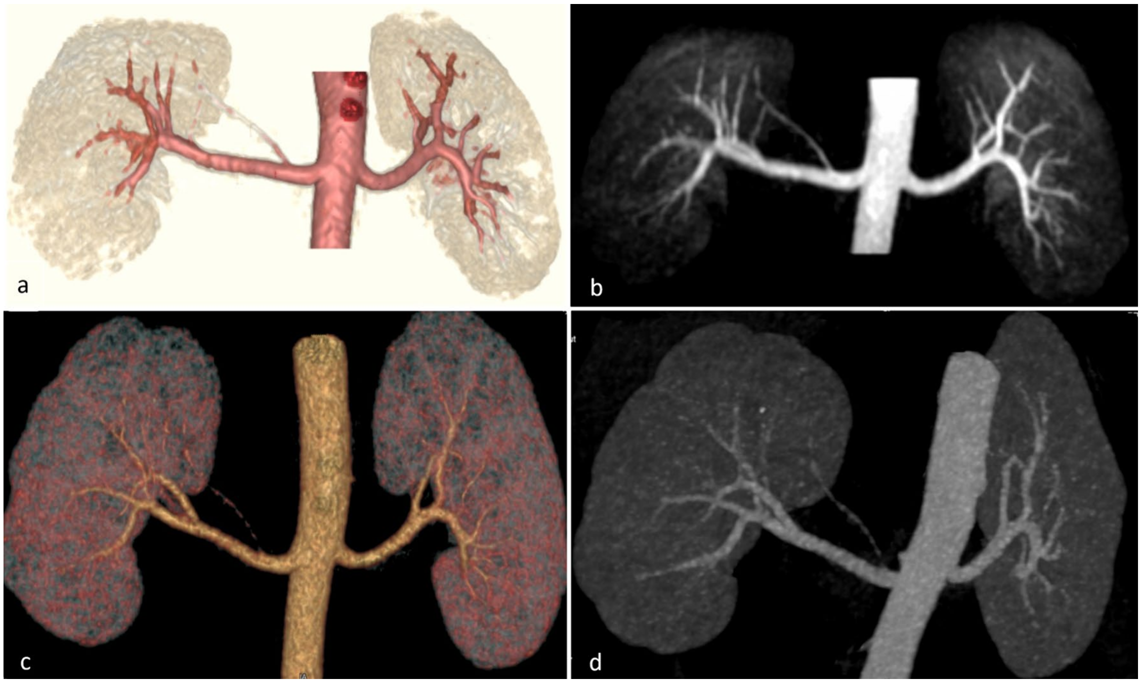

**Fig. 3** Early arterial division into right extra-parenchymal apical segmental branch in a 19-year-old male potential renal donor. **a**, **b** Coronal VR and MIP-processed NC-MRA images. **c**, **d** Coronal VR and MIP-processed CTA images

## Discussion

In donor transplantation cases, angiography is crucial to assess the renal vasculature. Multiple accessory renal arteries or early branching may become a challenge for transplantation and could result in severe complications and even transplant failure [13, 14]. CTA is considered the gold standard for the preoperative assessment of renal donors. However, the main drawbacks of CTA are exposure to nephrotoxic iodinated contrast and ionizing radiation [15]. NC-MRA is an attractive solution to avoid radiation exposure and contrast administration [16]. Recent studies have evaluated the NC-MRA technique to assess renal artery stenosis [12, 17–19] and vascular anatomy in potential renal donors and have produced promising results [2, 9, 20–25]. Nevertheless, the diagnostic accuracy of NC-MRA was not validated by CTA in all these studies. NC-MRA was compared to contrast-enhanced MRA in some studies [2, 17, 18, 20] or operative results [20, 23] or DSA as reported by Gue et al. [19]. Furthermore, the current study included a relatively large number of donors (n = 60); 120 kidneys were examined. They showed 144 renal arteries, 120 main, and 24 supernumerary renal arteries.

The current study investigated the inter-observer and inter-modality concordance of non-contrast MR angiography using Inhance Inflow Renal MRA, 3D SSFP sequence, and CT angiography for the preoperative assessment of potential renal donors. Our results showed excellent inter-modality concordance between traditional CTA and NC-MRA in detecting the most common anatomical variant, such as supernumerary renal arteries, their number, origins, and supplied renal poles. Readers successfully identified all main renal and accessory arteries in the study population. In concordance with our results, Patil et al. [24] reported a very good inter-reader agreement for supernumerary arteries (K = 0.97) and early branching (K = 0.88) on CTA and NC-MRA. Blankholm et al. [9] reported excellent agreement in the ostium and proximal segment caliber measurements by NC-MRA compared to CTA for both readers. These results are similar to the current study results regarding renal arteries caliber assessment between NC-MRA and CTA and between both observers. In another study compared the diagnostic accuracy of NC-MRA versus CTA for assessment of renal artery stenosis, there was an average of 6% variation in the measured percentage of renal artery stenosis between the two readers and explained that this variability occurred for both NC-MRA and CTA likely due to the modest linear correlation was seen between CTA and MRA [12].

Both observers in the current study detected all anatomical variants of renal arteries in NC-MRA apart from abnormal left testicular artery origin from the left kidney. Both observers detected the left testicular

**Table 2** CTA characteristics of the supernumerary and extra-parenchymal segmental branches

| | | |
|---|---|---|
| Aberrant artery* 14 (23.3%) | Number | |
| | One | 10 (16.6%) |
| | Two | 4 (6.7%) |
| | Side | |
| | Right | 4 (6.7%) |
| | Left | 6 (10%) |
| | Both | 4 (6.7%) |
| | Location | |
| | Upper pole | 8 (13.3%) |
| | Lower pole | 2 (3.3%) |
| | Lower pole on both sides | 2 (3.3%) |
| | RT lower pole and LT upper pole | 1 (1.7%) |
| | RT upper pole and LT lower pole | 1 (1.7%) |
| | Right aberrant artery caliber (mm)** | 2.7 ± 0.8 |
| | Left aberrant artery caliber (mm)** | 2.6 ± 0.7 |
| | Right aberrant artery length (mm)*** | 38.5 (27.5–59.7) |
| | Left aberrant artery length (mm)*** | 33.0 (26–35.2) |
| Accessory artery* 6 (10%) | Side | |
| | Right | 3 (5%) |
| | Left | 3 (5%) |
| | Accessory Caliber (mm)** | 3.03 ± 0.6 |
| | Accessory Length (mm)*** | 40 (35–60.5) |
| Extra-parenchymal Seg. branch* 6 (10%) | Number | |
| | One | 5 (8.3%) |
| | Two | 1 (1.7%) |
| | Side | |
| | Right | 3 (5%) |
| | Left | 2 (3.3%) |
| | Both | 1 (1.7%) |
| | Supplied segment | |
| | Apical segment | 3 (5%) |
| | Inferior segment | 1 (1.7%) |
| | Superior segment | 1 (1.7%) |
| | RT superior and LT posterior segments | 1 (1.7%) |
| | Extra-parenchymal Seg. branch caliber mm*** | 1.2 ± 0.3 |
| | Extra-parenchymal Seg. branch length mm** | 23.7 (13–34) |

Data are expressed as* N (%), **Median (IQR), ***Mean ± SD

artery in NC-MRA after the revision of CTA. The testicular artery variations are relatively rare, ranging from 0.4 to 14%, and maybe with respect to their number, origin, or course. Testicular arteries may originate from the aorta at an abnormal level or renal, suprarenal artery, or any one of the lumbar arteries [26]. This study included other unusual branches from the renal artery, such as the phrenic and adrenal arteries. We advise radiologists assigned to read preoperative scans for renal donors to know the detailed anatomy of the renal arteries and their branches to avoid such interpretation errors.

Although readers' confidence was slightly lower for NC-MRA images in the current study, image quality was more than acceptable in most cases. Similarly, Parienty et al. reported that the image quality of NC-MRA using the 3D b-SSFP technique was good in 87% and moderate in 13% of images using a 3-point scoring system, with good, moderate, and poor scores [27]. In another study assessed the vascular visualization quantitatively,

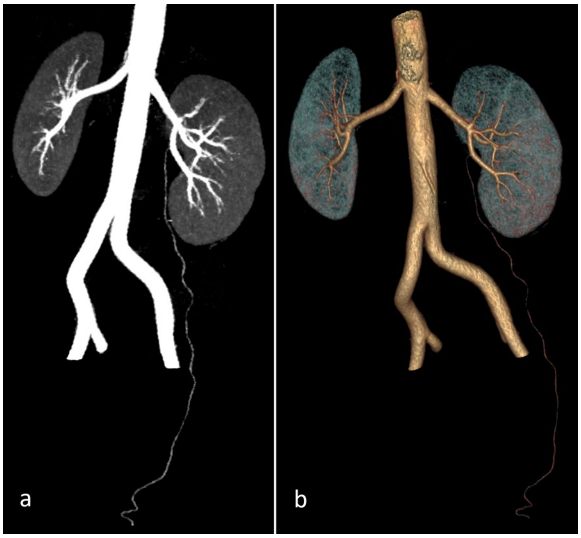


**Fig. 4** Left testicular artery arising from left inferior segmental renal artery in a 29-year-old male potential renal donor. **a**, **b** Coronal MIP and VR-processed CTA images

the signal-to-noise ratio (SNR) and contrast-to-noise ratio (CNR) of both renal arteries in SSFP MRA were all higher than those measured by CT angiography, and the differences were statistically significant ($p < 0.001$) [25].

In a study that included 40 subjects by Goetti et al. [20], NC-MRA's sensitivity, specificity, and accuracy were 100%, 89%, and 91%, respectively, compared to CE-MRA. They reported several technical advantages of NC-MRA over CE-MRA. First, problems with early parenchymal enhancement or venous contamination related to contrast agent bolus timing do not occur with NC-MRA. Second, respiratory triggering with NC-MRA allows subjects to breathe continuously during data acquisition and avoid motion and breathing artifacts commonly encountered with CE-MRA. Lastly, the higher in-plane resolution of the NC-MRA compared to the CE-MRA improves the delineation of small-caliber accessory renal arteries.

According to Blankholm et al. [9], CTA and MRI showed a specificity and sensitivity of 100% in detecting if there were > 1 artery compared with observations from nephrectomy. Another study concluded that unenhanced MRA, in comparison with CTA, showed high sensitivity (72.7–100%), specificity (96.3–100%), and overall accuracy (> 90%) for the identification of multiple arteries, with an excellent inter-observer agreement, and this could lead to establishing NC-MRI as an alternative to CTA for evaluating kidney donors. These findings are in concordance with current study results in our study with the reference standard CT renal angiography; the sensitivity and specificity were calculated for detection of early division (93.3% and 100%), extra-parenchymal segmental branch (85.7% and 100%), and other anatomical variants (83.3% and 100%). Generally, the best NC-MRA technique used for the evaluation of renal arteries is IFIR. Eleven studies used IFIR at 1.5 Tesla scanners in a total of 527 patients have reported a median sensitivity of ≈88% and a median specificity of ≈95% compared to either CEMRA, DSA, or CTA as the reference standard examination (evidence level 1b) [28]. Recently spatial labeling with multiple inversion pulses technique (SLEEK) has been introduced for one-step assessment of renal function and vascular anatomy. In a study included

**Table 3** Inter-observer agreement between two observers for quantitative variables

| Variable | Consistency | | Absolute agreement | |
|---|---|---|---|---|
| | ICC (95% CI) | *P* value | ICC (95% CI) | *P* value |
| Rt Renal artery caliber | 0.99 (0.995–0.998) | < 0.001 | 0.99 (0.995–0.998) | < 0.001 |
| Rt Renal artery length | 0.99 (0.999–1.0) | < 0.001 | 0.99 (0.999–1.0) | < 0.001 |
| Lt Renal artery caliber | 0.99 (0.995–0.998) | < 0.001 | 0.99 (0.995–0.998) | < 0.001 |
| Lt Renal artery length | 0.99 (0.998–0.999) | < 0.001 | 0.99 (0.998–0.999) | < 0.001 |
| Rt aberrant artery caliber | 0.99 (0.984–0.999) | < 0.001 | 0.99 (0.985–0.999) | < 0.001 |
| Rt aberrant artery length | 0.99 (0.993–0.999) | < 0.001 | 0.99 (0.993–0.999) | < 0.001 |
| Lt aberrant artery caliber | 0.99 (0.966–0.998) | < 0.001 | 0.99 (0.968–0.998) | < 0.001 |
| Lt aberrant artery length | 0.99 (0.997–0.999) | < 0.001 | 0.99 (0.997–0.999) | < 0.001 |
| Accessory artery caliber | 0.99 (0.971–0.999) | < 0.001 | 0.99 (0.975–1.0) | < 0.001 |
| Accessory artery length | 1.0 (0.999–1.0) | < 0.001 | 1.0 (0.999–1.0) | < 0.001 |
| Rt Extra-parenchymal segmental branch caliber | 0.76 (0.696–0.993) | 0.125 | 0.76 (0.400–0.993) | 0.125 |
| Rt Extra-parenchymal segmental branch length | 0.78 (0.720–0.994) | 0.001 | 0.78 (0.415–0.994) | < 0.001 |
| Lt Extra-parenchymal segmental branch caliber | 0.99 (0.848–1.0) | 0.002 | 0.99 (0.893–1.0) | 0.002 |
| Lt. Extra-parenchymal segmental branch length | 1.0 (1.0–1.0) | < 0.001 | 1.0 (1.0–1.0) | < 0.001 |

ICC, Interclass correlation coefficient; CI, confidence interval

**Table 4** Inter-observer agreement between two observers for non-quantitative variables

| Variable | CT | MR1 | MR2 | κ 1 | P1 | κ 2 | P2 | κ 3 | P3 |
|---|---|---|---|---|---|---|---|---|---|
| *Early division* | 15 | 14 | 15 | 0.955 | < 0.001 | 1.0 | < 0.001 | 0.955 | < 0.001 |
| *Aberrant artery* | 14 | 14 | 14 | 1.0 | < 0.001 | 1.0 | < 0.001 | 1.0 | < 0.001 |
| *Aberrant A. location* | | | | | | | | | |
| Upper pole | 8 | 8 | 8 | 1.0 | < 0.001 | 1.0 | < 0.001 | 1.0 | < 0.001 |
| Lower pole | 2 | 2 | 2 | | | | | | |
| Lower pole both | 2 | 2 | 2 | | | | | | |
| Lower RT and upper LT | 1 | 1 | 1 | | | | | | |
| Upper RT and lower LT | 1 | 1 | 1 | | | | | | |
| *Aberrant A. origin* | | | | | | | | | |
| Aorta | 14 | 14 | 14 | 1.0 | < 0.001 | 1.0 | < 0.001 | 1.0 | < 0.001 |
| Others | 0 | 0 | 0 | | | | | | |
| *Accessory A, number* | 6 | 6 | 6 | 1.0 | < 0.001 | 1.0 | < 0.001 | 1.0 | < 0.001 |
| *Accessory A. side* | | | | | | | | | |
| Right | 3 | 3 | 3 | 1.0 | < 0.001 | 1.0 | < 0.001 | 1.0 | < 0.001 |
| Left | 3 | 3 | 3 | | | | | | |
| *Accessory artery origin* | | | | | | | | | |
| Aorta | 6 | 6 | 6 | 1.0 | < 0.001 | 1.0 | < 0.001 | 1.0 | < 0.001 |
| Others | 0 | 0 | 0 | | | | | | |
| *Extra-parenchymal segmental branch N* | 6 | 5 | 5 | 0.90 | < 0.001 | 0.90 | < 0.001 | 1.0 | < 0.001 |
| *Extra-parenchymal Seg. Br. Side* | | | | | | | | | |
| Right | 3 | 2 | 2 | 0.760 | 0.002 | 0.760 | 0.002 | 1.0 | < 0.001 |
| Left | 2 | 2 | 2 | | | | | | |
| Bilateral | 1 | 1 | 1 | | | | | | |
| *Extra-parenchymal Seg. Br. Supplied* | | | | | | | | | |
| Apical | 3 | 2 | 2 | 0.778 | < 0.001 | 0.788 | < 0.001 | 1.0 | < 0.001 |
| Inferior | 1 | 1 | 1 | | | | | | |
| LT Superior | 1 | 1 | 1 | | | | | | |
| RT superior & LT posterior | 1 | 1 | 1 | | | | | | |
| *Other Variants* | | | | | | | | | |
| LT test a. from LT polar renal artery | 1 | 0 | 0 | 0.767 | < 0.001 | 0.767 | < 0.001 | 1.0 | < 0.001 |
| RT adrenal and phrenic a. from Rt RA | 1 | 1 | 1 | | | | | | |
| Small LT intra-renal aneurysm | 1 | 1 | 1 | | | | | | |
| RT phrenic a. from RT renal artery | 1 | 1 | 1 | | | | | | |
| RT precaval accessory renal artery | 1 | 1 | 1 | | | | | | |

*κ* = kappa. *κ*1 & P1 = CTA vs. MRA observer 1, *κ*2 & P2 = CTA vs. MRA observer 2, *κ*3 & P3 = MRA observer 1 vs. MRA observer 2

78 patients with or without chronic kidney disease and using the SLEEK technique, the performance of SLEEK to display the renal artery was highly consistent with the results of CTA (kappa = 0.713, 95% CI, 0.413–1.000) [29].

One of the critical limitations while using NC-MRA is the positioning of the 3D volume slab (i.e., limited craniocaudal volume coverage per slab in a single acquisition), which potentially may result in missing small accessory arteries arising from pelvic vessels [18]. This limitation did not occur in our study using 11-cm craniocaudal axis coverage. The current study has a few limitations. First, the renal venous anatomy was not assessed by NC-MRA. A recent study used SSFP-MRA to assess the renal artery and phase contrast MRA to assess the renal vein in potential donors. There was no significant difference regarding the vessels' length measured by MRA ($p > 0.05$); however, the diameter of the renal vessels measured by MRA was slightly smaller than that measured by CTA [25]. Secondly, the potential donors in the current study were examined on a 1.5-T scanner. We recommend further studies comparing the diagnostic accuracy of NC-MRA performed on 1.5-T and 3-T scanners.

**Table 5** Qualitative assessment of MRA images; (a) sharpness, (b) artifacts and (c) diagnositic acceptability

| Sharpness M2 | Sharpness M1 | | | | Total | Weighted Kappa |
|---|---|---|---|---|---|---|
| | 2 | 3 | 4 | 5 | | |
| (a) Inter-observer agreement for image sharpness of renal MRA | | | | | | |
| 2 | 1 | 1 | 0 | 0 | 2 (3.3%) | 0.94148 |
| 3 | 0 | 12 | 1 | 0 | 13 (21.7%) | |
| 4 | 0 | 0 | 25 | 1 | 26 (43.3%) | |
| 5 | 0 | 0 | 0 | 19 | 19 (31.7%) | |
| Total | 1 (1.7%) | 13 (21.7%) | 26 (43.3%) | 20 (33.3%) | 60 | |
| **Artifacts M2** | **Artifacts M1** | | | | **Total** | **Weighted Kappa** |
| | **1** | **2** | **3** | **4** | | |
| (b): Inter-observer agreement for artifacts of renal MRA | | | | | | |
| 1 | 1 | 0 | 0 | 0 | 1 (1.7%) | 0.85318 |
| 2 | 0 | 14 | 0 | 0 | 14 (23.3%) | |
| 3 | 0 | 0 | 20 | 6 | 26 (43.3%) | |
| 4 | 0 | 0 | 4 | 15 | 19 (31.6%) | |
| Total | 1 (1.7%) | 14 (23.3%) | 24 (40.0%) | 21 (35.0%) | 60 | |
| **Diagnostic acceptability M2** | **Diagnostic acceptability M1** | | | | **Total** | **Weighted Kappa** |
| | **2** | **3** | **4** | **5** | | |
| (c): Inter-observer agreement for diagnostic acceptability of renal MRA | | | | | | |
| 2 | 2 | 0 | 0 | 0 | 2 (3.3%) | 0.84334 |
| 3 | 0 | 12 | 4 | 0 | 16 (26.7%) | |
| 4 | 0 | 0 | 24 | 4 | 28 (46.7%) | |
| 5 | 0 | 0 | 0 | 14 | 14 (23.3%) | |
| Total | 2 (3.3%) | 12 (20.0%) | 28 (46.7%) | 18 (30.0%) | 60 | |

M1, observer 1; M2, observer 2

## Conclusions

Findings of the present study suggest that NC-MRA using IFIR with SSFP technique is an effective alternative for CTA renal protocol to assess the anatomy of renal arteries in potential donors and identify different variants.

**Abbreviations**

NC-MRA Non-contrast MR angiography
CE-MRA Contrast-enhanced MR angiography
CTA Computed tomography angiography
DSA Digital subtraction angiography
SSFP Steady-state free precession
IFIR Inflow Inversion Recovery
NFS Nephrogenic systemic fibrosis.
CKD Chronic kidney diseases.
MDCT Multi-detector computed tomography
MIP Maximum intensity projection
VR Volume rendering
SNR Signal-to-noise ratio
CNR Contrast-to-noise ratio

**Acknowledgements**
Not applicable.

**Author contributions**
All authors have read & approved the manuscript. Study concept and design were proposed by TA, TAE. Database search by performed by MAO, MZ. Analysis and interpretation of imaging data was done by MAO, AHE, TAE. Drafting of the manuscript was performed by MZ, AHE. Revision of the manuscript was done by AHE, TA. Technical and material support was done by TA, TAE, AHE.

**Funding**
This study did not receive funding.

**Availability of data and materials**
All data generated or analyzed during this study are included in this published article.

## Declarations

**Ethics approval and consent to participate**
The study was approved by our institution's ethics committee (Mansoura Faculty of Medicine Institutional Research Board). A written informed consent was obtained from all patients included in the study.

**Consent for publication**
The participants in the study were informed and consented to the possibility of research publication. Authors hereby transfer, assign, or otherwise convey all copyright ownership to the EJNR if such work is published in that journal.

**Competing interests**
The authors declare that they have no conflict of interest.

Received: 1 September 2023 Accepted: 4 July 2024
Published online: 09 July 2024

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