Is there a role for free breathing non-contrast steady-state free precession renal MRA imaging for assessing live donors? A preliminary study

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Objective: Accurate pre-operative evaluation of renal vascular anatomy is essential for successful renal harvest in live donor transplantation. Non-contrast renal MR angiographic (MRA) techniques are potentially well suited to the screening of donors; however, their restricted imaging field of view (FOV) has previously been an important limitation. We sought to assess whether the addition of a large FOV balanced fast field echo (BFFE) steady-state free precession (SSFP) sequence to non-contrast SSFP MRA could overcome this problem. Comparison with contrast-enhanced MRA (CE MRA) and findings at surgery were performed.

Methods: 22 potential renal donors each underwent SSFP and CE MRA. 11 out of 22 potential donors subsequently underwent a donor nephrectomy.

Results: All images were diagnostic. Both SSFP MRA and CE MRA identified an equal number of arteries. Surgery confirmed two accessory renal arteries, both demonstrated with both imaging techniques. A third accessory vessel was identified with both techniques on a kidney contralateral to the donated organ. 6 out of 11 procured kidneys demonstrated early branch arteries at surgery, 5 out of 6 of which had been depicted on both SSFP and CE MRA. The median grading of image quality for main renal arteries was slightly better for CE MRA ($p=0.048$), but for accessory vessels it was better for SSFP MRA.

Conclusion: This pilot study indicates that by combining free-breathing SSFP MRA with large-FOV BFFE images, an accurate depiction of renal vascular anatomy without the need for intravenous contrast administration can be obtained, as compared with surgical findings and CE MRA.

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Living donor transplantation is becoming an increasingly important treatment option for end-stage renal failure (ESRF). The high prevalence of anatomical variants in renal vascular anatomy underscores the importance of accurate pre-operative evaluation of the vascular anatomy [1, 2], particularly in patients undergoing a laparoscopic approach, as the surgical field of view (FOV) is limited. Multiple renal arteries in the donor kidney result in a substantial increase in the risk of complications. Moreover, the presence of accessory arteries and early branches of the renal arteries, as well as variants in venous anatomy, can all affect the surgical decision for suitability for donor harvest [3, 4].

Although there has been some debate about the optimal imaging strategy for potential renal donors [5–7], with concerns raised over the ability of contrast-enhanced MR angiography (CE MRA) to detect all renal arteries [8], there is evidence to support the sole use of CE MRA for

this purpose [9]. Non-contrast MRA techniques have been used for several years, but have been generally overshadowed by the more popular contrast-enhanced techniques [10]. CT angiography is a proven tool in this domain. It also has the ability to detect parenchymal abnormalities and calculi; however, its use of ionising radiation is a disadvantage that should be considered when evaluating a donor population [11, 12].

Balanced steady-state free precession (SSFP) MRA provides a high signal-to-noise ratio (SNR) of blood and a unique T_1/T_2 weighting [13]. SSFP MRA is a non-contrast technique that has been used for the imaging of renal vasculature in several studies [14–16]. SSFP MRA utilises an intrinsically fast sequence and is flow-compensated in all three axes [17]. For renal vascular imaging, SSFP MRA can be combined with cardiac triggering, respiratory navigator gating and slab-selection inversion for background signal suppression [18]. While a number of studies indicate that SSFP MRA can provide an alternative to CE MRA in the investigation of atherosclerotic renal artery stenosis [18, 19], the role of SSFP MRA in renal donor assessment remains uncertain, with concerns about the limited FOV resulting in the

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failure to identify accessory arteries [20]. We hypothesise that, with the addition of axial and coronal high-resolution breath-hold balanced fast field echo (BFFE) SSFP sequences to provide a large FOV, accurate localisation of vessels could be achieved prior to the planning of the SSFP MRA. We sought to compare the accuracy of free-breathing, non-contrast, balanced SSFP MRA with CE MRA and intra-operative findings at the time of renal harvest.

Materials and methods

This prospective study was approved by the Ealing and West London Mental Health Trust Local Research Ethics Committee. A total of 22 healthy, potential renal donors (12 female, 10 male; median age 45 years, range 29–64) undergoing CE MRA as part of the standard work-up procedure were recruited. Participants were excluded from the study if they were unsuitable for MRI scanning because of standard contraindications (e.g. having a pace-maker or ferrous implants).

MR data acquisition

MRI was performed on a 1.5T Philips Intera® MR system (Philips Medical Systems, Best, the Netherlands). The participants were scanned head first, supine, using the four-channel SENSE (sensitivity encoding for fast MRI) body receive-only coil. Vector cardiography was used for cardiac gating. The standard contrast-enhanced renal imaging protocol includes coronal and transverse stacks of 6 mm slice thickness for localisation of the renal arteries, a transverse single-shot T_1 weighted pre-contrast scan, a three-dimensional (3D) coronal stack renal CE MRA and a transverse T_1 weighted post-contrast scan. The combined protocol has two additional pre-contrast sequences: a phase-contrast velocity scan of the aorta and a 3D cardiac- and navigator-gated, free-breathing SSFP MRA.

The coronal and transverse stacks were acquired using a multislice single-shot balanced FFE with a voxel size of $1.5 \times 1.5 \times 6$ mm and a large FOV.

The phase contrast scan is a two-dimensional (2D) T_1 fast field echo (FFE) phase contrast sequence with breath-holding and retrospective cardiac gating. The single slice image is positioned just below the renal arteries and axially through the aorta, allowing a perpendicular cross-section of the vessel. Initial phase contrast velocity was set to 250 cm s^{-1} in the foot-head direction. Other parameters were repetition time (TR)/echo time (TE)=4.6/2.5 ms, FFE factor=6 and flip angle= 15° . A region of interest (ROI) is drawn in the aorta on the phase image and the time at which the intensity is zero is used as the cardiac trigger delay for the following navigator-gated non-contrast MRA scan. This is the time at which the main aortic wave has finished and therefore most of the blood will have flowed into the renal artery.

The non-contrast MRA sequence is a 3D multishot BFFE sequence that acquires 80 transverse slices per slab. Data acquisition is speeded up by using a parallel imaging SENSE factor of 1.2. The following parameters were used: TR/TE=5.9/2.7 ms, 85° flip angle, voxel size $0.6 \times 0.6 \times 0.8$ mm, TFE factor of 44, two signal averages

and a bandwidth of $769 \text{ Hz pixel}^{-1}$. The acquisition sequence includes a slice selective inversion pulse with an inversion delay time of 325 ms, spectral pre-saturation with inversion-recovery (SPIR) fat suppression, and a regional saturation technique slab to suppress signal from the inferior vena cava, renal vein and intestines. The purpose of the inversion pulse is to saturate the stationary tissue, such as renal parenchyma and slower-flowing blood, from the renal vein. The blood that then flows into the imaging volume is not inverted and therefore has a higher signal than the surrounding stationary tissue. SPIR fat suppression is used to enhance the contrast of the renal arteries with regard to surrounding fat. The non-contrast sequence is a free-breathe sequence with navigator gating and prospective cardiac triggering. The central line of k -space is acquired after a trigger delay set from the ROI measurements of the phase contrast scan. It is important that the acquisition time of the sequence, the FFE shot duration, is short enough to be completed during the stationary phase of the heart cycle (*i.e.* during diastole), or there is a risk of cardiac blurring.

The CE MRA sequence is a coronal 3D T_1 weighted FFE sequence with the following parameters: TR/TE=4.0/1.34 ms, flip angle= 35° , voxel size= $0.9 \times 0.9 \times 1.6$ mm, 60 slices, SENSE factor of 2, bandwidth= $362 \text{ Hz pixel}^{-1}$. A gadolinium dose of 0.1 mmol kg^{-1} of Gadovist® is used followed by a 25-ml saline chaser.

Post-processing and image analysis

Post-processing and image analysis was performed using Viewforum Cardiac Package V. 3.4 (Philips Medical Systems). All MR images were transferred to a computer workstation for post processing. Maximum intensity projection (MIP) images were created for the renal area with standardised procedures for both CE MRA and SSFP MRA images by a radiologist experienced in the technique. All source images were also available for assessment of renal anatomy. Image review and analysis was performed by two radiologists (one with 6 years' experience and one with 4 years' experience). A report was generated that included details of renal size, number of renal arteries, any stenotic lesion, presence of early branching arteries (defined as a branch artery arising within 2 cm of the renal ostium), any renal parenchymal lesion or collecting system abnormality, position and number of renal veins, and any incidental findings. A supplementary report was also given with grading of image quality for all renal arteries on both CE MRA and SSFP MRA. Corresponding SSFP and CE MRA for each patient were assessed separately, prospectively and in random order. Final agreement for reports was reached by consensus.

Surgical data

All donor nephrectomies were performed with the mini-open donor nephrectomy technique: incision of <10 cm and no rib resection. At renal harvest the following parameters were recorded: right or left kidney procured, number of renal arteries, quality of renal arteries, presence of early branching and position of renal vein.

Results

All MR examinations were of sufficient quality to allow analysis with no scan requiring repeating. No adverse events occurred during scanning. MIP and raw data were analysed except in the case of one SSFP MRA where motion degraded the images sufficiently to preclude MIP images being useful; in this case the raw data only were analysed.

The mean coronal large FOV was 417 mm [standard deviation (SD) ± 18.9] craniocaudally compared with the coronal FOV for SSFP MRA of 351 mm (SD ± 41). The mean difference between the large FOV and SSFP MRA was 65.6 mm (SD ± 38 ; $p < 0.0001$).

Comparison of steady-state free precession MRA and contrast-enhanced MRA images with operative findings

11 out of 22 patients underwent nephrectomy (Table 1). Of these 11 kidneys 10 were left-sided and 2 had accessory renal arteries. Both CE MRA and the large-FOV high-resolution BTFE SSFP images combined with the SSFP MRA correctly identified the number of renal arteries present in the 11 donated organs (Figures 1 and 2). Of the 11 procured kidneys, 6 were found to have early branching (defined as a branch artery arising within 2 cm of the main renal artery ostium) at surgery. Both SSFP MRA and CE MRA correctly identified all but one of the early branches. SSFP MRA had one false-positive result (*i.e.* one branch appeared to arise 17 mm from the ostium of the main artery on imaging when in fact it was >20 mm at surgery) and CE MRA one false-negative result (the early branch was not visualised).

The right kidney was donated in the case of patient 10 as both imaging techniques demonstrated a retroaortic left renal vein and a left duplex collecting system and this influenced the surgeon's decision to procure the right kidney.

Comparison of steady-state free precession MRA and contrast-enhanced MRA in patients who did not go on to donate

A total of 47 renal arteries were assessed with CE and SSFP MRA (44 main arteries and 3 accessories). Both

Figure 1. (a) Contrast-enhanced MR magnetic resonance angiographic (MRA) and (b) steady-state free precession MRA on the same patient demonstrating normal renal anatomy.

techniques identified the same number of renal arteries. In addition to the two accessory arteries confirmed at surgery a further third accessory renal artery was detected by both SSFP MRA and CE MRA on a kidney contralateral to the donated organ (two of these were in the same patient).

In those kidneys not donated, SSFP MRA identified an additional three early branch arteries compared with two with CE MRA (Figures 3–5).

The ability to visualise intrarenal arteries using the two techniques was assessed. 22 kidneys were analysed using the following scale: 1=well visualised; 2=visualised

Figure 2. (a) Contrast-enhanced MR angiographic (MRA) and (b) steady-state free precession MRA in the same patient. The accessory renal arteries (arrows) are very well demonstrated.

Table 1. Characteristics of the 11 renal donors and kidneys

Patient number	Sex	Side donated	Number of renal arteries	Early branching
1	Female	Left	2	No
2	Male	Left	1	Yes
3	Male	Left	2	Yes
4	Male	Left	1	No
5	Male	Left	1	Yes
6	Female	Left	1	No
7	Female	Left	1	Yes
8	Female	Left	1	Yes
9	Male	Left	1	No
10	Female	Right	1	Yes
11	Female	Left	1	No

(a)

(b)

Figure 3. (a) Contrast-enhanced MR angiographic (MRA) and (b) steady-state free precession (SSFP) MRA in the same patient. The early branch artery to the right upper pole is better delineated on the SSFP MRA.

reasonably well and diagnostic; 3=visualised but not diagnostic; 4=not visualised. The median was 2 with SSFP MRA (range 1–4) and 4 with CE MRA (range 3–4; $p<0.0001$; Figures 6 and 7). The difference in depiction of intrarenal vessels between the two techniques may be attributed to contrast timing and use of a saturation prepulse in the SSFP technique.

The quality of the main and accessory renal vessels demonstrated on SSFP and CE MRA images was analysed using the following scale. 1=excellent image quality

(a)

(b)

Figure 4. (a) Contrast-enhanced (CE) MR angiographic (MRA) and (b) steady-state free precession (SSFP) MRA on the same patient. The left side early branch artery is much more easily visualised on the SSFP MRA than on the CE MRA.

(a)

(b)

Figure 5. (a) Contrast-enhanced MR angiographic (MRA) and (b) steady-state free precession (SSFP) MRA on the same patient. Bilateral early branch arteries (arrows) are confidently visualised only on the SSFP MRA.

(high homogeneous signal intensity within the vessel lumen, optimal delineation of vessel border, evaluation possible with high diagnostic confidence); 2=good quality (good enhancement of vessel lumen, incomplete delineation of vessel border, evaluation possible with satisfactory diagnostic confidence); 3=vessel visualised (diagnostic but image quality moderate, low inhomogeneous signal intensity, incomplete delineation of vessel border, evaluation possible but with low diagnostic confidence); 4=visualised but non-diagnostic (minimal enhancement); 5=not visualised. The median grade for SSFP MRA was 2 (range 1–3) for the 44 main renal arteries and 1 (range 1–3) for CE MRA ($p=0.048$). Image quality for the three accessory arteries was better for

(a)

(b)

Figure 6. (a) Contrast-enhanced MR angiographic (MRA) and (b) steady-state free precession (SSFP) MRA on the same patient. The intrarenal vessels are better shown on the SSFP MRA.

Figure 7. (a) Contrast-enhanced (CE) MR angiographic (MRA) and (b) steady-state free precession (SSFP) MRA on the same patient. In this example the SSFP MRA gives much better intrarenal vascular detail than the CE MRA.

SSFP MRA, median 2 (range 2–3), than CE MRA, median 4 (range 3–4).

Additional findings

One patient had a left retroaortic renal vein plus a left duplex collecting system, as demonstrated on both techniques (Figure 8). This contributed to the decision to procure the right kidney in this patient. Small, simple, renal cysts were seen in three patients on SSFP MRA but in only two patients on CE MRA. No renal artery stenosis was demonstrated by either technique in any artery.

Discussion

This study compared cardiac-triggered, free-breathing, balanced SSFP MRA supplemented with high-resolution,

Figure 8. Axial planning balanced fast field echo non-contrast scan demonstrating the left retroaortic renal vein.

large-FOV coronal and axial BFFE images with CE MRA of the renal arteries in potential renal donors. Imaging data were compared with the surgical findings following renal harvest.

Live related renal transplantation is established as the most cost-effective treatment for ESRF [21]. The survival of transplants from living donors is significantly better than cadaveric transplants [22]. At renal harvest for live donor transplantation the surgeon dissects the kidney and renal vasculature from the hilum towards the aorta. Visibility can be limited, particularly with laparoscopic and mini-open techniques, and prior knowledge of the number of renal arteries, presence of early branching arteries and the renal vein position are essential to avoid intra-operative complications such as bleeding and organ damage. Multiple renal arteries are reported to be present in 19–40% of individuals and early branching of vessels in 10% [1, 23]. There is an increase in surgical complications in cases with multiple renal arteries; therefore, reliable detection with pre-operative scanning is essential [24].

There has been debate as to the most appropriate method for demonstrating the renal vascular anatomy in potential renal donors [5, 7, 25–27], but there is increasing evidence to support the sole use of CE MRA as a suitable method [4, 6, 9, 28–30]. However, the use of any contrast medium carries a potential risk and, in the case of gadolinium-based media, nephrotoxicity and allergic reactions can result [31, 32], although they are infrequent and usually mild.

A number of studies indicate that balanced SSFP MRA can provide a non-contrast alternative to CE MRA in the investigation of atherosclerotic renal artery stenosis [14, 19]. The role of balanced SSFP MRA in renal donor assessment, however, remains uncertain, with concerns about the limited FOV resulting in failure to identify accessory arteries [14, 20]. In this pilot study, additional sequences with a mean large FOV of 417 mm cranio-caudally were obtained, providing coverage from the level of the diaphragm down to the level of the symphysis pubis. This was significantly larger than the FOV eventually required for the SSFP MRA ($p < 0.0001$). 3/3 accessory vessels were identifiable on the large coronal FOV as was the single retroaortic vein, suggesting that the large-FOV images provide sufficient resolution to identify accessory renal vessels and thus facilitate the planning of the SSFP MRA to ensure inclusion of all renal vessels (Figure 9).

Our study has demonstrated that SSFP MRA produces images with consistent vessel signal throughout the main renal arteries and small accessory arteries—an observation in keeping with previous studies [14, 33].

Both SSFP MRA and the CE MRA identified the same number of vessels ($n=47$), including 3 accessory vessels. Two of these accessory vessels were confirmed at the time of surgery.

The detection of early branching of the renal artery (defined as branching of the artery <2 cm from its origin from the aorta) is important for planning the dissection, particularly as 1.0–1.5 cm of artery can be taken up with the ligation and anastomosis to the recipient iliac artery [34]. SSFP MRA was comparable with CE MRA for the demonstration of early branching, and in fact one case confirmed at surgery was not identified with CE MRA

Figure 9. Axial planning balanced fast field echo non-contrast scans. (a) The origins of the main renal arteries (right renal artery narrow, arrow; left renal artery, wide arrow). (b) The left accessory artery is shown originating from the aorta inferiorly, at the level of the lower moieties. The planning scans prevent accessory renal arteries from being omitted from the steady-state free precession MR angiography.

but with SSFP MRA. While the failure of CE MRA to identify early branching may reflect the difficulties in obtaining optimal contrast opacification of branch vessels, it is concerning as it may contribute to potential operative complications. Moreover, it underscores the importance of using surgical data as a gold standard for assessment of SSFP MRA as a new technique.

Intrarenal arterial branches were better visualised on SSFP MRA images than on CE MRA images, which may be attributable to the use of a saturation pre-pulse in the SSFP technique and/or the timing of contrast injection.

Variations in the renal venous anatomy can have an impact on the surgical decision for renal harvest, as a retroaortic configuration can preclude surgery [4]. The single retrocaval renal vein in our population was demonstrated with both techniques.

Limitations

Our study has some important limitations. The number of cases with a direct surgical correlation was small ($n=11$) and our SSFP MRA images were compared with

CE MRA rather than with catheter angiography. This can be justified given the acceptance by many that CE MRA is an adequate standard for potential renal donor assessment. The surgeon was aware of MRA reports before operating, therefore there could be bias in reporting of surgical findings. Differences in the sequences between SSFP MRA and CE MRA limit attempts to “blind” observers to the technique at the time of analysis.

Conclusion

This pilot study indicates that, by combining free-breathing SSFP MRA with large-FOV, high-resolution breath-hold BFFE SSFP axial and coronal images, an accurate depiction of renal vascular anatomy without the need for intravenous contrast administration can be obtained, as compared with surgical findings and CE MRA. Before SSFP MRA can be recommended for demonstration of renal vascular anatomy in potential donors, a larger study should be carried out to confirm these findings.

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