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Quadruple Inversion-Recovery b-SSFP MRA of the Abdomen: Initial Clinical Validation

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Abstract

The purpose of this study is to assess the image quality and diagnostic accuracy of non-contrast quadruple inversion-recovery balanced-SSFP MRA (QIR MRA) for detection of aortoiliac disease in a clinical population. QIR MRA was performed in 26 patients referred for routine clinical gadolinium-enhanced MRA (Gd-MRA) for known or suspected aortoiliac disease. Non-contrast images were independently evaluated for image quality and degree of stenosis by two radiologists, using consensus Gd-MRA as the reference standard. Hemodynamically significant stenosis (

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50%) was found in 10% (22/226) of all evaluable segments on Gd-MRA. The sensitivity and specificity for stenosis evaluation by QIR MRA for the two readers were 86%/86% and 95%/93% respectively. Negative predictive value and positive predictive value were 98%/98% and 63%/53% respectively. For stenosis evaluation of the aortoiliac region QIR MRA showed good agreement with the reference standard with high negative predictive value and a tendency to overestimate mild disease presumably due to the flow-dependence of the technique. QIR MRA could be a reasonable alternative to Gd-MRA for ruling out stenosis when contrast is contraindicated due to impaired kidney function or in patients who undergo abdominal MRA for screening purposes. Further work is necessary to improve performance and justify routine clinical use.

Introduction

While contrast-enhanced MR angiography with gadolinium-based contrast agents (Gd-MRA) [1] remains the gold-standard for MR evaluation of arterial disease, various MRA techniques that do not require exogenous contrast material have been developed over the past decade[2]. Recent interest in non-contrast MRA originated primarily from associations between gadolinium contrast and nephrogenic systemic fibrosis (NSF) in patients with renal insufficiency [3]. Nowadays, NSF risk can be minimized by appropriate selection of contrast type and contrast dose[4]. However, demand for unenhanced MRA continues to grow, with influencing factors including examination cost, patient comfort, and the ability to repeat scans.

Various flow-dependent approaches for artery-to-background contrast generation exist. Time-of-flight techniques [5, 6] rely on differences in exposure to radiofrequency excitation between stationary tissue and moving protons. Phase-contrast MRA [7], based on velocity-induced changes in phase of blood signal, offers the potential for quantification of blood flow in addition to angiographic images. Electrocardiographically (ECG)-triggered subtraction techniques [8] utilize differences in arterial flow between systole and diastole. Additionally, arterial spin labeling techniques[9, 10], with or without subtraction, use preparatory radiofrequency (RF) pulses to induce contrast between vessels and static background. Recently, velocity-sensitive techniques have also been proposed for unenhanced peripheral MRA [11].

Development of non-contrast MRA approaches for imaging of the abdominal region has primarily focused on renal artery applications. An inflow-based technique with balanced steady-state free precession (b-SSFP) readout and a slice-selective (SS) inversion recovery (IR) pulse has been designed for evaluation of renal arteries and validated in patients with renal artery stenosis (RAS) with promising sensitivity and specificity results compared to Gd-MRA [12-23]. Recent modifications of this approach include implementation with multiple IR pulses for improved background suppression [24] and with radial sampling for imaging within a breathhold [25]. IR b-SSFP MRA is typically performed axially with 100-120 mm superior-inferior coverage. Thus, the technique can lead to exclusion of accessory renal arteries and is unsuitable for large field-of-view (FOV) abdominopelvic imaging. As part of routine peripheral vascular MRA imaging, inclusion of renal arteries to

femoral arteries is desirable for inflow assessment and to identify incidental renal artery stenosis in high risk populations. Using an inflow approach such as IR b-SSFP MRA in the coronal plane of imaging with longer inversion times could allow for greater head-to-foot coverage [26, 27]. However, selecting a sufficiently long inversion time to allow unsaturated arterial blood to travel from the renal arteries to the distal iliac arteries typically compromises background suppression.

Recently, an extension of IR b-SSFP MRA with four IR preconditioning pulses, named quadruple inversion-recovery MRA (QIR MRA), has been developed for assessment of abdominopelvic arteries with a single three-dimensional large FOV abdominopelvic scan [28]. As illustrated in Figure 1, in QIR MRA, the initial non-selective IR pulse inverts the entire volume of interest, while the subsequent slice-selective IR reinverts the spins that are located inside the aorta. The combination of these IR pulses enables large FOV coverage by reducing the distance that fully magnetized aortic blood travels during the inversion time, starting at the aortic bifurcation and ending at the common femoral arteries. The third IR pulse is used to null signal from venous blood inferior to the imaging slab, while the final IR, a STIR pulse, suppresses background signal from tissue with short T_1 . The purpose of this study is to assess the image quality and diagnostic accuracy of abdominopelvic QIR MRA for detection of stenosis in a clinical population with suspected abdominal aortic or peripheral vascular disease, using conventional Gd-MRA as the reference method.

Materials and Methods

Patients

All patients referred for routine clinical peripheral or abdominal MRA at our institution were approached for potential participation in this study. A total of 26 patients (14 female, 12 male, mean age 70 years, range 33-89 years) were imaged: six referred for abdominal aortic assessment, four referred for RAS assessment, and 16 for peripheral arterial disease (PAD) evaluation (Table 1). This HIPAA-compliant study was approved by the Institutional Review Board, and written informed consent was obtained from all subjects.

MR Imaging Protocol

Imaging was performed on a whole-body 1.5T system (Avanto, Siemens Healthcare, Erlangen, Germany; maximum gradient strength = 45 mT/m; slew rate = 200 T/m/s). Radio-frequency excitation was performed using the body coil; two phased array body coils and a spine coil array were employed for signal reception with coil elements automatically selected by the system. Patients underwent initial localization scans, followed by QIR MRA of the abdomen, and finally gadolinium-enhanced MRA. Per clinical request, two subjects were imaged only with QIR MRA due to low eGFR (29.6 and 25.7 mL/min/1.73m²).

QIR MRA was performed using an oblique coronal imaging slab, oriented along the abdominal aorta with its superior edge positioned ~2 cm above the presumed origin of the renal arteries. Acquisition parameters are listed in Table 2. The inversion time (TI) that controls inflow of unsaturated arterial blood was heart rate dependent and was selected to ensure arterial inflow over two systolic periods prior to data acquisition. This was

accomplished typically by setting TI to twice the duration of the patient's cardiac cycle. Due to background signal considerations TI was restricted to a maximum of 1800 msec, and subjects with slower heart rates whose cycle exceeded 900 msec were imaged with TI = 1800 msec. Typical TI values used in the study ranged from 1400-1800ms. ECG leads were used to monitor heart rate. Compensation for respiratory motion was obtained with bellows triggering, using a trigger at 20% end inspiration. Given the use of long TI (> 1500ms), this choice of trigger time resulted in data readout during expiration.

The QIR MRA protocol described above was modified in two patients as follows. To evaluate the influence of ECG versus respiratory trigger on image quality, one patient (female, age 75, heart rate 60 beats/min) underwent an additional QIR MRA scan, performed without respiratory motion compensation. The scan was ECG-triggered, using trigger delay of 0 msec. TI was set to 1400 ms, selected such that data acquisition took place after two systolic events and during diastole. A male patient (age 75) who was referred for non-contrast MRA following endovascular AAA stent and a left kidney transplant was imaged with axial QIR MRA because the standard coronal QIR MRA scan was unsuccessful. The axial imaging volume (FOV = 350×350 mm², voxel size = 1.1×1.1 mm²) was positioned over the transplanted kidney.

Following QIR MRA, breath-hold Gd-MRA of the abdomen and pelvis was performed in an oblique coronal plane, oriented along the abdominal aorta, with 3D T1-weighted Fast Low-Angle Shot (FLASH) sequence. Acquisition parameters are listed in Table 2. Patients referred for renal or abdominal MRA underwent single station Gd-MRA. In these cases, the imaging slab was centered at the level of the renal arteries. For contrast enhancement 0.1 mmol/kg gadopentetate dimeglumine (Magnevist: Berlex Laboratories, Wayne, NJ) was injected at 2 mL/sec via automated injector (Spectris, Medrad, Indianola, PA), followed by a 20-mL saline flush, injected at the same rate. Timing was based on a time-to-peak enhancement of the aorta at the level of the renal arteries, measured using a 1-mL test dose and a standard formula [13].

Patients referred for peripheral MRA underwent time-resolved imaging of the calves (Time resolved imaging with stochastic trajectories, TWIST, Siemens, Germany)[14], followed by three-station bolus-chase MRA. A dose of 0.15 mmol/kg gadopentetate dimeglumine (Magnevist, Bayer Healthcare) was injected, diluted with normal saline to a volume of 40 mL (approximately 10 mL saline) of which 0.04 mmol/kg contrast material was used for time-resolved imaging and 0.11 mmol/kg for bolus-chase. The bolus-chase dose consisted of 30 mL of dilute contrast, injected initially at 2 mL/s for 20 mL, then at 1 mL/s for the remainder of the injection and a 20-mL saline flush. The abdominopelvic station of the bolus-chase exam was performed first, followed by sequential imaging of thigh and calf stations. Timing was based on a time-to-peak enhancement of distal infrarenal aorta, measured using a 1-mL test dose and a standard formula [13]. Abdominal and thigh stations were positioned relative to the calf station, which included the tibial plateau to the forefoot. 500 mm FOV in the head-foot direction was used for all stations, allowing 5mm overlap between adjacent positions. Thus, the exact location of the abdominal station varied depending on the height of the patient.

Image Evaluation

All images were loaded on a workstation with multiplanar reconstruction capability (Multimodality Workplace, Siemens, Germany) for review. Source and maximum intensity projection (MIP) images were used for evaluation of QIR MRA, while pre- and post-contrast source, subtracted, and MIP images were used for Gd-MRA. Two radiologists (with 5 and 7 years MRA experience) independently evaluated all QIR MRA images in random order, blinded to patient identity and clinical information. The same radiologists evaluated all Gd-DTPA images in consensus, again in random order and blinded to patient identity and clinical information.

For interpretation of both the QIR MRA and Gd-MRA images, the abdominal arteries were divided into 10 segments per patient: suprarenal aorta, infrarenal aorta, right/left renal artery, right/left common iliac artery, right/left external iliac artery, right/left internal iliac artery origin. Each segment was assessed for disease severity using the following grading system: 0 = no stenosis, 1 = 1-49% stenosis, 2 = 50-99% stenosis, 3 = 100% occlusion[15]. Presence of accessory renal arteries was reported. Any other incidental findings were noted. Image quality was rated on a per-segment basis on a scale from 0 to 3: 0 = non-diagnostic, 1 = poor, 2 = fair, 3 = excellent.

Statistical Analysis

The accuracy of QIR MRA for detection of hemodynamically significant stenosis was measured in terms of sensitivity, specificity, positive predictive value (PPV), and negative predictive value (NPV) relative to the reference standard, Gd-MRA. Stenosis grading of 2 or 3 (≥ 50%) was considered hemodynamically significant. Segments not included in the imaging FOV on either sequence were excluded from analysis. Segments that were evaluable on the reference standard, but could not be evaluated on QIR MRA due to poor image quality were counted as an incorrect assessment. Kappa statistic was used to assess interobserver agreement for QIR MRA. Image quality scores of Gd-MRA and QIR MRA were compared with the Wilcoxon signed rank test. All reported P-values were considered significant when less than 0.05. Analysis was performed in Matlab (The MathWorks, Inc., Natick, MA).

Results

Comparison of QIR MRA to Gd-MRA in 24 patients

A total of 24 patients underwent both Gd-MRA and QIR MRA. From these patients, 226 of 240 potential arterial segments (24 patients, 10 segments per patient) were available for quantitative analysis at Gd-MRA. 13 segments, comprising the right and left internal and external iliac arteries of three patients and the left external iliac of a fourth patient, were not included in the FOV on Gd-MRA because of the positioning of the imaging slab. A left renal artery was absent in one patient due to nephrectomy.

Image quality of Gd-MRA (2.8 ± 0.3) was statistically significantly superior to QIR MRA (2.2 ± 0.5) with P value < 0.0001. However, 98% of all evaluated non-contrast QIR MRA segments were judged diagnostic (score > 0). 85% of QIR MRA segments were rated with

fair (50%) or excellent (35%) image quality (Figure 2), while 13% segments were diagnostic despite exhibiting poor image quality. Nine (2%) segments were considered non-diagnostic, occurring in the left common and the left internal iliac arteries of one patient due to aliasing; in the suprarenal aorta (n=5) due to banding artifact; and in the external iliac arteries (n=2) due to insufficient inflow of unsaturated blood. Seven (1.5%) segments were non-diagnostic on Gd-MRA due to mistiming of contrast agent administration.

Hemodynamically significant stenosis (defined as $\geq 50\%$) was found in 22/226 (10%) segments on Gd-MRA (Figure 3). Atherosclerotic plaque was detected in the abdominal aorta, with no cases demonstrating aortic stenosis $\geq 50\%$. Hemodynamically significant disease occurred predominantly in the iliac arteries, with a total of 20 affected segments. In addition, two main renal arteries demonstrated significant disease. Seven accessory renal arteries were found on Gd-MRA of which none had significant disease. Reader 1 identified all accessory renal arteries on QIR MRA, while reader 2 identified 5/7. In addition to stenotic disease, one renal artery aneurysm (Figure 2) and three aortic aneurysms, ranging 3-6 cm in diameter, were identified on QIR MRA in agreement with Gd-MRA.

Using all evaluable segments with Gd-MRA as reference, overall sensitivity and specificity of QIR MRA were 86% and 95% (reader 1) and 86% and 93% (reader 2), respectively. NPV and PPV were 98% and 63% for reader 1, and 98% and 56% for reader 2, respectively. The two readers had three false negative readings each, and 12 and 15 false positive readings. The results of segmental analysis are summarized in Table 3.

Good interobserver agreement ($\kappa = 0.77$) for identification of significant stenosis was found for QIR MRI. Interobserver agreement for QIR MRA with respect to all disease severity categories (no stenosis, 1-49% stenosis, 50-99% stenosis, and 100% occlusion) was moderate ($\kappa = 0.56$).

Figure 4 displays images obtained in a female patient (age 75) who underwent an ECG-triggered QIR MRA scan in addition to respiratory-triggered QIR MRA. Both non-contrast images had identical image quality rating (score 2). Mild left external iliac stenosis (grade 1) was identified on Gd-MRA. Both readers graded the lesion as significant stenosis (grade 2) on the respiratory-triggered QIR scan and as mild stenosis (grade 1) on the ECG-triggered QIR image.

QIR MRA in patients with low GFR

QIR MRA angiograms were successfully obtained in two patients who could not undergo Gd-MRA due to low GFR. In a male patient with endovascular AAA stent and kidney transplant, image quality was poor due to: (1) susceptibility artifacts caused by the stent and (2) insufficient inflow to the transplant region (Figure 5a). Patency of the transplant renal artery was successfully evaluated on a repeat QIR MRA scan, positioned axially over the transplanted kidney (Figure 5b). In an 80 year-old female referred for suspected AAA (Figure 6), both readers independently identified mild stenotic narrowing of the main renal arteries and atherosclerotic plaque of the suprarenal and infrarenal aorta. The scan was rated with fair image quality (avg. score 2.4).

Discussion

Our results demonstrate good agreement between Gd-MRA and QIR MRA for detection of disease in the abdomen and pelvis. Overall image quality of QIR MRA was fair (2.2 ± 0.5 where 3.0 is highest) with a small percentage (2%) of non-diagnostic segments caused primarily by banding artifact at the edge of the FOV and aliasing.

QIR MRA is safe and easily-repeatable and provided visualization of the full abdominopelvic station in most patients. As such, QIR MRA is a reasonable alternative to Gd-MRA when contrast is contraindicated due to impaired kidney function (Figures 5, 6). QIR MRA shows high negative predictive value for evaluation of abdominopelvic arteries and could also be used as a safer alternative to Gd-MRA in patients who undergo abdominal MRA for screening purposes (e.g. males age > 60 years who are at elevated risk for AAA).

As part of routine peripheral vascular MRA imaging, inclusion of the renal arteries to femoral arteries is desirable for inflow assessment. The ability to image a large FOV, from renal to distal femoral arteries, without contrast is a key innovative aspect of QIR MRA. Our results indicate that QIR MRA produces consistent superior-inferior coverage across patients. While QIR MRA relies on sufficient inflow, our protocol has been optimized to ensure adequate coverage in most patients: in this study only two segments were deemed non-diagnostic due to insufficient inflow. In addition, Shin et al recently introduced a modification of IR b-SSFP MRA, which uses a velocity-selective IR pulse, designed to invert stationary tissue and venous blood while preserving inferiorly flowing arterial blood[11]. This technique has potential to eliminate some of the challenges related to dependence on inflow, particularly the trade-off between superior-inferior coverage and background suppression.

Our findings show that the main limitation of the QIR MRA method is its dependence on inflow. In some patients, reduced signal intensity was observed in the distal iliac arteries. Flow-dependence was particularly problematic in the presence of stenosis, causing signal attenuation distal to the lesion. In one patient incomplete filling of the distal iliac arteries was observed bilaterally due to near complete occlusion of the common iliac arteries (Figure 3). In six segments (two common iliac, three external iliac, and one internal iliac arteries) with mild disease reading on Gd-MRA, signal intensity drop distal to stenosis resulted in disease overestimation. This was presumably due to reduced forward flow distal to the lesion.

In this study, QIR MRA was respiratory-triggered, with acquisition times of approximately 5 min. With respiratory-triggering, timing of peak systole (maximum inflow) relative to the acquisition differed from excitation to excitation, leading to variations in the amount of arterial inflow between subsequent readouts. Furthermore, irregularities in the breathing pattern, particularly those that shorten the respiratory cycle, could cause reduced or no inflow during some excitations. These inconsistencies possibly exacerbated issues with insufficient coverage and stenosis overestimation.

One potential approach to alleviate the problem is to combine respiratory triggering with ECG-triggering, as has been done in prior studies focused on the renal arteries [16]. In one

patient, free-breathing QIR MRA scan with ECG-triggering resulted in accurate depiction of stenosis grade unlike the respiratory-triggered scan of the same patient in which disease was overestimated (Figure 4). However, further investigation is necessary to determine whether simultaneous ECG-triggering and respiratory compensation approach could improve the performance of QIR MRA.

We observed a tendency of the non-contrast technique to overestimate degree of stenosis, which was partially related to dependence on inflow as explained above. False positive readings occurred in 19 segments. In all 19 cases, lesions rated as mild disease (1-49% stenosis) on Gd-MRA were scored as hemodynamically significant (50-99% stenosis) on QIR MRA. Most of the discrepancies occurred in segments with fair or excellent image quality on QIR MRA with only six false positive readings related to image artifacts. In six segments disease overestimation was presumably caused by reduced forward flow distal to stenosis. Another postulated cause of error is lower spatial resolution of QIR MRA, particularly in the z-axis. For example, false positive readings occurred in two renal arteries with mild stenosis on Gd-MRA. Given the anterior-posterior orientation of the renal arteries, this discrepancy was likely due to small vessel caliber combined with relatively poor through-plane resolution of QIR MRA. Prior studies using inflow-based IR b-SSFP for renal artery evaluation have reported a tendency to overestimate disease [17, 18], particularly distal to severe stenosis [18]. Further study is necessary to determine whether disease overestimation is a fundamental limitation of the b-SSFP readout or was caused by our choice of sequence parameters.

Several recent studies have evaluated new non-contrast approaches for peripheral MRA such as ECG-gated fast spin echo (ECG-FSE)[19] and quiescent interval single shot (QISS) MRA[6] in the pelvic and/or abdominal region. Our results are superior to ECG-FSE, but less successful than QISS MRA. Mohrs et al [19] reported that ECG-FSE has a tendency to result in false positive readings in the pelvis due to relatively high diastolic flow in the abdomen. The physical principles of QIR MRI makes it better suited to imaging vessels with fast flow compared to ECG-FSE. In addition, QIR MRI does not rely on subtraction for contrast generation and is therefore more robust to respiratory motion artifacts. However, QIR MRA exhibits lower specificity and PPV compared to QISS, which has demonstrated specificity of 95-98% and PPV of 84-95% [6, 20-22].

This study has recognized limitations, including small number of patients and small number of segments with significant disease. Furthermore, at our institution, MRA findings often dictate management, with conventional catheter angiography performed only if intervention is being considered. As a result, angiographic correlation was not available in any of the patients requiring us to rely on gadolinium-enhanced MRA as the reference standard.

Conclusion

Our initial clinical evaluation of QIR MRA shows high negative predictive value for evaluation of abdominopelvic arteries. QIR MRA is safe and easily repeatable and provided visualization of the full abdominopelvic station in most patients. As such, QIR MRA could be a reasonable alternative to Gd-MRA when contrast is contraindicated due to impaired

kidney function or in patients who undergo abdominal MRA for screening purposes. QIR MRA exhibited a tendency to overestimate stenosis, and further work is necessary to improve performance and justify routine clinical use.

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Figure 1.

QIR MRA sequence diagram. The initial non-selective IR pulse inverts the entire volume of interest, while the subsequent slice-selective IR (first SS IR pulse) reinverts the spins that are located inside the aorta. In this way, during the inversion time, TI , aortic spins travel to the femoral arteries to permit large FOV coverage. The second SS IR pulse is used to null signal from venous blood inferior to the imaging slab. The final inversion pulse, a STIR pulse, improves vascular contrast by suppressing background signal from tissue with short T_1 .

Figure 2. Non-contrast MRA with excellent image quality in agreement with contrast-enhanced MRA in a 82 y.o. male referred for suspected peripheral arterial disease. Hemodynamically significant disease of the aortoiliac region was not observed. Right renal artery aneurysm (arrows) was identified on both Gd-MRA and QIR MRA.

Figure 3. QIR MRA and Gd-MRA in a 63 y.o. female patient with severe disease. Incomplete filling of the distal iliac arteries was observed bilaterally due to near complete occlusion of the common iliac arteries (arrows).

Figure 4.

QIR MRA with ECG-triggering (free breathing), QIR MRA with respiratory-triggering, and Gd-MRA in a 75 y.o. female referred for suspected PAD. Gd-MRA was rated with excellent image quality, while both non-contrast images had fair image quality ratings (score 2). Mild left external iliac stenosis (grade 1) was identified on Gd-MRA. The lesion was graded as mild stenosis (grade 1) on the ECG-triggered scan in agreement with the reference scan. However, both readers scored the stenosis as significant (grade 2) on the respiratory-triggered image, presumably due to the signal attenuation observed distal to the stenosis. ECG-triggering likely minimized the variation in the timing of peak systole relative to the readout, translating into better inflow during the TI, and thereby offered more accurate depiction of the stenotic lesion.

Figure 5.

QIR MRA angiograms obtained in a patient (male, age 75) with endovascular AAA stent, renal transplant and low eGFR (29.6 mL/min/1.73m²). The standard coronal QIR MRA scan (a) exhibited poor image quality due to: (1) susceptibility artifacts caused by the stent and (2) insufficient inflow to the transplant region. QIR MRA was repeated (b) with axial FOV, positioned over the transplant region (white box). Patency of the transplant renal artery was successfully evaluated on the repeat scan.

QIR MRA

Figure 6. QIR MRA patient with low GFR (25.7 mL/min/1.73m²).80 y.o. female referred for suspected AAA. Mild stenotic narrowing of the main renal arteries and atherosclerotic plaque of the suprarenal and infrarenal aorta were described by both readers.

Table 1

Summary of patient indications.

Exam Type	Indication
Abdominal aortic assessment	<ul style="list-style-type: none">- superior mesenteric artery stent patency (n = 1)- suspected abdominal aortic aneurysm (AAA) (n = 3)- suspected aortic dissection (n = 1)- follow-up status post endovascular AAA stent and kidney transplant (n=1)
Renal artery stenosis (RAS) assessment	<ul style="list-style-type: none">- RAS screening following left nephrectomy (n=1)- suspected RAS (n=3)
Peripheral MRA	<ul style="list-style-type: none">- suspected peripheral arterial disease (n=16)

Table 2

Summary of acquisition parameters.

Parameter	QIR MRA	Renal Gd-MRA	Peripheral Gd-MRA (abdominal station)
Sequence Type	3D IR-prepared b-SSFP	3D FLASH	3D FLASH
Orientation	Oblique coronal	Oblique coronal	Oblique coronal
Inplane FOV [mm²]	400×400	400×400	380×500
Matrix	306×320	336×448	336×448
Voxel size [mm²]	1.3×1.3	1.2×0.9	1.5×1.1
Nominal slice thickness	1.7 mm	1.4 mm	1.4 mm
Slice Resolution	65%	70%	70%
TR/TE [msec]	3.4/1.7	3.61/1.2	3.43/1.09
Flip angle	90°	20°	20°
Bandwidth [Hz/pixel]	1042	1010	1010
GRAPPA factor	2.7	2.6	2.6
Phase, slice partial Fourier	N/A	6/8, 6/8	6/8, 6/8

Table 3

Segmental analysis of the diagnostic accuracy of QIR MRA relative to the reference standard.

<i>Reader 1</i>	Accuracy	Sensitivity	Specificity	NPV	PPV
Suprarenal aorta	100% (24/24)	N/A (0/0)	100% (24/24)	100% (24/24)	N/A (0/0)
Infrarenal aorta	100% (24/24)	N/A (0/0)	100% (24/24)	100% (24/24)	N/A (0/0)
Renal artery	91% (43/47)	0% (0/2)	96% (43/45)	96% (43/45)	0% (0/2)
Common iliac artery	98% (46/47)	100% (6/6)	95% (40/42)	100% (40/40)	75% (6/8)
External iliac artery	90% (38/42)	100% (3/3)	90% (35/39)	100% (35/35)	43% (3/7)
Internal iliac artery	88% (37/42)	91% (10/11)	87% (27/31)	96% (27/28)	71% (10/14)
Overall	94% (212/226)	86% (19/22)	94% (193/205)	98% (193/196)	61% (19/31)
<i>Reader 2</i>	Accuracy	Sensitivity	Specificity	NPV	PPV
Suprarenal aorta	100% (24/24)	N/A (0/0)	100% (24/24)	100% (24/24)	N/A (0/0)
Infrarenal aorta	100% (24/24)	N/A (0/0)	100% (24/24)	100% (24/24)	N/A (0/0)
Renal artery	91% (44/47)	0% (0/2)	96% (43/45)	96% (43/45)	0% (0/2)
Common iliac artery	94% (44/47)	100% (6/6)	90% (38/42)	100% (38/38)	60% (6/10)
External iliac artery	90% (38/42)	100% (3/3)	87% (34/39)	100% (34/34)	38% (3/8)
Internal iliac artery	88% (37/42)	91% (10/11)	87% (27/31)	96% (27/28)	71% (10/14)
Overall	92% (209/226)	86% (19/22)	93% (190/205)	98% (190/193)	56% (19/34)