High Acceleration Quiescent-Interval Single Shot Magnetic Resonance Angiography at 1.5 and 3T

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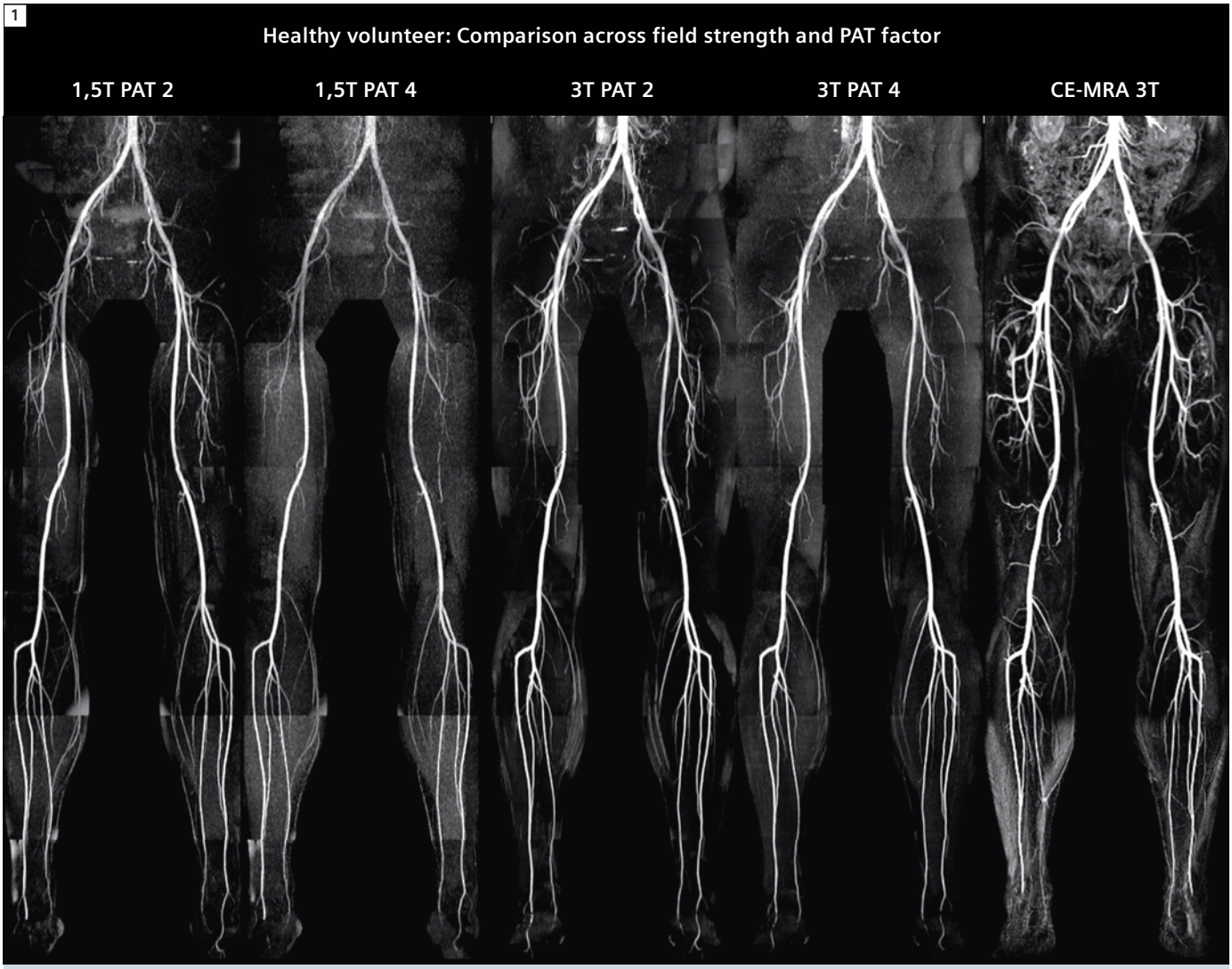


1 QISS maintains excellent image quality with PAT 4 acquisition. 3T imaging demonstrates higher SNR and potentially better results at high PAT factors. All protocols have high correlation to CE-MRA (right).

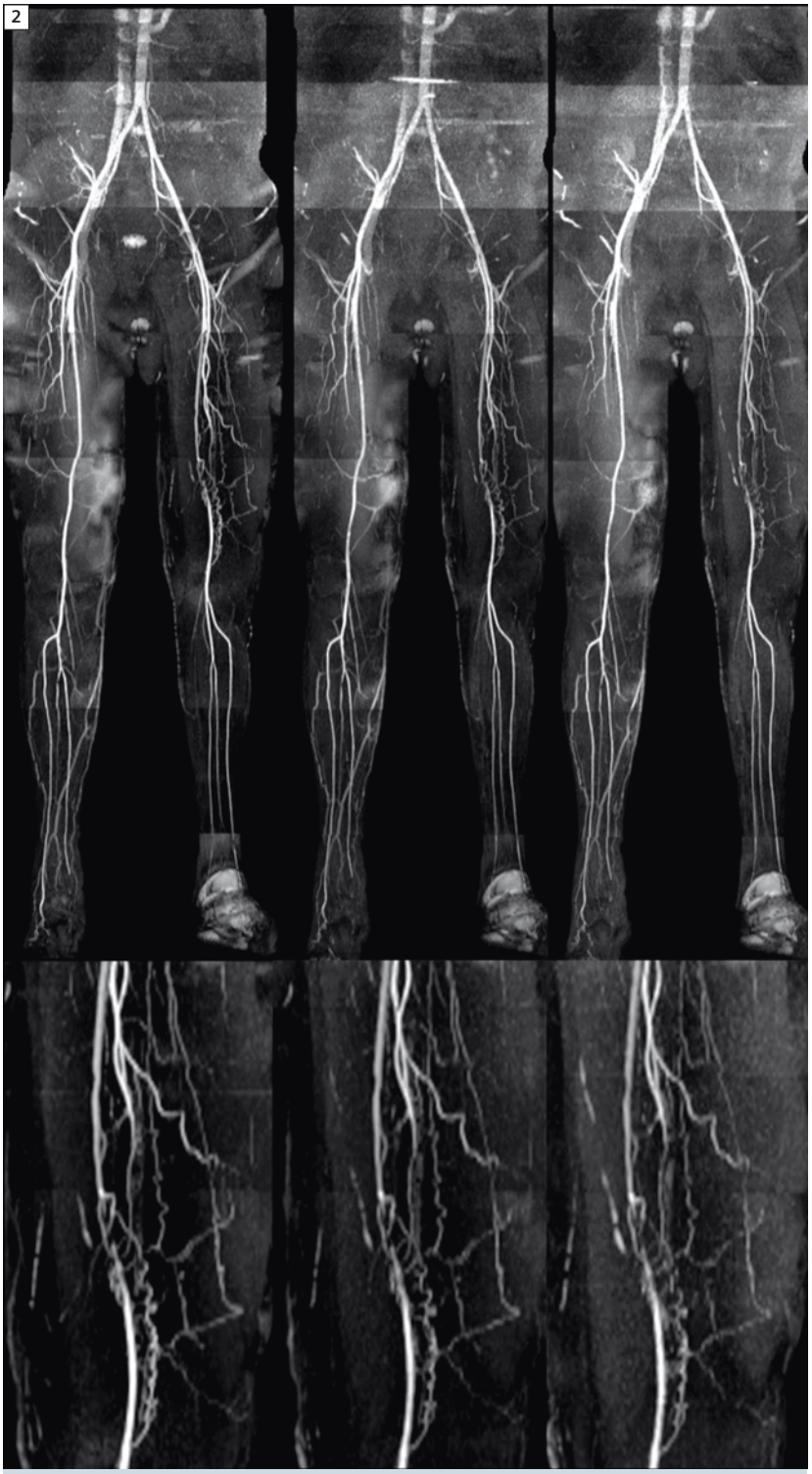
*This product is still under development and not yet commercially available. Its future availability cannot be ensured.

Background

Contrast-enhanced MR angiography (CE-MRA) is routinely used for the evaluation of peripheral arterial disease (PAD). However, due to the increased concern of nephrogenic systemic fibrosis (NSF) associated with gadolinium administration in patients with impaired renal function, there has been increased interest in the development of non-contrast MRA (NC-MRA) techniques. Quiescent-interval single-shot (QISS) imaging* has recently been described as an NC-MRA technique for assessment of the lower extremity vasculature [1] with proven clinical utility at 1.5T [2, 3]. These studies have demonstrated that QISS is easy to use, does not require patient-specific imaging parameters, has minimal flow dependence and is less sensitive to motion than subtractive techniques. Increased SNR at 3T potentially provides improved image quality and enable higher parallel imaging acceleration (PAT) factors. Increasing the PAT factor can be critical to maintaining an acquisition rate of one slice per heartbeat in patients with fast heart rates. In order to evaluate these aspects of QISS NC-MRA, the purpose of our study was to determine

1. the effect of field strength on QISS image quality,
2. the potential to accelerate imaging at 3T using higher PAT factors and
3. to compare NC-MRA QISS at 3T to a conventional CE-MRA protocol.

In addition, the diagnostic quality of QISS at 3T in patients with PAD was evaluated.



2 3T QISS in a patient shows segmental occlusion in the adductor canal with reconstitution in the profunda femoral collateral for patient with low GFR (no CE-MRA reference). Standard PAT factor 2 (left), as well as higher PAT factors 3 (center) and 4 (right) clearly depict disease, enabling shorter single shot acquisition capabilities for patients with fast heart rates.

Methods

QISS is a two-dimensional electrocardiographically gated single-shot balanced steady-state free precession acquisition of one axial slice per heartbeat. Image contrast is generated using in-plane saturation to suppress background tissue and a tracking saturation pulse to suppress venous signal prior to a quiescent inflow period. ECG gating ensures that the quiescent inflow period coincides with rapid systolic flow to maximize inflow of unsaturated spins into the imaging slice; since only a 2D slice is saturated, only minimal inflow is required. Images are acquired with a series of imaging stations, each with 70 slices around the magnet isocenter. Stations in the pelvis and abdomen typically use a series of breath-hold concatenations to minimize respiratory motion.

To validate QISS at 3T, twelve healthy volunteers (9 males age 22–49, 3 females age 26–43) were scanned at 1.5 and 3T within one week using a dedicated 36-channel peripheral vascular coil and an 18-channel body array coil (1.5T MAGNETOM Aera and 3T MAGNETOM Skyra, Siemens Healthcare, Erlangen, Germany). In addition, CE-MRA was performed at 3T (8.4–10 ml at 2 ml/sec, Ablavar, Lantheus Medical Imaging, N. Billerica, MA, USA). Additionally, 3 patients with lower extremity PAD were scanned using 3T QISS NC-MRA and CE-MRA as the reference standard if glomerular filtration rate (GFR) was sufficient. Imaging parameters are provided in Table 1. For each scan session, three QISS run-off scans were acquired in randomized order with GRAPPA PAT factors 2, 3 and 4. The total acquisition and shim time for each QISS NC-MRA run-off was approximately 10 minutes depending on the heart rate. Two blinded radiologists scored image quality for venous contamination, arterial conspicuity and arterial artifacts using a 4-point scale (0 = poor, 1 = fair, 2 = good, 3 = excellent) and inter-observer reliability was measured using the kappa statistic.

Validation results

QISS image quality was consistent for both field strengths. 3T results were particularly robust, even with high PAT factors and showed higher signal-to-noise ratio (SNR) relative to 1.5T (representative volunteer in Fig. 1). Arterial conspicuity and artifact scores were comparable to CE-MRA, and slightly higher for 3T (2.8 ± 0.1) relative to 1.5T (2.5 ± 0.2). Venous suppression was superior at 1.5T; venous signal did not impact arterial assessment at 3T, however. QISS at 3T also had higher inter-observer agreement ($\kappa = 0.759$) than at 1.5T ($\kappa = 0.426$) for image quality scoring. Overall, QISS performed comparably to CE-MRA at both field strengths, even with a high PAT factor of 4 [4]. Despite the presence of respiratory or bowel motion in some volunteers, QISS with concatenated breath-holding performed consistently in the abdomen and pelvis. Moreover, one always has the option to repeat all or part of the data acquisition in case of technical difficulty or macroscopic patient motion - an option that is not afforded by CE-MRA.

Clinical results

Based on impressive results in volunteers, several patients were scanned at 3T to demonstrate clinical utility. Initial results suggest that QISS is effective at 3T and has high correlation with CE-MRA.

Clinical case 1

42-year-old male with longstanding history of type I diabetes complicated by renal failure presents with left diabetic foot requiring transmetatarsal amputation. He subsequently received a kidney transplant and now presents to vascular surgery clinic with non-healing wounds of the right 3rd and 4th toes. The patient's renal function is poor, with a Creatinine of 2.35 mg/dl and an eGFR of 31 ml/min/1.73 m^2. The patient was referred for QISS NC-MRA at 3T to assess options for right lower extremity revascularization (Fig. 2). NC-MRA demonstrated segmental occlusion of the distal left superficial femoral artery at the adductor canal over a distance of approximately 3 cm with reconstitution via branches of the profunda femoris artery (Fig. 2). Small collateral vessels are clearly depicted for PAT factors 2, 3, and 4 (suitable for 738, 660 and 619 ms R-R intervals, respectively) suggesting that high PAT factors can be used to maintain acquisition of one slice per heartbeat for patients with high heart rates. The QISS NC-MRA images of the calves clearly depict the arterial run-off beyond the level of occlusion. No significant arterial stenoses were apparent in the right lower extremity and the patient was diagnosed with microvascular disease. The patient continued wound care, with plans for transmetatarsal amputation if conservative therapy was unsuccessful.

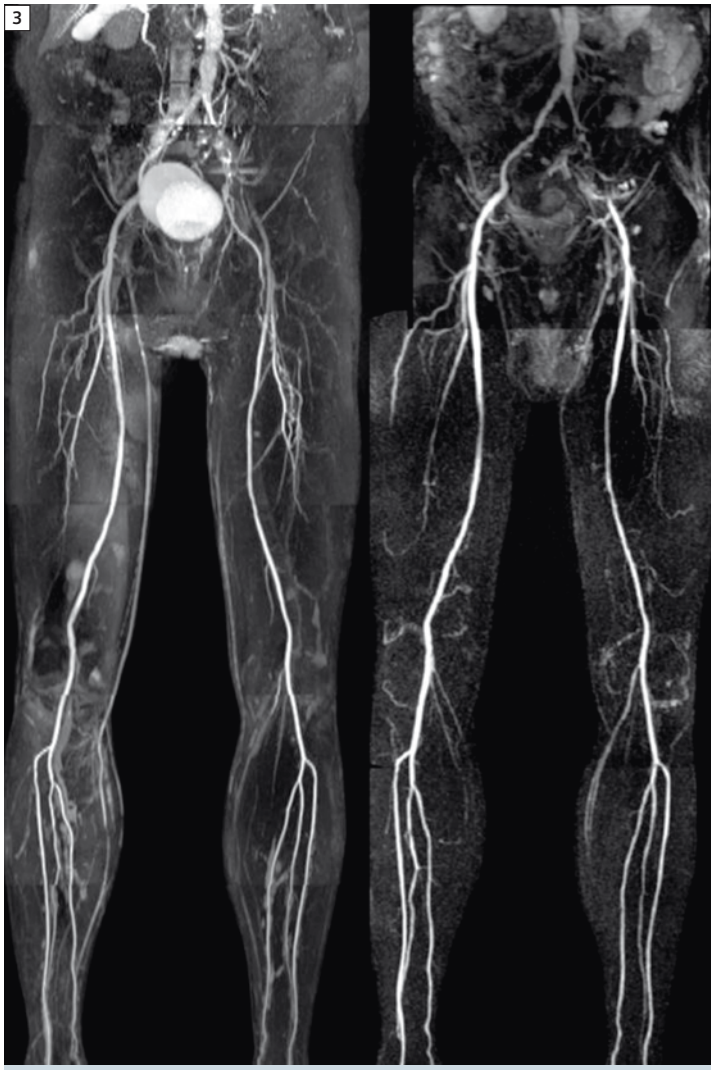
Clinical case 2

64-year-old male with a history of hypertension, chronic back pain, and tobacco abuse presents with diminished exercise tolerance. The patient reports that these symptoms have been slowly progressive over two years such that he is only able to walk half a block, limited by fatigue and left leg weakness of the hip and buttock. Lower extremity arterial flow studies demonstrated an ankle brachial index of 0.69 with duplex findings suggestive of inflow disease. The patient was referred for CE-MRA at 1.5T and underwent QISS NC-MRA at 3T for research purposes (Fig. 3). CE-MRA with a single dose of gadobenate dimeglumine (Multihance, Bracco Diagnostics Inc., Princeton, NJ, USA) demonstrated long segment occlusion of the left external iliac artery, with reconstitution of the common femoral artery. There was no significant left lower extremity outflow disease; three-vessel runoff was noted to the left foot. QISS NC-MRA demonstrated similar findings, with segmental occlusion of the external iliac artery, with the common femoral artery reconstituted by the inferior epi-

gastric and deep circumflex iliac arteries. The patient will undergo revascularization with left iliac stent placement at a later date.

Clinical case 3

56-year-old female with a history of hypertension, type II diabetes, and lumber radiculopathy presents with intermittent left lower extremity claudication gradually increasing in severity over the course of a year, now limiting her walking to a half block. The patient describes increased sensitivity to her left foot and pain in the anterior left thigh, which keeps her awake at night. She notes improved pain with Vicodin. The patient was referred for CE-MRA and underwent QISS NC-MRA at 3T for research purposes (Fig. 4). CE-MRA was performed at 1.5T following a double-dose of gadopentetate dimeglumine (Magnevist, Bayer Healthcare Pharmaceuticals, Inc, Wayne, NJ, USA) demonstrating long segment occlusion of the left mid to distal superficial femoral artery, with reconstitution of the popliteal artery via branches of the hypertrophied profunda femoris artery. These findings are well seen using QISS NC-MRA, which delineates the length of the occlusion and the run-off vessels without contrast media. Mild venous signal contamination is noted on QISS NC-



3 Both QISS and CE-MRA depict long segment occlusion of the left external iliac artery, with reconstitution of the common femoral artery. QISS PAT 3 acquisition (left) maximizes SNR while still maintaining single shot acquisition every heartbeat.

4 QISS and CE-MRA demonstrate long segment occlusion of the left mid to distal superficial femoral artery, with reconstitution of the popliteal artery via branches of the hypertrophied profunda femoris artery. For this patient, QISS PAT 4 acquisition (left) maintained single shot acquisition every heart beat.

MRA without impacting diagnostic yield of the maximum intensity projection (MIP) images. The patient underwent successful endovascular recanalization of the left superficial femoral artery with stent placement with resolution of her claudication symptoms.

Conclusion

QISS NC-MRA is promising at 3T and demonstrates comparable image quality to CE-MRA in depicting the peripheral arteries in both volunteers and patients with PAD. Improved SNR at 3T enables higher PAT factors to reduce image acquisition time while maintaining image quality in patients with faster heart rates. While QISS at 1.5T has shown excellent clinical utility, our results suggest that imaging at 3T may provide further clinical benefit. QISS NC-MRA at 3T demonstrated arterial vessels with slightly greater conspicuity and lower arterial artifacts compared to QISS NC-MRA at 1.5T. Although venous signal contamination is greater at 3T, the increased arterial signal enables ready differentiation on MIP imaging and does not impact diagnostic utility. Volunteer and patient data demonstrate that the QISS acquisition can be accelerated up to four fold without significant image quality degradation, suitable for heart rates approaching 100 beats per minute. At both field strengths, the QISS technique is a valuable alternative to CE-MRA especially in patients with renal insufficiency.

Table 1: Quiescent-interval single-shot (QISS) sequence details.

QISS sequence details	
TR (ms) / TE (ms) / flip angle (deg.)	3.2/1.7/90
In-plane resolution	1 x 1 mm
Partial Fourier	5/8
Slice thickness	3 mm
Orientation	axial
No. of slices per group	70
No. of slice groups	7
Acquisition time / slice group	~55 s (heart rate dependent)
Parallel imaging	GRAPPA x 2–4
ECG gating	Yes
Inversion time	345 ms

References

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