NON-CONTRAST INVERSION RECOVERY BALANCED SSFP MRA OF THE ABDOMINAL AORTA AT 3T: PREDICTING OPTIMAL INVERSION TIMES BY BLOOD VELOCITY MEASUREMENT

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Introduction Gadolinium-enhanced MRA is routinely used for evaluation of the abdominal vasculature. However, non-contrast-enhanced MRA is less invasive and especially desirable in patients with renal impairment who are at risk for Nephrogenic Systemic Fibrosis. Visualization of the abdominal aorta with non-contrast techniques remains challenging, because of demands for large field of view coverage and respiratory motion suppression, and the need to suppress veins and heterogeneous static tissue. 3D balanced steady-state free precession MRA with a slab-selective inversion (IR SSFP-MRA) exploits inflow effects to provide contrast between arteries and background. The inversion time (TI) is chosen to suppress the background and venous signals and allow non-inverted arterial blood to enter the imaging slab to generate high arterial signal. The TI and arterial blood flow velocity determine the arterial segmental length that can be visualized. Prior groups have demonstrated the promise of this approach for renal artery evaluation at 1.5T, using fixed TI of 325ms [1-2] or 800-1200ms [3], and so far validated in healthy subjects and in patients with renal artery stenosis [2] and renal transplant [3]. The feasibility of coronal plane imaging has been demonstrated in healthy volunteers at 1.5T with TI of 1100-1700ms [4-5]. In prior studies, the TI times have been determined a priori based on background suppression considerations, and similar values have been applied across all subjects. Patient-specific TI values have been reported [5], but no study has explored the relationship between TI and subject vascular hemodynamics. Our hypothesis is that an optimal TI can be chosen for each patient by measuring the arterial velocities within the arteries of interest prior to the MRA acquisition. We evaluate this hypothesis with respect to abdominopelvic MRA, aiming for comprehensive superior-inferior coverage from the suprarenal aorta to the external iliac arteries with coronal IR SSFP-MRA.

Fig. 1 Excellent superior-inferior coverage in a subject with mean aortic velocity 19.5 cm/s and predicted TI_{sup} = 1500ms (yellow). TI_{inf} = 800ms (red).

Anatomic Location	MeanArterialVel Range [cm/s]	MeanVenousVel Range [cm/s]
Suprarenal	13.0 - 28.5	7.5 - 20.9
Infrarenal 1	7.4 - 30.2	8.2 - 19.8
Infrerenal 1	6.5 - 18.9	7.1 - 22, 2
Common iliac	5.3 - 9.7	5.1 - 7.4
Mean Velocity	9.4 - 24.3	7.5 - 21.0
Predicted *TIsup*	1.2 – 3.2	

Table I Mean arterial and venous velocities and predicted TI_{sup} observed in 7 healthy volunteers

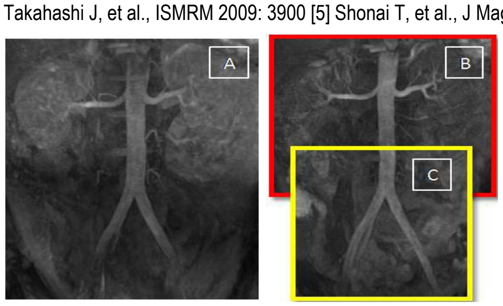
Methods This study was performed on a 3T Siemens scanner (Verio, Siemens) with two phased array coils. Seven healthy volunteers (5M, 2F, average age 35y (range 28-64y), heart rate 45-80bpm) were imaged using a respiratory-triggered 3D IR SSFP sequence with two selective inversion prepulses (NATIVE TrueFISP, Siemens) and the following parameters: matrix 320x307, FOV 500x500, slice thickness 1.6mm, partitions 48, FA 100°, BW 977Hz/px, echo spacing 3.2ms, TE 1.42ms, parallel factor 3, slice partial Fourier 6/8, 2 shots with linear reordering, acquisition time 4-8mins. Two slab-selective inversion pulses of 150mm thickness were prescribed in the transverse plane. The cranial inversion was centered at the level of the renal arteries; the second inversion slab was positioned caudally to the first, allowing for a gap of 1-2cm between the two (Fig.1).

Calculation of Inversion Times: TI_{sup}, the inversion time of the first prepulse applied to the superior slab, was subject-dependent and calculated as the arterial inflow time: TI_{sup} = *distance/Mean Arterial Velocity*, where *distance* is the desired vertical extent of the imaged artery and was set to 30cm for all calculations. *Mean Arterial Velocity* was computed by averaging mean arterial velocities over one cardiac cycle observed at four anatomic levels (suprarenal, infrarenal 1 (just caudal to renal arteries), infrarenal 2 (at aortic bifurcation), and common iliac). All velocity measurements were performed with phase contrast flow quantification (2D FLASH, TR 65.3ms, TE 5.07ms, FA 20°, venc 100-150cm/s, TA 18-24sec).The inversion time of the inferior slab, TI_{inf}, was varied from 600 to 1400ms in 200ms steps in order to determine the TI that minimized the venous contamination of the volume of interest. Image quality was evaluated with respect to length of visualized arterial segment and quality of background and venous suppression.

Results *Superior Inversion Slab:* The observed mean arterial velocities ranged considerably and resulted in a wide spectrum of calculated TI_{sup} times (Table I). Excellent visualization of the aorta was observed for subjects with faster flow (mean aortic velocity > 15 cm/s), which corresponded to TI_{sup} times on the order of 1.3-2.0sec (Fig.1). When mean aortic velocity was < 12-15 cm/s, TI_{sup} exceeded the longitudinal relaxation time of the background by more than two time constants (approximately 2-2.5sec). For example, two subjects (28 and 64 yrs) with mean aortic velocity 13 and 10 cm/s and inflow times longer than 2-2.5sec resulted in suboptimal visualization of the length of the artery and inadequate background suppression in the top half of the image (Fig. 2A). *Inferior Inversion Slab:* Imperfect nulling of inverted venous blood (T1 ~ 1500ms at 3T) was observed with TI_{inf} times shorter than 800ms (Fig.3A). Inversion times longer than 1200ms resulted in venous contamination of more than half of the image (Fig. 3C). In all volunteers the inflow of fresh venous blood was minimized with TI_{inf} = 800-1000ms, approximately the null point for venous blood. Such TIs also guaranteed adequate background suppression.

Conclusion Our results illustrate that visualization of the aortoiliac vessels using IR SSFP MRA varies considerably across subjects depending on blood flow velocities. Measuring flow velocities prior to MRA enables an examination tailored to the patient's physiology for improved arterial visualization. Large field of view IR SSFP MRA is challenging in subjects with slow inflow such as healthy individuals with very low heart rates, or in patients with low cardiac outputs. In such individuals, a multistation acquisition may be preferable (Fig.2 B-C) at the expense of imaging time. Further evaluation in a clinical population is planned.

References [1] Katoh M, et al., Kidney International 2004, 66: 1272-1278 [2] Wyttenbach R, et al., Radiology 2007, 245: 186-195 [3] Liu X, et al., Radiology 2009, 251: 535-542 [4] Takahashi J, et al., ISMRM 2009: 3900 [5] Shonai T, et al., J Magn Reson Imaging 2009, 29: 1471-1477 **Acknowledgments** This project was supported by NIH grant HL092439



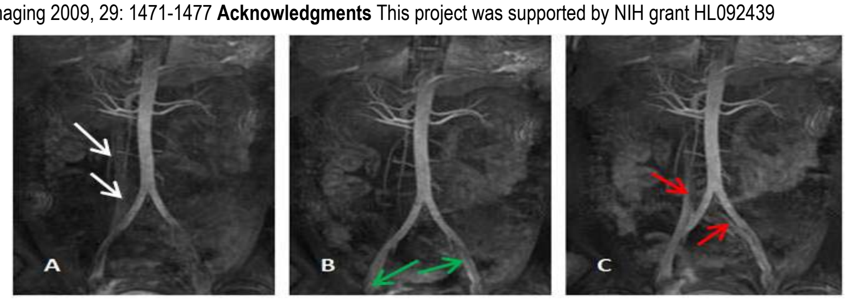


Fig. 2

Fig. 3

Fig. 2 Single station (A) vs 2-station (B,C) acquisition in a subject with mean aortic velocity 13.5 cm/s and predicted TI_{sup} 2200ms. A) TI_{sup}=2200ms results in inadequate background suppression and compromised vessel visualization B) Two separate 150mm slab acquisitions provide improved visualization. Cranial station: TI_{sup}=1500ms improves the contrast between renal arteries and parenchyma C) Caudal station: TI_{sup}=1700ms.

Fig. 3 Optimization of TI_{inf} for venous suppression. A) TI_{inf} =600ms results in incomplete nulling of venous blood B) TI_{inf} =1000ms, at approximately the null point of venous blood shows limited venous contamination at the bottom of the FOV C) TI_{inf} = 1400 allows non-inverted venous blood to travel superiorly as far as the top inversion slab