

# Benefits and Pitfalls in the Use of Contrast Agents in 4D Flow Imaging

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**Introduction** Recent advances in hardware and the emergence of various accelerated techniques have facilitated the use of 4D flow imaging for the simultaneous assessment of vascular anatomy and cine velocity fields. However, further advances in decreasing scan time and/or improving spatial resolution and coverage are complicated by the limited signal-to-noise ratio (SNR). Bock et al. [1] demonstrated improved SNR in the magnitude data, decreased noise in the velocity measurements, and improved vessel conspicuity in the derived angiograms in the aorta when using Gadolinium-based contrast agents with Cartesian acquisitions. Our initial experience with a radially undersampled phase contrast acquisition, PC VIPR, showed improved visualization of segmental renal arteries in precontrast PC VIPR scans compared to CE MRA and postcontrast PC VIPR scans, attributed to decreased contrast and susceptibility effects from parenchymal enhancement [2]. The purpose of this study is to determine the effects of residual contrast agent on radially encoded flow sensitive MR scan quality in both cardiac and renal vasculature.

**Materials and Methods** All studies were performed on clinical 1.5T and 3T systems (GE Healthcare, Waukesha, WI) after obtaining IRB approval and written informed consent from all subjects. PC VIPR images of the ascending and descending aorta were acquired before and after the administration of a contrast agent (Gd-BOPTA, Multihance®, Bracco Diagnostics Inc.) in 10 volunteers (6 males; 4 females; average age = 34.6 years). Scans were performed with the following parameters: imaging volume = 320 x 320 x 160 mm<sup>3</sup>, readout = 256-320, 1.0-1.25 mm<sup>3</sup> acquired isotropic spatial resolution, V<sub>enc</sub> of 80 cm/s (low V<sub>enc</sub> for optimized contrast in PC angiograms), TR/TE/flip = 8.7ms/2.8ms/10°, retrospective cardiac gating and adaptive respiratory gating with a 50% acceptance window, scan time ~ 10 min. The PC VIPR data were reconstructed as magnitude images, velocity vector fields, and angiograms calculated similar to complex difference images [3], all representing time averaged images. Signal measurements were conducted in the angiograms (source images) with ROI analysis in the ascending aorta, pulmonary artery, descending aorta, and subcutaneous fat, in a single axial plane using ImageJ (NIH, Bethesda, MD). All measurements were normalized by the fat signal and signal ratios were compared using the Student's t-test. Renal studies were performed on a 1.5T system (GE Healthcare, Waukesha, WI) on 5 volunteers (2 males; 3 females; average age = 31.8 years). Scan parameters were similar to the cardiac protocol but with a V<sub>enc</sub> of 40-60 cm/s. Signal levels were measured in the aorta and vena cava at three axial positions: at the renal bifurcation, 5 cm superior, and 5 cm inferior. An experienced radiologist assessed the quality of the segmented renal arteries and hepatic arteries by recording the depth in the segmentation tree as the number of major vessel branches from 0 to 3.

**Results** Representative angiograms for the chest and renal vasculature are shown in Fig.1. In the presence of residual contrast agent, vascular signal to fat ratios in the heart vessels showed a statistically significant increase (p<0.05) by an average factor of 2.61 ± 0.71 (see Fig. 2). In the abdominal images, the percent signal drop over 10 cm in the abdominal aorta, centered over the renal arteries, decreased from 30.7% to 6.0% after contrast injection, but was not found statistically significant. These results were not significant, but we believe this was due to the small sample size and large variations before contrast (some subject had little to no signal drop precontrast). The ratio of the signal in the vena cava over the aorta was increased from 0.79 ± 0.41 to 1.00 ± 0.31 after contrast injection and found to be statistically significant (p<0.05). The degree of branching visible in the renal arteries decreased from 2.7 ± 0.48 before contrast administration to 1.2 ± 0.79 after contrast injection (p<0.005). The degree of branching visible in the hepatic arteries was not significantly different in the presence of contrast (0.90 ± 0.74 before and 0.80 ± 0.79 after Gd injection).

**Conclusions** These results demonstrate advantages and disadvantages in using contrast agents with 4D phase contrast MRI. Imaging after a bolus injection generated statistically significant signal increases in all measured vessel segments. Vessel contrast is improved in PC angiograms as well as the velocity-to-noise ratio (VNR). In the chest, the use of a contrast agent resulted in improved images, confirming previous reports [1]. Vessel signal and contrast are higher, providing more consistent signal intensity (short arrow head in Fig 1) with better delineation of smaller vessels (long arrowhead in Fig 1). Intra-renal changes in the flow waveform and signal saturation effects caused signal drops over the length of the aorta that were decreased after contrast injection. This might be beneficial in the presence of distal accessory renal arteries. Venous signal was also significantly increased, possibly obscuring arterial signal in unprocessed MIP images yet allowing for much improved visualization of the renal venous vasculature (see short arrow in Fig. 1). A limitation seen with the post-contrast images is the statistically significantly reduced visualization of the segmental branches of the renal arteries (see long arrow in Fig. 1). We hypothesize that the rapid excretion of the Gd-based agent through the kidneys caused accumulation of the agent in the renal parenchyma, which in turn caused decreased contrast and signal reductions from susceptibility effects. This would also explain why the hepatic arteries did not decrease in quality. These effects should be considered when the use of a contrast agent is optional for a renal PC MRI scan. While the data in this study were acquired with a radial trajectory, we would anticipate similar results for 4D PC MRA with Cartesian k-space encoding.

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**References** [1] J. Bock et al, Proc ISMRM 2008, 103. [2] D. Lum et al., Proc ISMRM 2008, 2891. [3] A. Anderson et al., Proc ISMRM 2008, 934.

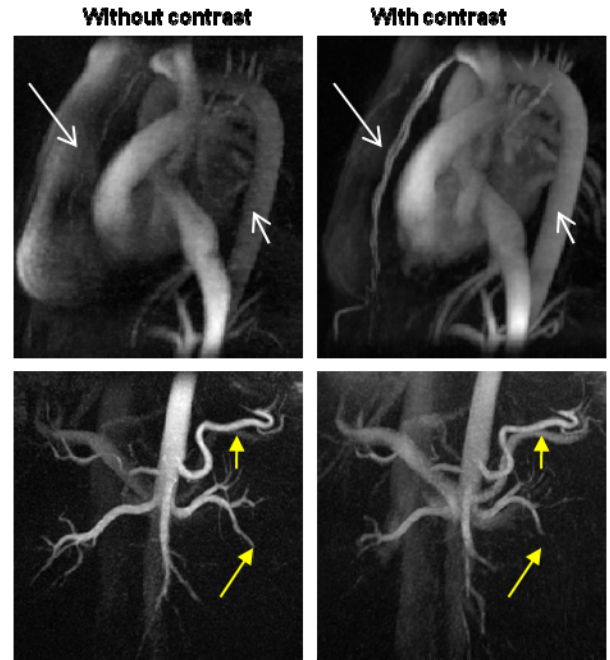


Fig. 1 Maximum intensity projections showing complex difference angiograms of the chest and renal arteries acquired without (left column) and with (right column) prior contrast injection.

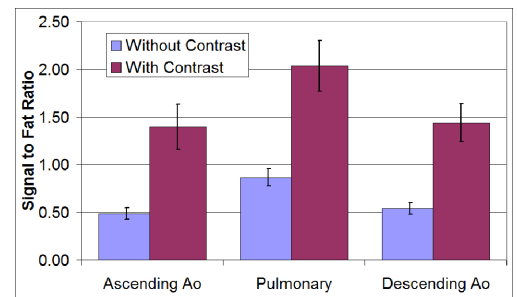


Fig. 2 Signal to fat ratios without and with contrast in various major cardiac arteries.