Contrast Enhanced Self-Gated Coronary Angiography at 7 Tesla Using Ultra-Short Echo Time Imaging

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TARGET AUDIENCE: Researcher and clinicians interested in performing contrast enhanced angiography at 7T.

BACKGROUND & PURPOSE: At lower field strengths (≤3T), high contrast and resolution whole-heart CMRA has been achieved with self-gated (SG) radial acquisitions capitalizing on increased SNR through the administration of contrast agents[1]. While employing such methods at 7T would be advantageous because both navigators and physiological monitoring are not required, the benefit of using the standard T1 shortening paramagnetic contrast agents are diminished due to the concomitant and dramatic increases in R2* relaxivity (r2*). r2* increases dramatically with field strength in the blood pool while R1 relaxivity (r1) remains relatively constant[2]. The large R2* impact of the contrast agent compromises the desired T1 based signal enhancement expected when using standard gradient echo imaging methods. Therefore, in this work we investigated the feasibility of using an ultra-short TE (UTE)[3] imaging method combined with the benefits of self-gating to perform contrast enhanced CMRA applications at 7T without needing prospective physiologic monitoring.

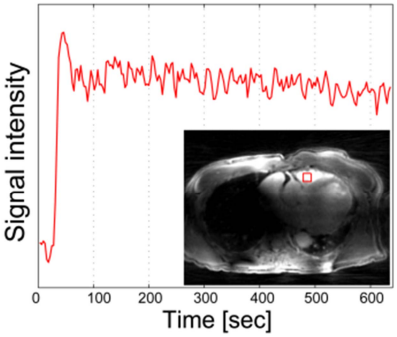

Fig.1. Signal enhancement in the blood pool from a ROI in the right ventricle.

METHODS: Studies were performed on a Siemens 7T with a 16-channel transceiver TEM stripline array driven by 16, 1 kW amplifiers with independent phase and gain control (CPC, Hauppauge, NY)[4] under an IRB approved protocol. A B_1^+ phase shim solution was optimized for a tradeoff between homogeneity and efficiency over the heart. **Injection Paradigm:** Contrast administration consisted of the injection of 0.1-mmol/kg gadobenate dimeglumine at a rate of 1.5 ml/s following by a flush of 30 ml of saline at the same rate. Imaging started with contrast administration to observe first pass kinetics (~30 s) and continued for an additional 10 minutes. **Sequence Details and Timing:** A complete imaging series was acquired both with and without contrast administration. Sequence details included: Non-selective hard pulse excitation with 250 μs pulse width, TR/TE=3/0.175 ms, and 196,608 radial views for both pre and post contrast. **Self-gating details:** Self-gating was performed by principal component analysis (PCA) on the center k-space point from each acquired profile for all receive channels. PCA separated three systematic components in the k-space center points: respiratory motion, cardiac motion and gradient related factors (e.g. eddy current). The 3 components were discriminated based on their specific frequencies (~1 Hz for cardiac motion, etc…). The cardiac signals were compared against a recording of the physiological signals acquired during the same acquisition. **Reconstruction:** The angiography data were sorted into 16 frames (2 and 8 frames for respiration and cardiac, respectively) according to retrospectively extracted trigger timings from the self-gating signals. The sorted radial data were reconstructed to 3D images for each frame separately by gridding onto Cartesian k-space followed by Fourier transform with a nominal isotropic resolution of 1 mm. To observe first pass and long term contrast based signal enhancement in the blood pool, a low resolution sliding window reconstruction was used providing 3 s temporal resolution. **Analysis:** Curved-planar reformats of the self-gated acquisitions, pre and post contrast, were generated following the proximal segment of the right coronary artery.

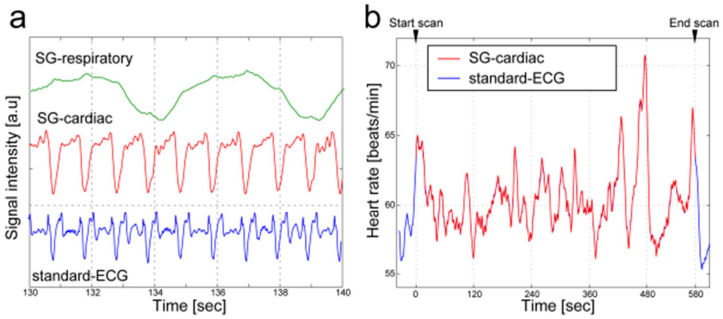

Fig.2. Comparison of PCA-based SG signal and standard monitoring.

RESULTS: Signal enhancement characteristics in the blood pool from an ROI in the right ventricle, show an initial first pass signal increase followed by consistent blood pool signal over the entire exam (Fig. 1). Self-gating signals extracted from the k-space center points with PCA matched well with the physiological ECG signals; self-gating accurately captured change of the heart rate during scans (Fig. 2). Images from the self-gating acquisition clearly visualized the right coronary artery (RCA) while, with contrast, vessel conspicuity increased as a result of increased blood-background contrast (Fig. 3).

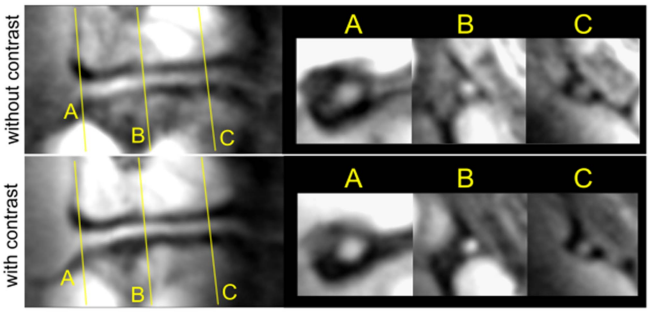

Fig.3. Curved-planar reformats of RCA pre and post contrast.

DISCUSSION: In this study, the UTE sequence with self-gating was implemented for CMRA at 7T. In addition to obtaining extremely short TEs, the k-space center point of this radial acquisition, consistently acquired in every TR, also provides the ability to detect cardiac and respiratory motion. In addition, the 16 coil elements used herein had considerable sensitivity variation in space, which enabled accurate motion extraction with a PCA-based approach. Currently, each of the 16 time frames was independently reconstructed (~12k radial views/frame); thereby more than 90% of data were ignored in the reconstruction of the images shown herein. Thus, the reconstructed images showed considerable blurring and undersampling artifacts. Significant improvement in image quality will be possible by extracting information from coil sensitivities (CG-SENSE) and/or data redundancy along the cardiac and respiratory dimensions (compressed sensing reconstruction). Parallel transmit RF pulse design promises to provide more consistent B_1^+ across the entire heart needed to extend the current methods to visualize larger segments of both coronary branches in a single acquisition.

CONCLUSION: PCA-based self-gating using the k-space center points in UTE acquisitions accurately detected respiratory and cardiac motion. Short TE in UTE (175 μs) diminished the T2* shortening effect due to the increased r2* at 7T, and maximized enhancement of T1 contrast for CMRA.

REFERENCES: 1) Pang J., et al. *ISMRM*, 246, 2014. 2) Kalavagunta C., et al. *Contrast media & molecular imaging* **9**:169-176, 2014. 3) Glover G. H., et al. *JMRI* **2**:47-52, 1992. 4) Snyder C.J., *et al. MRM* **61**:517-524, 2009. **ACKNOWLEDGEMENTS:** P41 EB015894 and S10 RR026783.