Coronary Artery MR Angiography at 3 Tesla – The Accelerated, Breath-Held 3D FIESTA Approach

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Purpose

It has been demonstrated that high magnetic field strengths improve the baseline signal-to-noise-ratio (SNR) in coronary artery MR angiography (1). It has been also predicted that high field strengths promise to reduce the noise amplification factor in parallel imaging (2). The need for reducing the RF deposition at high magnetic fields accentuates the complementary advantage of parallel imaging. Thus high field strengths together with parallel imaging strategies offer the potential to overcome physiological motion and SNR constraints of current coronary artery MRA approaches. This study (**i**) focuses on the implementation of an ECG gated 3D FIESTA technique in conjunction with sensitivity encoded parallel imaging (3) at 3 Tesla and (**ii**) examines its feasibility for short breath-hold imaging of the left and right coronary arterial systems.

Methods

3D FIESTA was implemented on a Signa EXCITE short bore 3.0T system (GE Medical Systems, Waukesha, WI, USA) equipped with eight independent receiver channels. 3D FIESTA was implemented using the following parameters: TE=(1.3-2.2) ms, TR=(3.7-6.8) ms, FOV=34 cm, data matrix=256x160, slice thickness=2.0 mm resulting in an effective voxel size of (0.7x1.0x1.0) mm^3. A spectrally selective inversion preparation pulse was applied (TI=85 ms) to enhance the contrast between the coronary blood pool and the surrounding epicardial fat. RF transmission was performed using the body coil, while reception was achieved using a prototype 8-element cardiac coil array (USA Instruments, Cleveland, OH, USA). A volume selective shim (FOV = 16 cm) was performed to minimize variations in the resonance frequency over the area of interest. Low spatial resolution calibration scans, covering a (48x48x35) cm^3 volume including the heart, were collected to determine receive coil sensitivity maps. The two-dimensional phase-encoding scheme was setup for coronary artery imaging so that complete k_x-k_y data sets were acquired for a given slice partition before the slice index k_z was incremented. Data acquisition was distributed over two consecutive R-R intervals for a given slice partition. For parallel imaging an acceleration factor f =2 was achieved by omitting phase encoding steps along the k_y-direction. Hence the acquisition window is shortened by f for each R-R interval so that it fits into the mid-diastolic cardiac rest period even for high heart rates. For short breath-hold CMRA 3D slabs consisting of 12 slices encompassing a volume of 2.5 cm were applied. No contrast agents were administered. Images were reconstructed using the ASSET approach (4).

Results

An elevated T-wave was observed but the application of high impedance leads together with an ECG noise filter supported a robust R-wave detection. The application of a volume selective shim substantially improved the image quality by minimizing off-resonance effects. No severe susceptibility artifacts were detected for the origin, the proximal and the mid coronary artery segments of the LCA and RCA. The flip angle of the excitation pulse was adjusted to permit appropriate contrast between the blood pool and the surrounding myocardium as illustrated in Fig. 1. For a flip angle $\alpha=30^0$ a CNR of ~7 was determined (Fig. 1a) while a CNR of ~45 was found for $\alpha=60^0$ (Fig. 1d). The increase in the RF deposition obtained for higher flip angle was counterbalanced by a TR elevation from 3.7 ms to 5.2 ms in order not to exceed the SAR-limits without impairing the image quality due to off-resonance effects or susceptibility artifacts as shown in Fig. 1d. High signal-to-noise ratio coronary artery images were obtained for the LCA (Fig 2a,b) and the RCA (Fig. 2d,e) using two fold accelerated parallel imaging resulting in a 84 ms acquisition window length and a breath-hold time of 18 sec for a heart rate of 80 bpm. An SNR of ~80 was derived for the left ventricle and the origin of the RCA, while the left main coronary artery segments showed an SNR of ~55. The field strength related SNR increase supports the identification of the more distal parts as demonstrated for the left anterior descending artery in Fig 2a. The high contrast-to-noise ratio permits a clear distinction of the vessel as illustrated for the left main, left anterior descending and left circumflex artery in Fig. 2.

Conclusions

We have demonstrated the feasibility of rapid breath-hold coronary artery MRA using parallel imaging combined with a 3D steady-state free precession sequence at high field strengths. Robust breath-held CMRA at 3 Tesla can be completed in 2-3 breath-holds covering the main branches of the coronary arterial systems as compared to an averaged acquisition time of ~7 min reported for each coronary artery in free-breathing techniques (1). Our initial experience suggests that the SNR improvement afforded by a 3 Tesla field strength coupled with the enhanced CNR between the blood pool and the myocardium may provide benefits for clinical coronary MR angiography. As larger acceleration factors are explored with high-channel MR systems, the benefits of high field strengths for CAI will become even more pronounced through an increase in the volume coverage which may permit the visualization of the entire coronary tree within a single breath hold acquisition. The access to higher accelerations would also (i) further reduce RF deposition constraints at high field strengths and (ii) would serve to enhance the immunity to physiological motion by using shorter acquisition windows. In summary, the findings presented here offer the potential to integrate breath-held CMRA into clinical cardiac examinations for the non-invasive detection of coronary artery anomalies or luminal stenoses in the proximal parts of the coronary arteries at high magnetic field strengths.

a) $\alpha=30^0$ **b)** $\alpha=40^0$ **c)** $\alpha=50^0$ **d)** $\alpha=60^0$

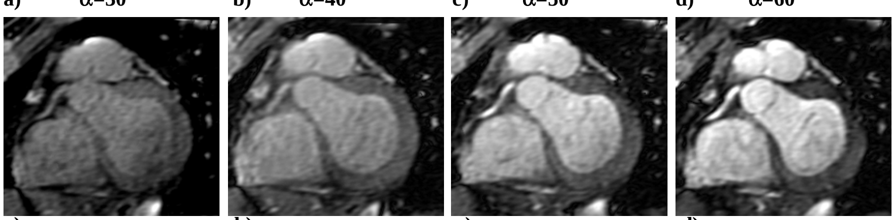

Fig. 1: Comparison of breath-held 3DFIESTA images (slice thickness= 1mm) depicting the left ventricle and the origin and the proximal segment of the right coronary artery . A flip angle of **a)** $\alpha=30^0$, **b)** $\alpha=40^0$, **c)** $\alpha=50^0$ and **d)** $\alpha=60^0$ was used to scrutinize the contrast-to-noise ratio between the blood pool and the surrounding myocardium.

a) **b)** **c)** **d)** **e)** **f)**

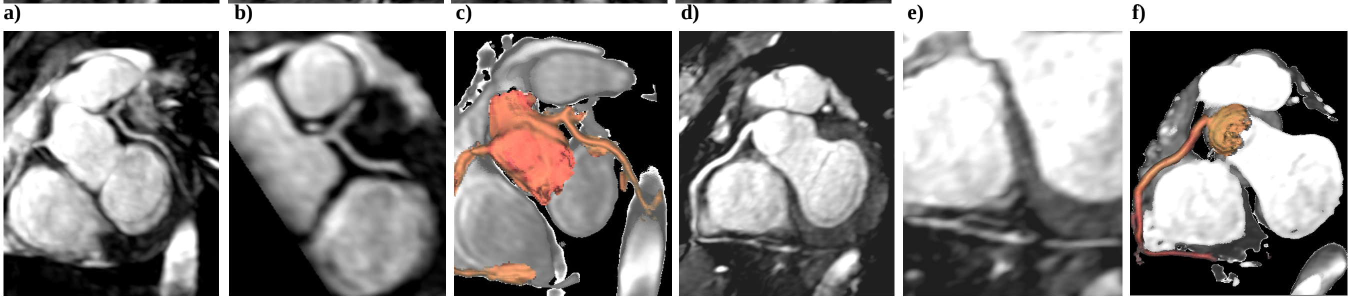

Fig. 2: Reformatted maximum intensity images(MIP) of the left (**a,b**) and the right (**c,d**) coronary arterial systems derived from a healthy volunteer using twofold accelerated 3D FIETSA. The breath-hold time was 20 sec. Note the clear delineation of the origin and the proximal segment of the left main coronary artery branching into the LAD and LCX (**a,b**) The origin, the proximal segments (**d**)and the more distal segments (**e**) of the RCA are well depicted. Volume rendered views (**c,f**) derived from automated segmentation of the coronary arteries manifest the robustness of the fat suppression and the high contrast-noise ratio between the blood pool and the surrounding myocardium.

References: (1) Stuber M. et. al, Magn Reson Med 48, 425:429 (2002); (2) Ohliger M.A. et. al, Magn Reson Med 50:1018-1030 (2003); (3) Pruessmann K.P. et al., Magn Reson Med, 42, 952-962 (1999); (4) King K.F. et al., ISMRM,153 (2000)