

Coronary artery imaging at 3T using a novel ECG gated SSFP-Dixon sequence and a motion insensitive view ordering scheme

M. Saranathan¹, E. Bayram², V. Nimbargi³, R. Venkatesan³, and J. Glockner⁴

¹Applied Science Laboratory, GE Healthcare, Rochester, MN, United States, ²MR Engineering, GE Healthcare, Waukesha, WI, United States, ³GE Healthcare, Bangalore, India, ⁴Dept. of Radiology, Mayo Clinic, Rochester, MN, United States

Purpose: MR Coronary Artery Imaging (CAI) remains challenging due to the need for high spatial resolution as well as due to constraints imposed by physiological motion and the stringent requirements for fat and muscle suppression to visualize the arterial signal with good contrast. 3D ECG gated balanced steady state free precession (SSFP) imaging has shown great promise due to its high SNR, excellent blood-myocardium contrast and short scan times. Robust fat suppression remains challenging at high field strengths due to B_0 and B_1 inhomogeneities. Furthermore, fat saturation pulses perturb the SSFP steady state and can result in severe artifacts. We report a novel ECG gated dual-echo 3D balanced SSFP sequence with a two-point Dixon fat-water reconstruction algorithm and demonstrate its potential for imaging the coronary arteries at 3T.

Methods: **Pulse sequence:** An ECG gated 3D dual-echo bipolar-readout balanced SSFP pulse sequence was developed. A robust 2-point Dixon reconstruction algorithm [1] was used for fat-water separation, eliminating the need for conventional fat suppression pulses, which are suboptimal at high field strengths and also interrupt the SSFP steady state. The elimination of fat suppression pulses enabled us to use a novel k-space segmentation scheme that is more efficient and has desirable motion insensitivity properties compared to the sequential or interleaved trajectories commonly employed with conventional fat saturation schemes. A radial fan beam k-space segmentation in k_y - k_z space was employed as shown in Figure 1. Note that within each radial sector, k-space points were acquired in the order of increasing k_r , the radial distance from the center of k-space. All k-space points were confined to the Cartesian grid, retaining the advantages of an FFT reconstruction and an alias-free fixed frequency encoding direction as in [2]. Each radial sector was acquired during mid-diastole of an R-R interval, minimizing the effects of cardiac motion. Motion point spread function simulations (omitted for clarity) indicate that the radial fan beam k-space segmentation scheme disperses ghosting energy from motion more widely than standard sequential/interleaved ordering schemes, exploiting effects similar to that used by radial under-sampling methods. This further reduces sensitivity to breath-hold loss and other physiological motion.

Experiments- Imaging parameters were as follows: 45° flip, ± 167 kHz bandwidth, TR/TE₁/TE₂ 4.1/1.2/2.4 ms, 256x224 matrix, 33 cm FOV, 20 sections of 2.4 mm thickness reconstructed into 1.2 mm thick sections. A self-calibrating hybrid space parallel imaging scheme [3] with an acceleration factor of 2.5 in the phase encoding direction was used. Typically, 32-36 k-space points were acquired in each R-R interval, resulting in an overall breath-holding time of 22-25s depending on the subject heart rate. All subjects were imaged on a GE 3T Excite system (GE Healthcare, Waukesha, WI) using an 8-channel cardiac phased array coil under an IRB-approved protocol.

Results: Figure 2 shows representative slices obtained using the proposed 2-point Dixon (a) and conventional fat suppressed (b) 3D balanced SSFP sequence with ECG-gating. Note the uniformity of fat suppression and improved image quality in (a) compared to (b). Zoomed images (c-d) show the small branch vessel near the origin of the RCA clearly visualized in the Dixon SSFP sequence (c) compared to the conventional fat-suppressed SSFP sequence (d). Figure 3 shows a reformatted volume rendering of the right coronary tree of a healthy subject demonstrating the high image SNR and contrast achievable using the proposed method.

Conclusion: The proposed ECG gated dual-echo 3D balanced SSFP acquisition with a 2-point Dixon-based fat-water separation method yields excellent fat suppression and high SNR and contrast, resulting in excellent visualization of the coronary arteries, especially at 3T where conventional fat saturation techniques are often suboptimal. While we restricted the slab thickness and spatial resolution to limit the acquisition time to a reasonable breath-holding duration, the method can also be easily combined with navigator gating to further improve the spatial resolution. The elimination of fat-suppression pulses permitted the use of a more efficient and relatively motion immune radial fan beam segmentation scheme.

References: [1] Ma et al. MRM. 52:415-419 (2004) [2] A Madhuranthakam et al. MRM; 55:50-58 (2006) [3] Beatty et al. Proc ISMRM 2007, p1749.

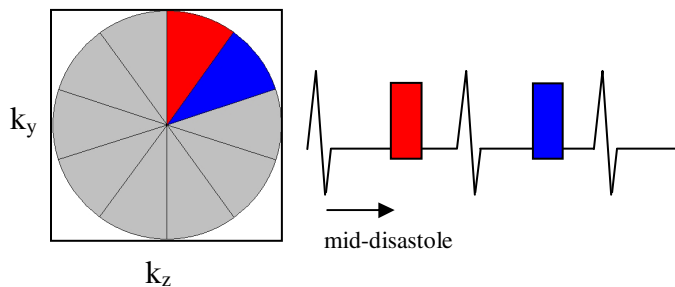


Figure 1. Radial fanbeam k-space segmentation scheme for the proposed Dixon-SSFP sequence. Each fanbeam is acquired in mid-diastole

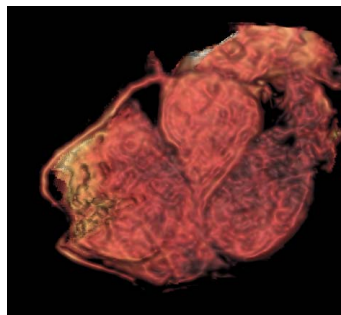


Figure 3. Volume rendered reformat of a highly tortuous RCA showing the excellent SNR and CNR of the Dixon-SSFP sequence.

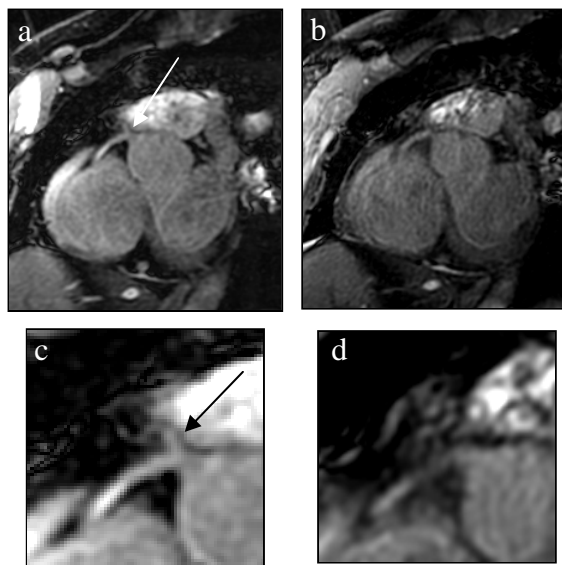


Figure 2. Comparison of a representative slices obtained using the Dixon SSFP sequence (a) and a conventional fat suppressed SSFP sequence (b). The small branch vessel near the origin of the RCA can be clearly visualized in (c) compared to (d) due to the uniform fat suppression and removal of SSFP steady state perturbations.