Free-Breathing Coronary Angiography using Alternating-TR Balanced SSFP and a 3D Cones Trajectory

P. T. Gurney[1], P. C. Yang[2], B. A. Hargreaves[3], and D. G. Nishimura[1]

[1]Electrical Engineering, Stanford University, Stanford, CA, United States, [2]Cardiovascular Medicine, Stanford University, Stanford, CA, United States, [3]Radiology, Stanford University, Stanford, CA, United States

Introduction

The 3D Cones trajectory [1], shown in Fig. 1, has a number of desirable properties for free-breathing coronary angiography, such as excellent motion properties, high SNR efficiency, and the ability to favorably trade off increases in readout length for reductions in scan time. However, since the trajectory samples the origin of k-space on every readout, it performs poorly in sequences with periodic fat saturation. Previous angiography methods using 3D Cones have used phase-sensitive fat suppression, but these techniques suffer from the significant off-resonance blurring of fat, which can lead to insidious artifacts. The 3D Cones trajectory is much more compatible with the recently described Alternating-TR (ATR) fat suppressed balanced SSFP [2] technique, which provides a fat-suppressed steady-state and significant flexibility in its design parameters. This flexibility can be used to optimize the generated contrast for coronary angiography.

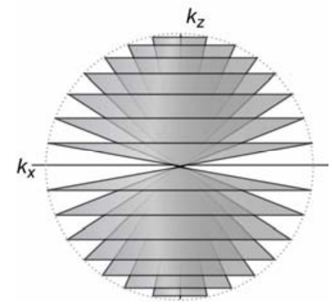

Fig. 1: *The 3D Cones trajectory samples the central region of k-space during every readout.*

Methods

Figure 2(a) shows the pulse sequence used, with TR1/TR2 = 0.7 ms / 4.1 ms. The effective RF flip angle for each TR (TR1/TR2) was 80° (40°/40°), with a phase difference of 135° between TR1 and TR2. The standard 180° phase cycling was applied after each TR1/TR2 sequence. The slab width was set to 15 cm FWHM with a TBW of 2.2. The 3D Cones trajectory was designed for a resolution of 1.1 x 1.1 x 1.5 mm^3, a field of view of 24 x 24 x 20 cm^3, and a readout plus rewinder length of 3 ms, resulting in a requirement of 10,000 readouts. For a desired temporal resolution of 100 ms during the diastolic rest period, a total of 480 heartbeats were acquired. A 2D sagittal navigator was acquired during the systolic rest period, from which motion estimates were obtained. These estimates were used to correct for respiratory motion and because of the excellent motion properties of the 3D Cones, no respiratory gating was required. All scans were performed on a GE Excite 1.5T system using an 8-channel cardiac coil.

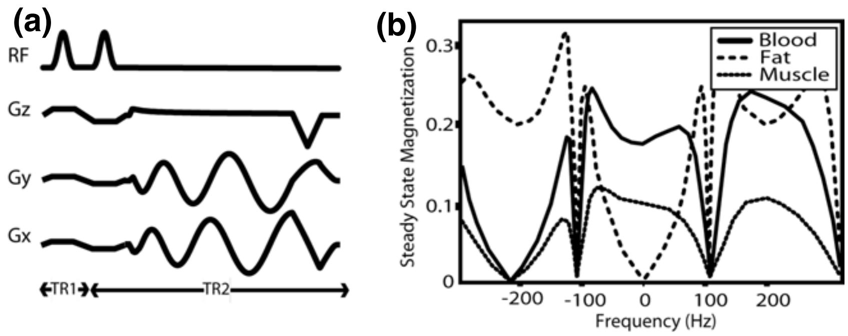

Fig. 2: *(a) the ATR pulse sequence, and (b) the frequency response of the sequence, showing excellent fat suppression over a large bandwidth.*

Results

Figure 2(b) shows the simulated frequency response of the ATR sequence. Excellent blood-fat contrast (3:1) is maintained over a range of off-resonance frequencies from -50 Hz to 50 Hz. Blood-muscle contrast (1.7:1) is also acceptable. Figure 3 shows several reformats of the acquired 3D dataset, which confirms that the expected steady-state contrast is obtained. Fat and muscle are both well suppressed as compared to blood signals as evidenced by the clear visibility of the main vessels (embedded in fat) and the marginals and diagonals (adjacent to myocardium).

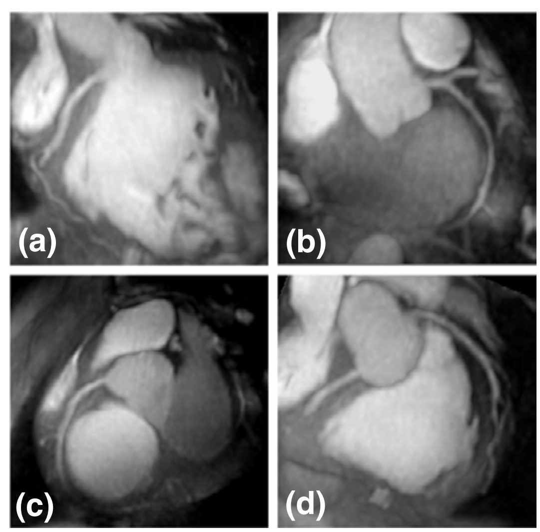

Fig. 3: *Multiplanar reformats of the acquired 3D dataset, showing (a) the RCA and right marginal, (b) the LCX and diagonals, (c) the proximal and distal RCA, and (d) the LAD and diagonals. Note the excellent suppression of fat and myocardium.*

Discussion

The ATR method does sacrifice some blood signal as compared to standard SSFP methods, and also requires a slightly longer RF time which reduces the available readout time. Also, like any SSFP sequence, this method requires sufficient field uniformity to ensure consistent contrast and avoid dark bands in blood signal (and bright-bands in fat signal). This uniformity may be an issue in certain regions of the heart, such as the heart-liver and heart-lung interfaces. However, with careful shimming, it is possible to achieve good image quality over the whole heart.

Conclusion

The combination of the ATR fat-suppressed balanced SSFP pulse sequence and the 3D Cones trajectory enables rapid, high-quality whole-heart imaging of the coronary arteries during free-breathing.

References [1] Gurney et al, MRM 2006; 55(3):575-82. [2] Leupold et al, MRM 2006; 55(3):557-65