Multi-phase Fat-Suppressed 3D SSFP For Robust Coronary Artery Imaging: Improvements over the single phase technique

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PURPOSE

Proper selection of the optimal ECG R-wave trigger delay is a critical parameter in the visualization of sharp blood vessels in coronary artery imaging. In current clinical routine, trigger delay is frequently chosen by observing the cardiac motion in a 2D CINE acquisition. It is often difficult to choose a single trigger delay, due to heart rate variability over time, and due to the differences in the quiescent periods of different coronary artery segments [1]. We propose a multi-cardiac-phase acquisition strategy to eliminate the need for accurate trigger delay selection, thus streamlining workflow and improving the robustness of coronary artery imaging.

METHODS

A navigator-echo-gated, T2-prepared, fat-suppressed 3D SSFP sequence was modified to acquire multiple (3-4) cardiac phases, centered about the quiescent diastolic period. Multi-phase coronary MRA [TR/TE/θ=5.1/2.5ms/65°, SENSE 2, 1 NEX, 1.1x1.1x2.0mm^3 true resolution, scan time=5 min/slab, 18-20 slices/slab, cartesian k-space trajectory] was performed on 10 volunteers (4 Male, 6 Female; age 42±17 years), using a 1.5T MRI with an 8-channel cardiac-array coil (GE Healthcare, USA). All volunteers provided informed consent for participation in this IRB-approved study. Images from 4 cardiac phases, spaced 50 ms apart, were acquired and reconstructed using view sharing. Spectrally-selective fat saturation pulses were applied prior to the acquisition of the central phase encodes, to maintain consistent fat suppression in later phases. In order to minimize steady state disturbances, a Kaiser ramp[2] magnetization preparation scheme was used to first ramp down and later ramp up the longitudinal magnetization about the fat suppression pulses (Figure 1). Since the total cardiac acquisition window was lengthened in the multi-phase technique, we incorporated an additional trailing navigator at the end of the acqusition window to suppress possible respiratory motion occurring during the acquisition window. To assess the improvement of this technique over a single phase approach, we compared the image quality of the coronary images at the phase with the best vessel visualization (best imaged phase), against those from the phase closest to the optimal trigger delay, as determined from a 2D CINE acquisition. Subjective image quality was assessed by an experienced radiologist (Scale: 1=Poor, 2=Inadequate but fair, 3=Adequate & good, 4=Excellent).

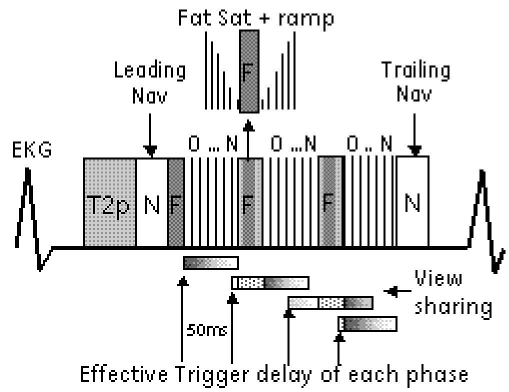

Figure 1. Sequence diagram of multi-phase SSFP.

RESULTS

Imaging was successfully completed in 9 subjects. In one subject, significant respiratory drifting occurred and the images were suboptimal for analysis. Figure 2 shows the multi-phase imaging results from a healthy volunteer. The right coronary arteries were most clearly delineated in the 3rd cardiac phase images (trigger delay 600ms), with a side branch (conus artery) visualized. This was consistent with the quiescent diastolic period observed from the CINE acquisition (657-900ms). Fat suppression was maintained in all phases and steady state was not significantly disturbed. Figure 3 shows a two-sample t-test on the image quality rating of the best imaged phase, acquired with the multi-phase approach, versus the best phase, as determined from CINE acquisition. Image quality was higher in the multi-phase approach relative to the single phase approach (3.59+/-0.38 vs. 3.09+/-0.54, $p<0.05$). This was due to heart rate variability over time, as the CINE acquisition was usually performed at least 15-30 minutes prior to the coronary MRA acquisition. Figure 4 shows the volume rendering of a multi-slab whole heart acquisition using this multi-phase approach, with the left coronary system clearly visualized. As compared to a full 3D CINE approach [3], this approach acquires only the phases critical for diagnosis, thereby reducing SAR deposition.

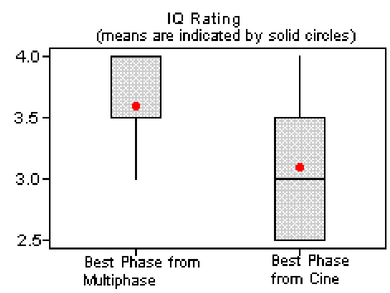

Figure 3. Image quality ratings in 9 volunteers. Multi-phase approach resulted in higher IQ rating, as compared to use of the best phase observed from CINE.

CONCLUSION

We have shown that the multi-phase 3D SSFP technique can obtain multi-phase fat-suppressed whole heart coronary artery images and consistently produce better image quality relative to the single phase approach. In conclusion, with this multi-phase technique, accurate determination of the optimal trigger delay is not required, thus reducing the overall planning time, and increasing the robustness of coronary artery imaging.

Figure 2. Multi-phase coronary artery MIP images in a volunteer, with trigger delay of a) 500ms, b) 550ms, c) 600ms. Phase c shows the sharpest delineation of the RCA, with the side branch (conus artery) clearly visualized (arrow).

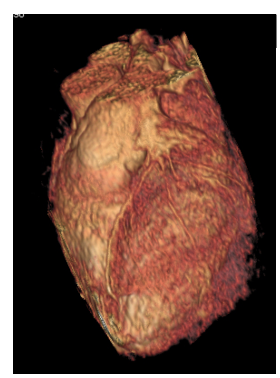

Figure 4. Volume rendering of a whole heart showing the optimal phase, acquired with the multi-phase approach.

REFERENCE: [1] Bi X, et al. MRM, 54:470, 2005, [2] Le Roux P, et al. JMR 163: 23-27, 2003, [3] Lai P, el al. ISMRM 2006, Proc 364.