Single Breath-Hold Whole-Heart MRCA with Variable-Density Spirals at 3T

J. M. Santos[1], C. H. Cunningham[1], B. A. Hargreaves[1], B. S. Hu[2], D. G. Nishimura[1], J. M. Pauly[1]

[1]Electrical Engineering, Stanford University, Stanford, California, United States, [2]Cardiovascular Medicine, Palo Alto Medical Foundation, Palo Alto, California, United States

Introduction: Previous breath-held and navigator-gated coronary sequences at 1.5T have demonstrated encouraging clinical accuracy [1,2]. However, long scan times and incomplete coverage continue to be major limitations for coronary MR angiography. Ideally the increased SNR of 3T whole-body imaging systems could be used to improve image quality, increase resolution, and reduce scan time. The higher resonance frequency at 3T could also improve the performance of chemically-selective contrast preparation. However, the increased susceptibility artifacts and increased T1 at the higher field strength have led to mixed reports at 3T [3,4]. We developed a new thin-slice, high-resolution, multi-slice sequence to effectively cover the entire heart in a single breath hold. The sequence leads to an improvement in SNR, a reduction in slice-to-slice misregistration, and a reduction of the susceptibility artifacts at 3T.

Methods: The improved spectral resolution and higher available signal at 3T encouraged us to redesign much shorter spectral-spatial excitations for improved imaging slice profile as well as more time-efficient readouts to improve volumetric coverage while simultaneously reduce off-resonance artifacts.

RF Excitation: We have designed a spectral-spatial RF pulse that excites thin 1.6 mm slices. This was achieved using a 1-3-3-1 1.2-ms sublobe envelope with 40 mT/m gradient amplitude and 4.8 ms total duration. By oscillating the polarity of the RF sublobes, the unwanted bipolar excitation at 440 Hz was suppressed. This allows good fat suppression with fewer spectral components while producing short RF pulses [5].

Readout: We have previously used uniform-density spirals, requiring 24 interleaves of duration 8 ms to achieve 0.8 mm in-plane resolution [4]. To improve temporal and spatial resolution, a spiral-based variable-density sampling scheme was utilized. Sampling density was linearly reduced from 20 cm FOV for low spatial frequencies to 5 cm FOV for high spatial frequencies. As the energy content of high frequencies is relatively low, there is no significant aliasing introduced by reducing the FOV. To obtain an in-plane resolution of 0.88 mm, each slice is acquired with 17 spirals of duration 5.8 ms. Such a short readout reduces the off-resonance artifacts and allows virtually no heart displacement between slices as the repetition time (TR) is from 11 to 14 ms. 40 slices covered a 8.8 cm FOV in the through-plane direction (1.6 to 2.2 mm slice thickness). The reduction in SNR due to variable density sampling and shorter acquisition time is compensated by the increased magnetization at 3T.

To reduce off-resonance artifacts, two complementary strategies were implemented. Non-linear volumetric shim calibration was done over the entire heart before the acquisitions. Additionally a multi-slice dynamic shim method was used [6]. Two acquisitions per slice were required to calculate a fieldmap. A 3D cylinder determines the ROI on where to calculate the fieldmap. To reduce discrepancy between slices, the results of this calculation are constrained assuming that the field changes are smooth. Linear shim components are calculated in real-time and set on the scanner before the immediately following acquisition (TR). Each slice is thus independently shimmed in a single breath-hold period.

The sequence was implemented on a GE Signa 3.0T VH/i system, with 40 mT/m maximum gradient amplitude and 150 T/m/s slew rate. A body coil was used for transmission and a 5-inch surface coil was used for reception. We used the RTHawk real-time system [7] as a framework for pulse programming. This provides the additional capability of precise real-time localization followed by an immediate switching to the multi-slice acquisition. Figure 1 show the time line of the sequence.

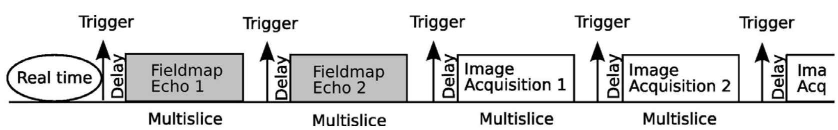

Figure 1: Sequence diagram. The system switches from real-time to multi-slice gated acquisition. Fieldmaps are acquired right before the image to calibrate each slice.

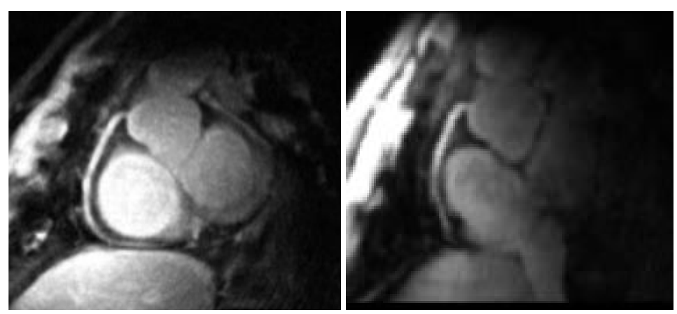

Figure 2: RCA acquired in the short axis direction vs. 3D reformatting from axial slices.

Results: Four healthy volunteers were studied. The left image of Fig. 1 shows the RCA for the whole-heart acquisition where the slices are in the short axis direction. The right image shows the same artery but acquired with the slices in the axial direction (orthogonal to the reconstruction plane).

Conclusions: Coronary imaging remains difficult with the need for higher temporal and spatial resolution, thinner slices, and volumetric coverage. The current sequence exploits the improved spectral separation and increased SNR of 3T to cover the entire heart in a single breath-hold at high spatial and temporal resolution. Given this basic sequence, internal or external contrast mechanisms can be incorporated.

References:

[1] Kim W, et al. N Eng J Med, 26:1863, 2001.
[2] Yang P, J Am CC, 7:1134, 2003.
[3] Stuber M, et al, Mag Res Med, 48:425, 2002.
[4] Santos J, et al. SCMR 7th, 217, 2004.
[5] Zur Y, Magn Res Med, 43:410, 2000.
[6] Morrell, G, et al,. Magn Res Med, 38:477-483, 1997.
[7] Santos J, et al., IEEE EMBS 26th, 1048, 2004.