3D Free-Breathing Radial Cine-SSFP Using a Retrospective Z-Center-of-Mass Self Navigator: A Feasibility Study

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INTRODUCTION: Current clinical cardiac MRI using a series of 2D cine-SSFP is limited by slice mis-registration due to inconsistent breath-holds and incapability of ill patients to perform satisfactory breath-holds. In this study, a 3D free-breathing cine-SSFP pulse sequence was developed to overcome these 2D limitations. The radial k-space sampling was employed to provide z-profile self-navigator to monitor respiratory motion.

MATERIALS AND METHODS: The study population included 6 healthy volunteers (5 male, 1 female, age 30.3 ± 7.8 years, weight 155 ± 27 lbs., IRB approved). Data were acquired using a "stack-of-stars" k-space radial trajectory (Fig. 1). Gradient delay errors were corrected by shifting the center of the readout trajectory using additional compensation gradients [2]. Each cardiac phase consisted of a complete set of slice encodes k_z that was repeatedly sampled within a cardiac cycle, and this is further repeated over a number of heartbeats determined by an oversampling parameter (~5) of the retrospective gating algorithm. Partial slice encoding of 70% was employed to improve temporal resolution.

Respiratory positions were determined from the center-of-mass of the image volume projection onto the z-axis, which is the Fourier transformation of the k_z-axis points acquired during each cardiac phase. A sliding window over the acquired sets of slice encodes was used to generate additional temporal frames. Results were band-pass filtered to suppress noise and cardiac motion. The respiratory position with the highest occurrence in acquired data was chosen as reference position for image reconstruction. Each readout contributed to a weighted average signal at its corresponding projection angle and slice encode position, based on a weight that was determined by a 2D Gaussian apodized sinc window function in the 2D plane of the respiratory position and cardiac phase. The widths of the 2D window function varied linearly according to readout position (wider window width at the periphery of k-space). Resultant k-space data were reconstructed using a modified PILS approach [3]. Projection data from each coil were individually centered in the FOV by multiplying a corresponding linear phase according to the center-of-mass of x and y projections. Projection k-space data were then gridded into Cartesian space, shifted back to the original image position, and inverse fast-fourier transformed. The result was cropped to the prescribed FOV to minimize aliasing artifacts interfering with other coil images.

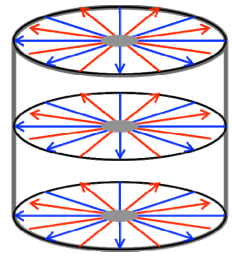

Figure 1: K-space sampling trajectory: classic "stack-of-stars" with alternating readout directions to average remnant projection mis-centering. The z-projection of the readouts is used for respiratory gating.

MR scans were performed using a GE Signa 1.5T scanner. Typical 2D cine SSFP imaging parameters were as follows: TR 3.3-4.5ms, flip angle 55-60, matrix size 256 readout points and 128 phase encodes, image dimensions 256x256, receiver bandwidth 125 kHz, FOV 290-400 x 240-360, slice thickness and slice gap 6mm & 4mm, respectively (total 10mm). The LV in each patient was imaged in 6-10 slices, 20-28 cardiac phases, 24 views per segment.

3D free-breathing cine SSFP scan parameters were as follows: TR 3.7-4ms, flip-angle 50, matrix size 512 readout points and 72 projections, reconstructed image dimensions 256 x 256, receiver bandwidth 250 kHz, FOV 640mm acquired (reconstructed to 320mm), and 7mm slice thickness. 20-22 partial slice encodes were acquired out of 28-30, respectively, yielding the same number of views-per-segment. Overscan factors of 4-6 were used, depending on volunteer, yielding scanning efficiencies of 16.6% to 25%. 20 cardiac phases were reconstructed.

RESULTS: 3D free-breathing projection cine-SSFP scans were successful on all 6 patients. Average scantime for 3D was 6.48 minutes. Average scantime for 2D breath-hold was 6 minutes. All slices in 3D were properly registered, as demonstrated in Fig. 2. Resultant temporal resolution was 67 ms, which resulted in good contrast across cardiac phases, as shown in Fig. 3. Ejection fraction difference in comparison to the 2D breath-hold sequence was -1.5 ± 1.2 %.

DISCUSSION: In summary, a free-breathing 3D projection cine-SSFP pulse sequence was developed. Good image quality was obtained, and scan times were less than 6.5 minutes on average. Further study in a larger cohort of clinical patients is necessary to validate the success rate of the respiratory navigator and to assess the differences, if any, in quantification of functional cardiac parameters, such as ejection fraction, stroke volume, and left-ventricular mass, as compared to 2D breath-hold cine. Limitations of the sequence include RF profile imperfections at the edge of the prescribed slab, and reduced inflow enhancement as in comparison to 2D scans. The first may be address by longer RF pulses or larger slabs at slightly reduced temporal or spatial resolution. The latter is an inherent property of 3D imaging; the effects of such on functional quantitation will need to be studied in further detail.

References: [1] Peters D.C., et al. JMRI 20:411-416 (2004) [2] Peters D.C., et al. MRM 50:1-6 (2003) [3] Kressler, B.M. et al. MRM 58:535-543 (2007)

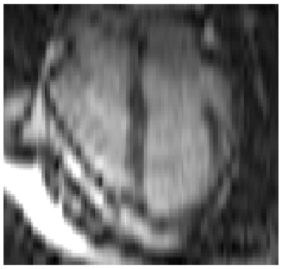

Figure 2: Long axis views of 3D cine demonstrated good coverage and slice registration.

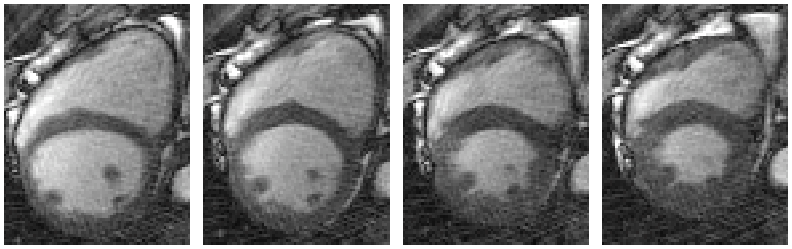

Figure 3: Achieved temporal resolution was 67 ms, which resulted in good contrast across cardiac phases.