A new approach toward free-breathing 3D cardiac imaging

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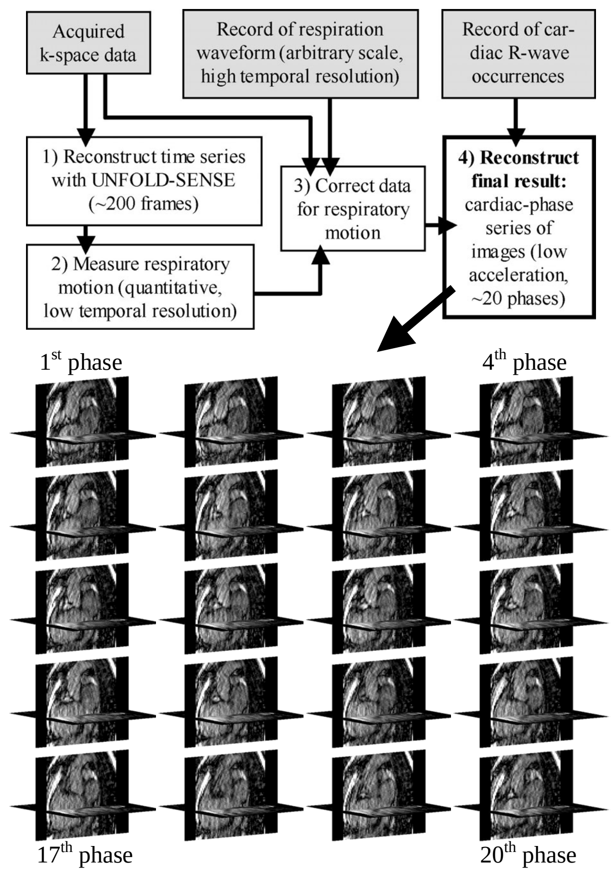
Introduction: Breath holding is widely used to avoid breathing artifacts in cardiac MRI. There are 2 main problems associated with breath-held imaging: 1) Some patients cannot hold their breath, e.g. the very sick, mentally impaired or infant patients, and 2) breath-holding imposes limits on scan time, which in turn limits SNR and spatial resolution. In contrast, free-breathing imaging can in principle open the door toward improved SNR, improved resolution, and imaging in 3D. But a very effective strategy is required to compensate for the respiration-induced motion.

The present work introduces a novel approach at compensating for respiration-induced motion, applied to 3D free-breathing cardiac imaging. A main characteristic of the approach comes from reconstructing the acquired data twice, in very different ways. A large number of highly sub-sampled data sets are first reconstructed using parallel imaging and UNFOLD [1], to display the motion caused by respiration. After detecting and correcting for the respiration-induced motion, a second reconstruction yields the final result. It consists of a number of 3D images showing the heart throughout the cardiac cycle. While the first reconstruction gives a time series of images, the second (final) reconstruction gives a cardiac-phase series of images. The approach is referred to as "Tracking to Remove Artifacts from Cardiac Kinetics" (TRACK).

Theory: Respiratory motion must first be monitored before being corrected. Some recent, successful approaches (e.g., [2]) have used navigator echoes placed on the right hemi-diaphragm to monitor respiratory motion. A factor of about 0.6 can convert measured diaphragm S/I displacements into cardiac S/I displacements [3]. A main goal of the present work is to allow respiratory motion to be detected directly on the heart instead of the diaphragm, and in 3D instead of in 1D. One could think of the present acquisition strategy as a time series of about two hundred 3D navigator echoes, each one covering the entire heart. The acquired data plays two roles at once, that of navigator echo and of actual image data. The acquisition is accelerated as much as possible, using a combination of parallel imaging and UNFOLD [1] along with partial-Fourier imaging. In principle, displacements in any direction as well as rotation and even stretching can be detected (although only S/I translation, A/P translation and S/I linear stretching were evaluated here). Cardiac motion causes blurring in these images, but no visible ghosting. Despite the use of fast-imaging methods, temporal resolution is insufficient to accurately depict respiratory motion (about one 3D frame every 4 s in the current implementation). The output from a respiration-monitoring belt, strapped around the patient, provides a rendering of respiration featuring great temporal resolution. The quantitative, lower-temporal resolution knowledge provided by analyzing the 3D images is combined with the qualitative, high-temporal resolution information from the monitoring belt. In other words, the waveform from the monitoring belt provides a functional basis to interpolate the lower-temporal resolution motion information from the 3D images.

Equipped with this knowledge of the respiration-induced motion, respiration compensation is performed through k-space operations (phase ramps and stretches). Finally, the time series of 3D images, now corrected for respiratory motion, can be reformatted according to cardiac phase. Because of appropriate temporal variations applied to the sampling function, the data from the large number of highly under-sampled acquired time frames can be combined to yield a smaller number (20 here) of nearly fully-sampled 3D cardiac phases.



Results and Conclusion: TRACK is a novel approach at compensating for respiration-induced motion, targeted toward free-breathing 3D cardiac MRI. The method was implemented on a 1.5 T GE scanner, and feasibility was demonstrated by obtaining 3D images of the beating heart in 3 free-breathing volunteers (results for one volunteer shown here). Although image quality may not yet be sufficient to match product sequences developed and polished over many years, the results obtained reinforce our belief in the validity of the proposed approach. With further developments and adjustments, along possibly with the use of a blood-pool agent to boost the signal from the heart, we aim at reaching clinical usefulness, especially in populations where breath-holding is not an option (e.g., very sick, mentally impaired and infant patients).

References: **[1]** Madore. MRM 2004:52:310. **[2]** Kim *et al*. N Eng JM 2001:345:1863. **[3]** Wang *et al.* MRM 1995:33:713.