Breath-hold 3D SSFP Coronary Imaging with Simultaneous Fat and Water Separation at 3T

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INTRODUCTION

A number of breath-hold and free-breathing coronary imaging techniques using fully refocused SSFP have been introduced. Most interrupt the steady-sate to prepare by saturating the myocardium and fat surrounding the coronaries prior to imaging in diastole. We introduce a CINE method to image throughout the cardiac cycle by using linear combination SSFP (LCSSFP) with a 3D hybrid dual-echo radial sequence to separate fat and water [1]. We demonstrate initial results in imaging the lumen and surrounding fat simultaneously within a breath-hold at 3T.

MATERIALS AND METHODS

The 3D SSFP hybrid CINE acquisition acquires two half-radial lines during each TR, where the first originates at the k-space origin and extends to the edge of k-space. After a small blip, the second line returns to the k-space origin. A k-space blade is acquired by sequentially varying the Fourier-encoding in the slice dimension before changing the in-plane angle, as shown in Fig. 1 [2]. We also implemented additional gradient and system calibration methods for robust oblique off-axis views [3].

Skipping a passband with LCSSFP by using a TR of 3.6 ms at 3T allows for a much longer time to achieve higher resolution than is available at the optimal time of 1.2 ms. The possible spectral separation for 3T LCSSFP is shown in Fig. 2, where the center frequency of the exam is placed at the midpoint between fat and water. Notice that the skipped passband between fat and water is attenuated. As both fat and water are off-resonance during the scan, we can track the phase of the desired component during reconstruction. This provides a Dixon-like capability to attenuate the undesired component in addition to the separation provided by LCSSFP.

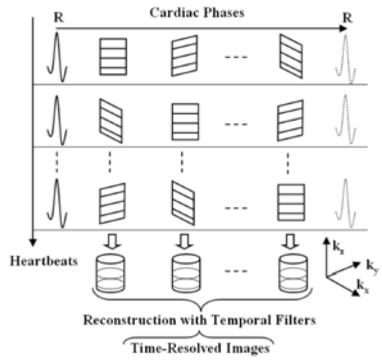

Fig. 1 Interleaved hybrid k-space CINE acquisition scheme.

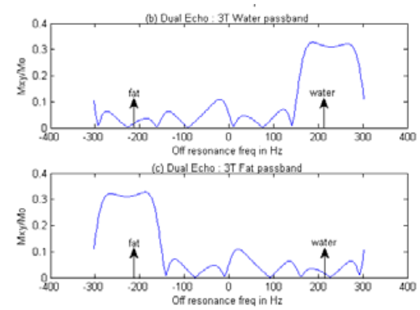

Fig. 2 Water (top row) and Fat (bottom row) passbands with 3T LCSSFP. TR =3.6 ms.

The variable density k_x-k_y sampling can be temporally filtered, using an iterative density compensation, to improve SNR, CNR, and limit the effects of undersampling. This method optimally narrows the temporal window for oversampled lower spatial frequencies while widening it to share undersampled, higher spatial frequencies [4].

RESULTS AND DISCUSSION

The method was implemented on a GE Signa EXCITE HD 3T scanner (GE Healthcare, Milwaukee, WI) using an eight-channel cardiac coil. A slab consisting of 6 slices was excited with a 3 mm slice thickness and 256 resolution over a 26 cm FOV with a 22^o flip angle, TR = 3.7 ms.

After orienting a 3D slab over the right coronary artery (RCA) in a healthy volunteer, a breath-hold scan was completed in 34 heartbeats (31 s) where the R-R interval was divided into 39 cardiac phases or blades, each 22 ms in duration. We applied a temporal filter which utilized 3 phases at the base and 19 phases (422 ms) as the highest spatial frequencies. Corresponding water and fat images of the proximal right coronary artery (RCA) are shown for a single slice, centered at a middle diastolic phase, shown in Fig. 3 a) and b). The images demonstrate the excellent registration achieved by imaging fat and water simultaneously, in Fig. 3 c) and d). A MIP through the volume shows a longer depiction of the RCA, shown in Fig3. e).

The method offers considerable possibilities. LCSSFP properly images voxels with both fat and water components. The fat volume may provide information for simplified segmentation of the coronary tree. The CINE time-frames of either fat or water may provide information for tracking the coronary throughout the coronary cycle. While feasibility has been proven, considerable opportunities exist for improving image quality through parallel imaging, larger coil arrays, minimizing flow artifacts by reordering the angle, and estimating signal components from static tissue across the entire scan to reduce aliasing. The difference spectral passbands in the individual passes may provide methods to increase robustness to off-resonance as well.

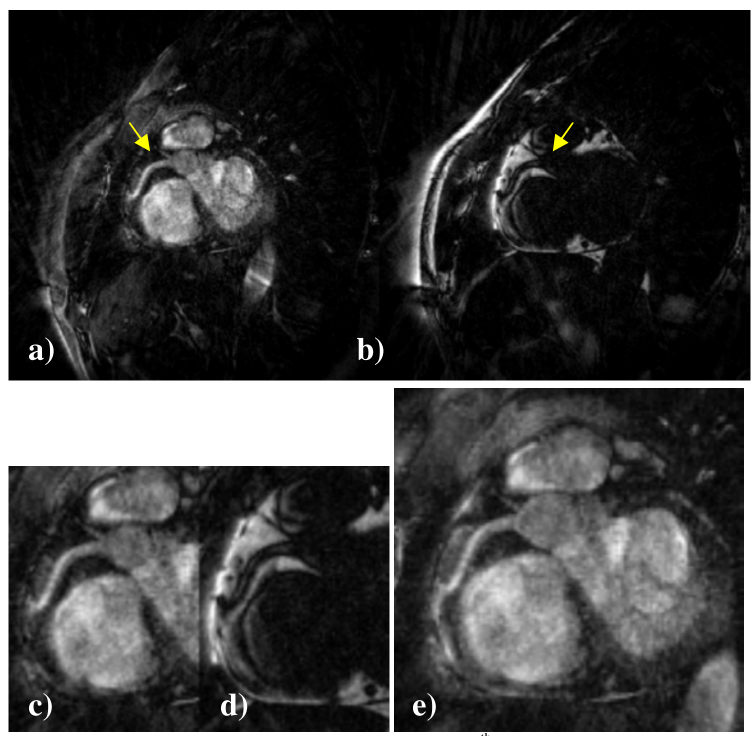

Fig. 3 a) Water and **b)** fat images of RCA at the 31^{th} cardiac phase out of total 39 phases. Scan parameters: 26 cm FOV, 1.0×1.0 mm in-plane resolution, 6 slices of thickness 3 mm, 67 ms temporal resolution with temporal filtering, in 34 heartbeats (31 s). **c)** shows the magnified proximal portion of the RCA and the d) corresponding fat image. **e)** MIP depicts longer segment of the RCA.

CONCLUSIONS

We have demonstrated a new method for coronary imaging using a hybrid radial acquisition that provides registered fat and water image volumes in a CINE format without magnetization preparation in a breath-hold. SSFP provides high signal without contrast while the radial acquisition provides robustness to motion.

ACKNOWLEDGEMENTS

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