Respiratory motion correction using TR-perturbed bSSFP for fat navigator acquisition and imaging

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Introduction Navigators based on lipid signal have been of interest for cardiac imaging because they enable direct measurement of the location of the heart using signal from epicardial fat [1-5]. Recent 3D coronary artery studies have shown improvements over traditional diaphragm navigators but have relied on relatively long (30–160 ms) fat navigator acquisitions. We propose an application of a new TR-perturbed bSSFP sequence [6] with integrated fat-selective navigator acquisitions (<10 ms) and bSSFP-like image contrast. We demonstrate the technique for respiratory motion correction for free-breathing 3D cardiac imaging.

Methods Interleaved acquisitions during odd and even TRs of a TR-perturbed bSSFP sequence (Fig. 1a) can be subtracted or added to yield the spectral profiles in Figs. 1b and 1c, respectively. The sequence parameters TR=4.6 ms, ΔTR=0.4 ms, and α=60° result in a fat-selective difference profile at 1.5 T and a bSSFP-like sum profile near the water resonance. This sequence was used for whole-heart 3D cardiac imaging using a GE 1.5 T scanner and a 5-inch surface coil. Cardiac-gated extended-breathheld scans were performed for reference to illustrate the two types of contrast. Cardiac-gated free-breathing scans were performed to test motion estimation and correction. The imaging parameters of the extended-breathheld scan were as follows: BW=±62.5 kHz, FOV=26x26x16 cm^3, res.=4x6x10 mm^3, matrix=128x64x16, scan orientation = sagittal, readout = S/I. Data acquisition occurred during a 220-ms interval in mid-diastole spanning 43 heartbeats. The imaging parameters of the free-breathing scan were as follows: BW=±62.5 kHz, FOV=26x26x19 cm^3, res.=1.4x2x3.5 mm^3, matrix=192x128x54, scan orientation = sagittal, readout = S/I. Data acquisition occurred during a 165-ms interval in mid-diastole spanning 384 heartbeats. For the free-breathing scan, fat navigator acquisitions along the k_x axis were obtained immediately before and after the data acquisition period to obtain a series of fat-only projection images along the S/I direction. A standard least-squares algorithm was used to compute S/I displacements using an ROI at the base of the heart [7]. The estimated motion was compensated via linear phase modulation in *k*-space.

Results The low-resolution extended-breathheld TR-perturbed bSSFP images show the expected fat-only contrast for the difference image (Fig. 2a) and bSSFP-like contrast for the sum image (Fig. 2b). The S/I position estimates (Fig. 3a) obtained from the fat navigators acquired during the free-breathing scan are in close agreement with the recorded respiratory bellows signal (Fig. 3b), which was acquired for reference. Motion correction of the TR-perturbed summed data using these position estimates results in an improvement in the depiction of the left ventricular (LV) wall and a nearby vessel (Figs. 4a,b), the papillary muscle (Figs. 4c,d), and the right ventricular (RV) trabeculae (Figs. 4e,f).

Discussion Unlike traditional pencil-beam navigator approaches and previously reported fat navigator approaches that both require interruption and subsequent re-catalyzation of the steady-state magnetization, the proposed technique uses the inherent contrast of the TR-perturbed bSSFP sequence, allowing fat navigator acquisition and bSSFP-like imaging during the same steady state. Furthermore, the sequence provides fat images, which could yield additional diagnostic utility. This approach shares the benefits of other self-navigated techniques by directly estimating motion from the region of interest without needing correlation factors or subject-specific motion models. The proposed technique can be applied for respiratory gating or motion correction in other anatomical regions where the motion of the region of interest is highly correlated with that of a large fat signal, such as the abdomen and skin. Traditional non-fat-based navigators are favored for imaging regions containing very little fat signal.

Conclusion We have proposed a new application of the TR-perturbed bSSFP sequence for cardiac fat navigator acquisition and have demonstrated the feasibility of the technique for retrospective motion correction for free-breathing 3D cardiac imaging.

References
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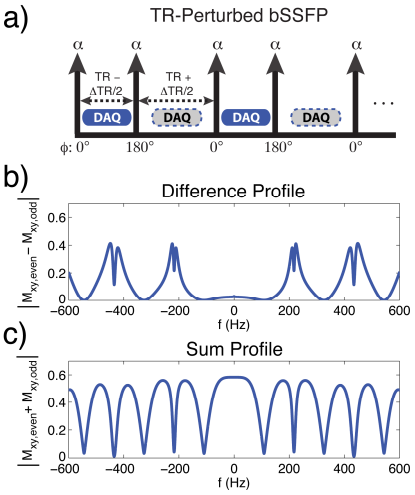

Figure 1. (a) TR-perturbed bSSFP pulse sequence. **(b)** Complex difference of spectral profiles in even and odd TRs. **(c)** Complex sum of even and odd spectral profiles. T_1/T_2 = 250/85 ms (fat at 1.5 T).

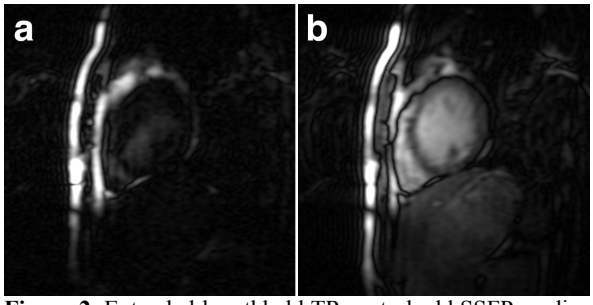

Figure 2. Extended-breathheld TR-perturbed bSSFP cardiac images acquired over 43 heartbeats. **(a)** Difference of even-TR and odd-TR acquisitions contains signal from fat only. **(b)** Sum of even-TR and odd-TR acquisitions contains signal from fat and water, with contrast similar to bSSFP.

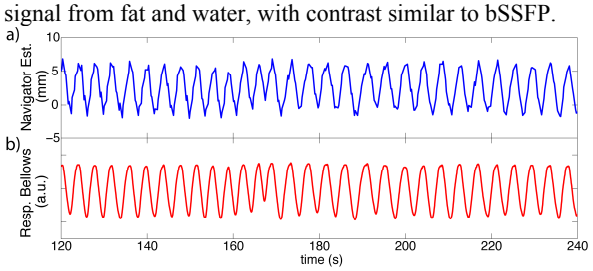

Figure 3. Respiratory motion during a two-minute interval of the free-breathing scan. **(a)** Estimated S/I motion (mm) derived from the proposed fat navigator. **(b)** Respiratory bellows signal (arbitrary units).

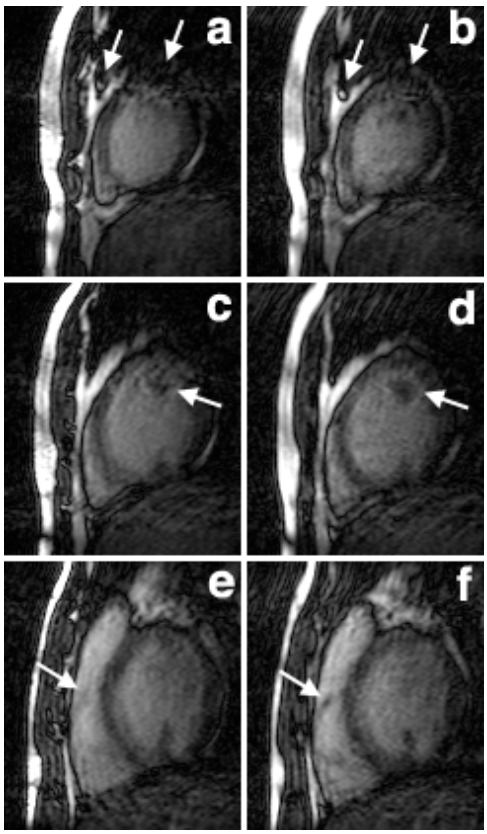

Figure 4. Free-breathing TR-perturbed bSSFP sum images showing three representative slices (cropped) from the 3D dataset before motion correction **(a,c,e)** and after motion correction **(b,d,f)**. Motion correction improves depiction of LV wall and nearby vessel **(a,b)**, papillary muscle **(c,d)**, and RV trabeculae **(e,f)**, all marked with arrows.