Virtual Coil Navigator: A Robust Localized Motion Estimation Approach for Free-Breathing Cardiac MRI

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PURPOSE MR scans are sensitive to various sources of motion, including respiratory and cardiac motion. The pattern and extent of motion usually varies across the imaging FOV. Thus accurate motion measurement requires spatial localization. For cardiac imaging, 1D navigators placed over the liver, and 2D&3D image-based navigators provide the ability to estimate localized motion. In radial MRI, Feng et al. proposed cropping image projections to the ROI for localized cardiac and respiratory motion detection [1]. In this work, we propose a "virtual coil navigator" approach for localized motion estimation, which automatically tracks motion in chosen ROIs and works for simple navigators and different k-space trajectories.

METHODS *Fitting for Virtual Coils* The virtual coil is a linear combination of array coils, which has high sensitivity inside and minimal sensitivity outside the chosen ROI. We use a simple least-square fitting to compute the weights of the linear combination. Let *S(r,c)* and *b(r)* be the multi-coil images and the root-sum-of-squares (RSOS) image obtained from the center k-space. 3D spatial locations and coils are respectively indexed with *r* and *c*. *m(r)* is a binary mask selecting voxels inside the ROI. The ideal virtual coil profile is diag(*m(r)*)*b(r)*. The optimization problem is $\text{minimize}_w \| Sw - \text{diag}(m)b \|_2$, where w(c) is the weights for the virtual coil. The analytical solution to this problem is $w = S^{\dagger}\text{diag}(m)b$, where $S^{\dagger} = \left(S^T S\right)^{-1} S^T$ is the pseudo-inverse of *S*.

Motion Estimation and Correction The multi-coil Butterfly navigators [2] are linearly combined using weights *w*, and then local motion is estimated from the virtual coil navigator. Rigid motion correction is performed by applying a linear phase to the samples in k-space. The motion measurements are also used to derive data-consistency weights in a soft-gated ESPIRiT reconstruction [3]. The motion artifacts in the ROI should be suppressed in the reconstructed image.

Experiments Free-breathing 4D-Flow scans were performed on pediatric subjects (Study 1: 3.8 yr male; Study 2: 5.6 yr female) in a 3T GE MR750 scanner using a 32-channel cardiac coil. Feraheme contrast-enhancement and a 3D SPGR sequence with fat saturation were used in the scans with the following parameters: min TE (1.8 ms), min TR (9.1 ms with fat-saturation pulse), flip angle = 15°, bandwidth = ±83.33 kHz, resolution = (0.8,0.8,1.4) mm, FOV = (24.0,16.8,16.8) cm. The scan time for both studies was about 11min (R=6). The cardiac acceptance window was set to 25% of RR-interval in end diastole. Two virtual coil ROIs were manually selected to cover the heart and the liver. The result was compared with the same correction and reconstruction scheme, using motion measurements from the original navigator signal of the coil with the largest motion variance over time.

RESULTS & DISCUSSIONS The virtual coil navigators had superior spatial selectivity compared to original navigators (FIG 1) and improved the efficacy and robustness of motion correction (FIG 2&3). Although virtual coil images have lower SNR (FIG 1b), sufficient signal is obtained for accurate motion estimation, since the navigators are sampled near the center of k-space. It is also worth noting that the localization ability of virtual coils depends on coil array configuration, and the performance should improve with a denser coil array.

We demonstrate how the use of virtual coils effectively localizes the spatial sensitivity of 1D projection navigators. In free-breathing cardiac MRI, virtual coil navigators improve correction for both cardiac motion and respiratory induced motion of the heart. This technique can be easily generalized to simpler navigators, such as DC navigators [4]. In addition to motion correction, the virtual coil navigators can robustly separate cardiac and respiratory motion (FIG 1a), which can be used in cardiac cycle synchronization/gating and respiratory triggering/gating.

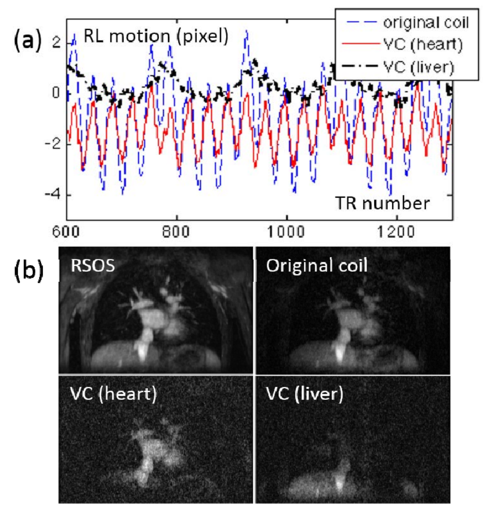

FIG. 1 a. Motion measured from an original coil, and virtual coils with ROIs in the heart and in the liver. b. Sensitivity profiles of one original coil and the virtual coils. Respiratory and cardiac motions are superimposed in the measurements of the original coil, which agrees with its flat sensitivity profile. The sensitivities of virtual coils are localized to the selected ROIs, and they can track motion of different parts separately.

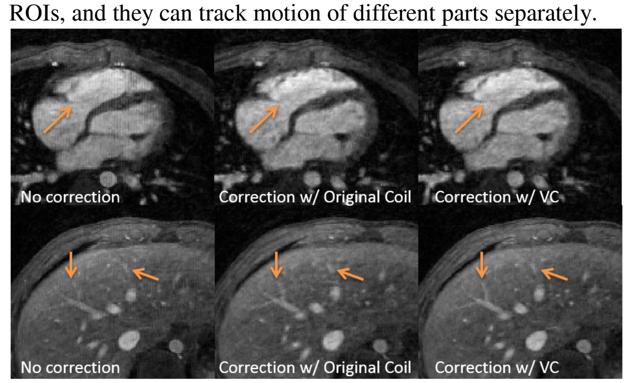

FIG. 2 Results in Study 1. After rigid motion correction based on the original coil measurements, motion induced blurring was reduced. The effect of correction was improved by using the localized virtual coils (VCs), as shown by the sharpening of the fine structures in the heart and the liver (the arrows).

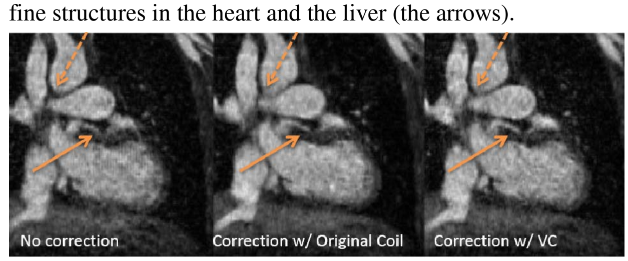

FIG. 3 Results in Study 2. In this case, motion correction using the original coil measurement introduced additional blurring in part of the heart (dashed arrows). Correction based on the localized VC measurement did not have this side effect, and the sharpness of coronary arteries was increased (solid arrows).

REFERENCE: [1] L Feng et al, ISMRM 2014, p4360; [2] JY Cheng et al, MRM 2012, 68: 1785-1797; [3] JY Cheng et al, JMRI 2014, doi: 10.1002/jmri.24785; [4] AC Brau and JH Brittain, MRM 2006, 55: 263-270.