Prospective motion correction using an MR-Tracking Tetrahedron for intra-cavitary MRI

L. Qin[1], E. J. Schmidt[1], W. S. Hoge[1], J. Santos[2], C. Tempany-Afdhal[1], K. Butts-Pauly[3], and C. L. Dumoulin[4]
[1]Radiology, Harvard Medical School, Boston, MA, United States, [2]Electrical Engineering, Stanford University, [3]Radiology, Stanford University, [4]Radiology, Cincinnati Children's Hospital

Introduction
Intra-cavitary imaging coils have been developed to achieve improvements in image signal-to-noise ratio (SNR) of the order of 5-10, such as those used for prostate, cardiac and arterial wall imaging. This increased local SNR can be used to generate higher spatial resolution. However, since both the anatomy and the coil are moving during imaging, imaging with such coils is more prone to motion artifacts. To resolve this issue, we propose integrating active MR-tracking coils into an intra-cavitary imaging coil for motion detection, and to perform prospective motion (rotation and translation) corrections in real-time [1], so that the entire image can be acquired in a "static" frame of reference.

Method
To test the feasibility of the proposed method, we constructed a Tetrahedral-shaped array of MR-tracking coils to provide motion information (Fig 1a,b). Four receive coils are fixed to its 4 vertices with a distance of 3cm from each other. The location of each coil is detected with a tracking sequence (Fig 1c), which includes a nonselective RF pulse followed by a gradient readout along a spatial axis [2]. A spoiler gradient in an orthogonal axis is used to eliminate background signal originating from the larger volume and coupling to the adjacent imaging coil, while preserving signal in the localized receive area of the coil. Peak location of the Fourier-transformed signal provides the coil location (Fig 1d). Since each coil is connected to an independent receive channel, their locations are detected simultaneously, from which rigid-body motion is calculated. The 3D shape of the Tetrahedral allows accurate 6-degree-of-freedom (DOF) motion detection (i.e. 3 rotations and 3 translations).
This tracking sequence is integrated with a 2D-GRE pulse sequence. Before each imaging segment (encompassing one or several k-space lines) the tracking segment is added. Calculated motion parameters are fed back to the imaging sequence, for real-time adjustment of its gradient rotation matrix, RF excitation and receiver frequency, and phase, thus compensating for the motion. To further increase robustness, the motion parameters acquired after the imaging segment are compared with the ones taken before the segment. If motion exceeds a preset threshold, the acquired k-space lines in this segment are discarded since motion occurred during acquisition, and the same k-space segment is then re-acquired later on.

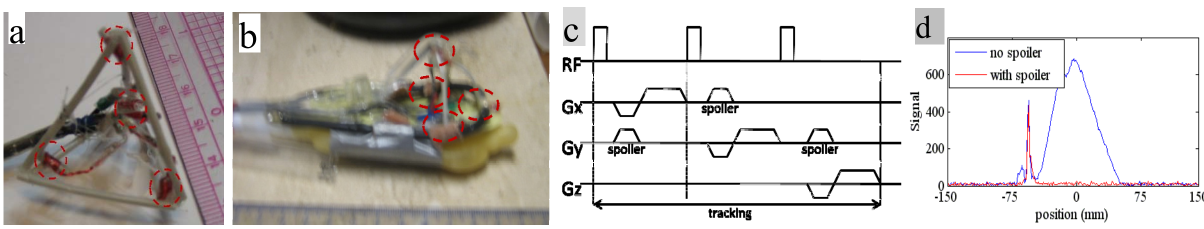

Fig.1 (a) Tetrahedron device (tracking coils: red dotted lines). (b) Endo-rectal coil integrated with Tetrahedron device. Device is folded during insertion. (c) Tracking sequence. (d) Example of tracking signal from one tracking coil, with &without spoiler gradients employed.

Results
The experiments were performed on a GE (Milwaukee, WI) 1.5T scanner. The tetrahedron was rigidly tied and integrated with multiple imaging coils. One such implementation, with a Medrad endo-rectal coil, is demonstrated (Fig. 1b). Proof-of-principle experiments were performed using a table rocking apparatus to simulate S/I motion with rapid motion (maximum speed 20mm/sec) followed by relatively "quiet" (motionless) periods. The tracking sequence tracks the motion at 20fps. Imaging was only performed when MR-Tracking detected "quiet" periods, based on below-threshold motion of 1 mm between adjacent tracking results. Imaging parameters: TR 17ms, TE 7ms, flip angle 30˚. Figure 2 shows motion correction results. Images (a) are coronal slices (resolution $0.7\times0.7\times3mm^3$) where S/I motion is applied in the frequency encoding direction. Images (c) are axial slices (resolution $0.8\times0.8\times3mm^3$) where motion is applied in the slice selection direction. (b) shows the 10 mm motion displacement. In this fast movement case, the prospective motion correction mainly acquires data in the upper and lower plateau periods. Most data acquired during fast motion (sloped periods) is discarded. Both in-plane and through-plane motion correction show significant image quality improvement compared to the images without correction.

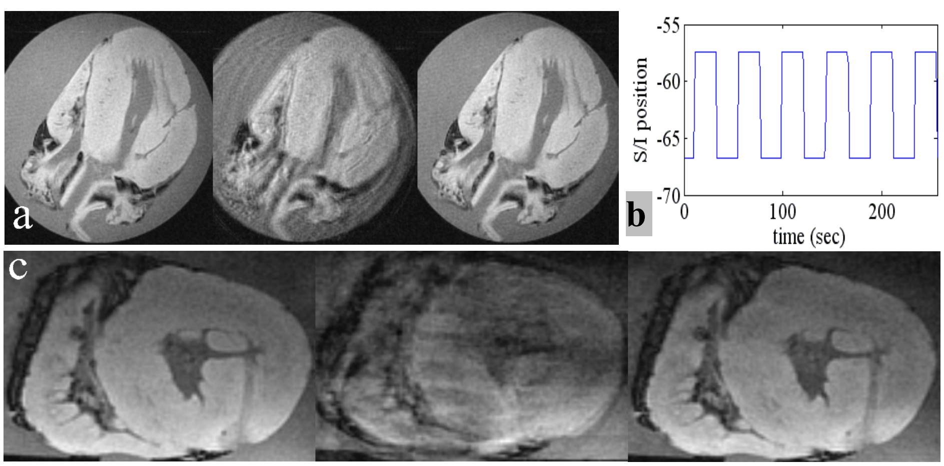

Fig.2 (a) Prospective motion correction in a moving ex-vivo swine heart using tetrahedral-based tracking. (a) in-plane motion correction, left: stationary image; middle: moving without correction; right: moving with correction; (b) moving pattern detected with tracking coils; (c) through-plane motion correction, left: stationary image; middle: moving without correction; right: moving with correction.

Conclusion
The proposed prospective motion correction using a Tetrahedron tracking coil removes motion artifacts that are frequently encountered with intra-cavitary coil imaging. In-vivo experiments will be performed in the near future.

Reference
[1] Qin L, et al, Magn Reson Med, 2009. 62:924-934.
[2] Dumoulin CL, et al. Magn Reson Med, 1993; 29: 411-415.