Respiratory Motion Estimation Using Real-Time 3D Imaging for Improving Roadmaps in Image Guided Interventions

R. Boubertakh[1,2], S. Uribe[1], R. S. Razavi[1], D. L.G. Hill[2], and T. Schaeffter[1]

[1]Interdisciplinary Medical Imaging Group, Division of Imaging Sciences, King's College London, London, United Kingdom, [2]Centre for Medical Image Computing, University College London, London, United Kingdom

Introduction: Image-guided cardiovascular intervention using a hybrid magnetic resonance (MR) and X-ray (XMR) system has been successfully applied in patients [1]. An important step in this procedure is the registration of a pre-acquired 3D surface rendered roadmap obtained from a breath-hold scan, with real-time X-ray fluoroscopy images. A major source of errors in catheter localization during the intervention is the displacement of the heart because of respiratory motion. Thus, it is extremely desirable to use the real-time diaphragm position from fluoroscopic images and a respiratory motion model of the heart to accurately deform the roadmap to the actual position of the breathing state. In this work we investigate the use of free-breathing scans from both low resolution real-time [2] and retrospectively self-gated respiratory volumes to obtain a patient specific respiratory motion model of the heart. Affine respiratory motion parameters have been derived for both acquisitions and validated on the retrospectively gated images.

Methods: Four healthy volunteers were imaged on a 1.5 T Achieva MR system (Philips Medical Systems, the Netherlands) using a five-channel cardiac coil. Low resolution real-time 3D volumes (50 dynamics) covering the whole heart were acquired in sagittal orientation using 2D-SENSE (R=2.0x1.2), 2D partial-Fourier (0.625x0.75), using a resolution of 3.3x3.3x5.5 mm^3, 25 slices and 920 ms/dynamic. For each subject, the end-exhale respiratory position was identified and all dynamics were registered to this reference using affine registration. Moreover, from the corresponding saved raw data, the central profiles ($k_y = k_z = 0$) were employed to generate a respiratory motion signal using the cross-correlation similarity measure.

To validate the affine registration parameters with a data set exempt from cardiac motion blurring, we acquired an additional series of four whole-heart free-breathing 3D volumes for retrospective cardiac and respiratory gating. We used a segmented balanced SSFP sequence modified by adding a center profile ($k_y = k_z = 0$) at the beginning of each *k*-space segment [3]. This profile served to derive the breathing motion. The acquired images consisted of 70 slices and 13 cardiac phases with an acquired spatial resolution of 2x2x2.3 mm^3, TR/TE 3.1/1.6 ms, 60 ° flip angle, SENSE factor 2 and 1D partial-Fourier (0.625). The duration of the series was 10 min.

The respiratory position was then determined by computing the cross-correlation between the center profiles. Offline retrospective respiratory gating was performed on the raw data to select: 1) end-exhale, 2) intermediate and 3) end-inhale positions. The corresponding end-diastolic phase was reconstructed using a 115 ms acquisition window. Finally, affine registration to end-exhale position was performed and the motion parameters compared to the ones obtained from the real-time images.

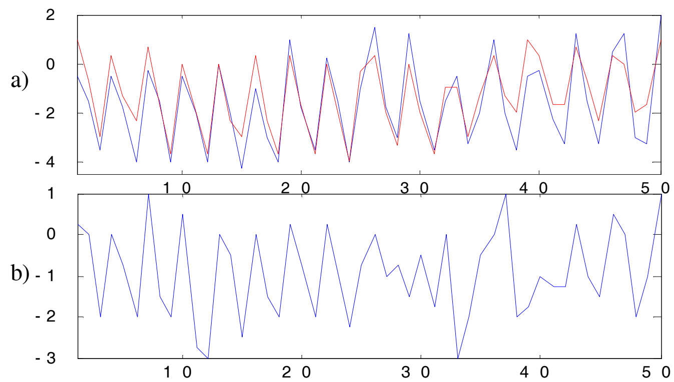

Figure 1. Affine motion parameters variations with time (dyamics): a) FH translation (blue line) and translation obtained from cross-correlation (red line). b) Shearing values in the FH/AP direction.

Volunteer	1	2	3	4
FH translation range [mm]	10.00	10.5	6.25	6.10
FH translation /cross-correlation scaling	0.61	0.37	0.76	0.74
Shearing range	7.50	6.50	4.00	9.25

Table 1. FH translation and shearing parameter ranges.

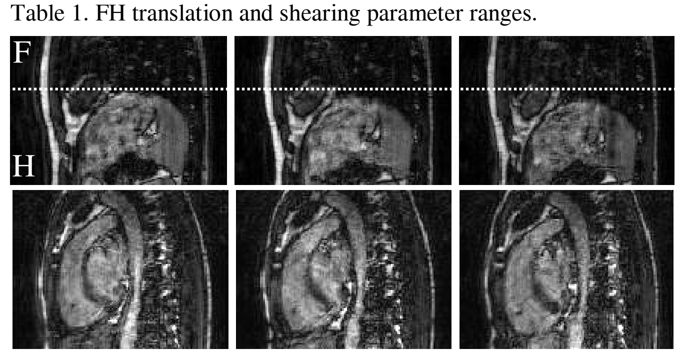

Figure 2. Retrospective respiratory gating: end-exhale (left), intermediate (center) and end-inhale positions (right). The top row indicates the liver position for the three breathing states.

Results: From the real-time volumes, the main translation motion component was found to be in the feet-head (FH) direction, corresponding to diaphragmatic translation (Fig 1). Rotation and scaling factors where negligible, which could be due to the blurring of cardiac motion. However, the shearing parameters were important.
Figure 2 shows the three retrospectively reconstructed respiratory positions. We can see that for the same cardiac phase (end-diastole), the shapes of the left and right ventricles vary with the breathing cycle. The registration to end-exhale showed a translation of +4.25 and +7.75 mm for the middle and end-inhale positions respectively. As with the low resolution scans, the other major components for the affine parameters were the shearing values along the FH direction.

Conclusion: In this work we showed that the main components of motion during respiration are the translation and shearing in the FH direction, and that these can be obtained from low resolution free-breathing acquisitions by using affine registration. The translation corresponding to the motion of the diaphragm can also be extracted from the *k*-space central profiles. This motion has been successfully used to retrospectively gate a cine free-breathing data set and reconstruct three distinct respiratory positions to validate the derived motion parameters. These parameters could subsequently be used to map a high resolution volume for a single breathing position, into different respiratory positions and thus improve image guidance during X-ray interventional procedures.

References: [1] Razavi et *al* Lancet 2003, [2] Manke et *al*, MRM 2003, [3] Uribe et *al*, in press, MRM 2006.