Prospective High Resolution Respiratory Resolved Whole-Heart MRI for Image-Guided Cardiovascular Interventions

C. Kolbitsch[1], C. Prieto[1], C. Buerger[1], R. Razavi[1], J. Smink[2], and T. Schaeffter[1]
[1]Division of Imaging Sciences and Biomedical Engineering, King's College London, London, United Kingdom, [2]Philips Healthcare, Best, Netherlands

INTRODUCTION: Image-guided cardiac catheterisations are an important clinical tool to diagnose and treat cardiovascular diseases minimal-invasively. Several approaches have been presented to improve this procedure using 3D whole-heart MRI data ("roadmap") as additional guidance information during the procedure, which is performed under X-ray [1]. Recently the use of dynamic roadmaps has been proposed to model an affine deformation of the 3D roadmap due to respiratory motion [2]. This is important for the interventionalist (e.g. in an EP-ablation procedure) to avoid aligning errors (up to 20mm) due to breathing motion. However, for this several MRI scans are needed, making the procedure very time consuming and sometimes strenuous for the patient. Here we propose a method that acquires simultaneously a high-resolution 3D image and all the necessary respiratory motion information in one scan. In particular, the high-resolution data is used to segment the 3D roadmap [3] of the heart and the information of the respiratory motion is used to derive an affine model to deform the roadmap.

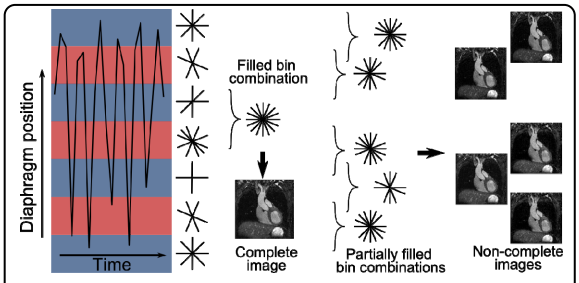

Fig. 1: Sampling scheme. Data is acquired simultaneously at different respiratory phases, so called bins (blue/red bars). Data from two adjacent bins is complementary and can be combined for image reconstruction. The scan finishes if two contiguous bins yield a complete k-space and a 3D high resolution image can be obtained from this data. Due to the interleaved bit reversed sampling scheme additional non-completely filled images can be reconstructed at different breathing phases providing respiratory motion information.

METHODS: Data was acquired through the whole respiratory cycle using the recently introduced Radial Phase Encoding (RPE) trajectory [4] with a radial bit reversed order. RPE combines Cartesian frequency encoding (FE) with an interleaved bit reversed radial-like sampling pattern in the phase encoding plane. The sampling strategy allows for the combination of k-space data from any two consecutive respiratory phases, so called respiratory bins. The acquisition ends when one combination of bins is completed allowing for the reconstruction of a "complete" (not necessary fully sampled) image (high resolution 3D roadmap) and several "non-completely filled" images (Fig. 1). The undersampling properties of the RPE scheme [5] ensure that images can be reconstructed also for the non-completely filled images providing information about respiratory motion.

Image acquisition: The proposed method was implemented on a 1.5T MRI scanner (Philips Medical Systems, Best, The Netherlands) and whole-heart data was acquired in five healthy volunteers: balanced SSFP sequence with T2 prep pulse (TE=50ms), FOV: 288mm^3, isotropic resolution: 1.5mm^3, SPIR, flip angle: 90°, TR/TE = 4.3/2.2ms, segmented approach (TFE factor = 24) with low-high profile order and an undersampling factor of 8 for the complete image. Each bin covered a diaphragm displacement of 3mm and mid-diastolic cardiac triggering was applied. The total acquisition time was between 8.4 – 14.8min depending on the breathing type. Images were reconstructed using an iterative SENSE reconstruction [6].

Motion model: A 3D affine registration[2] between the complete (C) and non-complete (nC) images was carried out to determine the respiratory motion. In order to assess the accuracy of the obtained model, the maximum target registration error (maxTRE) was determined comparing the nC images to the acquired C image (Orig) and comparing the nC images to the C image which was transformed with the obtained motion model to the respiratory stages of the nC images (Trans) (Fig. 2). This was carried out for 8 anatomical landmarks (left/right apex, left/right tricuspid valve, offspring of left/right coronary artery, left/right annulus) in each volunteer.

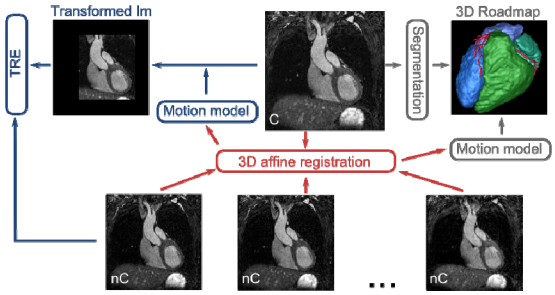

Fig.2: A 3D affine registration is carried out between the complete (C) and non-completely filled (nC) images to obtain a motion model. The target registration error (TRE) is determined by comparing nC to C which has been transformed by the motion model. The 3D roadmap is obtained as a segmentation of the C image combined with the affine motion model.

RESULTS: The validation of the motion model yields a maxTRE of 3.4mm with a very small standard deviation of 0.77 in contrast to the original images with a maxTRE of more than 15mm (Fig. 3a). A segmented 3D roadmap and a segmented coronary tree transformed to different respiratory stages are shown in Fig. 3b and c.

CONCLUSION: We have presented a method which yields a respiratory resolved 3D high resolution roadmap within one 3D whole-heart scan. The maximum inaccuracy of the motion model was determined to be less than 3.4 mm and seems to be independent of the landmark position. This suggests that maxTRE is caused mainly by inaccuracy during the measurements of landmark positions rather than by a shortcoming of the motion model. The respiratory resolution (respiratory bin size) is defined prospectively, and therefore the resulting number of non-complete image depends on the subject specific respiratory motion. The availability of a full respiratory motion model in addition to 3D high resolution data without an increase in scan time can be of great value for many interventional procedures.

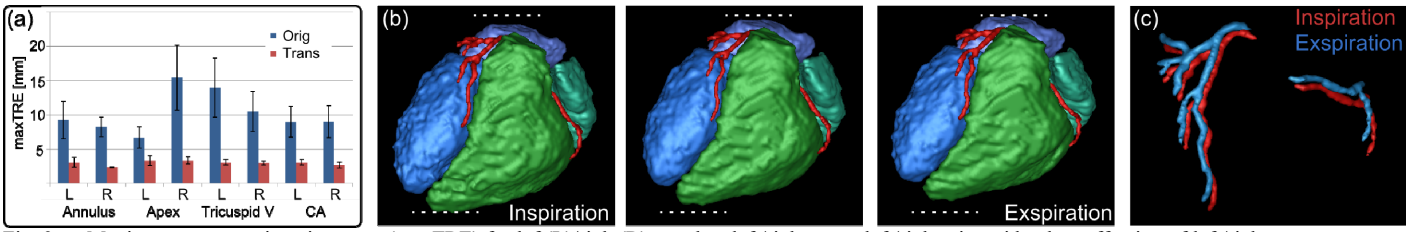

Fig. 3. a: Maximum target registration error (maxTRE) for left(L)/right(R) annulus, left/right apex, left/right tricuspid valve, offspring of left/right coronary artery (CA) comparing the original images (Orig) to the images transformed with the motion model (Trans). The error bars indicate the standard deviation of maxTRE for the volunteers. b: Segmented heart transformed to inspiration, mid-inspiration and expiration with the obtained motion model. c: Segmented coronary tree

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