

Highly efficient respiratory gating in whole heart MR employing non-rigid retrospective motion correction

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Introduction: Three-dimensional whole heart imaging becomes the method of choice in various cardiac applications [1] as it avoids extensive planning of imaging slices and allows reconstructing arbitrary slice orientations. The drawback of the method is a relatively long scan time (on the order of several minutes) which requires motion compensation to suppress motion artifacts. A typical approach to respiratory motion correction uses prospective navigator based gating or triggering including slice tracking. The technique has proven relatively robust; however a lot of data are rejected and only 30-60% of the overall scan time contributes to the reconstructed images. Recently, retrospective approaches have successfully been implemented by extending the image encoding matrix with motion operators and solving the system iteratively [2-4]. This allows for increased gating window widths or even continuous scanning during the entire breathing cycle but necessitates detailed information of the underlying motion vector field during each acquisition. In this work, a template-based approach for non-rigid retrospective motion correction is proposed to correct for respiratory motion artifacts in free-breathing coronary MR scans with gating windows as large as 20mm. The volunteer-specific motion model is computed from a low-resolution multi-slice scan acquired in an interleaved manner simultaneously with the 3D acquisition.

Methods: 3D whole heart images were acquired in four healthy subjects on a 1.5T Philips Achieva System (Philips Healthcare, Best, The Netherlands). The pulse sequence was modified based on a standard navigator-gated 3D balanced SSFP sequence with an increased gating window of 20mm and an isotropic voxel size of 1.33mm. To collect motion information an additional sagittal slice was acquired interleaved in single-shot mode with a voxel size of 4x4x4mm² (Fig. 1). The slice was automatically cycled through a range of locations in consecutive heart cycles to cover the entire heart in left-right direction. Upon image reconstruction, information from the set of low-resolution multi-slice images served as input to motion model calculation. The actual motion vector fields for different respiratory states were calculated using an image registration algorithm [5]. Missing respiratory states or image slices were linearly inter- and extrapolated. For comparison, a reference 3D scan with a gating window of 5mm was acquired. Before image reconstruction, signals from all coil elements were combined to two virtual coils using array compression [6] to reduce the memory load and reconstruction time. The extended encoding matrix (Fig. 2) was inverted iteratively with an LSQR algorithm using six iterations for each reconstruction. Reconstruction time using Matlab (Mathworks, Natick, MA, USA) on a standard computer was on the order of 15min per virtual coil.

Results: The average gating efficiency increased from 47%±18% for the 5mm gated reference to 93%±7% for the 20mm gated scan. The image quality of the motion corrected image was found to be comparable to the reference scan (Fig. 3). Image contrast and sharpness of fine structures and vessels improved considerably when comparing data with retrospective motion correction relative to the uncorrected data of the same scan.

Discussion: It has been shown that respiratory motion artifacts in cardiac 3D imaging can be retrospectively corrected using a non-rigid motion model derived from data acquired during the sequence pauses in each heart cycle. Respiratory drifts are automatically accounted for by continuous acquisition of the motion model data during segmented 3D acquisitions. With this method, gating efficiency could be doubled and thus scan times reduced underlining the potential of the method to significantly reduce scan times in whole-heart acquisitions.

References:

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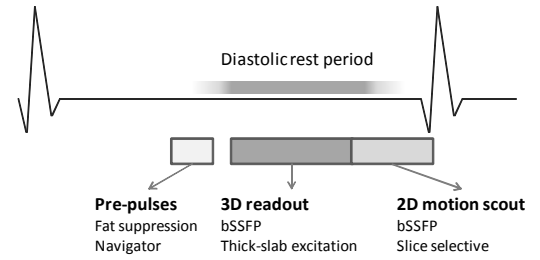


Figure 1: Schematic pulse sequence of the 3D whole-heart acquisition and the additional image slice for retrieving the motion model.

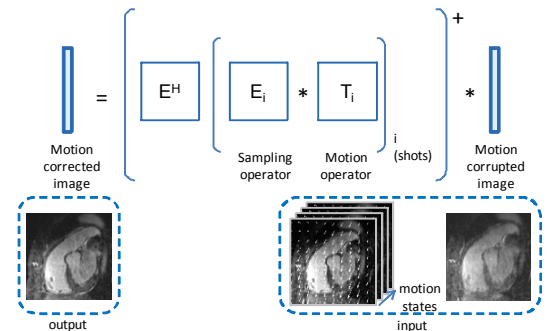


Figure 2: Matrix formalism describing motion during a multi-shot scan. T_i are motion operators which capture the motion per voxel from the reference to the respiratory state at the given shot. E_i and E^H are standard sampling operators and their Hermitian conjugate, respectively. The '+' indicates the pseudo-inverse.

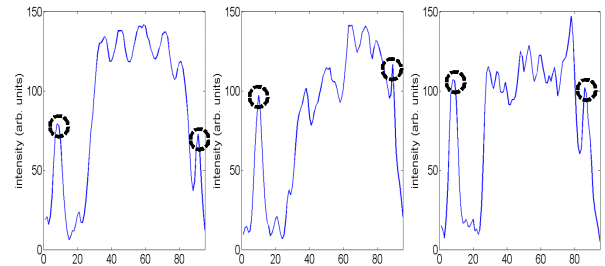
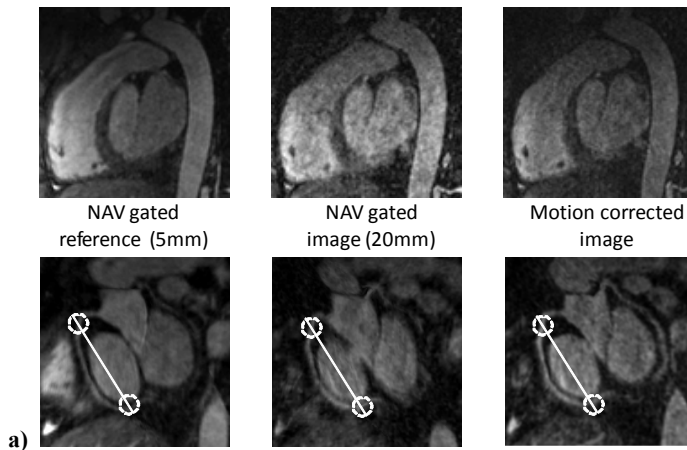


Figure 3: a) Sagittal slice (upper row) and slice along the coronary arteries (lower row) for the 5mm gated reference, the 20mm gated image and the retrospectively corrected image. b) Intensity profile plots along the white line.