Comparison of image-based and reconstruction-based respiratory motion correction techniques for 3D whole-heart MRI

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INTRODUCTION: MRI is an important clinical tool for whole-heart imaging [1]. In order to obtain 3D high-resolution anatomical information, data acquisition needs to be carried out over multiple respiratory cycles. Gating techniques are commonly used to reduce respiratory motion artefacts [2]. Nevertheless, the efficiency of gated MRI acquisitions is highly subject dependent and can lead to long scan times. Recently, several approaches have been presented which use motion correction to minimize artefacts due to breathing and ensure scan efficiencies larger than 90% [3]. The majority of these techniques carry out motion correction on the reconstructed (usually highly undersampled) images and the final image is obtained by averaging the motion corrected images (image based motion correction – IMC). Batchelor et al. have proposed to incorporate the obtained motion information directly into an iterative reconstruction approach (reconstruction based motion correction – RMC) [4].
Here we compare IMC and RMC to a standard respiratory gated (RG) approach for whole-heart MRI. Data is acquired with a Golden Radial Phase Encoding (GRPE) trajectory allowing for retrospective motion compensation due to its advantageous sampling properties [5]. A comparison in 4 volunteers shows that RMC leads to similar image quality but shorter scan times than RG and a higher vessel sharpness compared to IMC.

METHODS: GRPE sampling scheme: For GRPE data is obtained using Cartesian frequency encoding with the phase encoding points located on radial spokes (Fig 1a). Successively acquired radial spokes are rotated by the Golden angle of 111.24^o which ensures a homogenous covering of k-space over time. This allows for retrospective gating and also for the separation of data into multiple respiratory bins.
Image acquisition: GRPE data was acquired in 4 healthy volunteers on a 1.5T Philips MRI scanner. The imaging sequence consisted of a balanced SSFP sequence (FOV: $269x269x269mm^3$, isotropic resolution: $1.4mm^3$, TR/TE/angle = $4.9/2.5ms/90^o$) preceded by a T2 prep pulse (TE=50ms) and fat suppression (SPIR). A SENSE factor of 2 was used along each radial phase encoding line. For comparison, data was 2-fold oversampled along the angular direction to ensure enough data is available in each bin to calculate highly accurate motion fields and to allow for retrospective gating yielding the same amount of data than IMC and RMC.
Respiratory motion compensation: For IMC and RMC the acquired data was separated into multiple respiratory bins (3mm width) based on a diaphragmatic pencil-beam navigator signal. For bins with high undersampling factors the bin width was increased to ensure the maximum undersampling factor was 6 [5]. For some volunteers outliers were removed which slightly reduced the scan efficiency (Eff) from 100% to ~98%. Intra-bin correction of foot-head translation was carried out for all bins and also for the gating RG window using a scaling factor between diaphragm and heart motion of 0.6. Motion parameters were obtained using an affine registration in a region-of-interest (ROI) covering the heart [6] (Fig 1b). The same amount of data (50% of the total acquired data) was used for all three approaches, to ensure this does not influence the evaluation. An overview of IMC, RMC and RG is shown in Fig 1c. All image reconstructions were carried out using an iterative SENSE approach [7].
Image analysis: A Quantitative analysis was carried out using the soapbubble tool [8] to compare IMC, RMC and RG with regard to visible vessel length (VL) and vessel sharpness (VS) of the left (LCA) and right (RCA) coronary artery. In addition image quality (Q) was assessed by two experienced reviewers on reformatted images showing LCA and RCA using a 5-point scale: 0(not interpretable), 1(poor), 2(fair), 3(acceptable) and 4(excellent) coronary vessel detection.

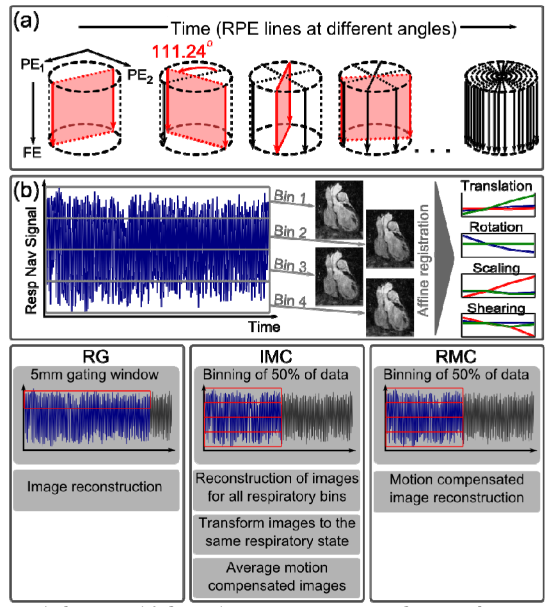

Fig 1: Overview. (a) GRPE 3D data acquisition with Cartesian fequency encoding (FE) and phase encoding (PE) along radial lines tilted by 111.24°. (b) Binning of data using a respiratory navigator signal and calculation of affine motion parameters. (c) Workflow for respiratory gating (RG), image (IMC) and reconstruction based motion correction.

Tab. 1: Results of comparison between respiratory gating, image and reconstruction based motion correction. All values mean ± standard deviation. Best vessel depiction is VS = 1.

	LCA		RCA			
	VS	VL [mm]	VS	VL [mm]	Eff [%]	Q
RG	0.66±0.05	4.73±0.38	0.65±0.09	15.09±5.09	54.97±2.18	3.13±0.44
IMC	0.40±0.06	4.57±0.54	0.43±0.07	17.04±7.23	98.36±1.43	1.44±0.68
RMC	0.59±0.10	4.51±1.45	0.61±0.10	15.04±7.45	98.36±1.43	2.56±0.82

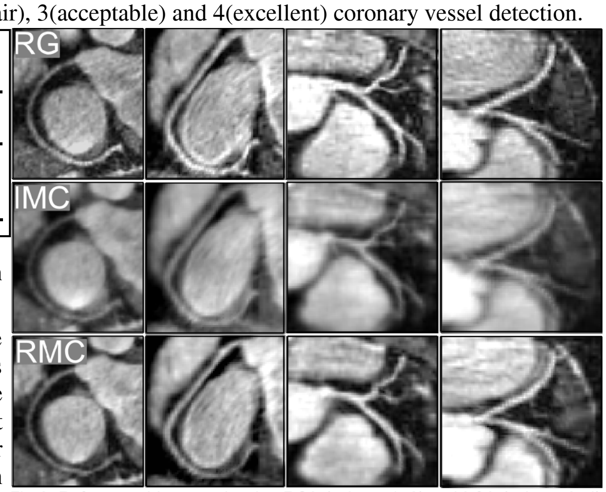

Fig 2: Reformatted images showing RCA (column 1+2) and LCA (column 3+4) using respiratory gating (RG) and image (IMC) and reconstruction (RMC) based motion correction.

RESULTS: Reformatted RCA and LCA images for RG, IMC and RMC are shown in Fig.2 for different volunteers. The mean values for VS, VL and Q are given in Tab. 1.

CONCLUSION: We have compared three different approaches to minimise respiratory motion artefacts in high-resolution 3D whole-heart imaging. RMC was shown to yield a better depiction of the coronary arteries than IMC. Compared to the standard approach of respiratory gating RMC provided similar image quality but allowed for a scan time reduction of 43%, making it a highly efficient approach for whole-heart MRI. Future studies will analyse the effect of inaccuracies in the motion parameter estimation on IMC and RMC.

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