A patient-adapted navigator tracking approach for prospective 3D respiratory motion correction in free-breathing myocardial perfusion imaging

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INTRODUCTION Quantitative analysis of myocardial perfusion using free-breathing first-pass perfusion MRI is degraded by respiratory induced motion of the heart. Conventional strategies to correct this motion include the manual alignment of each image to fit a reference image and automated retrospective registration algorithms, such as [1]. However, with current 2D multi-slice techniques, the through-plane motion cannot be corrected after the acquisition due to the poor spatial resolution in the slice-selection direction (≥10 mm). Therefore, the purpose of this work is to develop a prospective method of both in- and through-plane correction applicable to free-breathing myocardial perfusion imaging. The implemented approach is based on real-time navigator tracking [2] with the use of subject-specific scale factors to relate diaphragmatic and cardiac motion. The scale factors were estimated from a free-breathing calibration scan [3] to allow accurate prediction and correction of the cardiac motion during the scan. The efficiency of the strategy was evaluated in healthy volunteers, and a first- pass perfusion study was performed to demonstrate the clinical potential of the technique.

METHODS Experiments were conducted on five healthy volunteers and one patient with a myocardial infarction. The examinations were performed on a whole body 1.5T MR system (Gyroscan INTERA, Philips Medical Systems) equipped with a five-element cardiac receive coil. A calibration scan was initially performed on all individuals to determine the subject-specific scale factors used for navigator tracking: The left ventricular (LV) position was automatically registered in two time-series of orthogonal images (sagittal and coronal view), acquired during free-breathing using a single-shot, ECG-triggered, balanced-FFE sequence (α=55°, T_R=2.32ms, FOV 384x384mm^2, 128x128 matrix, slice thickness=10mm, 1.5x1.5mm^2 reconstructed pixel size). A conventional right diaphragm navigator was applied immediately prior to each imaging block, and the registered LV positions were related to the corresponding navigator positions using linear regression (see figure 1), such that during subsequent scans the LV translation could be predicted and used for 3D navigator tracking.

The subject-specific scale factors were subsequently used for 3D navigator tracking in free-breathing dynamic studies of two short-axis slices. Contrast agent was only administered for the patient study (0.1 mmol/kg Gd-DTPA). Motion correction was performed in an interleaved fashion, as depicted in figure 2, in order to simultaneously acquire a corrected and non-corrected data set under the same respiratory (and contrast agent) conditions. Images were acquired for a total of 120 consecutive cardiac cycles using a single-shot, ECG-triggered, spoiled gradient echo sequence (α=15°, T_R=2.62ms, FOV 430x430mm^2, 96x128 matrix, slice thickness=10mm, 1.67x1.67mm^2 reconstructed pixel size). Heavily T1-weighted images were achieved by applying a regional saturation (REST) slab prior to each imaging block (α=90°, SR delay time T_D=130ms). The REST-slab was aligned such that it covered the entire heart and as much as possible of the thorax, but without interfering with the navigator. This alignment minimizes in-flow effects from unsaturated spins while at the same time keeping the navigator signal intact (a non-selective saturation pulse applied before the navigator would destroy the navigator signal). The navigator was applied during the saturation delay period, immediately prior to each image acquisition block, in order to provide the most accurate measurement of the respiratory curve and for time efficiency reasons. The residual in-plane displacement of the LV was calculated in all images from three manually selected landmarks (see figure 3). The standard deviation of the displacements in both in-plane directions (denoted σ_x and σ_y) was used for comparing the residual motion in the corrected and non-corrected images.

RESULTS Experiments were successfully completed on all individuals. The developed strategy allowed a decrease in LV in-plane motion from 2.5±0.8mm to 0.9±0.4mm (mean± SD of all σ_x and σ_y), which is within the pixel size. Visual (CINE) inspections of the images showed a clear decrease in myocardial wall deformations and rotation within the corrected images, which is assumed to be due to the reduction of the through-plane motion. The first-pass signal-intensity time curves acquired in the patient study showed a remarkable decrease in signal variability in the corrected images (see figure 3).

DISCUSSION AND CONCLUSION The present work has demonstrated that patient-adapted navigator tracking can accurately correct the respiratory motion in all three dimensions during free-breathing MR myocardial perfusion imaging. The implemented approach is accurate and maintains both temporal resolution and spatial coverage (the number of acquired slices per RR-interval) by exploiting the "waste-time" between the saturation pulse and data sampling for applying the navigator. The observed decrease in myocardial wall deformations and rotation in the corrected images, due to the reduction of through-plane motion, suggests that retrospective motion correction strategies may in general over- or under-estimate the actual motion and thereby lead to incorrect results in the perfusion analysis. Patient studies are currently being carried out in order to evaluate the impact of through-plane motion correction on quantitative first-pass perfusion analysis.

REFERENCES [1] Dornier et al., J. MRI 2003;18:160–168. [2] Danias PG et al., Radiology 1997;203:733-736. [3] Manke et al., Magn. Res. Med. 2003;50:122–131.

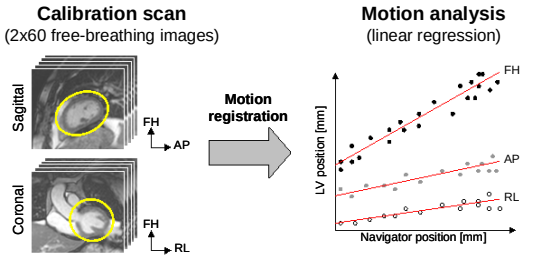

Figure 1. Estimating the subject-specific scale factors used for navigator tracking. The scale factors correspond to the linear regression slopes.

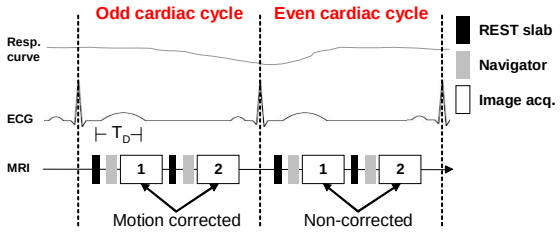

Figure 2. Timing diagram of the free-breathing myocardial perfusion sequence. Prospective respiratory motion correction was performed only in odd cardiac cycles.

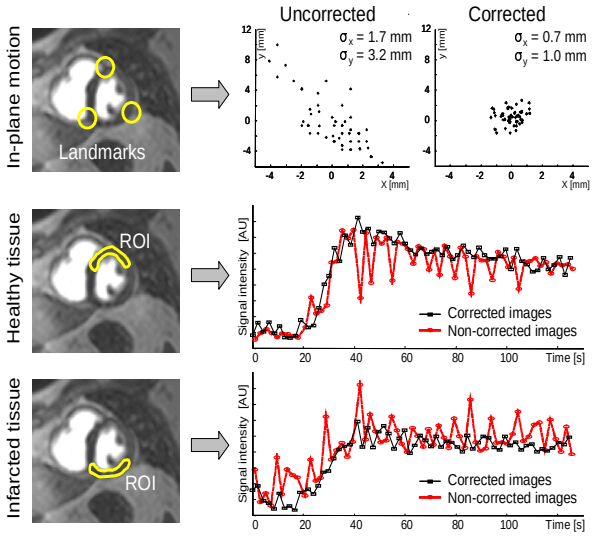

Figure 3. Corrected and non-corrected data from the patient first-pass perfusion study: The top row illustrates the residual in-plane motion, estimated from the three landmarks. The bottom rows show two signal-intensity time curves from healthy and infarcted tissue, respectively.