Quantification of myocardial perfusion using free-breathing MRI and prospective slice-tracking

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INTRODUCTION Quantification of myocardial perfusion using first-pass MRI conceptually fails in the presence of respiratory motion of the heart. This currently limits the clinical potential of the method. Indeed, breath-holding can be utilized in some patients to account for this problem, but in cases where the patient is not able to properly hold his/her breath or when there is a misalignment between images acquired at rest and stress, realignment of the images is required. The process of aligning the images can to some extent be automated, but reliable motion detection is often difficult before and during bolus arrival. Furthermore, misalignments along the through-plane direction cannot be corrected retrospectively. It has previously been suggested in a study of respiratory motion in healthy volunteers that prospective slice-tracking might overcome the problems related to breath-holding and retrospective correction by facilitating free-breathing myocardial perfusion MRI [1]. The purpose of this study was to investigate quantification of myocardial perfusion using free-breathing first-pass MRI and prospective slice-tracking.

METHODS Rest and stress myocardial perfusion MRI was performed in a total of 8 patients. All patients were examined on a whole-body 3.0T MR system (Gyroscan Achieva, Philips Medical Systems) equipped with a six-element cardiac receive coil. For prospective slice-tracking we used navigator echoes to monitor the motion of the right diaphragm and an underlying motion model of the heart. To take into account hysteretic effects and the variation between patients, a patient-calibrated 3-D translational motion model related to two temporally separated navigators was used (cf. figure 1). The calibration was performed automatically by an additional pre-scan depicting the respiratory motion of the heart [2, 3].

The calibrated motion model was used for prospective slice-tracking in free-breathing myocardial perfusion studies performed at stress and rest. Contrast agent was administered in a dose of 0.025 mmol/kg (Gd-DTPA) and for the stress exam adenosine was administered with an injection rate of 140 µg/kg/min. The first-pass of the contrast agent was imaged in 3 short-axis slices using an ECG-triggered, spoiled gradient echo sequence (α=18°, TR=2.53ms, FOV 420x370mm^2, matrix 144x136, slice thickness=8mm, SENSE factor 2, non-selective 90° SR prepulse). The navigator echoes were evenly distributed, appr. 150 ms. apart, and for any of the three slices the two immediately preceding navigators were used for motion prediction (cf. figure 2). In order to acquire both corrected and non-corrected data under the same physiological conditions prospective correction was performed in an interleaved fashion, as depicted in figure 2.

The residual in-plane displacement of the left ventricle (LV) was registered in all images using a normalized cross-correlation algorithm. Possible outliers were registered manually. A total of four data sets were generated for each slice: **A**: no correction, $\mathbf{A}_{ref}$: registered, **B**: prospective correction, and $\mathbf{B}_{ref}$: prospective correction and registered. For each data set, the myocardium was divided into 6 equidistant segments and each of the corresponding signal curves was fitted to a mono-exponential perfusion model using the signal in the LV cavity as the arterial input:

$$s_{myo}(t) = k_1 s_{LV}(t) \otimes e^{-(t-t_d)/k_2}$$

where k_1 represents perfusion. The baseline signal was subtracted from all signals and the time delay between the arterial input and myocardial signal curve (t_d) was manually assessed.

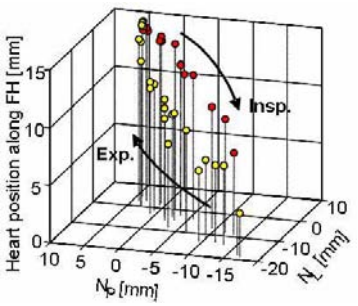

Figure 1. Calibration results from a patient illustrating that translation along the feet-to-head (FH) direction follows a different path during inspiration and expiration. This *hysteretic* effect can be modelled using two navigators (N_P, N_L) applied 150 ms apart.

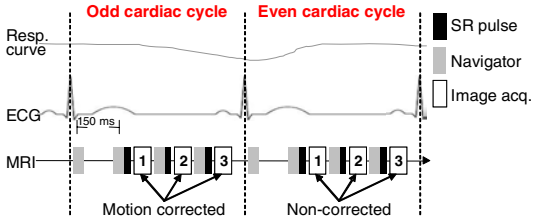

Figure 2. Timing diagram of the myocardial perfusion sequence.

RESULTS Experiments were successfully completed in all individuals. Prospective slice-tracking allowed a decrease in residual LV in-plane motion from 2.7±0.8mm to 1.4±0.4mm (mean±SD of the RMS errors). The mean error of k_1 *without* prospective correction was 79% (**A** vs. $\mathbf{A}_{ref}$) whereas *with* prospective correction the corresponding error was reduced to 20% (**B** vs. $\mathbf{B}_{ref}$). In general, there was no significant difference in performance between rest and stress examinations. Assuming that a 10% error of k_1 is acceptable for diagnostic use 64% of the myocardial segments acquired with prospective correction could be used, whereas only 35% of could be used without correction. See also figure 3.

DISCUSSION AND CONCLUSION The present study has demonstrated that it is possible to quantify myocardial perfusion using free-breathing first-pass MRI and prospective slice-tracking. Our results suggest that when in-plane motion is reduced by a factor of 2, the associated error of the calculated perfusion (k_1) is decreased by a factor of 4. This asymmetric relationship follows from the fact that the signal fluctuations are remarkably reduced in *both* the myocardial tissue curves and the arterial input function. Our results also suggest that in about one third of the myocardial segments the estimated perfusion might not be sufficiently accurate for diagnostic purposes. In most cases this is due to signal contaminations from regions outside the myocardium (e.g. the LV cavity), which occur during the bolus wash-in. To the extent that respiration is fairly stable during the wash-in, it should be possible to apply respiratory gating of the myocardial tissue curves to correct such segments. This needs to be studied in further detail. It could also be interesting to study the influence of the through-plane correction achieved with prospective slice-tracking (i.e. $\mathbf{A}_{ref}$ vs. $\mathbf{B}_{ref}$). This is not possible in the present setup due to the lack of a true reference data set. As a final remark, it should be mentioned that we did in fact experience some problems with the accuracy and reliability of the navigator, which has clearly affected the accuracy of the approach in a couple of the patients. It is believed that these problems arise from the field inhomogeneities at 3.0T combined with a decrease in SNR resulting from the repeated SR pulses. We are currently investigating alternative implementations of the navigator pulse in order to address this problem [1, 4].

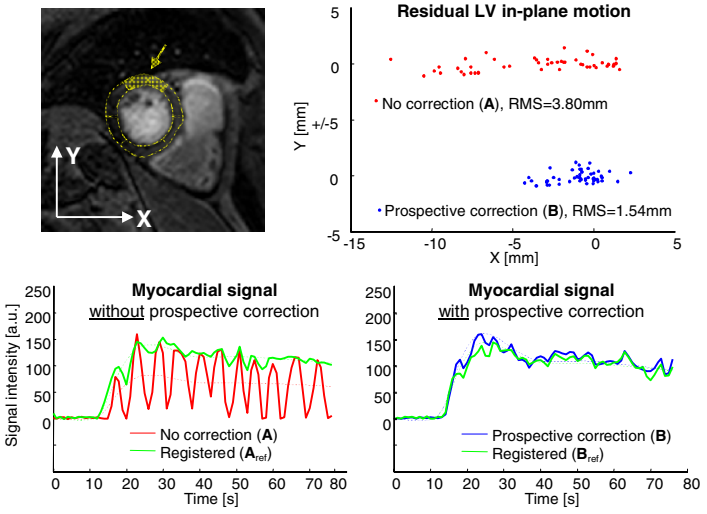

Figure 3. Example patient results comparing non-corrected and prospectively corrected data. Top right: Residual left ventricular in-plane displacements. Bottom: The 4 different signals from the same myocardial segment (**A**, $\mathbf{A}_{ref}$, **B**, and $\mathbf{B}_{ref}$) and their corresponding mono-exponential model fit (dotted lines).

REFERENCES [1] Pedersen et al., Proc ISMRM 2005 p. 512. [2] Manke et al., Magn Res Med 2003;50:122–131. [3] Nehrke et al., Magn Res Med 2005;54:1130-1138. [4] Stehning et al, Proc ISMRM 2006