On the influence of respiratory motion in quantitative myocardial perfusion MRI

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INTRODUCTION Pixel-based analysis of myocardial perfusion using first-pass MRI has the advantage of using the full underlying spatial resolution of the images, but requires accurate motion compensation in the presence of respiratory motion to maintain the true spatial resolution. Numerous motion compensation strategies have been proposed (e.g. breath-holding and image registration), yet little is known about how accurate such approaches should be in order to obtain reliable perfusion measurements. For instance, it is a well-known problem that breath-holding has relatively low reproducibility, which increases the risk of image misalignments between rest and stress examinations. It remains elusive, however, to what extent this affects measurements of myocardial perfusion. Another common problem is that the models employed for correcting image misalignments are typically too simple to adequately resemble the physiological motion of the heart. For example, image registration is fundamentally limited to in-plane correction, and it is often (false)ly assumed that the motion of the heart is described by a global translation. Therefore, the purpose of this work was to investigate the influence of insufficient respiratory motion correction in pixel-based quantification of myocardial perfusion. In particular, we examined the effect of through-plane misalignments and whether insufficient correction might leave subendocardial perfusion defects undetected.

METHODS To study in detail the influence of respiratory motion a realistic and flexible 3-D model of the heart was developed. The model was constructed from an actual first-pass data set acquired during free breathing (see figure 1) and consists of 3 closely spaced short-axis slices, each of which is characterized by four parametric maps: A motion map, which is used to model in-plane motion, and three maps containing the parameters of a one-compartment perfusion model: where $s(x)$ is the simulated signal in a given pixel (without respiratory motion), $s_{AIF}(t)$ is the arterial input function, $k_1$ represents perfusion, and $t_1$ and $t_2$ are time constants.

RESULTS The absolute errors of $k_1$ are shown in figure 3 for the left ventricle (LV), and similarly in figure 4 for the subendocardial perfusion defect. As expected, the errors increase as the motion amplitude is increased. The asymmetric nature of some of the curves is due to the geometry of the heart. According to figure 3, the peak error for the LV is approximately 400% for in-plane translation, 100% for in-plane deformation, and 50% for through-plane translation. These errors become considerably larger when looking at smaller regions of the myocardium, such as the subendocardial perfusion (cf. figure 4). The in-vivo results are shown in figure 5.

DISCUSSION AND CONCLUSION A framework has been presented for simulating the influence of respiratory motion of the heart in measurements of myocardial perfusion using first-pass MRI. Overall, in-plane translation is by far the primary source of error. It is relatively straight forward, however, to correct this type of motion by applying dedicated image registration algorithms. Non-rigid deformations and through-plane movements, on the other hand, are not as easily removed and may induce significant errors. In particular, for the simulated subendocardial perfusion defect (cf. figure 4), errors of $k_1$ may reach a level of more than 100% even for the relatively small motion amplitudes presented in this study. This observation is supported by the in-vivo data. With errors of this magnitude, small subendocardial perfusion defects are easily left undetected. Therefore, our main conclusion is that non-rigid deformations of the heart and through-plane motion should be taken into account when performing pixel-based analysis of myocardial perfusion. As suggested, a possible way to reduce through-plane motion (and at least some of the myocardial deformations) is to use prospective slice-tracking [1]. We are currently investigating this approach in more detail.