About the performance of multi-dimensional radial self-navigation incorporating compressed sensing for free-breathing coronary MRI

Gabriele Bonanno1,2, Gilles Puy3,4, Yves Wiaux3,5, Ruud B. van Heeswijk1,2, and Matthias Stuber1,2

1Department of Radiology, University Hospital (CHUV) and University of Lausanne, Lausanne, Vaud, Switzerland, 2Center for Biomedical Imaging (CIBM), Lausanne, Vaud, Switzerland, 3Institute of Electrical Engineering, École Polytechnique Fédérale de Lausanne (EPFL), Lausanne, Vaud, Switzerland, 4Institute of the Physics and Biological Systems, École Polytechnique Fédérale de Lausanne (EPFL), Lausanne, Vaud, Switzerland, 5Institute of Bioengineering, École Polytechnique Fédérale de Lausanne (EPFL), Lausanne, Vaud, Switzerland

Introduction: Respiratory motion is a major challenge in cardiac magnetic resonance imaging (MRI) and contemporary state-of-the-art motion compensation strategies like diaphragmatic navigators still suffer from sub-optimal time efficiency. In response, k-space-based one-dimensional self-navigation techniques have recently been developed that extract respiratory-induced motion of the heart directly from the imaging data themselves for subsequent motion correction on a beat-to-beat basis [1]. This affords the advantage of 100% scan efficiency while meticulous plan scanning and navigator placement can be avoided. In the present study, this concept was advanced to the next level by implementing an image-based self-navigation technique that incorporates compressed sensing and allowing for multi-dimensional motion correction. The new approach was investigated using computer simulations of a moving heart phantom before it was implemented on a 3T human scanner. In 12 healthy adult human subjects, the performance of this methodology was then quantitatively ascertained in comparison to free-breathing coronary MRI, both with and without conventional respiratory navigators.

Materials and Methods: To estimate motion parameters, under-sampled sub-images were collected during each cardiac cycle and co-registered to a reference sub-image. In-plane displacement parameters were then extracted for each heartbeat before they were applied for motion correction in k-space. A computer simulation that mimics cardiac and liver anatomy with superimposed cardiac and respiratory motion was implemented in MATLAB (The Mathworks, Natick, MA, USA). Motion patterns and signal intensity levels were borrowed from conventional coronary MRI in vivo data. Sub-image reconstruction was then simulated using A) a non-linear Total-Variation-based reconstruction [4,5], that is related to compressed sensing, and B) a conventional method [2].

Results and Discussion: Using the numerical simulation, significant streaking artifacts were observed on the sub-images that were generated using the conventional reconstruction (Fig.1B). This adversely affected motion estimation as demonstrated by a modest correlation between the actual and the measured displacement (R²=0.89). In contrast, non-linear reconstruction yielded sub-images in which the anatomy was better defined (Fig.1C) and motion estimation substantially improved (R²=0.99). This is consistent with the findings on the corresponding in vivo sub-images in Fig.1E and 1F, where the non-linear reconstruction leads to a higher signal from the heart while streaking artifacts are reduced. Based on these results, Self-NAV with compressed sensing was used for in vivo acquisitions and compared to the conventional NAV. In a representative in vivo coronary MR image (Fig.2) after motion correction (Fig.2C), an improved visual delineation of the RCA was obtained with Self-NAV (compared to motion corrupted, Fig.2A) and the image quality approaches that of the reference standard (NAV, Fig.2B). According to the percentage (%) SNR (Fig.3) is significantly improved with Self-NAV (motion-corrupted vs. Self-NAV: 24.2±4 vs. 29.8±4, p<0.005). By comparison, conventional navigator gating still leads to the highest vessel sharpness (55±5, p<0.001 vs. motion corrupted, p=0.005 vs. Self-NAV) but suffers from a low scan efficiency (34.3±9%) and long scanning time (NAV vs. Self-NAV: 72.0±26s vs. 23.4±9s, p<0.001). SNR of the blood pool, CNR between the blood pool and the myocardium, average vessel diameter and vessel sharpness (%VS) were obtained for comparison. For statistical analyses, a paired two-tailed Student’s t-test was used and p < 0.05 was considered statistically significant after Bonferroni correction for multiple comparisons.

Conclusion: We have developed and tested a new image-based self-navigation approach that exploits non-linear reconstruction for multi-dimensional motion correction in free-breathing coronary MRI. Motion correction parameters are directly extracted from the sub-images while avoiding the need for a motion model or navigator planning. In a computer simulation, the accuracy of motion estimation was significantly higher with this technique when compared to that obtained with conventional reconstruction. In vivo and in humans, Self-NAV improved %VS significantly by 25% relative to the motion corrupted images. When comparing NAV and Self-NAV, scanning time for Self-NAV was reduced by 50% while its %VS was 14% lower. SNR, CNR or vessel diameter measurements remained unchanged between the two techniques.