Fast Velocity Mapping of Myocardial Motion with k-Space Segmented Black Blood Echo Planar and Gradient Echo Imaging

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Introduction: Cine or multi-phase cardiac imaging offers a variety of applications such as assessment of global cardiac function, measurement of the heart wall motion with phase contrast [1] or tagging techniques [2] as well as determination of flow inside the ventricular system. Here, we present two fast imaging methods for assessment of myocardial motion: Interleaved Echo Planar Imaging (EPI) with multiple excitations per phase of the heart movement and fast k-space segmented gradient echo imaging. In comparison to previous velocity mapping approaches [3] our new methods permit to obtain full in-plane velocity information of the heart wall motion within a single breath-hold. The resulting multi-phase images can be used to evaluate global cardiac function.

Materials and Methods: All experiments were performed on a 1.5T scanner (Magnetom Vision, Siemens, Germany) equipped with conventional gradients (25mT/m, 600µs risetime) using a 4-dimensional phased array body coil. Images (slice thickness=8mm, 300x400mm² rectangular FoV) were acquired in short axis view. The EPI pulse sequence consisted of a blipped multi-shot scan with an echo train length of 8 echoes per excitation (flip angle=25°, bandwidth =780Hz/pixel). Phase encoding gradients were rewinded for each excitation and data was read out with 3 shots per cardiac phase. 5 ECG cycles were thus required to collect a 120x256 matrix in an interleaved manner which was then reconstructed to 256x256 using zero padding. In order to achieve short echo times the second echo was positioned in the center of k-space resulting in asymmetric sampling in the phase encoding direction. An even-odd phase correction was performed using a calibration scan acquired under reversed switching gradients. Fat saturation was applied for every phase. For comparison we implemented a k-space segmented gradient echo sequence with first order motion compensation along read and phase direction. 14 phase encoding steps per image were acquired within each ECG cycle, such that over 5 ECG cycles a 70x256 matrix could be collected. Images were reconstructed to 128x256 using zero padding.

Postprocessing of the acquired images was performed on an external workstation using a home-made software package. Analysis included semi-automatic segmentation of the left ventricle, transformation of the velocities into an internal coordinate system positioned at the center of mass of the moving myocardium and a variety of visualization and processing options including arrow plots, color coded velocity images, mean velocity evolution as well as calculation of ejection fraction and wall thickening from the segmentation masks.

Results: Figure 2 demonstrates the result of a multi-phase measurement of a healthy volunteer's heart in short axis view. The temporal resolution of the ventricular motion was 92ms for the EPI and 99ms for the gradient echo sequence. The major postprocessing steps and one example of presenting the resulting functional information are illustrated in Figure 3 for a systolic phase of the cardiac cycle.

Discussion: Phase contrast measurements with both imaging methods have been shown to produce reliable data and consistent image quality sufficient for our semi-automatic segmentation. Concerning artifacts due to blood flow, off-resonance and susceptibility effects the gradient echo approach has proven to be more robust whereas EPI provides a higher spatial resolution. The measurements during one breath-hold resolve a drawbacks of previous implementations [3] where breath-hold examinations had to be performed for each the reference scan and to resolve a drawbacks of previous implementations [3]. In order to improve the suboptimal time resolution within the ECG cycle of 90-100ms stronger and faster gradients are necessary. These impose, however, serious problems in terms of scanner noise. Even with the current hardware we do not use the full performance of the gradients in order to make the measurement tolerable for patients.

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