Introduction: In the last years MRI has shown the capability for real-time applications. However, continuous changes within the excited slice caused by motion lead to artifacts in the reconstructed images. These artifacts strongly depend on the k-space trajectory. In projection-reconstruction-based techniques motion-induced artifacts result in radial streaks and a severe image blurring. Recently methods have been developed which use additional MR-measurements to obtain motion information [1]. In this study, a new reconstruction approach is presented to reduce motion artifacts using a radial acquisition scheme. This method estimates motion by using the acquired projections only and avoids the need of additional measurements.

Methods: In order to follow the dynamic process, data is continuously acquired on radial lines in k-space. The use of large angular increment \( \theta \) between succeeding projections provides a faster but coarser coverage of k-space and thus a more frequent update of the spatial information [2]. After \( N_\theta = 2\pi/\theta \) projections k-space is covered at coarse angular resolution. From such a subset a low-resolution (LR) image \( I_{LR}(\vec{x}) \) can be reconstructed. The projections of the next subset are then interleaved to increase the angular resolution, which is illustrated in Fig. 1. After acquiring a number of data subsets, a high-resolution (HR) image \( I_{HR}(\vec{x}) \) can be reconstructed.

Assuming that motion takes place only between the acquisition of low-resolution images, the influence of the motion can be removed by using the following reconstruction:

\[
I_{HR}(\vec{x}) = \sum_{i=1}^{2\pi} \sum_{\theta} p_\theta^i( \vec{u}_\theta \cdot (\vec{x} + \vec{d}_i(\vec{x}))), \quad \vec{u}_\theta = (\cos \theta, \sin \theta) \quad (1)
\]

where \( p_\theta^i \) are the filtered projections of the \( i \)-th subset and \( \vec{d}_i(\vec{x}) \) denotes the motion field containing the displacements for each pixel. Under the assumption that brightness changes in an image are only due to object movement (“optical flow”), a block-matching algorithm can estimate these displacements \( \vec{d}_i(\vec{x}) \): A rectangular block of neighboring pixels is taken in a reference sub-image, and it is tried to locate a block in the second sub-image which matches optimally the intensity values of the first one. To value the match a correlation function is used as a similarity measure. A hierarchical motion estimation [3] improves motion estimation where the displacement fields are refined on different resolution levels. The estimated displacement fields \( \vec{d}_i(\vec{x}) \) are then used to reconstruct a motion-compensated HR-image according to Eq. (1).

Experimental: Measurements were performed on a 0.5 T and 1.5 T whole-body research imager (Philips). For signal reception, coil arrays were used. MR-images were obtained by an FFE sequence acquiring data on radial lines in k-space. HR-images (256 x 256) of the knee-joint at four different positions were obtained. Continuous scans of the moving knee and the moving hand were obtained using a \( T_R = 3.6 \text{ms} \), a \( T_E = 1.5 \text{ms} \) and a resolution of (256 x 256). The movement was performed continuously between two flexion-positions during 10s continuous scanning. Furthermore, MR-movies of the beating heart were obtained.

Results and Discussion: In order to test the feasibility of the given approach, projections were extracted from the data of the different positions. The extracted projections were used to reconstruct LR-images. A hierarchical motion estimation based on these images provided displacement fields between the different motion states. A block-size of 9 x 9 pixel and strongly overlapping blocks increase the quality of the motion detection. In Fig. 2, results of one motion state are shown. For comparison, a reference-image is reconstructed from 256 static projections which is given in Fig. 2a. The image in Fig. 2b is reconstructed from the subsets of different motion states, which shows streak artifacts and image blur. The image in Fig. 2c is reconstructed by using the motion-compensated (MC) reconstruction. The artifacts in this image are considerably reduced, showing the feasibility of the approach. Fig. 3 shows one frame of an MR-image sequence of a moving hand. The motion-compensated (MC) reconstruction remarkably reduces blurring artifacts visible in the standard reconstruction (a). The standard reconstruction of the cardiac movie leads to blurred images without resolving the cardiac motion, due to fact that the acquisition time of one HR image was in the order of the cardiac cycle. The motion-compensated (MC) reconstruction reduces the blurring effects and resolves four different motion states of the cardiac cycle.

Conclusion: A reconstruction technique in combination with a hierarchical motion estimation was proposed for a radial acquisition scheme. This technique does not need any additional MR-measurement to detect the motion. It was shown that such a reconstruction can reduce motion artifacts in different applications. The motion compensated reconstruction can be used to reduce artifacts from inherent patient motion or to increase the temporal resolution of MR movies.

References: