Simulation Tool for *k*-Space Reordering in Free-Breathing Navigator-Gated 3D Coronary MRA

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Introduction:

In coronary MR angiography (MRA) breathing motion during data acquisition may result in image artifacts. One solution is the use of MR navigators to gate to the respiratory cycle, but the use of narrow gating windows often lead to prolonged/time inefficient scans. Therefore sophisticated *k*-space reordering techniques [1, 2] have been proposed to reduce motion artifacts in free-breathing navigator-gated coronary MRA, while improving scan efficiency. Currently proposed techniques are based on a 2D reordering of the acquired profiles, and we hypothesized that a true 3D *k*-space reordering may further improve both image quality and scan efficiency. To study this, we developed a 3D reordered *k*-space acquisition scheme [Zonal Motion-Adapted Acquisition and Reordering Technique (ZMART)] using a comprehensive MATLAB simulation tool (MATLAB 5.2, The MathWorks, Inc. Natick, MA). It allows simulation of MR data acquisition in the presence of moving objects and for an evaluation of the obtained images. The new method was compared to a conventional non-reordered navigator gating technique.

Methods:

Data Acquisition: The MR data set used for the simulation was a 3D data set with isotropic voxels obtained from a static phantom. The data acquisition was performed using a fast field echo sequence (FFE) with full magnetization for each excitation (TR=9000ms, TE=2.4ms, 260mm field-of-view (FOV) 512x512 image matrix, 40 slices). In the simulation, a 3D data acquisition with a navigator gated and corrected segmented *k*-space gradient echo (TFE) sequence is calculated (TR=100ms, TE=10ms, 32mm FOV, 64x64 image matrix, 32 slices of 0.5mm thickness) using the data taken from the static phantom. A simulated translational or/and rotational motion was added to the data set.

Reordering Technique: Using the MATLAB simulation tool, prospective motion adaptive reordering of profiles in k_y plane (MAG[1]) or the extended 3D reordering of profiles in both k_y and k_z plane (ZMART) can be compared with conventional non-reordered data acquisition. In addition the signal intensity of *k*-space can be weighted according to a predefined signal weighting function. Based on the defined signal distribution in *k*-space and the Bloch equation for a specific T1 value, the flip angle is prospectively calculated for each shot.

Data Analysis: To analyze the acquired images an evaluation tool is included. In addition to some basic image processing functions (measuring distances and profiles) it allows to determine signal-to-noise (SNR), contrast-to-noise (CNR) or the sharpness of edges [3]. The edge sharpness was defined as the average intensity value along an edge in the image. Further an additional parameter (artifact level) was used to objectively describes the influence of the motion[1] based on the difference of intensities in a region of interest (ROI) from the static 3D data set and the simulated motion data set.

$$\boxed{\textit{Artifact Level} = \frac{\sum_{ROI} (I_{static} - I_{motion})^2}{\sum_{ROI} (I_{static})}}$$

(*I*: Intensity of pixel)

Simulation Example: For the simulated data acquisition, the diaphragmatic navigator of a patient was applied into fold over direction to the static 3D data set to obtain the volume of interest with superimposed motion (maximum amplitude=2.5cm). ZMART was compared to the motion adapted gating (MAG) and the conventional non-reordered constant gating technique. For all three cases the signal intensity of *k*-space was constant.

Results:

The results of the simulation show image artifacts like they may occur in MR data acquisition in the presence of motion. Applying ZMART as prospective adaptive *k*-space 3D reordering resulted in improved image quality parameters (Fig.1, Table 1) when compared to the 2D reordering technique MAG and the conventional navigator gated non-reordered data acquisition.

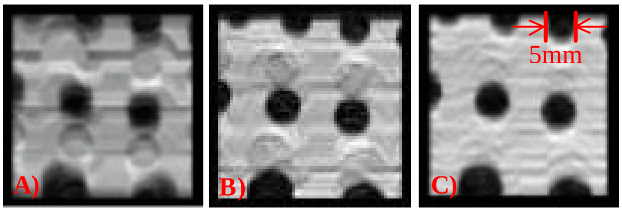

Fig. 1 Comparison of simulated data acquisition with a 5mm gating window using conventional non-reordered gating (A), the 2D reordering MAG (B) and the novel 3D reordering technique ZMART (B).

5mm window	SNR	CNR	Artifact Level	Sharpness
Conventional	6.5	7.3	4.4	55.8%
MAG	8.3	9.6	1.2	71.5%
ZMART	10.5	13.5	0.7	74.3%

Table 1 Image quality parameters of the simulations

Discussion:

The implemented MATLAB simulation tool allows for detailed investigation of respiratory and cardiac phenomenon as anticipated in cardiac MRI. Using the MATLAB software tool, different motion compensating strategies can be analyzed and objectively compared. Our simulations demonstrate that the 3D *k*-space reordering method, ZMART, has the potential to improve image quality in 3D navigator gated MRI.
Due to the modular structure of the simulation tool, the user defined extensions may be implemented which allow for further detailed investigation of data acquisition during breathing motion.

References:

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