Breathing motion artifact reduction for MRI with continuously moving table using motion consistent retrospective data selection

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Introduction: In MRI with continuously moving table (CMT-MRI) the compensation of breathing motion is a difficult problem. Existing breathing motion compensation techniques for CMT-MRI are either limited to TSE-based sequences where motion consistent snapshots are acquired with one single echo train [1,2], or they apply respiratory gating [3]. The latter approach can fail, however, if the true gating efficiency is lower than estimated a priori, resulting in an insufficient amount of data which can be acquired for the desired region due to the continuous table motion. In this work a novel breathing motion compensation approach for CMT-MRI is proposed. It acquires data redundantly during the whole breathing cycle and retrospectively extracts motion consistent undersampled k-spaces for parallel imaging reconstruction from that data. This approach is particularly suitable for acquisition schemes where the rapid sampling of motion consistent snapshots is not possible.

Methods: Abdominal data were acquired from one healthy volunteer during free breathing using a T_1-weighted gradient echo CMT-MRI sequence based on the sliding multislice technique (TR = 102ms, TE = 2.01ms, 32 slices, table speed = 2.33mm/s, TA = 85s) [4]. The breathing cycle position during the acquisition of each k-space line was determined with a breathing cushion placed on the abdominal wall. The k-space was sampled twice for each slice position in an interleaved fashion, i.e. for both k-space traversals the odd numbered lines were acquired before the even numbered lines. From that data a motion consistent undersampled k-space and a motion consistent set of calibration lines was extracted for GRAPPA reconstruction as follows. Calibration data were obtained by sorting all 48 lines acquired for the 24 central k_y-positions (two lines per position) into four bins according to the breathing states during their acquisition. Then the most occupied bin was determined and one line per k_y-position was selected, if possible, from that bin. If no data were available for a certain k_y-position, data from the closest bin, which contained a line for that particular position, was used. To obtain the undersampled imaging data, odd and even numbered k-space lines were separated and binned in the above described way for each slice position, resulting in 8 bins (4 each for even and odd numbered lines, respectively; Fig.2) for each pair of k_y-positions. As for the calibration data, the most occupied bin was determined and lines from that bin, and, if necessary, from adjacent bins, were included in the undersampled k-space for image reconstruction. (Bins with odd and even numbered lines were not combined.) Thus calibration and imaging data sets with the best possible consistency with respect to the breathing motion were extracted.
Additionally, two measurements were performed for comparison with the described method: For the first one the k-space was partially undersampled during breath holding (TR = 102ms, TE = 2.01ms, 32 slices, table speed = 7.52ms, TA = 26s) and GRAPPA with a reduction factor of 2 and 24 calibration lines was used for image reconstruction. For the second one the k-space was fully sampled during free breathing (TR = 102ms, TE =2.01ms, 32 slices, table speed = 4.65, TA = 43s) and conventional Fourier image reconstruction was applied.

Results: In comparison to the breath-hold acquisition (Fig. 1a), the reconstruction of the free breathing data with the proposed algorithm (Fig. 1b) shows no additional artifacts but increased noise. Ghosting and blurring are avoided, whereas the conventional free breathing reconstruction (Fig. 1c) shows clearly degraded image quality due to motion. If the k-space is acquired only once per slice position and images are reconstructed with the proposed algorithm, residual motion artifacts are recognized, particularly in the liver and at the abdominal wall (Fig. 1d). This observation demonstrates the benefit of a second acquisition, if there is a substantial phase shift between the breathing states of the lines from both acquisitions (Fig. 2). That phase shift causes a better coverage of the k_y-positions within the different bins, resulting in artifact reduction. The phase shift can be different for the odd and the even lines as shown in Fig. 2. Therefore, exploiting additional data redundancy by using parallel imaging can improve image quality further, as an undersampled k-space is potentially better covered with data from a single bin than a fully sampled k-space.

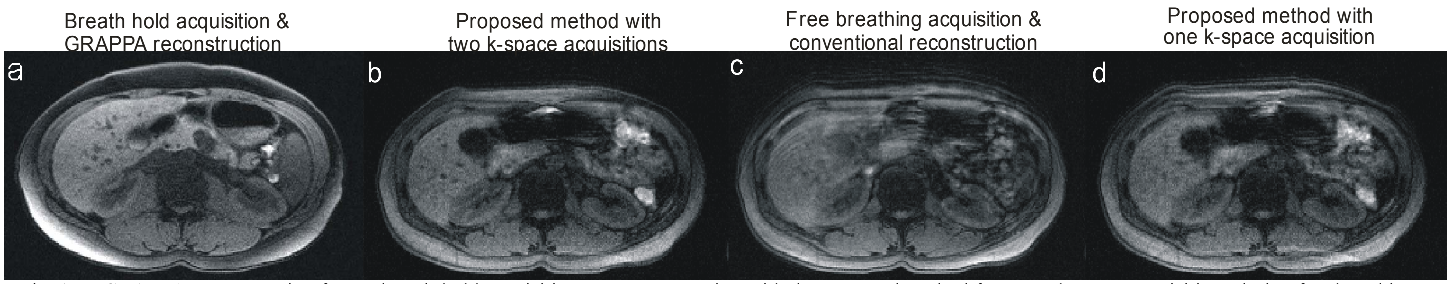

Fig. 1: **a**: GRAPPA reconstruction from a breath-hold acquisition. **b**: Reconstruction with the proposed method from two k-space acquisitions during free breathing. **c**: Conventional reconstruction from data acquired sequentially during free breathing. **d**: As (b) but using only one k-space acquisition. For (a) another slice position than for (b)-(d) is shown to compensate for the breathing related organ displacement during a breath-hold at maximum inspiration.

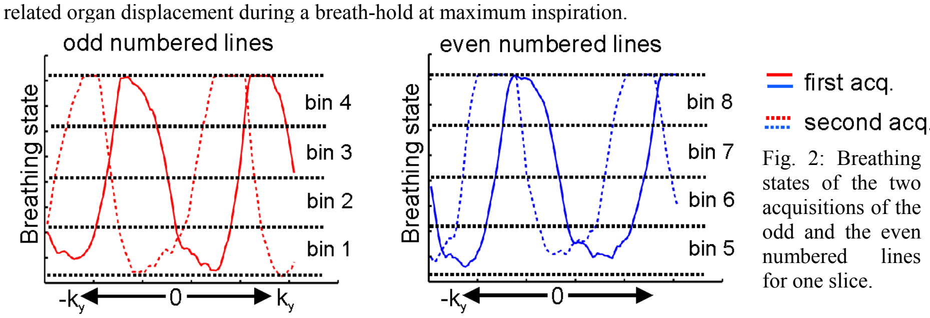

Fig. 2: Breathing states of the two acquisitions of the odd and the even numbered lines for one slice.

Discussion: Breathing motion induced artifacts were successfully reduced in axial gradient echo free breathing CMT-MRI by appropriately selecting k-space lines from redundantly acquired data. Further improvement of the diagnostic image quality, especially noise reduction, can be expected by the application of contrast agent, which is of clinical importance, as contrast-enhanced T_1-weighted gradient echo sequences are a cornerstone of abdominal CMT protocols [5]. Despite the adaptation of the slice position in Fig. 1a, clear anatomic differences between the breath-hold data and the free breathing reconstructions are observed. Hence, as the proposed algorithm can potentially provide free breathing images without motion artifacts, better comparability with data from other modalities such as PET, which also relies on free breathing acquisitions, can be expected. The improvement of the bin coverage due to the redundant acquisitions, however, heavily depends on the period of the breathing motion and on the sequence timing. Furthermore, more than one half of the acquired data is discarded as only one undersampled k-space and a calibration data matrix are extracted for image reconstruction from two full k-space acquisitions. Future developments will, therefore, focus on the online calculation of the phase encoding trajectory based on the breathing motion in order to exploit the acquisition time more effectively and to achieve good data consistency independently of the breathing motion period. If thereby two bins could be filled sufficiently to reconstruct one image per bin, the images from different breathing states could be fused using a registration technique proposed in [2] to obtain a consistent volume with improved quality.

References
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