Respiratory gating with measurement time constraints applied to MRI with continuously moving table

M. Honal[1], and T. Baumann[2]
[1]Department of Radiology, Medical Physics, University Medical Center Freiburg, Freiburg, Germany, [2]Department of Radiology, University Medical Center Freiburg, Germany

Introduction

The compensation of breathing motion for MRI with continuously moving table (CMT-MRI) is a challenging problem. Due to the long measurement time, breath holding is often not applicable and conventional gating techniques are difficult to combine with the continuous table motion due to the variability of the breathing motion over time. In this study a variant of respiratory gating similar to [1] is proposed for CMT multi-slice acquisitions which provides the best possible data consistency with respect to motion in a constant measurement time per slice. Thus a good compatibility with the continuous table motion is achieved.

Methods

Seven data sets from six patients suffering from pelvic malignancies (rectal, $n = 5$; uterine, $n = 2$) were acquired during free breathing on a 1.5T scanner (MAGNETOM Avanto, Siemens, Erlangen, Germany). A region ranging from the thorax into the pelvis was covered with a multi-slice CMT gradient echo sequence (TR = 47.24ms, TE = 2.03ms, flip angle = 70°, voxel size = $1.6x1.3x6mm^3$, GRAPPA with a reduction factor of $R = 2$) in a measurement time of 2:50min. The sliding multi slice method [2] was applied to avoid table motion induced artifacts in slice direction by reordering the k-space acquisition appropriately for each slice. Therefore a different breathing pattern occurs during the k-space acquisition of different slices. A breathing cushion placed on the abdominal wall of the patients was used to obtain the breathing state during the measurement of each phase encoding line. The table speed was set to allow an acquisition time of $m \cdot T_s$ per slice position where T_s is the time required to measure all phase encoding lines once and $m = 3$ in all conducted experiments. Initially the complete k-space was acquired for each slice position in the time T_s regardless of the breathing motion (Fig. 1, blue dots). All phase encoding lines which had been acquired during a breathing state above a threshold τ were marked for reacquisition. In the remaining acquisition time $T_s \cdot (m - 1)$ as many marked phase encoding lines as possible were measured anew during a breathing state below τ (Fig. 1, green and red dots). Thus full k-space coverage is guaranteed and the motion consistency of the data is optimized in the limited acquisition time. The threshold τ was obtained from breathing motion data acquired a few seconds before the actual measurement. From that data a histogram was built and τ was set such that $1/m \cdot 100\%$ of all measured breathing states ranged below that threshold. The reconstructions with the proposed method were compared to images reconstructed from the first k-space acquisition only without motion correction. As a quantitative parameter of the image quality the entropy of the image gradient in phase encoding direction was evaluated That parameter has been shown to exhibit a good correlation with the degree of motion artifacts [3].

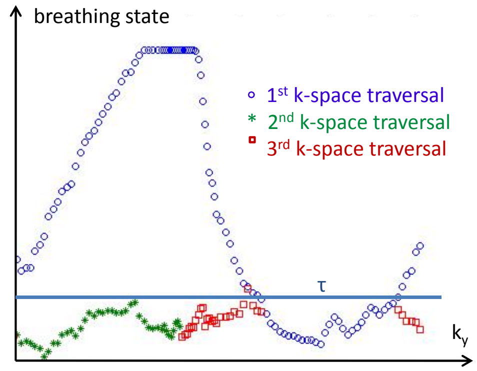

Fig. 1: Proposed acquisition scheme for one slice position.

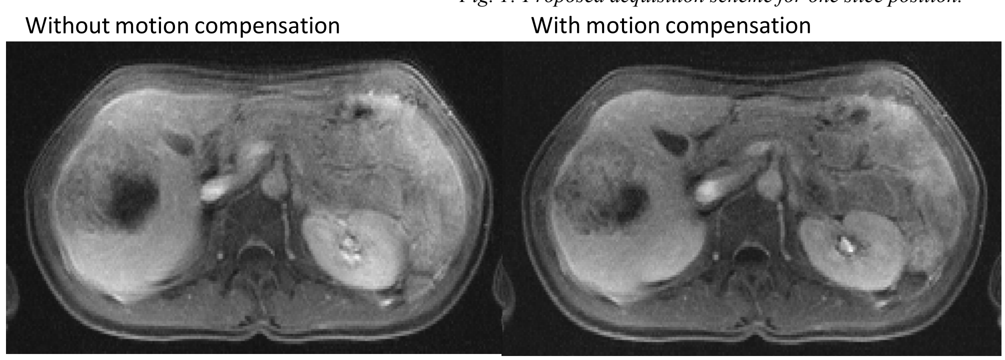

Fig.2: Images acquired without and with motion compensation.

Results

The proposed motion correction method significantly reduces blurring in the reconstructed images as shown in Fig. 2. This observation is supported by the gradient entropy values which are clearly lower for the motion corrected data compared to the non-corrected data indicating increased blurring in the latter (Fig. 3). For data set 5 where the gradient entropy values are almost equal, also visually only a small benefit of the motion correction is observed.

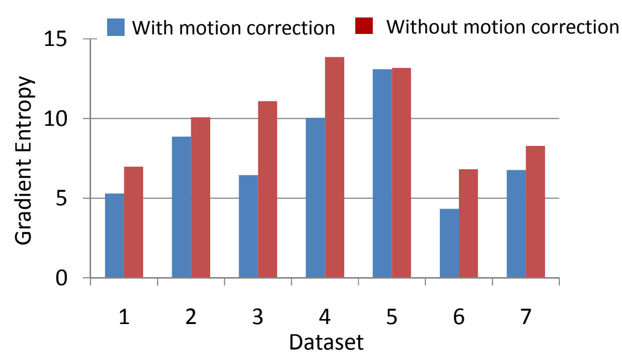

Fig.3: Gradient entropy values for the reconstructions with and without motion correction for the different data sets.

Discussion

A variant of conventional respiratory gating has been presented which allows for data acquisition in a fixed measurement time and is therefore suitable for the application in CMT-MRI exams. Compared to free breathing acquisitions without motion compensation blurring was significantly reduced. As a drawback the proposed method does not guarantee motion consistency of the acquired data and residual artifacts can appear in the reconstructed images depending on the variability of the breathing motion. While this problem cannot be avoided completely it can potentially be alleviated by adapting the threshold τ during the acquisition to account at least for the variability in expiration depth. The investigation of that issue is a subject for future work.

References

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