High-quality free-breathing abdominal MR imaging enabled by Repeated K-t-subsampling and Artifact-Minimization (ReKAM)

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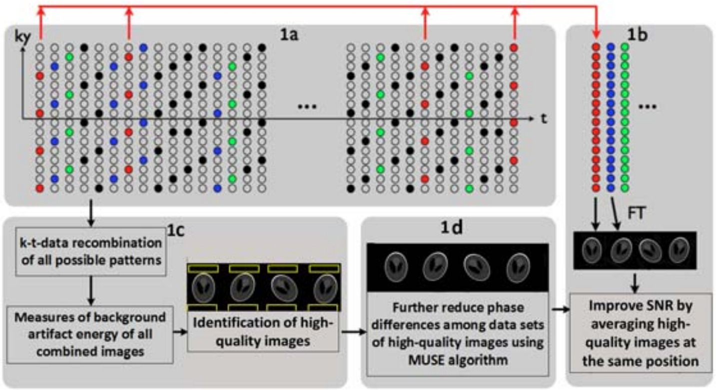
INTRODUCTION: It has been highly challenging to generate high-quality MRI data in the presence of continual motion. For this reason, existing abdominal MR imaging protocols largely rely on either respiratory gating or breath-holding, to reduce motion-related artifacts. However, the respiration-gated acquisition has lower scan efficiency, particularly when the subjects have irregular respiratory rate. The breath-hold MRI has higher scan efficiency, but unfortunately may not be feasible for seriously ill patients. For challenging patients, free-breathing MRI is preferred, and it is possible to reduce the motion-related artifact in free-breathing abdominal MRI using information derived from either navigator echoes[1] or the over-sampled low k-space data (e.g., with PROPELLER[2]). However, it may be difficult to use navigator signals of low spatial resolution to effectively remove artifacts resulting from local and nonlinear motion. To address the above-mentioned challenges, here we report a new strategy for producing high-quality and artifact-free abdominal MRI data. The new method, termed *Re*peated *K*-t-subsampling and *A*rtifact-*M*inimization (ReKAM), is capable of effectively removing motion-related artifacts resulting from global and local (nonlinear) motion during free-breathing abdominal MRI scan, without navigator echo or any pulse sequence modification.

METHODS: The developed method comprises three modules. First, a fast imaging pulse sequence (e.g., echo-planar imaging (EPI) and fast spin-echo (FSE)) is used to repeatedly acquire subsets of k-t-space data corresponding to different subject positions. Second, multiple images are reconstructed from the acquired data using all possible k-t-data grouping patterns (i.e., bootstrapping in k-t-space), and high-quality images corresponding to multiple subject positions are then identified from all the reconstructed images using an automatic procedure. Third, the recently developed multiplex sensitivity encoding (MUSE)[3] post-processing algorithm is applied to further minimize the motion-induced aliasing artifacts in high-quality images produced from the second module, and the corrected images can then be averaged to produce a final image with high signal-to-noise ratio (SNR) and minimal motion related artifact.

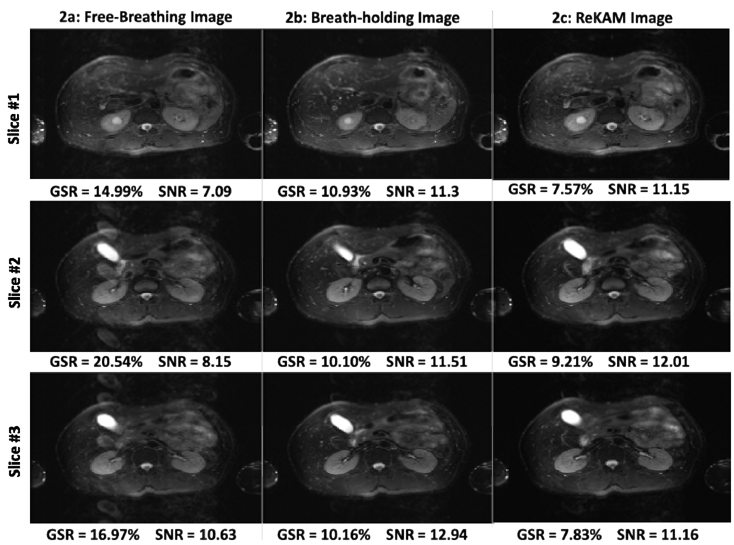
In Figure 1 we schematically illustrate the procedure of eliminating motion artifacts using a 4-shot interleaved MRI pulse sequence (e.g., 4-shot EPI or 4-shot FSE) as an example. The data acquisition module (i.e., module 1) is shown in Figure 1a, where the solid and empty circles represent sampled and unsampled ky lines respectively, and the circles with the same color (e.g., red) correspond to approximately the same subject position. As illustrated in Figure 1b, if the position information corresponding to every time point is known, then k-t-data corresponding to a particular position can be grouped to form an artifact-free image. Practically, the patterns of intra-scan motion are unknown and unpredictable. Therefore, in the bootstrapping based reconstruction module (i.e., module 2: shown in Figure 1c), a brute-force search strategy is used to identify high-quality images. Specifically, the acquired k-t-space sub-sampled data are regrouped using all possible data grouping patterns, producing a series of images. Afterward, the background artifact energy levels of the produced images are measured from pre-defined background ROIs, and high-quality images (i.e. with the lowest background artifact energy level in ROIs) can then be identified.

Although the high-quality images can be produced with the above-mentioned k-t-bootstrapping procedure, the motion-induced aliasing artifact may still exist (e.g., due to subtle image-domain phase differences among data sets corresponding to slightly different positions). Therefore, in the MUSE module (i.e., module 3: Figure 1d), the constrained reconstruction is used to further minimize the motion-induced aliasing artifact. The motion-immune images corresponding to the same positions can be averaged to produce a final image with high SNR.



The developed technique is evaluated with T2-weighted free-breathing body MRI data obtained from a 3 Tesla GE scanner using a fast spin echo (FSE) sequence with a 8-channel receiver coil. The imaging parameters included TR = 3750 ms, TE = 101 ms, slice thickness = 8mm, FOV = 32 cm x 40 cm, the image matrix = 206 x 320, and echo train length = 16. We acquired three repetitions of free-breathing data for ReKAM reconstruction, and one set of breath-holding FSE data for comparison.

RESULTS: Reconstructed images of three selected slices are shown in three rows of Figure 2. The conventional free-breathing and breath-holding data are shown in Figure 2a and 2b, respectively. It can be seen that the free-breathing images (2a) are severely corrupted by motion artifacts, with ghost-to-signal ratio (GSR) > 14%. Figure 2c shows the high-quality images generated by ReKAM, reconstructed from 3 sets of free-breathing data, with low artifact levels (comparable to breath-holding data) and high anatomic resolvability. These results demonstrate the robustness and effectiveness of the developed motion-immune ReKAM technique.



DISCUSSION: High-quality abdominal MR data can be produced with ReKAM even from patients who are unable to hold their breath. It is therefore thought that ReKAM could substantially improve image quality when applied to certain pulse sequences used in abdominal MRI. One of the major advantages of the ReKAM-based method is its higher scan efficiency, as compared with the respiration-gated MRI, since multiple k-t-space data obtained during different respiratory phases of ReKAM scans can be re-combined to produce multiple sets of artifact-free images.

CONCLUSION: Here we present a novel motion-immune MRI strategy to enable high-quality and free-breathing abdominal MRI, which is significant particularly for patients who cannot hold their breath for an extended period of time. The developed ReKAM technique is compatible with various MRI pulse sequences, and can be generally applied to remove motion related artifacts in abdominal MRI.

REFERENCES: 1. Ehman RL *Radiology* 1989;173(1):255. 2. Forbes KP *J Magn Reson Imaging* 2001;14(3):215. 3. Chen, NK *NeuroImage* 2013; 72:41.