Suppression of Respiratory Motion Artifacts in Free-Breathing Cardiac Cine MR Imaging

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Introduction

Respiratory motion causes artifacts such as blurring and ghosts in cardiac MR images. For coronary-artery imaging, respiratory gating using navigator echoes is used to suppress the artifacts [1]. In cardiac cine MRI, however, there are demands for a method that can suppress the artifacts without loss of scanning time. For example, if some pulses for navigation are inserted during the cine imaging, scanning time is prolonged because the pulses make the spins in the slice change to an unsteady state. A simple breath-hold is thus usually used to freeze respiratory motion, but it limits total scanning time to twenty to thirty seconds which is not long enough to obtain high-quality images. To address these issues, we have therefore developed a new method for monitoring respiratory motion in cardiac cine imaging by using linear correlation coefficients between a reference projection and time-series projections of the imaging slice. This method uses information from the imaging slice to detect the motion so that the spins in the slice are kept in a steady state. We used the method for retrospective respiratory gating in free-breathing cardiac cine imaging and obtained good images without respiratory-induced artifacts.

Method

Figure 1 shows the schematic imaging sequence used in the proposed method for monitoring respiratory motion. The pulse sequence used is a steady-state free precession [2] (TR/TE = 5/2.5 ms). The subject first expires and stays at end-expiration for about 5 s. A reference projection is acquired by averaging the multiple projections obtained during a heartbeat in the end-expiration. Then the patient breaths freely, during which time the pulse sequence for imaging is performed and the phase encoding of the sequence is set to zero every 16 TRs so that projections for monitoring the respiratory motion are acquired. The time resolution of the monitor is 80 ms, i.e., 5 ms x16. The linear correlation coefficient r between the reference projection and each projection for the monitoring is calculated by the following equation:

$$r = \frac{\sum_{i=1}^{N}(x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum_{i=1}^{N}(x_i - \bar{x})^2}\sqrt{\sum_{i=1}^{N}(y_i - \bar{y})^2}},$$

where x_i and y_i are the intensities at each point of the reference projection and the projection for the monitoring, respectively, $i = 1, \cdots, N$, and $\bar{x_i}$ and $\bar{y_i}$ are the average of x_i and y_i, respectively. The reference projection is acquired at end-expiration, so r increases to one during the expiratory phase, whereas it decreases from one during the inspiratory phase. To obtain r that is not influenced by cardiac motion, a fifteen-point moving average filter was applied.

Results and Discussion

Experiments were performed on a 1.5-T whole-body scanner and the following parameters were used for normal volunteer scans: FOV: 32 cm; slice thickness: 1 cm; and matrix size: 128x128. Images obtained in three typical (transaxial, sagittal, and coronal) slice directions were evaluated (because the stability of the developed method may depend on the orientation of the imaging slice). For each slice direction, vertical and horizontal readout directions were evaluated, and the number of multi-slices was three (18 slices were evaluated in total). Figure 2 shows the procedure and results of the respiratory motion monitoring. The imaging slice (a transaxial slice with a readout direction from left to right) and the temporal display of the projections of the slice are shown in Figs. 2(a) and 2(b), respectively. Figure 2(c) shows the linear correlation coefficient calculated from the reference projection and the projections for motion monitoring. The figure shows that the developed method can successfully monitor the respiratory phase. Similar results were obtained in the case of other slices. However, in the case of sagittal and coronal slices with head-to-foot phase-encoding direction, the waveforms were not so stable. In these slices, the readout direction of the projections can be changed to head to foot. Retrospective cardiac gated cine imaging [3] was performed on all slices, and the proposed method was used for retrospective respiratory gating. Echoes were obtained over 90 heartbeats during free breathing, and cine images with 10 frames per heartbeat were reconstructed by using the quarter of the total echoes that have the largest linear correlation coefficients. One of the cine images is shown in Fig. 3. It is clear from this figure that images without respiratory-induced artifacts can be obtained. Similar good images were obtained in the case of the sagittal and coronal slices.

References

[1] Sachs TS et al., *MRM*, **32**, 639, 1994. [2] Oppelt A et al., *Electromedica*, **54**, 15, 1986. [3] Lenz GW et al., *MRI*, **7**, 445, 1989.

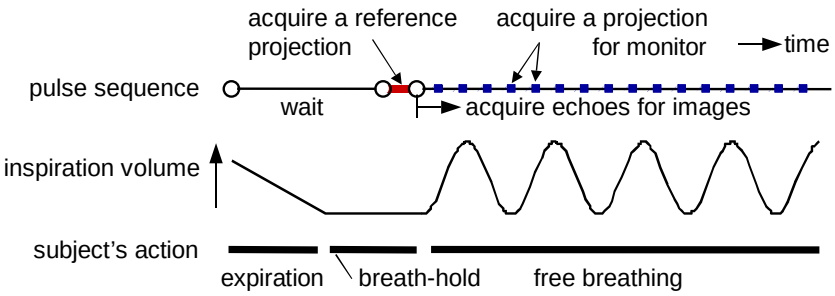

Figure 1: Schematic sequence of the developed method for monitoring respiratory motion

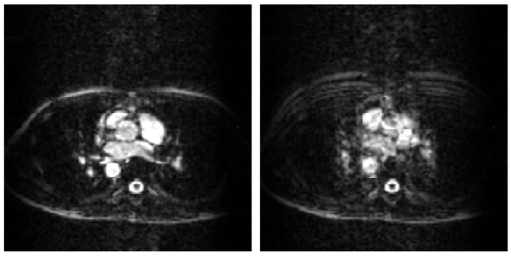

Figure 3: Cine images with 10 frames (first frame shown)

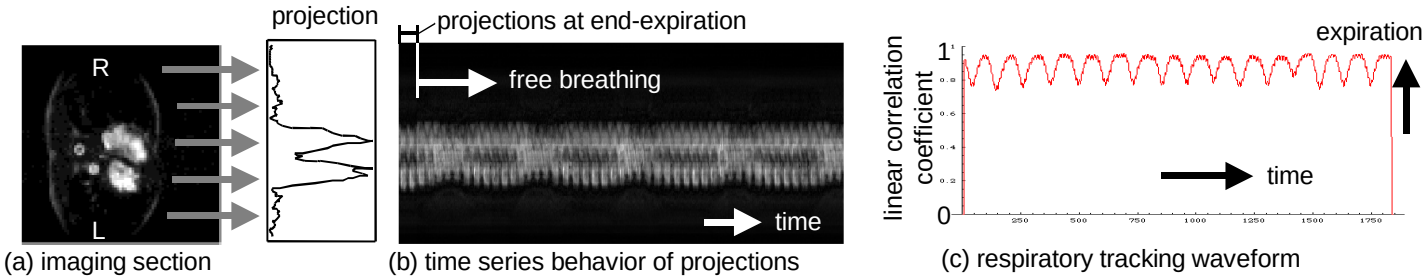

Figure 2: Procedure and result of the respiratory-monitoring method