An MR-compatible active breathing control (MR-ABC)

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Purpose/Objective: Motion is a major obstacle for cardiac, chest, and abdominal imaging. Gating techniques are usually mandatory to achieve artifact-free high resolution images. Several approaches have been proposed which allow for segmented k-space acquisition while avoiding motion artifacts. Most of these methods focus solely on the detection of motion, e.g. navigator techniques or a respiratory belt. Nevertheless, respiratory movement during data acquisition which can be fairly substantial even during acquisition windows as short as 150 ms is not prevented [1]. To avoid respiratory movement during the data sampling period, an MR-compatible active breathing control (MR-ABC) was developed [2]. The MR-ABC monitors respiration via a pneumotachograph and is able to temporarily block the breathing gas delivery to the subject at a preset lung volume. In addition, in combination with ECG the MR-ABC allows for cardiorespiratoy-synchronized MRI while "freezing" the breathing motion. The potential of an MR-ABC device is demonstrated in lung imaging.

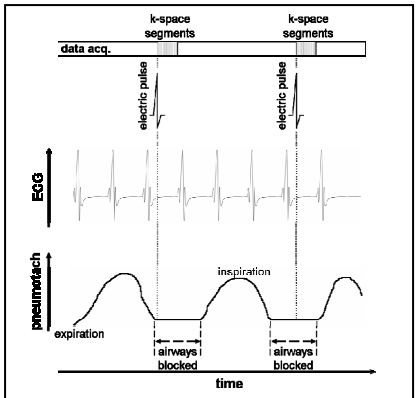

Figure 1: *Schematic of cardiorespiratory synchronized data acquisition. In this example, the airflow was stopped each time that end-expiration was reached. At the beginning of the following diastole an electric pulse was generated by the MR-ABC unit, which in turn triggered the MR scanner's ECG device to initiate the data acquisition.*

Methods: The flow-volume curve detected by a spirometer was instantly evaluated to automatically control a shutter device, which closed or opened the airflow to the subject. The MR data acquisition of each segment was triggered by an electronic pulse generated by the MR-ABC unit when preset gating conditions were reached (Figure 1). Imaging experiments were performed on a 1.5 T scanner (Vision, Siemens) and 5 healthy volunteers were examined. To evaluate the potential of the MR-ABC, three image series of 50 FLASH images were dynamically acquired, each series with ECG triggering in combination with a different respiratory gating technique: breath-holding, a respiratory belt and the MR-ABC. For comparison, an image series of 100 FLASH images was acquired during free breathing as well. Sequence parameters were TE/TR 1.2/2.4 ms, FA 10°, FOV 400x 400 mm^2, ST 10 mm, matrix size 80x128. For each of the four approaches the translation of the diaphragm position throughout the imaging series was evaluated. To demonstrate the feasibility of prolonged acquisition windows using the MR-ABC, cardiorespiratory synchronized 3D gradient echo (GE) imaging of the entire chest was performed. Sequence parameters were TE/TR 1.8/4.6 ms, FA 5°, FOV 341x390x150 mm^3, matrix size 355x512x32. 32 segments were sampled, each in about 1.5 seconds. Breathing was suspended during the data acquisition by an MR-ABC-caused forced breath-hold of 2.5 seconds.

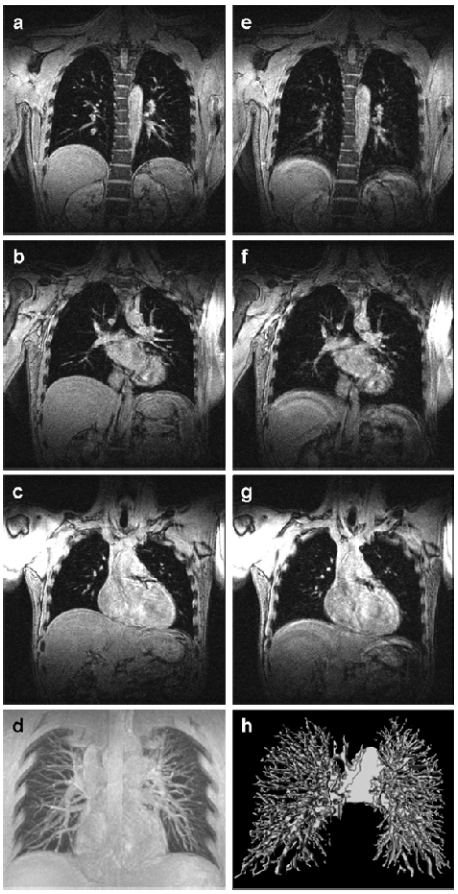

Figure 3: *Example of 0.96x0.76x2.34 mm^3 3D-GE images. In a) to c), slices of the chest acquired using MR-ABC are depicted. Images from e) to g) show corresponding slices acquired using cardiorespiratory synchronization, but without forced suspension of breathing during data acquisition. The first column shows no breathing artifacts, which, in contrast, are present in e) to g). In d) a maximum intensity projection (MIP) is depicted and h) shows the segmented vasculature.*

Results: An example of the comparison between the gating techniques used is shown in Figure 2. The results for all five subjects indicated that breath-holding, a respiratory belt or MR-ABC all yield similar standard deviations in diaphragm displacement throughout the imaging. The potential of an MR-ABC for using a prolonged acquisition time per trigger event is demonstrated in Figure 3. Due to the long acquisition time of about 1.5 seconds per trigger event, 3D GE imaging of the entire chest could be performed in 4 minutes with an effective resolution of 0.96x0.76x2.34 mm^3. The 2.5 s of valve closure assured the appearance of an R-wave to trigger the MR scanner during every period of airflow stoppage. Because of the cardiorespiratory synchronization in combination with the flow stoppage, no motion artifacts were present. In contrast, simultaneous ECG- and respiratory gating without flow stoppage showed severe breathing artifacts (Figure 3 e-g).

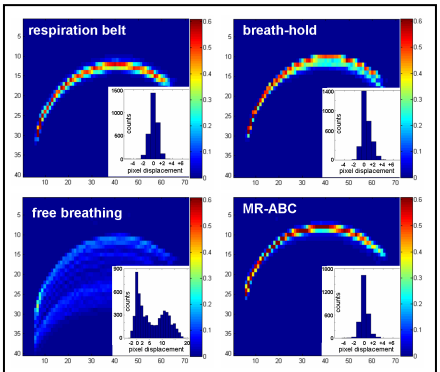

Figure 2: *The diaphragm positions of 50 images for each gating technique (100 in case of free breathing) were summed and normalized to 1. The sum for each pixel is depicted with the colorbar. In the right lower corners are histograms of the pixel displacements from the most frequent position. The width of the distribution of pixel displacements is the lowest for MR-ABC, with a standard deviation of 0.85*

Conclusions: In this study, an MR-compatible active breathing control (MR-ABC) system was developed and applied to pulmonary MRI. To perform segmented k-space acquisition of the lung, respiratory and cardiac gating is essential. An MR-ABC allows for prolonged acquisition windows, since breathing motion is prevented during data sampling. The MR-ABC enabled the acquisition of clear images from sequences with long acquisition windows that would otherwise have been blurred by respiratory motion. Therefore, total imaging time can be reduced as compared to navigator gating or the use of a respiratory belt. An MR-ABC may be useful in MR pulmonary angiography, perfusion imaging, and other functional lung imaging methods as well as in abdominal imaging or coronary angiography. An MR-ABC can be used in conjunction with any kind of traditional MR sequence protocol. The impact of the MR-ABC for clinical applications, however, will have to be investigated in future work.

References: 1) Fischer RW, et al [2006] MRM 55 :612-618 2) Arnold JFT, et al [2007] MRM in press