Reproducibility of Diffusion Weighted MRI under Active Breathing Coordinator control

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Introduction: An Active Breathing Coordinator (ABC) (Elekta Oncology Systems, Crawley, UK) is a respiratory control apparatus employed during lung, liver or breast radiotherapy to reduce motion and treatment margins [1] by holding respiration at a specified level for a preset duration. We aim to acquire diffusion-weighted (DW) Magnetic Resonance (MR) images in ABC-induced breath holds (BHs) at the same lung volume as during radiotherapy, which would help guide treatment planning. We also aim to assess the reproducibility of organ position during different ABC BHs, which is key to radiotherapy delivery.

Materials and methods: DW imaging was performed in two sessions, each on a different healthy volunteer laying supine with his arms superior to his head, using an ABC system modified for MR applications [2]. Session1 took place in a 1.5T Siemens Avanto employing a DW echo-planar imaging (EPI) sequence axially oriented on the volunteer's abdomen (TR 1110ms, TE 67ms, matrix 208x256, FoV 308x380 mm^2, partition thickness 6mm, flip angle 90°, GRAPPA factor 2, Spectral Selection Attenuated Inversion Recovery (SPAIR), b-values: 0, 100, 500, 750 s/mm^2, 3 scan trace mode). The EPI sequence of nominal duration 73s was repeated twice, acquired in segments defined and externally triggered by ABC-induced BHs at 1.2l inhaled air volume for a preset span of up to 15s.
Session2 was carried out in a 1.5T Siemens Aera, acquiring 42 axial, 6mm thick slices covering the second volunteer's thorax with FOV 306*377mm, matrix 104*128 of an EPI DW sequence in 3 scan trace mode with flip angle 90° and GRAPPA factor 2, segmented and externally triggered by five ABC-BHs of up to 20s duration each at 1.7l inhaled air volume. The sequence was applied first with TR 3.3s, TE 45ms, Short TI Inversion Recovery (STIR) with TI 170ms, b-values: 100 and 600 s/mm^2, scanning time 89s. Afterwards the sequence was acquired with changed parameters TR 7.5s, TE 59s, SPAIR, b-values: 0, 100, 500, 750 s/mm^2, scanning time 98s.
For each session, the reproducibility of organ position during different ABC BHs was assessed by comparing the same slice between the different measurements.

Results: Three equally windowed abdominal slices, the same between the two measurements a) and b) of session1 for b = 0 s/mm^2, are shown in figure 1. The level of organs such as the liver, kidneys, pancreas, stomach and spleen is obviously well replicated by repeating the same sequence in BHs induced by the ABC at the same volume threshold. Therefore the corresponding images of the different measurements a) and b) can be aggregated as in c) to increase the signal to noise ratio (SNR), in this case by 40% in the liver. The difference images b) - a) in d) also suggest a very good repeatability of organ position, considering effects of flow, peristalsis and ghosting artifacts in EPI sequences.
Figure 2 depicts three equally windowed thoracic images of the second volunteer with b = 100 s/mm^2, acquired at the same slice positions during measurements a) and b) of session2. Although the two measurements employed different fat suppression techniques and had different timing parameters, b-values and total acquisition times, diaphragm and major vessel positions remained unchanged for the same slice under ABC-controlled BHs at the same lung volume.

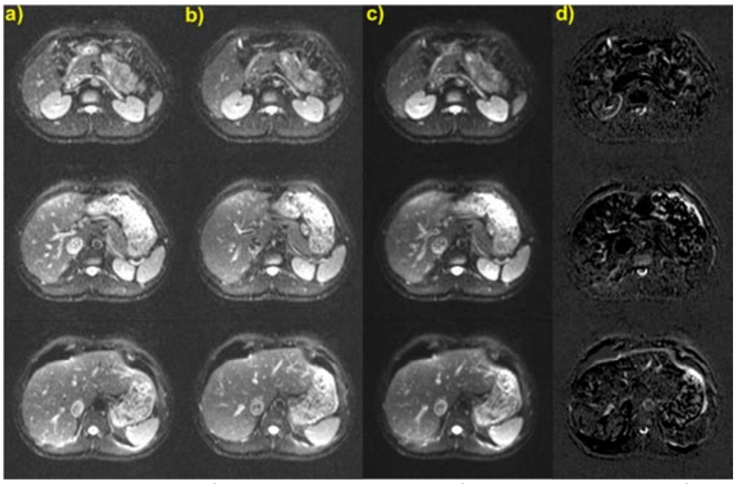

Figure 1. DW-EPI of session1, volunteer 1 for the same slices of two separate measurements a) and b) with b-value 0 s/mm^2. c) Average images of a) and b). d) Difference images b) - a). All images are equally windowed.

Discussion: We demonstrated that clinically relevant DWI of the thorax and abdomen is feasible using a modified, MR compatible ABC device. Thanks to recent advances in DWI, this method has evolved into a diagnostically useful tool for the characterisation of lung cancer [3]. In order to inform treatment planning, DWI and CT should depict identical body planes. The same external patient positioning devices for the two modalities are available, yet it is crucial that lung imaging is performed at the same point of the respiratory cycle in both cases.
The assumed reproducibility of organ position under ABC BH was tested during two different DW-MRI sessions on two different volunteers using different sequences and BH volume thresholds. It was shown that control of respiration achieved by the ABC system at a specific air volume corresponds to a well-defined position of the diaphragm, major vessels and abdominal organs. Thus images acquired at different time points using the same DW-EPI sequence with the same ABC settings can be aggregated to increase the SNR. Moreover, modifications of non-spatial sequence parameters do not affect the repeatability of the image slice position using the same ABC threshold level. These results suggest that MR-ABC images are expected to match CT images acquired with the same ABC settings and thus successfully support radiotherapy treatment planning.

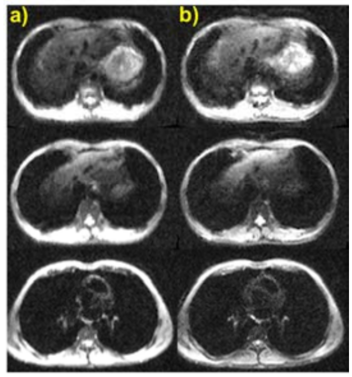

Figure 2. DW-EPI of session2, volunteer 2 with b = 100 s/mm^2 from measurements a) and b) at the same slice position. All images are equally windowed.

Conclusion: The feasibility of clinically relevant thoracic and abdominal DW-MRI acquired automatically during breath holding enforced by a modified, MR-compatible Active Breathing Coordinator (ABC) system was demonstrated. A very good repeatability of the imaged organs position under ABC control at a specific inhaled air volume was observed.

References: 1. Wong JW. et al, Int J Radiat Oncol Biol Phys 1999; 44:911-919. 2. Kaza E. et al, in Proc ISMRM 2013, 1488. 3. Tuerkbey B. et al, Diagn Interv Radiol 2012; 18:46-59

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