IMPLEMENTATION OF AN ACTIVE BREATHING COORDINATOR DURING MRI TO SUPPORT RADIOTHERAPY TREATMENT PLANNING

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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]. This device monitors patient breathing by means of a propeller flow transducer and obstructs airflow at a preset air volume for a defined duration by inflation of a balloon valve. Our purpose is to acquire Magnetic Resonance (MR) images in ABC-induced breath holds as applied during irradiation, which would be useful for treatment planning and imaging for response assessment, and to assess their quality compared to standard motion control techniques.

Materials and methods: A healthy volunteer was scanned supine with arms above his head in a 1.5T Siemens Avanto in two sessions with a T2-weighted selective single slab 3D Sampling Perfection with Application optimized Contrasts using different flip angle Evolution (SPACE) sequence [2]. During session 1) the flip angle was variable, during session 2) it was constant 150°. The rest parameters were the same (TR 3s, TE 100ms, TI 180ms, matrix 192x196, partition thickness 5mm, FoV 360x360 mm^2, echo train length 107, GRAPPA factor 3). For both sessions, imaging was performed firstly in free breathing using a navigator on the diaphragm with a 2mm acceptance window. Then SPACE was applied in segments of self-sustained breath holds, externally triggered with a manually generated TTL signal train. In 1) four 17s long segments on inhalation, in 2) eight 16s long segments on exhalation were applied. Lastly an ABC spirometer, successfully tested for MR function and compatibility, was placed in the volunteer's mouth whilst the nose was closed. After an initial monitoring of the volunteer's breathing cycle, inflation of the balloon valve was defined as over 1.6l for 18s for 1) and under 0.2l for 16.5s for 2). Inflation time exceeded by 1s for 1) and by 0.5s for 2) the trigger burst duration to account for possible operator reaction and valve closure delays. The same sequence was applied in manually triggered segments as before, each during an ABC-induced breath hold.

Results: The same slice with the same windowing along session 1) is shown in figure 1 for the navigated free breathing, self-controlled and ABC-controlled breath holding on inhalation. Figure 2 depicts a corresponding slice, kept same and equally windowed along session 2), for the navigated free breathing, self-controlled and ABC-controlled breath holding on exhalation. The lung horizontal fissure can be discerned in the constant flip angle images, especially for the ABC condition. Images were acquired with the same field of view during both sessions but were cropped in the figures in order to zoom on the lungs.

For both sessions, navigated free breathing yielded good resolution images. Acquisition in self-sustained breath holds resulted in shadowing of liver borders and vessels, due to position variations during the different breath holds. Using the ABC improved organ delineation, as the same lung volume was sustained during all breath holds without causing volunteer discomfort. No noise or artifacts resulted by the ABC presence and operation in the MR images; the ABC function was not affected by the static or gradient magnetic field.

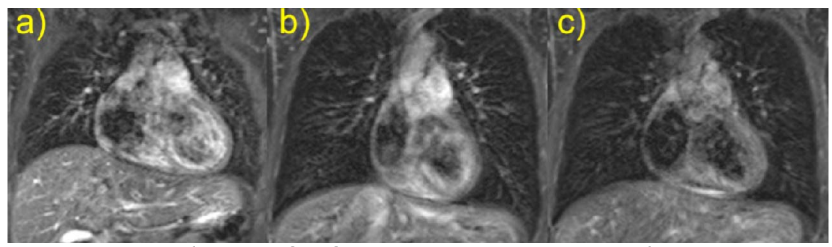

Figure 1. Variable flip angle SPACE imaging during a) navigated free breathing, total acquisition time TA 1:32min; b) self-controlled breath holding on inhalation, TA 2:44min; c) ABC-controlled breath holding on inhalation, TA 2:41min.

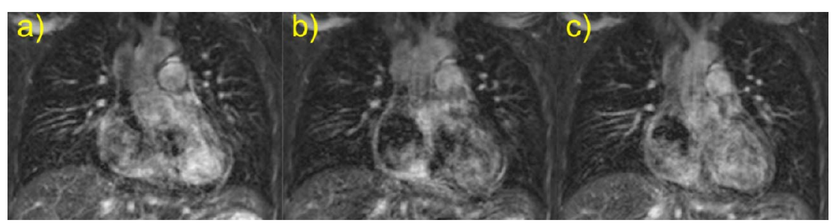

Figure 2. Constant flip angle SPACE imaging during a) navigated free breathing, TA 3:04min; b) self-controlled breath holding on exhalation, TA 5:01min; c) ABC-controlled breath holding on exhalation, TA 4:57min.

Discussion: Comparing the different acquisitions, navigated free breathing seems to provide adequate images in the least time. However, it works well on healthy subjects with regular breathing patterns but may be compromised on patients and does not conform to the radiotherapy treatment lung volumes. The navigator can be applied at specific diaphragm positions whereas the ABC can block any phase of the respiratory cycle for an arbitrary duration, according to the subject's abilities and the purpose of the examination. Normal volunteers are unable to attain the same lung volume in different voluntary breath holds, leading to image artifacts that are alleviated by the ABC. This apparatus can be used with clinically relevant imaging protocols to achieve the same organ positions required during radiotherapy to inform treatment planning and assess irradiation effects. Moreover, its application can improve thoracic and abdominal MRI routinely performed under self-controlled breath holds and is useful for longitudinal MRI studies of structures or regions especially affected by breathing. An automatic external triggering system activated by the balloon valve closure is under construction to facilitate clinical deployment of the ABC. The various contrast options of the SPACE sequence applied in this study are currently under evaluation for clinical lung imaging.

Conclusion: The feasibility of implementing an ABC device during thoracic MR imaging with a high quality 3D TSE sequence and its advantages over routine self-sustained breath holding were demonstrated.

References: [1] Wong JW. et al. The use of active breathing control (ABC) to reduce margin for breathing motion. Int J Radiat Oncol Biol Phys 1999; 44:911-919. [2] Park J, Mugler JP, Hughes T. Reduction of B1 Sensitivity in Selective Single-Slab 3D Turbo Spin Echo Imaging with Very Long Echo Trains. Magn Res Med 2009; 62:1060-1066.

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