A Phase-contrast Single Shot Fast Spin Echo Sequence for Lung Motion Analysis

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Introduction

The assessment of the mechanics of lung parenchyma is important for several diseases of the pulmonary system as e.g. the in-growth of a solid tumor. To quantify local mechanical properties of lung tissue such as motility or strain, grid tagging techniques have been proposed [1,2]. Due to the low spin density of lung tissue and the presence of static field gradients surrounding the alveoli, low MR signal with rapid dephasing of the transverse magnetization is observed in lung parenchyma. Nevertheless, using gradient echo techniques with very short echo times well below 1 ms and optimized inversion recovery tagging pulse trains, lung tissue grid tagging method has successfully been demonstrated. A major disadvantage of grid tagging is the inherent low spatial resolution of the functional information, which can only be extracted from the grid points. These points are typically spaced far less dense than the imaging matrix (e.g. grid: 16x16, image matrix 128x128), so that local variations on a small spatial scale become difficult to describe.

In this work we propose a new imaging pulse sequence to measure the local velocity of the lung parenchyma during the breathing cycle. Using velocity sensitive gradients, motion of the lung parenchyma is encoded in a phase value so that motion information is available at the same spatial resolution as the imaging matrix. To achieve a sufficient signal-to-noise ratio in lung parenchyma, a single-shot fast spin echo technique (RARE/HASTE) with centric reordering is utilized.

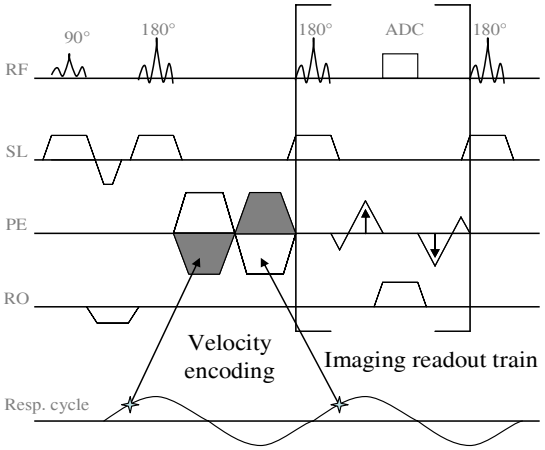

Fig. 1: Schematic of the phase contrast pulse sequence. The polarity of the velocity encoding gradients is changed from one acquisition to the next, which are acquired in subsequent breathing cycles using prospective respiratory triggering.

Materials and Methods

The phase contrast technique was implemented on a clinical 1.5 Tesla whole body MR scanner (Siemens Symphony, Erlangen, Germany). To encode in-plane motion of the lung parenchyma, an additional 180° pulse with bipolar velocity sensitizing gradients was added to a single-shot fast spin echo pulse sequence (RARE/HASTE). The sequence was repeated 5 times with different settings of the velocity encoding (VENC) gradients to measure with two gradient polarities for each in-plane direction (readout direction, phase encoding direction) and one reference data set without bipolar gradients. A schematic of the pulse sequence is shown in Fig. 1.

To maintain the velocity information created by the bipolar gradient, motion compensation was needed during the whole readout echo train. Fast flow compensation was implemented in readout direction to reduce the inter-echo spacing [3, 4] and abbreviated moment-compensation in the central 60%-part of k-space was applied along phase encoding direction to minimize both the time between phase and frequency encoding and TE [5]. To achieve a short effective TE a centric k-space reordering scheme was utilized.

Phantom experiments were performed with an agar-filled bottle mounted on a sled that was cyclically moved within the imaging FOV. For triggering the driving motor was delivering one TTL signal per cycle. In vivo measurements were acquired in 3 healthy volunteers using the respiratory belt for triggering. The following imaging parameters were used: TE/TR/α = 7.6ms/1000ms/180°, 48x128 matrix, FOV 500x375 mm^2, VENC=300 mm/s. The trigger level was set such that images were acquired at maximum motion during the breathing cycle (60% of the expiration), and one image was sampled per respiratory cycle. For comparison, a grid tagging image series was acquired with the following parameters: TE / TR / α = 0.54 ms / 1.30 ms / 5°, 64x128 matrix, FOV 500x375 mm^2, temporal resolution: 84 ms / image.

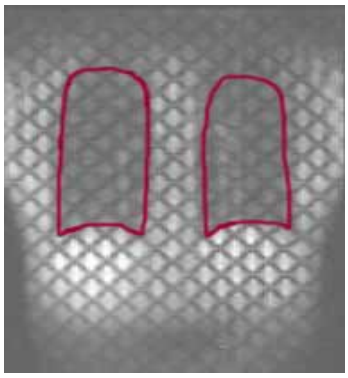

Fig. 2: Grid tagging in the lung.

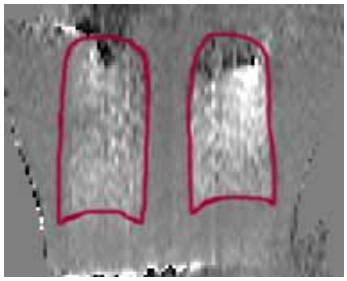

Fig. 3: Velocity image with motion encoding direction in head-feet direction (VENC = 30 cm/s).

Results and Discussion

In the grid tagging experiment the grid pattern inside lung tissue remained visible in the first 5-6 images. Following the grid pattern time evolution, velocity values of 0.0±0.2 cm/s and 3.0±0.2 cm/s were measured at the upper and lower section of the lung (Fig.2). The phase-contrast sequence provides velocity maps with a much higher spatial resolution (cf. Fig. 3). Lung parenchyma is clearly visible in the amplitude images and phase information can be extracted yielding velocity values of 0.1±0.2 cm/s (upper part) and 2.0±0.3 cm/s (lower part) in the right lung. In the phase contrast images artifacts were visible in the upper part of the lung which might be caused by imperfect repetition of the breathing cycle.

The presented method overcomes the reduced signal amplitudes found in lung parenchyma with the help of a fast spin echo technique, and thus provides for the first time a direct quantitative measure of the motion of the lung parenchyma.

References

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