A double echo ultra short echo time acquisition for respiratory motion suppressed high resolution imaging of the lung

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TARGET AUDIENCE: Clinicians and researchers interested in lung imaging and motion suppression for free breathing acquisitions.

PURPOSE: Magnetic resonance imaging is a promising radiation free alternative to computed tomography for lung imaging. However, several technical challenges remain: First, to avoid motion corruption of the images, patients are required to hold their breath for long durations. These breath holds are uncomfortable and may be especially difficult to achieve for patients with lung disease. Failure to sustain the breath hold for a sufficient duration causes blurring, ghosting or other motion related artefacts limiting diagnostic performance. Diaphragmatic navigators are not well suited for lung imaging since the associated excitation and readout in the lung will interfere with image acquisition in the same region. A second challenge is the abundance of air-tissue interfaces, resulting in a very short T_2*, of the order of 2 ms at 1.5 T[1], that provides images with poor signal to noise ratio (SNR). Ultra short echo time (UTE) sequences have been introduced as a way to improve signal from short T_2* tissue in the parenchyma[2]. In order to improve patient comfort and image quality we developed a method to obtain 3D UTE volumes covering the entire lung in a single free breathing acquisition with isotropic spatial resolution.

METHODS**:** A 3D radial UTE sequence based on a spiral phyllotaxis trajectory[3] was implemented and used to acquire data in an interleaved fashion (898 interleaves, 100 readouts per interleaf, which corresponds to 77% of the Nyquist criterion for radial imaging) with ECG triggering to obtain radial projections in k-space at a fixed position in the cardiac cycle. Two echoes were acquired for each k-space line (TE_1=0.1 ms, TE_2=2.88 ms). The second echo, acquired with a conventional gradient echo contrast, allows respiratory motion detection using an automated segmentation of the superior-inferior projections acquired at the beginning of each interleave, as outlined in[4]. Since consecutive interleaves of the spiral phyllotaxis sequence are rotated by the golden angle about the z-axis, arbitrary subsets of data still sample k-space pseudo-uniformly. Therefore, subsets of interleaves acquired during user-selected phases of the respiratory cycle could be selected retrospectively and used for image reconstruction with low impact due to undersampling. This novel method was tested in 6 healthy adult volunteers (28±5 years old, 5 male) using a 1.5T clinical MRI scanner (MAGNETOM Aera, Siemens AG, Healthcare Sector, Erlangen, Germany). Image volumes with an isotropic voxel size of $(1.3\text{mm})^3$ were reconstructed offline for the expiratory phase using a threshold set to keep 50% of the total acquired data (449 interleaves) and compared to motion corrupted images reconstructed using the full dataset (898 interleaves). Vessel sharpness was measured using Soapbubble[5] in the UTE images in the right medial basal segment starting from the beginning of the right medial segmental pulmonary artery. At each successive bifurcation of the vessel, the subsegment deviating the least from the previous vessel segment was followed in order to generate the least tortuous path for the measurement. The SNR was computed by dividing the signal intensity of blood in the aorta by the standard deviation measured in a region of interest outside the chest wall. Statistical significance was assessed with a paired two-tailed Student's t-test with $p<0.05$ considered as statistically significant.

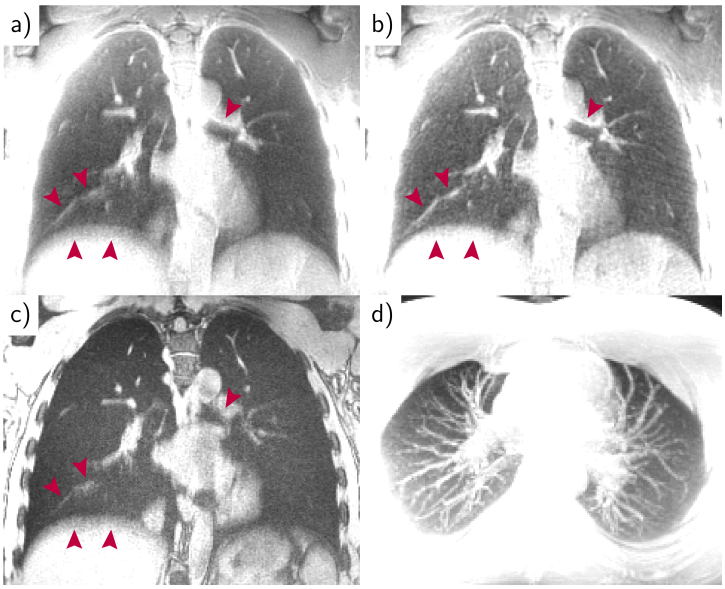

Figure 1: Example from subject 5. a) Motion corrupted reconstruction of the UTE image; b) motion suppressed reconstruction of the UTE image. Sharper features were observed after gating (indicated by arrows); c) motion suppressed reconstruction of the second echo; d) axial MIP (52mm thickness) of the motion suppressed UTE image.

RESULTS: In the expiratory phase reconstruction example UTE image from subject 5 (figure 1b), the lung-liver interface appears better defined compared to the motion-corrupted image (figure 1a). Sharper vessels are observed overall, as well as reduced blurring of the bronchial walls, despite increased streaking artifacts due to undersampling. The proximal bronchi are very well defined in the UTE image when compared to the reconstruction of the second echo shown in figure 1c. Note that the lower signal intensity of the second echo image compared to the first, ultra short, echo image is also apparent. The vessels can be seen even in the periphery as shown in the axial maximum intensity projection (MIP) of 52 mm thickness in figure 1d. As seen in figure 2, all subjects exhibited higher vessel sharpness in the motion-suppressed reconstructions than in the motion-corrupted datasets. The average vessel sharpness rose significantly ($p = 0.04$) from 34.6% for the uncorrected datasets to 38.2% in the expiratory reconstruction and in 6/6 subjects. While 50% of the acquired data were discarded, a 12% SNR penalty ($p = 0.007$) was measured in the UTE images and 26% ($p<0.001$) on those reconstructed using the second echo.

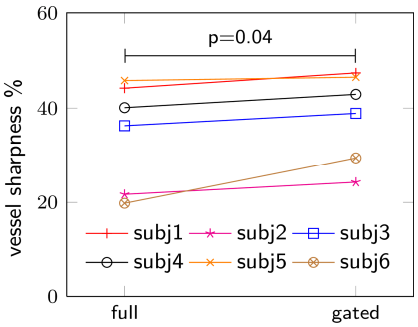

Figure 2: Vessel sharpness measured in UTE reconstructions for 6 volunteers. Comparison between the full motion corrupted dataset and the dataset retrospectively gated to end expiration.

DISCUSSION AND CONCLUSION: The presented method was used successfully to reduce image blurring in free-breathing 3D isotropic UTE lung imaging. Moving forward, and having removed the constraints associated with breath-holding, a high and isotropic spatial resolution for UTE lung imaging is enabled. Improvements in image quality were confirmed by objective, quantitative measures of increased vessel sharpness. This improvement comes at the slight expense of SNR. This SNR penalty remains small, especially in the UTE images, considering that half the data were discarded. This technique, which does not require respiratory gating hardware, increases comfort for the subject, as no breath hold is required, and may therefore be well suited for examination of patients with lung disease. Moreover, the acquisition of two different contrasts in a single acquisition could provide additional diagnostic information.

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