Ultrashort Echo Time (UTE) MR Lung Imaging with Respiratory Motion Compensation

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Introduction: Conventional gradient-echo based magnetic resonance imaging of lung parenchyma suffers from poor signal-to-noise ratios due to low proton density and short T2* caused by susceptibility gradients between airways and tissue. In addition, respiratory and cardiac motions seriously degrade the achievable image quality. Ultra-short echo time (UTE) MRI has recently gained renewed attention for imaging short T2* species by utilizing a half-echo projection acquisition in combination with half pulse excitation to achieve a echo times well below 100us. UTE MRI has been successfully applied to lung imaging [1-3], but so far the issue of respiratory motion during imaging the lung parenchyma has not yet been addressed. In this work, a respiratory motion-compensated UTE lung MRI technique is presented. This technique combines the self-gating properties of projection imaging [4] with the reconstruction flexibility provided by the golden-angle view-order strategy [5].

Methods: 2D and hybrid ("stack of stars") 3D UTE sequences were implemented on a Siemens Sonata 1.5T MRI system. An echo time of ~50us was achieved by combination of half-sinc RF excitation, variable rate excitation (VERSE) [6], half-echo projection acquisition and ramp sampling [7]. A three-lobe half-sinc RF pulse utilizing VERSE during slice selection ramp down had a duration time of 587us, and there was a 50us delay before the beginning of the readout. A variable echo time (VTE) technique was utilized for the 3D UTE sequence to ensure that minimum TE was always used for the different k_z-phase encoding steps [8].

A healthy male volunteer was imaged with a spine array coil. The key scan parameters for the 2D UTE sequence were: FOV=300mm; slice thickness=20mm; TR/TE=10ms/50us; flip angle=7° (Ernst angle, assuming lung T1~1.4s); 256 readout points; 651Hz/Pixel BW. For the 3D UTE, six slices were prescribed with slice thickness=10mm. Due to the utilization of VTE technique, TE varied from 50us (k-space center) to 170us (outer-most k_z). Data acquisition starts 30us in advance of the readout gradient and thus the k-space center was oversampled by six points. The average of these six points were used for respiratory self-gating [4]. An angle of 137.51°, which is the golden angle corresponding to half k-space projection acquisition, advanced successive views during the free breathing acquisitions. This "pseudo-random" view angle ordering was chosen as it permits reconstruction of images using an arbitrary set of views, e.g. those corresponding to end-expiration or end-inspiration as determined by self-gating [5].

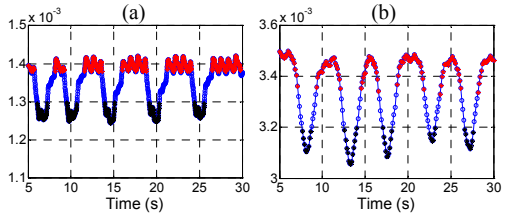

Fig. 1. K-space center signal plotted against time during free-breathing lung imaging acquired with (a) 2D and (b) 3D UTE sequences. The views corresponding to the red (peaks) and black (valleys) segments were used to reconstruct images at end expiration and end inspiration, respectively.

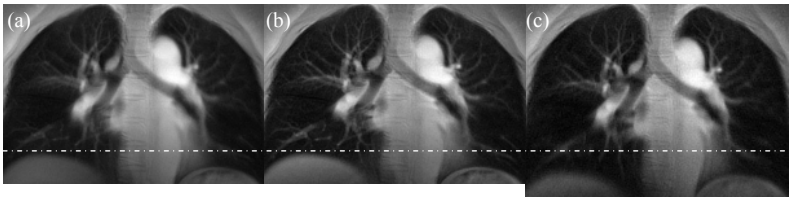

Fig. 2. 2D UTE lung images (a) without gating (30000 views); (b) at end expiration (14292 views); and (c) at end inspiration (7261 views). The dotted line emphasizes the displacement of the diaphragm at the different respiratory phases.

Result and Discussion: Figure 1 shows the signal amplitude at k-space center of radial lines during a free-breathing lung imaging acquired with the 2D and 3D UTE sequences. Respiratory cycles can be clearly observed in the figure. Thresholds were manually chosen to separate the end expiratory and the end inspiratory periods. Figures 2 and 3 demonstrate the image quality improvement with the self-gated motion compensation technique. In Figure 2, 2D UTE lung images are reconstructed without gating, at end expiration and at end inspiration. In Figure 3, 3D UTE lung images are reconstructed without gating and at end expiration. It can be readily observed that delineation of small blood vessels within the lung is significantly improved following self-gating, particularly at end-expiration. Figure 4 shows the SNR comparison between images acquired with UTE (TE=0.05ms) and FLASH (TE=4.3ms) sequences, where SNR is defined as the ratio of the average of the region of interest to the average of the background where no signal is present.

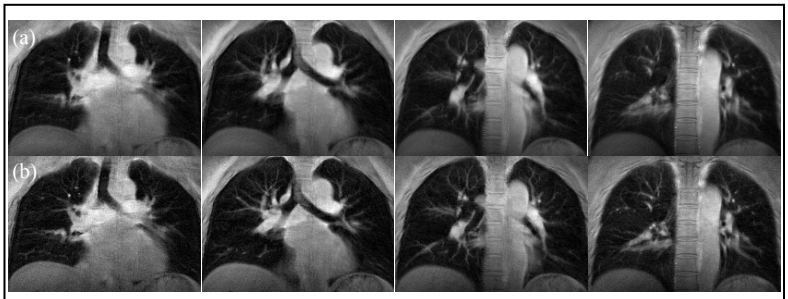

Fig. 3. 3D UTE lung images (4 slices) reconstructed (a) using all data (5000 views) (b) using only end-expiratory data (3050 views).

Conclusion: In this work, a respiratory motion-compensated UTE lung MRI technique is presented. This technique applies the golden-angle view increment strategy in conjunction with respiratory self-gating to reconstruct images at different respiratory phases to reduce respiratory motion artifacts. The in-vivo results demonstrate that lung image quality is significantly enhanced with improved visualization and delineation of lung vasculature, as well as improved SNR, as compared to conventional gradient echo images.

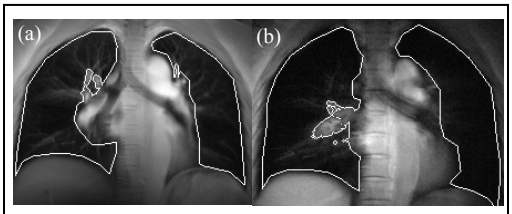

Fig. 4 Signal-to-noise (SNR) comparison between lung images acquired with (a) UTE and (b) FLASH sequences. The SNRs of left and right lungs of UTE image are 21.8 and 19.0, while the corresponding regions of FLASH image are 6.4 and 5.4.

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References: [1] Bergin CJ et. al., Radiology, 179:777-781 (1991). [2] Gewalt SL et al., Magn Reson Med, 29(1):99-106 (1993). [3] Takahashi M et. al., ISMRM 2009, p.11. [4] Larson AC et. al., Magn Reson Med, 51:93–102 (2004). [5] Lin W et. al., Magn Reson Med, 60:1135-1146 (2008). [6] Conolly S et. al., J Magn Reson, 78: 440–458 (1988). [7] Techawiboonwong A et. al., NMR biomed 21:59-70 (2008). [8] Robson M et. al., Magn Reson Med, 53:267-274 (2005).