Optimized Ultra-short Echo Time Breathhold 3D Lung Imaging

Neville D Gai[1], Robert Evers[1], Harsh Agarwal[2], Ashkan Malayeri[1], and David Bluemke[1]
[1]*Radiology & Imaging Sciences, NIH, Bethesda, MD, United States,* [2]*Philips Research N.A., Briarcliff Manor, NY, United States*

Target Audience: MRI physicists and clinicians interested in robust, high SNR lung imaging.

Purpose: MRI of the lung is being increasingly used in the clinical setting because of lack of ionizing radiation which allows repeated scans for longitudinal follow-up. However, structural imaging of the lung is challenging due to the extremely short T2* of lung, the low proton density and the possibility of motion related artifacts on relatively longer MRI scans. Earlier use of the ultra-short echo time (UTE) imaging technique was hampered by poor gradient hardware and other shortcomings unique to a radial trajectory beginning at the center of k-space. UTE imaging is uniquely suited for morphological lung imaging because of reduced T2* relaxation and dephasing as well as increased motion robustness. The more common implementations of UTE sequences are based on 2D using half pulse excitation [1] or 3D spokes trajectory [2.3]. In this work, we optimize a 3D stack of stars trajectory for breath-hold scans. The sequence requires no special hardware or calibration and is suitable for quick screening in a clinical setting without use of contrast agents.

Materials and Methods: The stack of radials (STAR) k-space geometry has some unique advantages which allow for breath-hold (BH) scans. Radial sampling in the in-plane direction ensures short echo time while Cartesian sampling along k_z provides tradeoff between resolution and coverage. In addition, SENSE can be applied in a straightforward manner along the k_z direction to reduce breath-hold time. For shortest echo time, a non-selective pulse is used. To reduce wraparound artifacts, a slab selective RF pulse is employed at the expense of slightly increased scan time (by ~ 0.05 ms).

The T2* of lung at 3T has been measured to be 0.74 ms (1). Optimal SNR for a radial acquisition scheme has been studied by Rahmer et al. (2) where nominal resolution (resulting from blurring) was offset against SNR considerations in order to determine the optimal data acquisition window. For a stack of radials trajectory such as used in this work, the optimal acquisition window is ~ 0.81×T2*. Consequently, the acquisition window was fixed at 0.6 ms. T1 of lung parenchyma has been measured to be 1374 ms at 3T (3). With a spoiled gradient echo radial acquisition scheme as used here, the optimal flip angle is then given by the Ernst angle: $\theta = \cos^{-1}(\exp(-TR/T1))$.

Simulations: The magnetization resulting from the spoiled gradient stack of radials trajectory was simulated using sequence parameters corresponding to the scanning sequence. Parameters used were: TR/TE = 2/0.09 ms, θ = 3.1°, T_{acq} = 0.6 ms, T2* = 0.74 ms, FOV = 380 mm, res = 2 mm, 494 radial spokes.

Scanning: Ten consecutive healthy volunteers (7M,3F; weight: 87.4±19.7 kg) were recruited under an IRB approved protocol. Coronal and axial breath-hold scanning was performed on a Philips 3T Achieva TX scanner using a 16-channel (SENSE Torso XL) receive only coil.

Scan parameters (Coronal): FOV=38-39 cm, TR/TE=2/0.09 ms, radial spokes = 494, parallel imaging: SENSE (k_z) = 2, 25-34 slices for full lung coverage, res=2×2×8mm^3, scan time: 16-21s. Axial breath-hold parameters were similar except res=2.5×2.5×8mm^3, selective RF (TE = 0.14ms), 19-23 slices, scan time: 18-23s and SENSE along k_z was not used. To measure SNR in lung parenchyma, signal and noise only images (two separate breath-holds) were obtained. A semi-automated technique was implemented in Matlab® to measure whole lung SNR by manually drawing a region in the chest wall around the lungs and using thresholding to segment out the lungs. A correction factor of 1.42 for multi-channel magnitude images was applied to calculate SNR [4, 5].

Results: From simulations, peak of the PSF was 0.022 (where peak PSF=1 denotes the case without relaxation and θ=90°) while FWHM was ~ 2mm. Figure 1 shows representative MIPed (25 mm slab) axial and coronal images for a healthy volunteer. Mean SNR (after normalization for different number of slices) was 47±16.02 and 37.2±11.6 across 10 volunteers for coronal and axial scans, respectively. Mean coefficient of variation across slices was 0.307 and 0.116 for coronal and axial images.

Discussion: A hybrid technique such as stack of stars allows for complete lung coverage in a breath-hold when combined with Cartesian SENSE along the coronal direction. SENSE was not utilized for axial scans due to wraparound artifacts despite the use of a slab selective RF pulse. While isotropic imaging as done with a 3D spokes trajectory readily provides reformatted images along the three dimensions, performing separate breath-hold scans along more than one orientation as done here offsets some of the drawbacks of non-isotropic STAR imaging. To achieve a similar voxel resolution with similar sampling density for a 3D spokes trajectory would require ~ 1min which is beyond the realm of a single BH. The variation in SNR between subjects was a result of the different coil loading and consequent different coil receive field patterns. Increased COV along the coronal slab when compared to the axial slab was likely a result of increased signal in the dependent part of the lungs. This can be seen as a higher signal when moving from anterior to posterior coronal images (left to right in Figure1) or as a decreased signal in the anterior part of axial images when compared with the posterior part. While higher resolution scans can be achieved with respiratory triggering and longer scan times, the probability of motion artifacts due to patient movement or respiratory cycle variations increases while the possibility of repeating a scan due to failure in such a situation decreases. Although none of the scans needed reacquisition in our study, breath-hold scans offer the added advantage of the possibility of reacquisition in case of failure to breath-hold in a clinical setting.

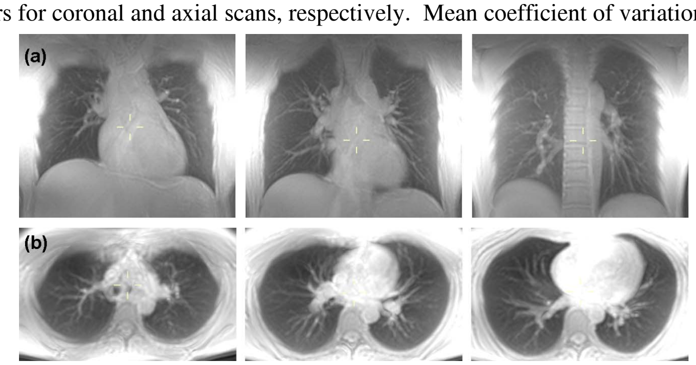

Figure 1: Coronal (a) and axial (b) non-contrast lung images (MIPed: 25 mm thick) displayed at three levels. (a) A → P (left → right) and (b) H → F (L → R).

References: [1] C. Bergin et al. *Radiology* 1991; 179:777-781. [2] M.Takahashi et al. *JMRI* 2010; 32:326-332. [3] K. Johnson et al. *MRM* 2013; 70 :1241-1250. [4] C. Constantinides et al. *MRM* 1997 ; 38 : 852-857. [5] C. Koay et al. *JMR* 2006 ; 179 :317-322.