Pulmonary Ultra-short Echo-time (UTE) Two-dimensional Radial Acquisition with Compressed Sensing: Preliminary Quantitative Results with Comparison to Thoracic CT

Weijing Ma[1], Khadija Sheikh[1,2], Jonathon Leipsic[3], Harvey O Coxson[3], David G McCormack[4], Roya Etemad-Rezai[5], and Grace Parraga[1,2]

[1]Imaging Research Laboratories, Robarts Research Institute, London, Ontario, Canada, [2]Department of Medical Biophysics, The University of Western Ontario, Ontario, Canada, [3]Department of Radiology, University of British Columbia, Vancouver, British Columbia, Canada, [4]Department of Medicine, The University of Western Ontario, London, Ontario, Canada, [5]Department of Medical Imaging, The University of Western Ontario, London, Ontario, Canada

Target Audience: Scientists who are interested in multichannel ^{1}H pulmonary MRI and clinicians who are interested in new visualizations tools for parenchymal and airways disease in chronic respiratory conditions.

Purpose: Magnetic resonance imaging for pulmonary applications and especially for quantitative pulmonary parenchyma measurements is challenging in patients due to the fast T2* decay and the inherently low proton content of the lungs. Previous research has demonstrated that MR pulse sequences with two-dimensional (2D) interleaved half pulse excitation and radial *k*-space trajectories provide a way to reduce echo time and subsequently enhance pulmonary signal intensity and tissue contrast.[1] Compressed sensing methods have also been shown to be helpful in the efficient reconstruction of MR images from incoherently under-sampled *k*-space data. Hence, here we aimed to combine ultrashort echo time radial acquisitions and compressed sensing to achieve rapid breath-hold ^{1}H pulmonary MRI on a clinical 3T scanner for quantitative measurements of the lung parenchyma. Such measurements were directly compared in healthy volunteers at different lung volumes and in patients with COPD and bronchiectasis with ^{3}He MRI apparent diffusion coefficients, CT measurements of tissue density and pulmonary function measurements of lung volume and airspace abnormalities.

Methods: Three techniques were combined to achieve high signal to noise ratio (SNR), fast imaging acquisition and low imaging artifacts. A research prototype 2D radial UTE sequence with interleaved half pulse excitation was implemented on a whole body 3.0 Tesla Discovery 750MR scanner (General Electric Health Care, Milwaukee, WI). By combining the interleaved half pulse excitation and ramp-sampling radial trajectory, the echo time was reduced to 50 µs. A single channel birdcage body coil was used for RF excitation and a 32 channel torso coil was used as the receive coil to reduce scan time without compromising image quality and signal intensity. To reduce respiratory motion artifacts, images were acquired during breath-hold conditions at functional residual capacity + 1 litre of air. Complete imaging parameters are in Table 1. We used an iterative algorithm to reconstruct UTE images from radially under-sampled *k*-space data. [2] The following objective optimization function was used:

$$\min_u |\mathcal{F}(u) - y|_{l1} + \lambda_1 \|(G - I)u\|^2 + \lambda_2 |\Psi(u)|_{l1} \qquad (1)$$

where $y = (y_1, y_2, y_3, \ldots, y_n)$ is the measured *k*-space data of *n* individual coils, $u = (u_1, u_2, u_3, \ldots, u_n)$ is the reconstructed image of *n* individual coils, $\Psi(\cdot)$ is the Daubechies wavelet transform, $\mathcal{F}(\cdot)$ is the non-uniform Fourier Transform (nuFFT), [3] G is a series of multiplication operators that regulate unmeasured data points from their entire neighbourhood across all coils. The first term is the data fidelity term that ensures data acquisition consistency, the second term enforces calibration consistency between the acquired data and the synthesized points, and the third term puts a constraint on the wavelet sparsity of the *k*-space. Since a 32 channel torso coil array was used as the receive coil, the acquired images showed artefacts due to field inhomogeneity, which leads to subject-dependent systematic errors for image quantification. A non-parametric, entropy-minimization based, post-processing method (LEMS) [4] was implemented to correct for this field inhomogeneity artefact. The mean signal intensity (SI) was subsequently normalized to the mean SI in the liver to reduce systemic inter-scan variability. In this work, both normalized mean SI and apparent signal to noise ratio ($S_R = SI_{lung}/SI_{air}$) were used to evaluate image quality.

Results: Figure 1 shows the centre coronal slice for a healthy 22yr male using a conventional FGRE sequence and two different UTE imaging schemes. The top row shows the magnitude images of the corresponding slices: from left to right, the normalized lung parenchyma signal increased from 6% using FGRE to 27% using 32-channel UTE with compressed sensing.

Discussion: UTE MRI can be optimized using 2D radial approaches, compressed sensing and field inhomogeneity correction to allow for the quantitative evaluation of pulmonary parenchyma measurements including those associated with mucous plugging in bronchiectasis and tissue destruction that accompanies emphysema.

Conclusion: Thirty-two channel UTE MRI with compressed sensing was successfully implemented at 3T and showed significant improvement in SI and S_R for images acquired at expiration breath-hold (functional residual capacity) and this was safe and practical for patients with chronic respiratory disease.

Table 1. Imaging Parameters

Sequence	*UTE*	*FGRE*
Coil type	1ch birdcage /32ch torso coil	32-ch torso coil
FOV (cm)	40×40	40×40
Flip angle (°)	10	30
Freq encoding	256	256
Phase encoding	439	128
TE (µs)	50	1200
TR (ms)	13	4.7
NEX	4	1
Slice thickness (mm)	15	15
Number of slices	1	14
Acquisition time (s)	13	16

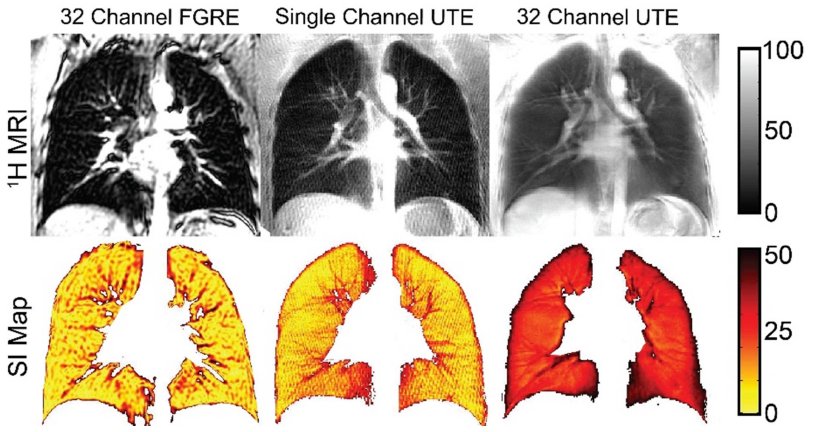

Figure 1. Centre coronal slice MRI of a representative healthy volunteer
Left panel: 32-channel FGRE MRI with mean normalized ^{1}H SI=6%, S_R=1. Middle panel: single-channel UTE MRI with normalized mean ^{1}H SI=11%, S_R=3. Right panel: 32-channel UTE MRI using compressed sensing (CS) with mean normalized ^{1}H SI=27%, S_R=7.

References

1 Bergin CJ, Glover GM, Pauly J. J Thorac Imaging 1993; 8:12-17
2 Lustig M, Pauly JM. SPIRiT: Magn Reson Med 2010; 64:457-471
3 Fessler JA. J Magn Reson 2007; 188:191-195
4 Salvado O, Hillenbrand C, Zhang S, et al. IEEE Trans Med Imaging 2006; 25:539-552