Lung Tissue Differentiation with Magnetization Transfer Prepared Multi-Echo Ultrashort Echo Time MRI

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TARGET AUDIENCE: Clinicians and scientists interested in MRI in lung disease.

PURPOSE: Ultra-short echo time (UTE) imaging holds promise for vastly improved imaging of lung structures[1-4], but is typically proton density or T1 weighted, providing limited tissue contrast. Thus it is challenging to differentiate normal lung, fibrosis, and edema. In this work, we investigate the combination of UTE with multi-echo (ME) sampling and magnetization transfer (MT) to investigate T2 contrast at two very different time scales. In this manner, we hypothesize we will be able to separate fibrotic tissue from edema and normal lung.

THEORY: T2* values of hydrogen spins in biological tissue span a considerable range. With conventional echo times (TE >1ms), long T2* spins such as water molecules in muscle and fat are easily visualized; and imaging of short T2* spins (T2* > 100μs, e.g. lung) can be performed with ultra-short echo time sequences. Even with UTE, spins with ultra-short T2 (T2 < 100μs), which are common in connective tissue (e.g. fibrosis) are not visible. However, short T2 tissue components can be probed indirectly by magnetization transfer (MT) experiments[5-6], given the assumption that there are sufficient spins with longer T2*'s in spin exchange. To separate long T2* (T2*>2ms, edema), short T2* (T2* =0.1-1ms, lung tissue, bone), and bound T2* (T2* < 100μs, macromolecules) spins, we model signal as a function of echo time (TE) and MT pulse:

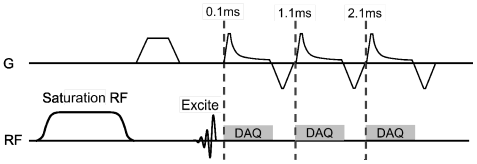

Figure 1. *Multi-echo fly-back UTE Magnetization transfer pulse sequence with, for example, 3 echoes.*

$$S(\mathrm{TE}, MT) = (1 - MTR) \cdot \left(\rho_{Short} e^{-\mathrm{TE}/\mathrm{T2}^{*}_{\mathrm{Short}}} + \left(\rho_{Water} + \rho_{Fat} e^{i 2\pi \Delta f} \right) e^{-\mathrm{TE}/\mathrm{T2}^{*}_{\mathrm{Long}}} \right) \cdot e^{i\psi \cdot \mathrm{TE}} \qquad \text{Eq 1.}$$

where Ψ is off resonance and MTR is the magnetization transfer ratio($(MToff - MTon)/MToff$). To reduce the number of measurements, the T2* of the short component is assumed to be sufficiently short such that when imaged with echo times greater than 1ms, the signal is insubstantial. Given these assumptions, separation of the two T2* decay components and estimation of ultrashort T2 component (via MTR) requires images with and without MT pulses at an ultra-short TE and several conventional TEs.

METHODS: All experiments were performed on a 1.5T scanner (HDx, GE Healthcare, Waukesha, WI) with an 8-ch coil (HD Cardiac, GE Healthcare, Waukesha, WI). To assess feasibility, images were acquired in an inflated excised swine lung and in a healthy human subject with a magnetization transfer multi-echo 3D UTE sequence shown in Figure 1. Images were acquired with and without magnetization transfer utilizing: 8-echoes (TE_1=100μs, ΔTE=1ms), TR=30ms, α=15°, variable density readouts, 2.5mm isotropic image resolution, 8ms 700° MT pulse 2kHz off-resonance, 10,000 projections, respiratory gating with 50% efficiency, scan time ~20min (10 minutes ex-vivo). Images were reconstructed offline and subsequently fit to Eq 1 with non-linear least squares to solve for: magnetization transfer ratio, short T2 tissue, and long T2 tissue.

RESULTS: Figure 2 shows coronal and axial reformats from ex-vivo and in-vivo imaging. In swine images, fluid accumulation due to ex-vivo preparation is well visualized in long T2 signal and separated from short T2 signal. MTR images show insensitivity to fluid accumulation with a mean value of 18.6±4.2 in the lung. Human images show successful separation of the short T2* lung tissue and bone from long T2 fat/water. MTR in in the lungs was measured to be 12.6±4.2.

DISCUSSION AND CONCLUSION: UTE with MT shows potential to differentiate species based on T2 regime. This may be of great value in diseases involving pulmonary fibrosis (increased MTR) and mucus plugging (increased long T2). However, substantial work is needed to validate techniques in cases of disease and corroborate changes in MTR with changes at a cellular level. Furthermore, reduction of scan times and improved motion compensation will be required for clinical translation.

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REFERENCES:*[1] Bergin et al. Radiology,179:777 [2] Johnson et al. ISMRM 12' #64:1491 [3] Takahashi et al. JMRI 32(20) [4] Togao et al. JMRI 34(3) [5] Jakob et al. MAGMA 15:10 [6] Kuzo et al. I Radiology. 30(2):118*

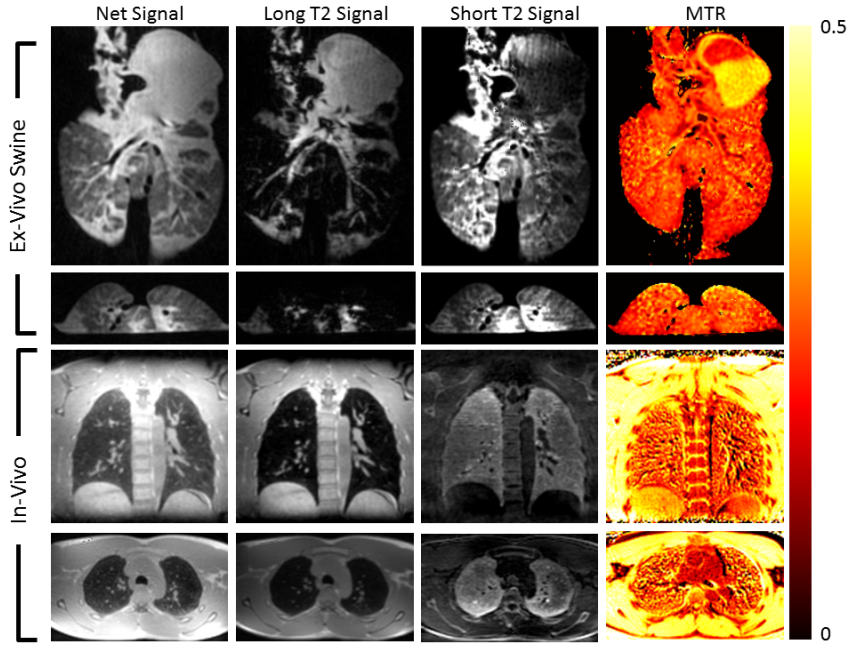

Figure 2. *UTE MT images of an excised porcine lung (top). Note the excellent separation of accumulated fluid from short T2 and independence of MTR in inferior section of lung. In-vivo results (bottom) show separation of bone and lung from long T2. Modest registration errors occurred between MT scans leading to errors in the MTR map.*