Ultra-short echo time MRI Measurements of Emphysema using Principal Component Analysis

Khadija Sheikh[1,2], Dante Capaldi[1,2], Sarah Svenningsen[1,2], David G McCormack[3], 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, London, Ontario, Canada,* [3]*Division of Respirology, Department of Medicine, The University of Western Ontario, London, Ontario, Canada*

Target Audience: Scientists interested in ^{1}H magnetic resonance imaging of the lung.

Purpose: Pulmonary emphysema is defined as a "progressive condition of the lung characterized by abnormal and permanent enlargement of the airspaces distal to the terminal bronchioles, accompanied by the destruction of their walls, and without obvious fibrosis".[1] Pulmonary emphysema has been quantified using mean signal intensity and T2* measurements enabled by ultra-short echo time (UTE) ^{1}H MRI.[2] Previous work also showed the utility of a single MRI signal intensity threshold based on thoracic x-ray computed tomography (CT) emphysema thresholds.[3] Thoracic CT threshold-based emphysema measurements are correlated to pulmonary function tests, and both microscopic and macroscopic measurements of emphysema, but there is no consensus regarding an optimal threshold. Recent work has used principal component analysis (PCA) of CT density histograms to assess emphysema. This method uses a broad frequency distribution of pixel intensities across a wide range of density values to produce a single score and measurements derived from this method have been shown to correlate with pulmonary function tests and expert radiologist emphysema scores.[4] To better identify meaningful MRI signal intensity thresholds, we used principal component analysis to evaluate the UTE signal intensity histograms to generate principal components based on each frequency-signal intensity pair. We hypothesized that a UTE MRI principal component score would provide a clinically and physiologically-relevant measurement of emphysema that would be strongly related to ^{3}He MRI and CT measurements of emphysema.

Methods:

***Subjects*:** Subjects with chronic obstructive lung disease (COPD) and CT evidence of emphysema, defined as $RA_{950} \geq 5\%$,[5] provided written informed consent to an approved study protocol and underwent spirometry, plethysmography, the six-minute-walk test, ^{1}H UTE and thoracic CT.

***Image Acquisition and Analysis*:** Imaging was performed on a whole body 3.0 Tesla Discovery MR750 (General Electric Health Care, Milwaukee, WI) with broadband imaging capability as previously described.[4] UTE ^{1}H MRI was obtained using a 32-channel torso coil (GEHC) and a half RF excitation, 2D radial acquisition UTE sequence (GEHC). UTE MRI was used to acquire a single centre slice in the coronal plane with the following parameters: 13s acquisition time, TE/TR/flip angle=0.05ms/13.0ms/10°, field-of-view (FOV)=40×40cm, matrix=256×439, NEX=4, and 15mm slice thickness. Thoracic CT was performed as previously described.[4] The lung parenchyma was segmented from the heart, mediastinum, central pulmonary vessels, diaphragm, and chest wall. Frequency histograms of MR signal intensity (SI) and CT tissue attenuation (Hounsfield Units, HU) were generated and PCA was performed on the relative area under the histogram curve for each SI and HU value. PCA generated principal components based on the variation between input variables. The first two PCs that have the highest eigenvalues were selected and the density histogram principal component score (D_HP_CS) and signal intensity histogram principal component score (S_HP_CS) were determined, as previously described.[4]

***Statistical Analysis*:** Univariate relationships were determined using linear regression (r^2) and Pearson correlation coefficients (r) using GraphPad Prism version 6.00 (GraphPad Software, San Diego, CA).

Results: In this proof of concept demonstration in 10 COPD ex-smokers (68±8yrs) with CT evidence of emphysema UTE signal intensity histogram PC scores were determined. Figure 1 shows mean signal intensity, CT density histograms and corresponding principal components. S_HP_CS was significantly correlated with D_HP_CS (r^2=0.49, p=0.02). As shown in Figure 2, S_HP_CS significantly correlated with RA_{950} (r^2=0.43, p=0.04) and FEV_1/FVC (r^2=0.50, p=0.02), but not HU_{15} (r^2=0.34, p=0.08), DL_{CO} (r^2=0.08, p=0.5) or six minute walk distance (6MWD) (r^2=0.14, p=0.3). SI_{15} was not significantly correlated with RA_{950} (r^2=0.05, p=0.5), HU_{15} (r^2=0.08, p=0.4), FEV_1/FVC (r^2=0.09, p=0.4), DL_{CO} (r^2=0.0004, p=0.9) or 6MWD (r^2=0.34, p=0.06).

Figure 1. ^{1}H signal intensity and CT density histograms (Fig. 1A and 1B) and corresponding principal components generated by PC analysis (Fig. 1C and 1D) for all subjects.

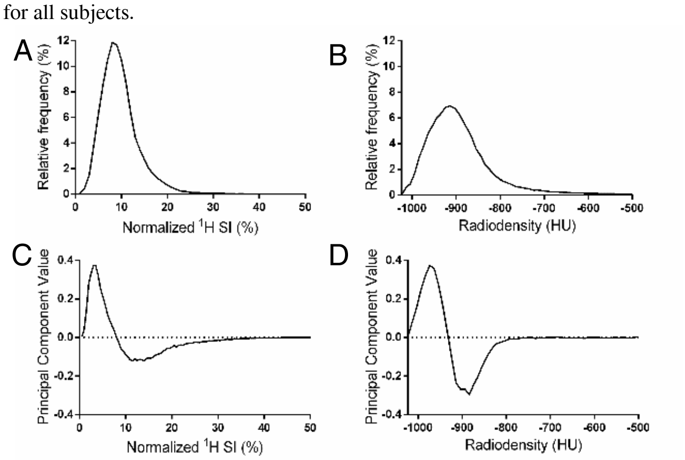
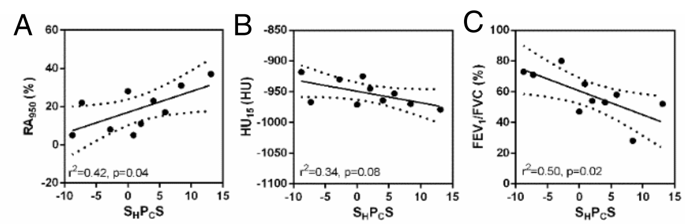


Figure 2. Relationship between S_HP_CS and CT and pulmonary function test measurements.



Discussion: We determined a UTE signal intensity histogram PC score (S_HP_CS) taking into account all frequency-signal intensity pairs to assess emphysema. Single threshold SI measurements are sensitive to inter-scan variability, RF amplification, coil positioning and scanning parameters, and therefore S_HP_CS may provide a more robust measurement because it is derived across a wide range of the frequency distribution of signal intensities.

Conclusions: We evaluated the ^{1}H UTE frequency-signal intensity pairs to assess emphysema using principal component analysis and showed in a small group of 10 COPD ex-smokers with emphysema that PCA can be used to derive a UTE MRI score that is related to RA_{950} and FEV_1/FVC.

References:

1 Snider, G *et al. The American review of respiratory disease* **132**, 182-185 (1985).

2 Zurek, M *et al.Magnetic Resonance in Medicine* **68**, 898-904, doi:10.1002/mrm.23281 (2012).

3 Ma, W. *et al.* Ultra-short echo-time pulmonary MRI: Evaluation and reproducibility in COPD subjects with and without bronchiectasis. *Journal of magnetic resonance imaging : JMRI*, doi:10.1002/jmri.24680 (2014).

4 Owrangi, A. M. *et al. Academic radiology* **20**, 537-545, doi:10.1016/j.acra.2012.11.010 (2013).

5 Schroeder, J. D. *et al. American Journal of Roentgenology* **201**, W460-W470 (2013).