3D radial oxygen enhanced imaging in normal and asthmatic human subjects

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INTRODUCTION: Robust assessment of pulmonary ventilation with MRI is challenging due to the poor imaging characteristics of lung parenchyma [1] and the expensive and specialized hardware requirements of hyperpolarized noble gas MRI [2]. Oxygen Enhanced (OE) MRI has potential as an inexpensive and readily available technique for ventilation imaging. The presence of molecular oxygen lowers the T1 of tissue, increasing signal intensities in ventilated lung [3]. The feasibility of 3D radial Ultrashort Echo Time (UTE) SPGR sequences for OE imaging has been previously demonstrated in rats [4] and humans [5]. The purpose of this work is to explore the utility of 3D radial UTE for pulmonary OE MRI in human subjects with and without obstructive lung disease.

METHODS: Seven normal and five asthma subjects underwent imaging in this IRB-approved, prospective study on a 1.5T scanner (Signa HDX, GE Healthcare, Waukesha, WI, USA) using a commercial 8-channel cardiac coil. A 5.5 min 3D radial UTE acquisition was performed under adaptive end-expiratory respiratory gating with a 50% acceptance window. The scan was performed twice while the subject freely breathed a medical air mixture, the first time at 21% O_2, the second time at 100% O_2. Gas was delivered continuously through a non-rebreather mask with a 1-2 min pause between concentrations to avoid transient effects. Asthma subjects were imaged on two separate visits; normal subjects had one visit, but underwent multiple acquisitions if time permitted. Specific imaging parameters: optimal FA=8° based on literature T1 values [6], TE/TR=.08/4.2ms, FOV = 32cm^3, 38000 projections, spatial resolution of 5 mm isotropic.

ANALYSIS: Volumes acquired at 21% O_2 (V_{air}) and 100% O_2 (V_{oxy}) were spatially registered using a 3D affine algorithm written in Elastix [7]. 3D lung masks were generated from each V_{oxy} volume with a fully automated region growing algorithm written in Matlab [8]. Registration and masking took less than thirty minutes per volume. Voxelwise OE ventilation volumes were then generated using the equation $V_{OE} = (V_{oxy}-V_{air}) / V_{air} * 100$ (**Fig. 1**). Mean Signal Enhancement (MSE) was measured as the mean of V_{OE} within the OE lung volume. One normal subject was excluded due to technical difficulties with the oxygen delivery system. Two normal OE volumes and two asthmatic OE volumes were omitted from analysis after a prospective blinded review due to non-physical MSE (MSE<0) paired with gross artifacts remaining after registration, leading to a technical failure rate of 5/19 or 26%. This resulted in 5 normal and 4 asthma subjects remaining for statistical comparisons. MSE of normal vs. asthma subjects was compared using a Welch's t-test. MSE for posterior and anterior (P/A) lung regions was compared via a Wilcoxon signed rank test. Both tests were modified for repeated measures.

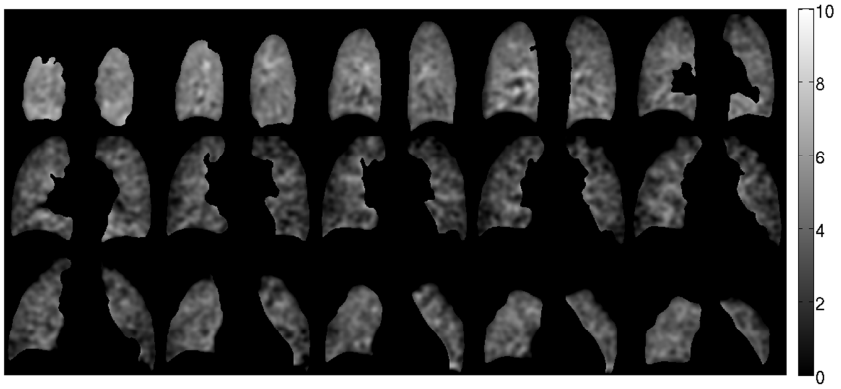

Fig. 1: Sequential coronally oriented slices from posterior to anterior (P/A) of masked oxygen enhanced lung in a normal volunteer. The scale is in units of percent change.

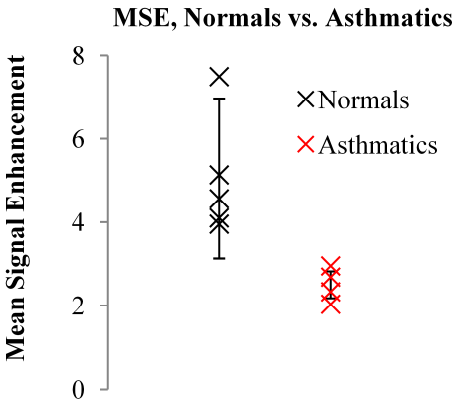

Fig. 2: Whole lung MSE for 5 normal subjects and 4 asthma subjects. Individual points are averages of intrasubject repeat measures; error bars represent the weighted group mean and standard deviation.

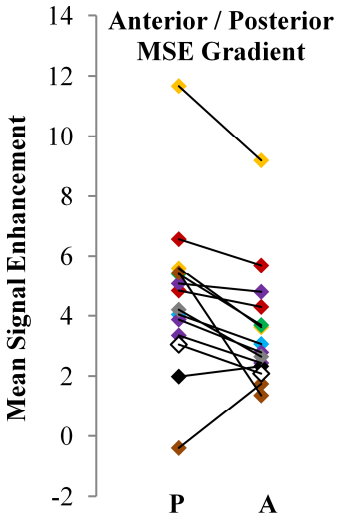

Fig. 3: MSE of posterior (P) and anterior (A) regions of all 14 OE volumes from all 9 included subjects. Data points are color coded by subject. A trend toward lower MSE in anterior regions is evident.

RESULTS: Individual MSE measurements from asthmatic subjects were all lower than those from normal subjects ($p < .1$, **Fig. 2**). Average MSE for normal subjects was 5.0% ± 1.3% compared to 2.6% ± .3% for asthma subjects. MSE also tended to decrease along a P/A gradient, with 12 of 14 volumes having a lower anterior vs. posterior MSE ($p < .05$, **Fig. 3**).

DISCUSSION: The lower observed MSE in asthma compared to normal subjects is consistent with results in the literature for COPD [9,10]. The P/A gradient in MSE follows the expected gravity dependence of ventilation in the supine position that is well established physiologically and in other imaging techniques such as hyperpolarized gas MRI [11]. However, the small sample size and high technical failure rate limit the significance of these results.

CONCLUSION: OE MRI with 3D radial UTE SPGR shows promise for detecting changes in ventilation associated with obstructive disease both in whole lung and regional measures. The gravity dependence of OE MRI was readily demonstrated owing to the availability of 3D volumetric data intrinsic to the isotropic resolution 3D approach. Ongoing studies of both normal and asthmatic subjects will address the noted technical and sample size limitations of the current study.

REFERENCES: [1] Hatabu, Eur J Radiol 1999, [2], Fain, JMRI 2007, [3] Edelman, Nature Medicine 1996, [4] Togao, JMRI 2011, [5] Kruger, ISMRM 2012 poster #1344, [6] Jakob, JMRI 2001, [7] Klein, IEEE Transactions on Medical Imaging, 2010, [8] v7.9.0, the MathWorks Inc. 2010, [9] Ohno, AJR 2001, [10] Molinari, JMRI 2007, [11] Van Beek, JMRI 2004