Oxygen Enhanced Lung MRI Using 3D Radial UTE SPGR in Humans

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INTRODUCTION: Pulmonary Magnetic Resonance Imaging (MRI) of ventilation is challenging due to low proton density and very short T2*[1]. Hyperpolarized noble gas MRI has shown marked success [2] but requires specialized hardware that is expensive and not widely available. Oxygen Enhanced (OE) MRI is an inexpensive and simple alternative for pulmonary ventilation imaging [3] that utilizes the T1 shortening effect of paramagnetic molecular oxygen. Traditional OE MRI methods have relied on 2D Inversion-Recovery Single Shot Fast Spin Echo (IR-SSFSE) acquisitions with thick slices and incomplete lung coverage. Recent work by Togao, *et al* has demonstrated the potential of Ultrashort Echo Time (UTE) methods to increase the baseline lung signal of OE MRI, allowing acquisition of 3D ventilation images in a rat model [4]. The purpose of this work is to demonstrate the feasibility of performing 3D OE MRI in humans using commercial hardware with an UTE approach that provides full lung coverage, resistance to T2* decay, and sufficient contrast in the absence of a lengthy inversion pulse.

METHODS: Three normal subjects were scanned in this HIPAA-compliant, IRB-approved prospective study on a 1.5T clinical scanner (Signa HDX, GE healthcare, Waukesha, WI, USA) using a commercial 8-channel cardiac coil. Subjects were imaged with both a conventional IR-SSFSE and a 3D radial UTE Spoiled Gradient Recalled Echo (SPGR) approach. A medical air mixture (21% oxygen) or 100% oxygen was delivered to each subject through a tight-fitting non-rebreather mask. Gas was delivered continuously for a 5-10 min period, with a 1-2 min pause between 21% O_2 and 100% O_2 imaging to avoid transient effects. Percent change maps were generated from both IR-SSFSE and UTE images using the equation $P_c = (S_{oxy}-S_{air}) / S_{air}$ for each pixel. Optimal Inversion time for IR-SSFSE and flip angle for 3D UTE were calculated to maximize contrast between air and oxygen volumes based on previously reported T1 values [5].

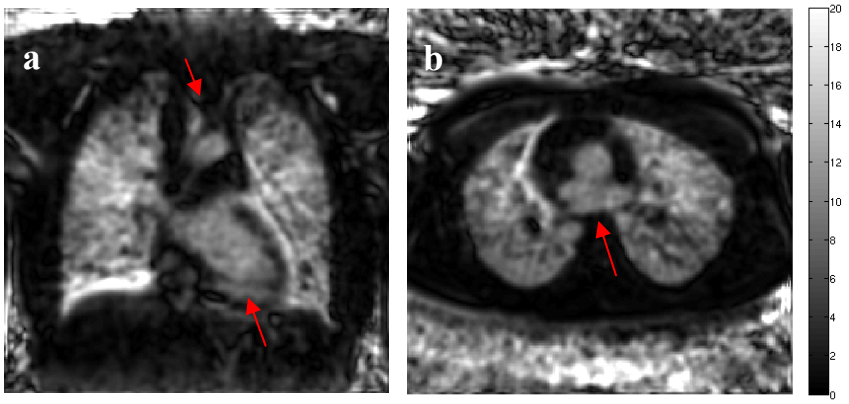

Figure 1: Oxygen Enhanced 3D Radial UTE. 5 mm isotropic resolution percent change images of (a) coronal and (b) axial slices with TE = .08 ms. The oxygenated blood in the left heart chambers and aortic arch (arrows) also display oxygen enhancement, while the deoxygenated blood in the right chambers do not.

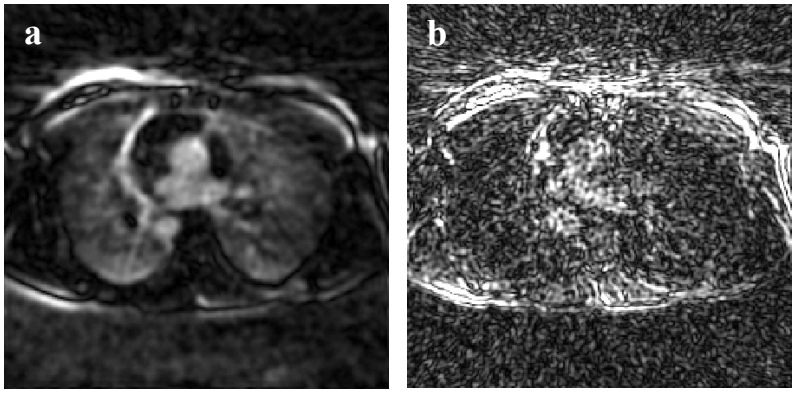

Figure 2 UTE vs. conventional TE. Axial difference images (oxy – air) at (a) TE = .08 ms and (b) TE = 2.1ms. Image quality and SNR are poor in a conventional echo time 3D Radial SPGR acquisition due to the very short T2* environment.

IR-SSFSE: 20 respiratory-gated IR-SSFSE images were acquired at end-expiration during 5 min of tidal breathing at each of the 2 oxygen concentrations. Other scan parameters include: TR/TE_{eff} 5s/3.9ms, FOV=48 cm, matrix size=128 (in-plane true resolution 3.75 x 3.75 mm), slice thickness=20mm, TI=1250 ms, parallel imaging (ARC) factor=1.6, in a 56% partial Fourier acquisition with linear view ordering. After discarding images that demonstrated marked cardiac signal (likely due to acquisition during systole), deformable registration was performed using built-in plugins in FIJI [6]. These registered images were then signal-averaged to generate a single 2D coronal "oxygen" and "air" image.

3D RADIAL UTE: 3D datasets were collected with a dual echo 3D radial UTE sequence during two 5-6min free-breathing scans at 21% O_2 and 100% O_2. Radial trajectory gradients were designed with a variable density 1 ms readout time per echo. Respiratory motion was minimized with real-time gating to end-expiration through adaptive feedback from the respiratory bellows signal with a 50% acceptance window. Other scan parameters included: FA=8°, FOV=32cm, isotropic resolution=2.5mm, TE1/TE2/TR=.08/2.1/4.2ms, 38000 projections. To improve SNR, images were low-pass filtered in k-space to 5 mm isotropic resolution, and interpolated with zero-filling to a 256^3 matrix size.

RESULTS: Over all subjects the IR-SSFSE images of the 2cm-thick coronal slice showed a 7.6±1.4% increase in lung signal at 100% O_2 relative to 21% O_2, as measured in an ROI in the right upper lobe. This was comparable to previously reported values [7]. The UTE images (**Fig. 1)** at TE=.08ms demonstrated an 11.5±2.5% increase in signal over all subjects in a similar ROI. Respiratory and cardiac motion artifacts were not apparent in the UTE images.

DISCUSSION: By mitigating the signal loss due to T2* decay in an SPGR sequence, 3D radial UTE oxygen-enhanced MRI is able to scan more efficiently than IR-SSFSE, without the need for a long inversion time. This enables full-chest 3D coverage with isotropic spatial resolution in a comparable total scan time. Furthermore, because the center of k-space is acquired with each projection, there is inherent signal averaging creating a robust acquisition without artifacts due to cardiac motion. If an ultra-short TE is not utilized, image quality degrades rapidly as T2* decay reduces SNR (**Fig 2).** This approach is promising for improving scan efficiency compared to 2D respiratory and cardiac gated OE-MRI techniques.

CONCLUSION: To our knowledge this is the first UTE 3D radial sequence utilized in human subjects for the purpose of Oxygen enhanced ventilation mapping. Oxygen-enhanced 3D radial UTE MRI holds great promise as a widely accessible, simple, and robust method for obtaining 3D ventilation images in clinical and research applications.

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