

Ventilation Quantification Using Volumetric Interpolated Breath-hold Examination (VIBE): Preliminary Findings

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Introduction Traditional magnetic resonance imaging (MRI) in human lung has been a challenge due to the low tissue density in the lung and the short T_2 of lung tissue (1,2). As an alternate approach, hyperpolarized gas (HPG) MRI, which images gas in the lung air spaces, yields high signal strengths, and has been increasingly used as a research tool to image lung function and structure (3,4). The requirement for specialized technology and personnel, however, has limited the wide use of HPG MRI in the clinic. In recent years, direct imaging of lung tissue has regained much attention with the development of short acquisition time technique (5) and frequency-sweep NMR (SWIFT) (6-8). In particular, a recently proposed Fourier decomposition (FD) technique using steady state signal acquisition at free breathing allows simultaneous imaging of ventilation and perfusion (9). However, in order to gain speed, this technique only acquires a single slice. In this work we demonstrate the feasibility of imaging regional ventilation using 3D proton MRI and computer-aided image registration at different lung volumes. Quantitative results from healthy volunteers and patients with lung disease are compared with the corresponding ^3He ventilation images.

Methods Three healthy volunteers, three post lung-transplant patients, and three asthma patients were imaged using a Siemens 1.5 T whole body scanner. The study was approved by our IRB. Written consent was obtained from all volunteers. Proton images were acquired at 3 or 4 standard lung volumes (RV – residual volume; FRC – functional residual capacity; FRC+1 L; TLC – total lung capacity) with breath-holds of 10-11 s, using volumetric-interpolated breath-hold examination (VIBE). Imaging parameters include: TR/TE = 3.1/0.8 ms, 5 mm slice thickness, 450X270 mm² field of view, 2.3X2.3 mm² in-plane resolution. In post processing, a custom program was used to register the proton images at different volumes using the Demons algorithm (10). Signal intensities in parenchymal areas of the registered images were normalized to spinal-cord signal to eliminate the effect of sensitivity changes due to volume differences. Differences between the normalized images were computed as indications of density change in lung tissue. 2D ^3He ventilation images were also acquired at 12 mm thick and in-plane resolution of 3.125X3.125 mm² to compare with the proton difference images.

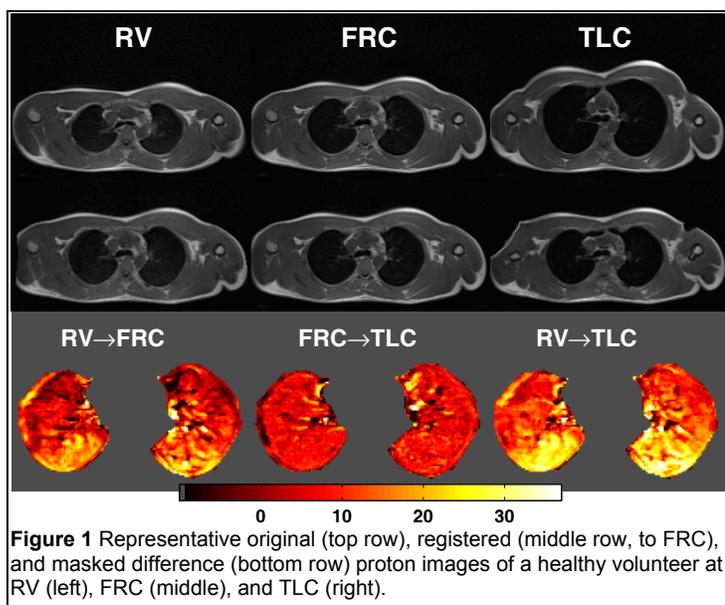


Figure 1 Representative original (top row), registered (middle row, to FRC), and masked difference (bottom row) proton images of a healthy volunteer at RV (left), FRC (middle), and TLC (right).

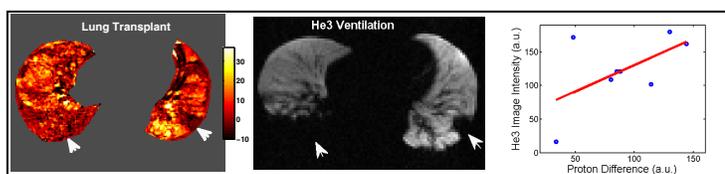


Figure 2 Proton difference image (left), the corresponding ^3He ventilation image (middle), and correlation between the intensities of the two images of 8 regions (right) for a lung-transplant recipient one year after surgery. Arrows indicate regions of ventilation defects which can be seen on both images. A linear fit to the correlation plot yielded a positive correlation between the proton difference image and ^3He ventilation image ($R^2=0.33$).

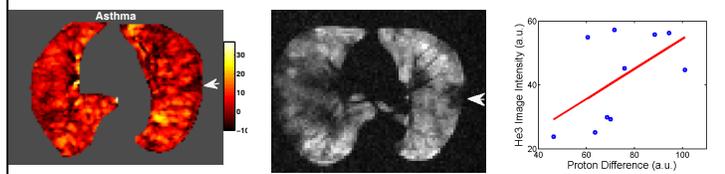


Figure 3 Proton difference image (left), the corresponding ^3He ventilation image (middle), and correlation (right) from a severe asthma patient. The significant ventilation defect on the right lung (arrow) can be seen on both images. Linear fit to correlation yielded a positive slope with $R^2 = 0.31$.

Differences between the normalized images were computed as indications of density change in lung tissue. 2D ^3He ventilation images were also acquired at 12 mm thick and in-plane resolution of 3.125X3.125 mm² to compare with the proton difference images.

Results Figure 1 shows representative original (top), registered (middle), and masked difference (bottom) images of the healthy volunteer at RV (left), FRC (middle), and TLC (right). The difference image between RV and FRC displays a strong posterior-anterior gradient, which is expected from gravitational effects (11); from FRC to TLC, however, the difference image is highly uniform, demonstrating a uniform expansion throughout the healthy lungs, with some complementarity to RV->FRC. Figure 2 depicts the proton difference image of a 1-year post-transplantation patient. Poorly ventilated areas can be identified by the low difference areas indicated by arrows. These areas are also seen in the corresponding ^3He ventilation image (middle). The correlation between the proton difference image and the ^3He ventilation image is shown in the right of Fig. 2 by plotting the intensities of 8 selected areas in each image with spatial correspondence that uniformly cover the lungs. Data were fitted linearly which resulted in R^2 of 0.33. Figure 3 shows results from an asthma patient. The significant ventilation defect, as shown by the arrows, can be easily identified on both proton difference (left) and ^3He ventilation (middle) images. A similar measure of correspondence yielded R^2 of 0.31. Results shown in Figs. 2 and 3 are representative of the post lung-transplant/OB patients and asthma patients, respectively.

Discussion Although positive correlations were found between the proton difference images and the corresponding ^3He ventilation images, the correlations are weak as indicated by the low values of R^2 . This is mainly caused by the low signal-to-noise ratio (SNR) of the proton images (between 2 and 5). At 1.5 T, the T_2 of lung tissue is about 1 ms (12), therefore our acquisitions with TE of 0.8 ms likely suffered significant signal loss in lung parenchyma. Low SNR is also evidenced by the regional signal non-uniformity in the proton difference images as compared to the ^3He ventilation images. The current level of SNR limits the application of the method to only identifying significant ventilation defects in the lung. Further investigation of the method will focus on improving SNR by reducing TE (e.g., ultra-short TE or UTE methods).

Conclusions Our preliminary results of VIBE imaging in combination of image registration demonstrated the feasibility of imaging regional ventilation of the lung using breath-hold proton MRI. Further work will focus on improving SNR in lung parenchyma by using imaging methods with shorter TE.

References (1) Bergin CJ et al. Radiology 1991;179:77 (2) Bergin CJ et al. Radiology 1992;183:673 (3) Yablonskiy DA et al. J App Physiol 2009;107:1258 (4) Mugler III JP et al. PNAS 2010;107:12107 (5) Kuethe DO et al. MRM 2007;57:1058 (6) Garwood M et al. J Magn Reson 2001;153:155 (7) Idiyattullin D et al. ISMRM 2006:2433 (8) Corum CA et al. ISMRM 2010:204 (9) Bauman G et al. MRM 2009;62:656 (10) Thirion JP. Med Image Anal 1998;2:243 (11) Salerno M et al. MRM 2001;46:667 (12) Hatabu H et al. Euro J Rad 1999;29:245

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