Regional Mapping of Gas Uptake by Blood and Tissue in the Human Lung using Hyperpolarized Xe129 MRI

Category: Biosciences and Health
School of Engineering and Applied Science, School of Medicine
Biomedical Engineering, Radiology and Medical Imaging, Department of Medicine, Pulmonary and Critical Care

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Introduction: Hyperpolarized xenon-129 (129Xe) has been used as a gaseous MRI contrast agent for evaluating the structure and function of the lung using numerous unique approaches. Upon inhalation, most 129Xe resides in the airspaces of the lung (gas-phase) and corresponds to a single large peak in the spectrum, while ~2% is dissolved in the lung parenchyma and blood (dissolved-phase), and gives rise to two or more smaller peaks with chemical shifts of about 200ppm from the gas peak (see Fig.1). These characteristics of 129Xe provide the opportunity to assess gas exchange and uptake in the lung.

Methods: A multi-echo 3D-radial MRI method was designed to collect 3 echoes of dissolved-phase data, for calculation of tissue and red blood cell (RBC) images, followed by 2 echoes of gas-phase data, for calculation of ventilation images and a field map (Fig. 2). Total acquisition time is ~10 seconds and well tolerated by all subjects (5 healthy [denoted subjects H1-H5], 1 healthy smoker [S1], 1 diagnosed as COPD GOLD Stage III [S2], and 2 asthmatics [A1 and A2]).

Results: Healthy subjects: H1-H4 (age 18-21) demonstrated generally uniform signal distributions within each coronal images, as Fig. 3a shows. H5 (age 54) had several ventilation defects, and his whole lung values for all ratios (Fig. 4) were lower than other healthy subjects.

Smokers: COPD subject S2 showed much lower ratio values, and ratio maps that were very inhomogeneous (Fig. 3b, 4), while the healthy smoker (S1) had higher values for 3 of the 4 ratios, but still lower than most healthy subjects.

Asthmatics: Subject A2 (age 16) showed relatively uniform tissue-to-gas ratios, and RBC-to-gas ratios higher than all other subjects, while subject A1 (age 53) had elevated values in both apices in conjunction with reduced RBC-to-gas ratios (Fig. 3c, arrows).

Summary: Whole-lung mean values for all ratios, except RBC-to-tissue, for healthy subjects were significantly larger than those for the diseased group (p<0.01). Percent differences between repeated acquisitions (denoted by * in Fig. 4 for subjects H3, A1 and S2) were ~10% or less. We have successfully demonstrated regional mapping of ventilation, and gas uptake into blood and lung tissue, from a 10-s MRI acquisition.

Acknowledgement: The authors gratefully thank Drs. F.W. Hersman and I.C. Ruset from Xemed LLC, and Yun Jiang from Case Western Reserve University for the technical support they provided.

The primary function of the lung is exchange of respiratory gases, which can vary substantially within the lung, especially for heterogeneous conditions like chronic obstructive pulmonary disease (COPD). Thus, regional assessment of ventilation and gas uptake would permit investigation of the fundamental process of gas exchange, improve our understanding of how heterogeneous diseases such as COPD affect gas exchange, and also prove invaluable for evaluating new therapeutics for lung diseases. Nonetheless, there is no clinical imaging method that permits quantitative regional assessment of both gas delivery to the alveolar airspaces and gas uptake into the lung parenchyma and blood.

Here we present a breath-hold acquisition method (~10 s) for regional mapping of ventilation and gas uptake by blood and tissue in the human lung using hyperpolarized 129Xe MRI. Marked differences were observed in spatial distributions and overall amounts of 129Xe dissolved in blood and tissue among healthy subjects, smokers (healthy and COPD), and asthmatics.

Annual Presidential Research Poster Competition May 3, 2013