

Proton based lung MRI

Lothar R. Schad, PhD

Professor of Medical Physics, Chair in Computer Assisted Clinical Medicine
University of Heidelberg, Faculty of Medicine Mannheim, Mannheim, Germany

Introduction

Assessment of regional lung perfusion and ventilation has significant clinical value for the diagnosis and follow up of pulmonary diseases since perfusion and ventilation plays an important role as an indicator of lung function and gas exchange. Currently the standard approaches for functional lung assessment comprise different imaging modalities where methods based on application of radioactive nuclides still remain the gold-standard for functional lung imaging. However, important advantages of functional MRI are lack of ionizing radiation and higher spatial and temporal resolution than nuclear medicine imaging. Although during the past decades MRI became a highly-valued diagnostic tool in medicine but its application for assessment of regional pulmonary lung functions is still limited.

This presentation aims to give a brief overview of various ^1H MRI techniques for lung imaging with focus on a new non-invasive method to assess functional information of human lung perfusion and ventilation without the application of intravenous contrast agents or gaseous media. The presented method offers short acquisition time and does not require any triggering or gating technique.

Methods

Radial ^1H MRI: lung morphology. There are several technological and methodological reasons why proton based MRI of the lung is challenging. Lungs have a unique foam-like structure and the NMR signal from the pulmonary parenchyma is hampered by low proton density. A large number of air-tissue interfaces within alveoli induce local gradients affecting magnetic field homogeneity. High susceptibility differences on intravoxel scales are responsible for phase dispersion of spins and signal loss. Susceptibility effects are dominant on MR systems with increasing magnetic field strength. The sophisticated lung structure results in extremely short relaxation times in 1.5 T magnetic field, T_2^* of 1-2 ms and T_2 of 30-80 ms influenced by a significant molecular diffusion. On the other hand the longitudinal relaxation time T_1 of 1100-1500 ms is relatively long. In addition, factors contributing in image artifacts comprise respiratory, cardiac motion, pulsation and blood flow. To overcome these restrictions very short TE gradient echo or spin-echo sequences have to be used with different k -space ordering schemes, e.g. radial or spiral improve the signal-to-noise ratio. They allow to use half radio frequency pulse excitations but require more complicated reconstruction algorithms. Application of parallel imaging techniques helps to minimize the acquisition time which is crucial to reduce the influence of motion artifacts. Combination of minimal inter-echo spacing with asymmetric echo sampling and parallel MRI can increase remarkably the visibility of lung structure as well as the spatial and temporal resolution.

DCE ^1H MRI: lung perfusion. Dynamic Contrast-Enhanced MRI (DCE-MRI) has recently become popular to study lung perfusion. The method is based on enhancement of lung parenchyma by shortening the T_1 relaxation time using intravenously injected contrast agent. DCE-MRI allows for quantitative perfusion assessment. Three dimensional imaging of the whole chest volume is performed during the first pass of the contrast at inspiratory breath-hold. Subtraction of images before and after contrast injection creates an image representing perfused areas and major vessels. Application of gadolinium based contrast agents may be responsible for allergic reactions or increase the risk of nephrogenic systemic fibrosis for patients with renal dysfunction.

ASL 1H MRI: lung perfusion. Alternative techniques such as Arterial Spin Labeling (ASL) MRI can be used to evaluate perfusion in the lung tissue. The ASL technique uses magnetically tagged water protons in arterial blood as a contrast bolus to measure blood delivery to the lung parenchyma. Blood is tagged by application of radio-frequency pulses to invert the magnetization. Although the method is noninvasive it suffers from low temporal resolution making it inapplicable to cover the whole volume of the lung in a reasonable time.

O₂ enhanced 1H MRI: lung ventilation. Visualization of regional lung ventilation can be performed using oxygen enhanced imaging. The method relies on the paramagnetic properties of the molecular oxygen, which serves as a T_1 -shortening contrast agent.

Fourier Decomposition 1H MRI: lung perfusion and ventilation. This new lung imaging technique uses a fast steady state free precession 2D trueFISP pulse sequence to assess functional information of human lung perfusion and ventilation without the application of intravenous contrast agents or gaseous media. This method implemented on a 1.5 T whole body MR scanner offers short acquisition time and does not require any triggering or gating technique. The imaging protocol comprises sets of 198 images of the lung images acquired with an imaging rate of 3.33 images/second in coronal or sagittal view. A non-rigid image registration algorithm can be applied to compensate for respiratory motion. Rapid data acquisition allows observing intensity changes in corresponding lung areas with respect to the cardiac and respiratory frequencies. After a Fourier analysis along the time domain two spectral lines corresponding to both frequencies can be used to calculate the perfusion and ventilation maps. The described method was applied in preliminary studies on volunteers and patients showing clinical relevance to obtain non-contrast enhanced perfusion and ventilation data.