Oxygen-enhanced MRI of the Lung

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Highlights
- Molecular oxygen is paramagnetic and lowers the T1 of nearby protons
- Altering the concentration of inhaled O_2 changes lung T1-weighted signal
- Potential tool for assessing lung function with widespread availability
- While usually considered a measure of regional lung ventilation, likely also a function of regional perfusion
- Emerging methods address inherently low SNR and improve spatial resolution

Target Audience: Thoracic radiologists and MRI physicists interested in lung MRI

Objectives
1. To provide an overview of how oxygen-enhanced (OE) lung MRI can be performed on commercially available scanners
2. To describe the current state-of-the-art on how OE MRI can be used to evaluate lung disease
3. To summarize both the principal technical challenges to implementing OE MRI clinically as well as some potential solutions

Background

Molecular oxygen is paramagnetic and therefore decreases the T_1 of nearby protons. This fact makes it possible in theory to visualize differences in oxygen concentration in the lungs using a T_1-weighted pulse sequence, as first reported in 1996 by Edelman, et al.(1) Using inhaled oxygen as a contrast agent for imaging lung function has obvious potential widespread utility. However, the technical difficulties of oxygen-enhanced MRI of the lungs are considerable, principally due to the very low intrinsic lung signal using conventional pulse sequences, the relatively mild effect of changing the inhaled oxygen concentration, and the combined effects of respiratory and cardiac motion. Despite this, several groups over the past decade have made great strides towards demonstrating the feasibility of using this method to image lung function in several different diseases.

Methods

The very low intrinsic signal-to-noise ratio of lung signal with conventional sequences necessitates long acquisitions. Typically, oxygen-enhanced MRI is performed using a block design in which the subject is imaged over several minutes while breathing room air (21% O_2) and over several minutes while breathing 100% O_2. In theory, this should decrease the lung T_1 by ~10%. Imaging is usually performed using a conventional 2D inversion-recovery single shot fast spin echo (IR-SSFSE) pulse sequence to image a small number of relatively thick slices. The images are then subtracted in order to visualize the effects of oxygen. Cardiac and respiratory motion artifacts can be as large or greater than the oxygen-enhanced effect and must be addressed either prospectively during the acquisition or retrospectively through image registration and/or gating techniques. Focal defects in the resulting oxygen-enhanced maps are usually interpreted as abnormalities in ventilation. The diffusion of O_2 into blood also increases the blood signal and therefore lung perfusion also likely plays a role in the oxygen-enhanced signal. Alternative approaches include explicit T_1 mapping and observing the dynamic changes in lung signal during the switch between inhaled O_2 concentrations. (2,3)

Results

OE MRI has been used successfully in several clinical studies involving different lung diseases, led by the work of Ohno, et al, who first applied the technique to lung cancer and emphysema in 2001.(4) Since then, studies have been performed in cystic fibrosis, pulmonary hypertension, lung volume reduction surgery, and interstitial fibrosis, with variable but generally promising results. At the same time, the technical challenges of OE MRI have been tackled using accelerated imaging methods (5), respiratory and cardiac gating schemes (6), and 3D radial ultrashort echo time approaches (7).

Discussion

Technical advances over the last decade and recent clinical trials show the promise of oxygen-enhanced MRI as a widely available method for assessing lung function. Future work will need to improve the robustness of oxygen-enhanced MRI to enable adoption outside of a few academic centers and will need to more thoroughly evaluate the relative contributions of ventilation and perfusion to the oxygen-enhanced lung signal.

References

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