Hyperpolarized Noble Gas Magnetic Resonance Imaging

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Introduction

Hyperpolarized noble gas magnetic resonance imaging (HP gas MRI) is a new and innovative imaging method that has made it possible, for the first time, to obtain high resolution MR images of air-filled organs such as the lungs, as well as lipid rich tissue such as the brain. Unlike conventional MRI which relies on the detection of water protons in biological tissue, HP gas MRI is based on the detection of helium (3He) or xenon (129Xe) gas that is inhaled by the subject. Though 3He and 129Xe are normally below the detection threshold for MRI, the process of hyperpolarization increases their detectability by about a hundred thousand times. Systems for generating hyperpolarized gas are now available, and because image resolution with this technique is not dependent on high magnetic field strength, it can be feasibly carried out in most any clinical or research setting.

Brain Functional Imaging with Hyperpolarized Xenon MRI

Several characteristics make HP 129Xe MRI especially promising for studies of brain function and pathology. These unique characteristics of HP 129Xe MRS and MRI may reveal additional structural, chemical, and functional information in both normal and diseased brain, and thereby benefit the diagnosis and treatment of a number of CNS diseases including multiple sclerosis, stroke, cancer, and Alzheimer’s disease. In the past year we have made significant progress in the development of HP 129Xe MRI for functional brain imaging. Our group previously demonstrated the use of HP 129Xe to track blood flow changes evoked by vasodilation. Recently we have demonstrated the specificity to which HP 129Xe MRI can map changes in brain activity by using it to image a well defined functional response evoked by a pain stimulus in the forepaw of a rat. These results demonstrate that HP 129Xe MRI can be used for functional brain imaging and that its anatomical specificity is comparable to conventional fMRI methods. Future directions include development of HP 129Xe functional imaging based on oxygen sensitivity.

3D Airway Tree Rendering from Hyperpolarized Helium Lung MRI

3D airway tree renderings from dynamic multislice images of the lung were acquired using hyperpolarized 3He MRI. They, however, suffer from the high aspect ratio of its voxels (the in-plane resolution of the images are 1.8 mm, while the slice thickness is 13 mm). Furthermore, the 3D airway tree rendering is hampered by the uneven polarization consumption of the hyperpolarized 3He during the simultaneous scan and gas inhalation. A simulation study is in progress to assess whether the development of a CT-like projection reconstruction pulse sequence would alleviate both issues simultaneously. By using projection imaging instead of finite-thickness slice imaging, the polarization of the 3He will be uniformly consumed, leaving no residual polarization to reach the lung periphery and cloud up airways past the 4th generation. By using the Radon transform-projection reconstruction combination, the resolution within each axial slice will be close to the axial slice thickness, thereby yielding uniform spatial resolution in all directions.

Very Low Field (VLF) Hyperpolarized Gas Lung Imaging

We designed a VLF HP gas MR system with a wire-wound solenoid 15 mT magnet. In this design, the magnet is situated inside an RF enclosure. Circular waveguide filters, a filtered connector panel, and custom-made gradient filters were installed for noise reduction. Our preliminary results demonstrate the successful operation of the new VLF HP gas MRI system.

RF coil design however remains to be one of the major challenges at very low field. In this work, various volume coil design topologies were evaluated for very low field imaging. From a theoretical study, a suitable coil design, which is a rectangular planer multiple-turn Helmholtz-type coil, is proposed. A sample coil was constructed and the B1 field was measured to verify the design.

The non-recoverable magnetization of HP-Gas presents an interesting variable in the pulse sequence design for MR imaging and often times has to be understood by a trial and error approach. Therefore, a simulation tool that can integrate the properties of hyperpolarized magnetization with RF pulse sequences could potentially provide an alternative means to gain insights into HP-Gas MRI methodology. The formulations for solving both Maxwell’s equations and Bloch’s equations numerically are presented.