LAYMAN SUMMARY FOR MAJOR RESEARCH PROJECT

Improved diffusion MRI with an ultra-strong gradient head insert

Introduction

Demyelination and dysmyelination diseases are medical conditions that cause damage to the white matter in the central nervous system. This damage is characterized by lesions that disrupt the myelin sheaths on axons, leading to the loss of its protective and insulating properties. Diffusion MRI (dMRI) measures the movement of water molecules in biological tissues. However, conventional diffusion MRI methods are unable to detect myelin water. The use of ultra-strong gradients can significantly shorten the echo time, thereby regaining sensitivity to myelin water, but presents technical difficulties, including expensive setup and risk of peripheral nerve stimulation. In this work, the potential of using an ultra-strong gradient insert coil that can be interfaced with existing scanners is addressed. Additionally, a preprocessing pipeline is implemented to improve image quality. Finally, the feasibility of quantifying myelin water diffusion with the ultra-strong gradient insert was investigated in simulations.

Methods

First, the magnetic force experienced by the cables that supply power to the coil had to be reduced to enable strong diffusion MRI. This enabled the acquisition of healthy human brain images with two different gradient settings. The first acquisition uses the gradient insert coil and another without (whole-body gradient) this auxiliary coil. Next, the preprocessing pipeline is implemented to correct for linear eddy currents using a commercial dynamic field camera, susceptibility-induced distortions, and to perform B-matrix correction. B-matrix correction refers to correcting spatial nonuniformities in the apparent diffusion coefficient (ADC) images. The pipeline is applied to both data scans. Through this approach, a comparison is made between the two settings. Last, a signal model was fitted, considering the echo times obtained from the acquisition. Additive Gaussian noise with a standard deviation of 0.01 was applied for 500 iterations. Ground truth values were chosen based on a previous study.

Results

An optimal cable configuration for the gradient insert coil is presented, along with a proposed mechanical design to reduce the magnetic force on cables. Compared with the whole-body scans, the echo times of the gradient insert scans are lower for the same b-value scans. The spatial deformations caused by eddy currents in the gradient insert coil are successfully corrected using the field camera. For the whole-body gradient scans, the deformations are less noticeable but can be spotted on the readout waveform. FSL Topup software is used to correct susceptibility-induced distortions, effectively reducing distortions for both datasets. When performing ADC B-matrix correction for the gradient insert, the correction can reach 20%. When comparing the ADC values obtained from gradient insert scans, higher values of ADC are spotted in the whole-body images. Considering the hypothesis of using an inversion-recovery MRI pulse sequence, the simulations show that using whole-body settings for acquisition yields too far estimations from the ground truth value. When looking at the gradient insert simulated histogram, the estimated distribution is very close to the reference value.

Conclusion

A solution was offered to resolve technical challenges associated with the cable arrangements for the gradient insert coil. A preprocessing pipeline for dMRI images using an ultra-strong gradient insert is proposed to improve the quality of the images. The simulations showed the capability to model myelin water diffusion properties at short echo times with an ultra-strong gradient insert coil, highlighting the usefulness of an inversion-recovery pulse sequence.