Contiguous-Slice Diffusion Tensor Imaging of the Optic Nerve with CSF Suppressed IR CO-ZOOM

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Introduction

The onset of Multiple Sclerosis is often accompanied by optic neuritis and the presence of lesions on the optic nerve. Diffusion MRI sequences may be used to evaluate the diffusion properties of water along the nerve and hence determine the extent of demyelination. However, the optic nerve provides significant challenges to such a study [1]: the small size of the nerve, with a diameter of 3-5 mm; the confounding signal from the surrounding orbital fat and cerebrospinal fluid (CSF); the persistent motion of the nerve through eye movement; the significant distortions due to magnetic susceptibility changes around the bone cavity of the optic canal and the sinuses. EPI sequences are most commonly used when studying diffusion owing to their rapid signal acquisition. However, EPI is particularly sensitive to magnetic susceptibility changes and significant distortions are observed near the optic nerve. The distortions can be reduced by limiting the signal acquisition time (reducing the k-space matrix size in the phase-encoding direction). Higher resolution can be restored by selecting a narrower field of view (FOV) [2]. The zonal oblique multislice EPI (ZOOM-EPI) technique introduced by Wheeler-Kingshott et al [3] was developed to selectively excite narrow FOVs in the human head but it is not possible to acquire contiguous slices in one shot with this technique. The acquisition of contiguous slices allows a full inspection along the nerve and opens the possibility of nerve tracking. Here, we introduce an Inversion Recovery COntiguous ZOnally Orthogonal Multislice (IR CO-ZOOM) EPI technique that can yield high-resolution contiguous images of the optic nerve over a narrow FOV without aliasing in the phase encoding direction.

Method

Selective excitation of a narrow FOV in a multislice EPI sequence was achieved using the modified single-shot dual spin echo EPI pulse sequence in Fig. 1. Slice selection is performed with the application of a spatial-spectral 90° RF pulse with a slice select gradient. The second and third (180°) pulses are applied with a gradient orthogonal to that of the slice select gradient. As a consequence, only the spins in a narrow "inner volume" of each slice is excited and refocused and transverse magnetisation from the remaining spins in the slice is dephased. The orthogonal refocusing pulses perturb the spins of all slices in the prescribed volume, but since both pulses are 180° the spins in neighbouring slices experience a net 360° pulse such that magnetisation is restored to the +z axis. An inversion pulse prior to excitation is used to null the signal from the CSF. Since the refocusing pulses are applied orthogonally with respect to the excited slice, each slice is acquired sequentially to ensure a common inversion time for CSF for all slices.

A GE 1.5 T Signa scanner equipped with an 8-channel phased array head coil was used for this study. Scanning parameters: 4 slices, TR=6 s, TE=88 ms, TI=1100 ms, FOV=80 mm × 40 mm, acquisition matrix=64 × 32, in-plane resolution 1.25 × 1.25 mm^2 and 4 mm through-plane resolution. A total of 1176 images were acquired comprising of 42 averages of 6 diffusion directions and a b_0 (T_2 weighted) image. Total imaging time: 30 minutes. The subject was a 28 year-old male. Informed consent was given and ethical approval for the study was obtained by the local ethics committee.

Results

Figure 3a-b shows the position of the contiguous slices (Fig. 3c) on sagittal and axial localizers. Four contiguous mean diffusivity (MD) maps of the optic nerve were acquired yielding Mean Diffusivity = 0.550 × 10^{-9}m^{2}s^{-1} (before Rayleigh noise correction) which is comparable to previously published data [3]. Fractional Anisotropy maps yield FA = 0.4 for the optic nerve. This lies in the lower range of FA observed in normal controls [4]. We intend to collect noise images to make the necessary Rayleigh noise correction.

Discussion and Conclusions

The method introduced here permits the acquisition of contiguous ADC maps of the optic nerve using a narrow FOV in the phase-encoding direction. Aliasing is avoided by applying excitation and refocusing pulses in the presence of orthogonal magnetic field gradients so that only the volume of interest is refocused. Signal from the CSF and fat are suppressed and susceptibility-induced distortions are limited by the use of a small matrix size. In addition, using a dual spin echo sequence helps to reduce eddy current effects. Further improvements are in development to reduce overall scan time by allowing multiple slices to be excited during the inversion time. This will yield improved coverage of the nerve and may enable tracking algorithms to be implemented along it.

References

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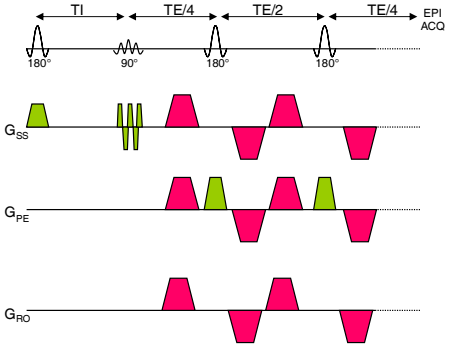

Figure 1
The RF and gradient pulse sequence diagram for the modified single-shot dual spin echo diffusion experiment. Diffusion and slice-select gradients are shown in red and green, respectively. The gradients of the excitation and refocusing pulses are orthogonal. For clarity, standard EPI acquisition is not shown.

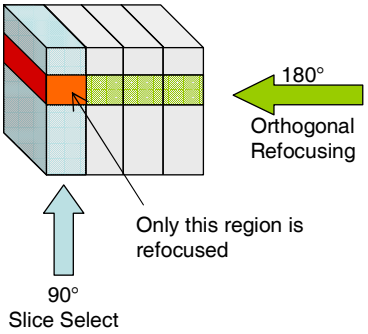

Figure 2
Schematic representation of inner-volume selection using a 90° slice-selective pulse and orthogonal 180° refocusing pulses.

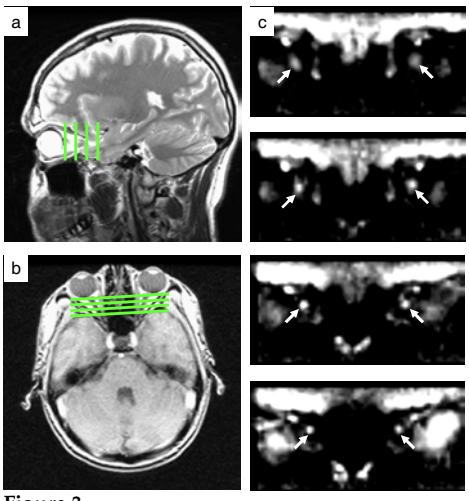

Figure 3
The position of the prescribed slices using the (a) sagittal and (b) axial localizer. (c) Four contiguous T_2-weighted (b_0) slices. The optic nerve is marked with an arrow.