Diffusion Tensor Micro-Imaging of Rat Brain Using High-Angular Diffusion Encoding Scheme

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Introduction

With the increasing availability of transgenic animal models for studying disease mechanisms, non-invasive imaging technology is becoming very important for many applications. MR Diffusion Tensor Imaging (MR-DTI) is a novel method to measure water diffusion anisotropy in living tissues, and it is particularly useful for studying human brain functions in normal and diseased status. Recently, the same technology has been applied to image brain tissue in small animals. For example, DTI has been applied to the axonal projections reconstruction on the rat brain [1] and the study of acute stroke on a mouse model [2] at 4.7T, using the basic 6 directional DTI sequence. New studies have shown that multiple-angular diffusion encoding scheme provided more accurate estimate of diffusion anisotropy measurements [3]. Another study demonstrated that rat optic tracts can be mapped using diffusion spectrum magnetic resonance imaging (DSI) of rat brain *in vitro* [4]. The specific aim of this study is to implement the highly angular-resolved diffusion encoding scheme on a 7T small animal scanner, and to demonstrate its effectiveness to measure diffusion anisotropic maps and the fiber structure in small animal brain in vivo.

Methods

Experiments were conducted on a 7T/30cm horizontal bore BioSpec scanner (Bruker, Ettlingen, Germany), with a gradient coil capable of generating maximum gradient amplitude of 400mT/m. A 5cm (ID) linear birdcage coil was used for RF transmitting, and a 2.5 cm diameter surface coil was used for receiving the signal. Adult Fisher rats were anesthetized with 3% isoflurane in O_2 (3 liters/min) and were maintained with 1.5% isoflurane in O_2 (1 liter/min) by a gas anesthesia system. Standard 2D spin echo sequence with diffusion encoding gradients was applied. Diffusion gradients are evenly distributed on the surface of a 3D sphere, representing the spherical angular resolutions. For each animal, the acquisition parameters were: FOV = 35mm, slice thickness = 1mm, image matrix size = 128*128, with in-plane resolution of 273μm*273μm, and b = 1000 s/mm^2. Diffusion-weighted images along 6 directions and 25 directions were acquired for comparison. The echo time (TE), repetition time (TR) and total scan time were 36ms/1000ms/15mins (6 directions) and 36ms/900ms/50mins (25 directions). One image was collected without diffusion encoding for reference. After calculating the diffusion tensors, the eigenvalues and eigenvectors were computed to derive the scalar DTI maps (fractional anisotropy FA images), as well as diffusion orientation maps.

Results

In order to make an accurate comparison, three axial slices located in the middle of brain were scanned with 6 and 25 diffusion encoding directions respectively. Figures 1 a) – c) show the FA maps calculated from 6 directions and d) – f) are FA maps obtained from 25 directions. The FA map obtained from the experiment with 25 diffusion encoding directions showed much better resolved fiber tracks, mainly from improved FA contrast between highly-organized and less organized structures. Figures 1 g) and h) display the FA color maps encoded with principle eigenvector calculated from diffusion tensors. The areas in red denote vectors orienting left-right, green for superior-inferior and blue for anterior-posterior. The fiber orientations computed from 25 directions exhibit higher consistency with neighbor voxels than the results from 6 directions in g). Figures 1 i) and j) show the tensor orientations, overlapped with FA maps on the ROIs specified in Figures g) and h). It is demonstrated that many improvements were obtained in the detection of fiber orientation. In general, the images calculated from 25 directional experiments showed much higher scalar contrast and more accurate fiber structures as well. These improvements are obtained because of the better estimation of diffusion tensor model from the high angular diffusion encoding scheme.

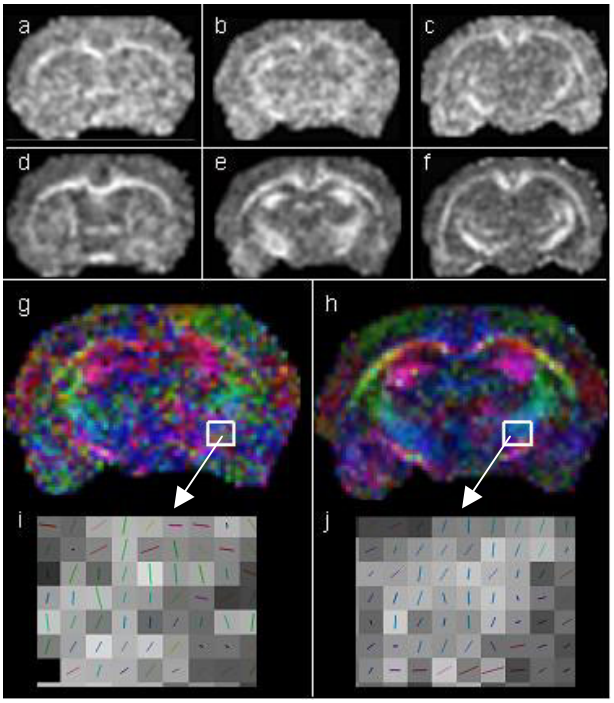

Figure 1. Comparison between 6 and 25 diffusion encoding gradients on FA maps and color coded FA maps

Discussion and Conclusion

The higher magnetic field provides us not only more imaging sensitivity, but also more challenges in diffusion imaging of small animal brains at the high resolution, especially, due to susceptibility effects. The improvement in spatial resolution will allow more accurate estimation of diffusion tensors due to the reduction of partial volume effects. The multiple diffusion encoding scheme will further improve the accuracy of DTI measurement. Results in this work demonstrated the improvements from 6 to 25 directions, and this is in agreement with earlier works [5]. Therefore, the high angular encoding scheme is recommended for DTI imaging at higher field strength to allow more accurate neuron fiber tractography. Currently, the long scanning time associated with a large number of diffusion encoding directions limits the wide applications of the proposed scheme. Fast diffusion imaging sequence would be necessary for DTI imaging of small animals at high fields. Nevertheless, this work showed the large improvement in image quality and resolution by using more diffusion encoding directions in DTI data acquisition.

References

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