Assessment of Reduced Encoding Diffusion Spectrum Imaging Implemented with a Bi-Gaussian Model Using Phantoms and Manganese-Enhanced Optic Tracts

Introduction

Diffusion MRI has become an essential tool for contrast imaging mechanism of the central nervous system. This has led to and made a significant improvement in clinical diagnosis. Further progress advancement to the technique has been made with the design introduction of diffusion tensor imaging (DTI) [1, 2]. The technique makes further progress along with the design of diffusion tensor imaging (DTI) [1, 2], which is a feasible valuable technique for identifying model anisotropic diffusion as well as non-invasively delineating the principle orientations of white matter tracts non-invasively [3-5]. However, the assumption of a single Gaussian diffusion compartment in the tensor model results in the ambiguous orientations of fibers in regions where they cross each other containing crossing fibers [6]. Thus, it with the typical resolution of a MRI, it may be becomes intricate difficult to interpret the complex neural connections between functional areas of the human brain with under typical resolution of an MRI.

In recent years, various diffusion imaging strategies have been developed to improve the depiction of water diffusion and to resolve the intravoxel fiber orientations. Diffusion spectrum imaging (DSI) [7], for example, utilizes the 3-D spectra of water displacements to characterize the heterogeneity of fiber architectures. DSI was based on the theory established by the q-space imaging
technique—which describes the Fourier relationship between echo signal attenuation and the probability density function (PDF) of the displacement of water molecules with the prerequisite of a narrow pulse approximation [8-10]. The DSI technique has been used to map the tissue architecture of biological systems DSI has shown its capability of mapping tissue architectures in biological systems–[7,–11] providing information on the intravoxel compartment sizes scales of the–neural fibers [12], thus allowing and interpreting the physiological and structural conditions of the–neural tissues to be interpreted. In addition, 3-D tractography and comparative segmentation of human brain structures have been identified based on DSI and the proceeding orientation distribution function (ODF) [13].

Notwithstanding the utility of DSI comes at a cost; a complete reconstruction of the diffusion PDF requires 515 q-value encoding points distributed on a Cartesian lattice across 3-D q-space. This involves long acquisition times as well as adequate q-values for sufficient resolution. Since the available gradient strength in clinical systems are limited, the latter requirement is achieved by prolonging the diffusion gradient duration (δ) and the diffusion time (Δ) since the available gradient strength in clinical systems is limited. Unfortunately, this would accompany leads to a long echo time (TE) and a decline in the SNR–level due to a severe T2 decay in the echo planar imaging (EPI) sequence. As a consequence of this, the angular accuracy and discrimination would be are unavoidably diminished as a consequence–[11]. Both the lengthy acquisition times, cost and the requirements of the gradient system, request have retarded hindered the further applications of DSI on clinical scanners.

Comment [TK2]: CHECK: Please clarify this sentence further. It seems you are saying that tractography and comparative segmentation of brain structures were identified with DSI. Then you write about what appears to be another technique, ODF. However, it is not clear how this technique is related to DSI or was it just another technique used in conjunction with DSI? Consider rewording to clarify. Also, if ODF is another technique (in addition to DSI), which has been helpful in reconstructing tissue structure, it may useful for readers to point that out.

Comment [TK3]: CHECK: Consider not using the word “adequate”. Perhaps use ‘large quantities of” if that is appropriate.
These limitations basically stem from the need to exhaustively sample on a 3-D Cartesian sampling lattice. A hemispheric encoding scheme (half-q-DSI) can be applied to halve the scan time in DSI since the diffusion contrast is positive and spherically symmetric [7, 14]. However, uncorrected cross-term interactions between diffusion and imaging gradients might result in a misunderstanding of the q-space analysis and inaccurate ODFs in half-q-DSI [15, 16]. Instead of a Cartesian lattice, a body-centered cubic lattice (BBCBCC) sampling scheme was proposed to improve the imaging efficiency of DSI by 30% [17]. Another non-Cartesian q-space encoding scheme, hybrid diffusion imaging (HYDI), was also employed for DSI-PDF reconstruction. This scheme consists of five concentric spherical shells and may be applied to multiple types of diffusion analyses [18], which is flexible for multiple diffusion analyses. Although it was possible to shorten the acquisition times, all of the above q-space sampling strategies described above, the requirement for a large number of high q-values to preserve adequate spatial resolution could not be omitted to preserve adequate spatial resolution.

Another category of diffusion imaging techniques utilizes an encoding scheme formed by a single spherical shell with a constant diffusion weighting, as opposed to the 3-D Cartesian lattice with multiple diffusion weightings. These techniques include high angular resolution diffusion imaging (HARDI) [19, 20], q-ball imaging (QBI).
[21, 22], persistent angular structure MRI (PAS-MRI) [23], fiber orientation estimation using continuous axially symmetrical tensors (FORECAST) [24], diffusion orientation transformation (DOT) [25], and spherical deconvolution methods [26, 27]. These approaches provide information on the orientation of complex neural fiber networks within a reasonable scan time and may be implemented. The substantial increase in imaging efficiency mainly results from the fewer numbers of diffusion-weighted images (DWIs) needed for data analysis. In addition, the shortened TE following a moderate b-value could enhance the SNR of DWIs. These conditions, however, may be insufficient to characterize the 3-D diffusion function that is derived from the multiple q-value diffusion measurements, and would thus be unable to infer tissue microstructural tissue conditions, shape and orientations. However, they might be insufficient to characterize the 3-D diffusion function derived from the multiple q-values diffusion measurements.

In this study, it is proposed that the reduced-encoding DSI implemented with a bi-Gaussian model (RE-DSI), is proposed to trim down the drawbacks of DSI as well as retain q-space information. In RE-DSI, a reduced Cartesian sampling scheme, where high q-value acquisitions are omitted, is used to bypass long acquisition times and gradient system demands in DSI. To achieve sufficient resolution for resolving the fiber orientations of fibers, the 1-D bi-Gaussian model fitting is performed using the sampled data at low q-space to regain all diffusion signals at high q-space. Previous studies on animal and...