Spherical Encoding Method in Clinical Machine

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Synopsis

High angular resolution diffusion imaging (HARDI) methods maps the distribution of fiber orientations by mapping its orientation distribution function from q-space data on an icosahedral sphere [1, 2]. In this study we applied the spherical encoding method to human brain to examine its capability in in-vivo applications [2]. DSI with optimized cutoff b-value was served as a standard in comparison with spherical encoding images. With half images acquisition time in contrast to DSI, spherical encoding images in 3000 mTm^{-1} shows an error of $–0.15 \pm 17.5^{o}$ in the coherent white matter area and $–0.66 \pm 22.6^{o}$ in area with fiber crossing.

Introduction

Diffusion spectrum imaging (DSI) maps multi-fiber orientations by acquiring 3D q-space data to obtain probability density function (PDF) and the spherical projection of proton diffusion, i.e. orientation distribution function (ODF). However, DSI suffers from the prolonged scan time and the stringent requirements on gradient performance, which bring difficulties to clinical applications. Spherical encoding imaging (SEI) provides an alternative with shorter scan time and lower gradient, yet retains the ability of resolving crossing fibers. This method reduces the encoding steps by obtaining spherical points in q-space and has been verified in phantom models [2]. In this study DSI with optimized cutoff b-value was served as a standard in comparison with SEI. Our result shows that SEI in 3000 mTm^{-1} shows an error of $–0.15 \pm 17.5^{o}$ in the coherent white matter area and $–0.66 \pm 22.6^{o}$ in area with fiber crossing.

Materials and Methods

The data were acquired using 1.5T Sonata system (Siemens, Erlangen, Germany) in National Taiwan University Hospital (NTUH). Spherical encoding images with 253 encoding directions in the 5 fold-tessellated icosahedral sphere with b-value = 1000, 2000, 3000, 4000, and 6000 mTm^{-1} were acquired. Using diffusion-EPI with TR/TE = 500/150 ms, resolution of 2.1x 2.1 x 1.7mm^3, each spherical encoding images were acquired in 4 min. Optimized DSI with 515 encoding directions and cutoff b-value of 4000 mTm^{-1} was also acquired as a standard for comparison [3].

Spherical encoding images were analyzed using rotating spherical fourier transform (Eq. 1) and its further evolution form by the assumption that a properly selected b-value can be used to differentiate the crossing fibers (Eq. 2):

$$\mathrm{ODF}\ (\Theta = 0, \Phi = 0) = \int^{\pi}\int^{2\pi}\int^{\infty} S(r, \theta, \phi)\ \exp\left[i\, 2\pi\, Rr\, (\cos\theta)\right] r^2 \sin\theta\, dR\, dr\, d\phi\, d\theta \qquad (1)$$

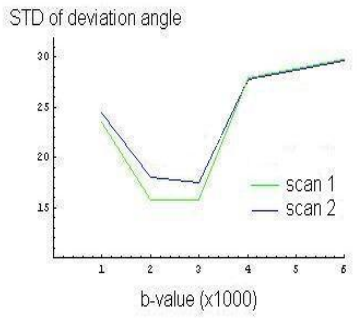
$$\mathrm{ODF}\ (0,0) = 2\int^{\pi}\int^{2\pi} S(\theta, \phi)\ G(\theta)\, d\phi\, d\theta \qquad (2)$$

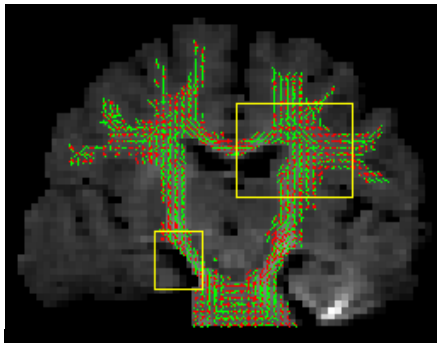
where $S(\theta, \phi)$ is the q-space echo signal; θ is the angle between diffusion echo signal and the direction of interested ODF ($\Theta = 0, \Phi = 0$) in rotating frame, and $G(\theta) = \cos[2\pi(\cos\theta)] \sin\theta$.

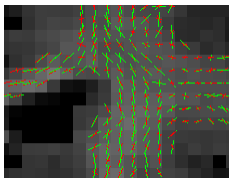
The primary orientation of DSI and SEI was superimposed and compared to determine the minimum deviation angle of SEI results.

Results

Our result shows that spherical encoding with b value of 3000 mTm^{-1} was of most consistency with standard DSI results (fig.1). The primary orientation of DSI and spherical encoding images in white matter tracts were superimposed in fig.2; the error between spherical encoding method and DSI was $–0.15 \pm 17.5^{o}$ where an error of $–0.66 \pm 22.6^{o}$ was in the crossing areas.







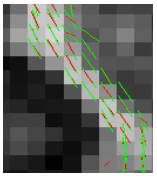


Fig.1 Deviation angles between SEI primary orientation and DSI primary orientation. Minimum error was found in b value of 3000 mT/m.

Fig.2 Primary and secondary diffusion orientation vectors in white matter region of DSI (red) and SEI (green), fig 2a. indicates the area with fiber crossing and fig2b indicates the area with coherent fiber tract.

Conclusions

Our preliminary results indicate deviation degree of 17.5 between SEI and DSI in coherent white matter tract and 22.6 in crossing fibers. These errors might come from single b value reduction in SEI, angular resolution of 14.6^{o} in 253 direction spherical encoding, heavy T2 decay, motion artifacts, and error induced from diffusion-EPI sequence. Though SEI with b value of 3000 mTm^{-1} and 4 min acquisition time in clinical machine is reasonable, further evaluation for error reduction is necessary.

References

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