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Software Development for the Visualization of the Orientation of Brain Fiber Tracts in Diffusion Tensor Imaging Using a 24 bit Color Coding

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요 약 : 뇌의 기능성과 분산 영역간의 연결성에 대한 관심이 매우 증대되고 있는 추세다. 그 중에서 DTI (확산 텐서 영상)는 비침습적으로 뇌에서의 물분자의 확산과 뇌의 회백질 신경 다발 구조에 대한 정보를 제공할 수 있는 자기공명영상 기법이다. 따라서 우리는 이 기법을 통해 다른 해부학적 혹은 기능적 자기공명영상 기법으로는 얻을 수 없는 뇌의 신경 섬유 다발과 대뇌 피질 영역의 연결성 정보를 얻을 수 있다. 본 연구에서는 컬러 코딩 방식에 의하여 뇌의 주된 신경 다발의 방향성을 가시화 하고자 한다. 인간 뇌의 방향성 지도는 연합섬유, 방사섬유, 교련섬유, 운동 및 감각회로 섬유의 다발들을 구별하기 쉽게 하여준다. 우리는 이 목적 하에 24비트 칼라코딩 방법을 윈도우 PC 환경에서 IDL을 이용하여 구현하였다. 덧붙여 방향성의 각각의 성분 및 이방성(異方性)에 대한 컬러 코딩과 이들을 표현하기 위한 다양한 색상표를 구현하였다. 결론적으로 우리의 24 비트 컬러 코딩을 이용한 뇌 회백질의 신경 다발의 방향성 가시화에 성공하였다. 우리가 구현한 방법에 의해 뇌의 주요 신경 다발들이 잘 가시화 됨을 확인하였다.

Abstract : Interests in human brain functionality and its connectivity have much grown up. DTI (Diffusion tensor imaging) has been known as a non-invasive MRI technique capable of providing information on water diffusion in tissues and the organization of white matter tract. Thus, it can provide us the information on the direction of brain fiber tract and the connectivity among many important cortical regions which can not be examined by other anatomical or functional MRI techniques. In this study, we used the 24 bit color coding scheme on the IDL platform in the windows environment to visualize the orientation of major fiber tracts of brain such as main association, projection, commissural fibers and corticospinal tracts. We additionally implemented a color coding scheme for each directional component and FA (fractional anisotropy), and used various color tables for them to be visualized more definitely. Consequently we implemented a fancy and basic technique to visualize the directional information of fiber tracts efficiently and we confirmed the feasibility of the 24 bit color coding scheme in DTI by visualizing main fiber tracts.
Key words : Diffusion Tensor Imaging , 24bit color coding, Brain, Fiber tract

INTRODUCTION

In recent years, interests in the visualization of the orientation of fiber tract and in the connectivity among various cortical areas of human brain have been much grown up because of the advent of a new DTI technique [1][2]. DTI (Diffusion tensor imaging) is a non-invasive MRI technique capable of providing information on water diffusion in various brain tissues and especially on the organization of fiber tracts using directional diffusion data. Thus, DTI can provide us the information on the direction of brain fiber tract and the connectivity among many important cortical regions connected through fiber tracts, which can not be in vivo examined by other anatomical or functional MRI techniques.

There have been lots of prior researches for visualization of orientation of fiber tract. The color coding and fiber-tractography methods, however, have been known to be promising among them. Other methods like two dimensional line fields of the in-plane projection, ellipsoid and 3D rendering of diffusion anisotropy[3][4][5] were rather crude and hard to discriminate the orientation of fiber tracts at a glance. And as an another new technique, fiber-tractography[6] method has a merit of

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visualizing the fiber tracts directly, but it needs some special techniques for implementation. It has problems in reliability, reproducibility for visualization of fiber tracts and a computation burden due to the intensive iteration. Moreover, it has been known that crossing in fiber tracts may cause severe problems in tractography.

On the other hand, a color coding method was very simple for implementation and its visualization of fiber tracts was definite and clear in crossing problem. Although a color coding method was more definite for discriminate the direction of fiber tract than other methods, additional information on separate component of directional vector and FA would be more helpful for the discrimination of each fiber tracts.

We implemented a home-made PC-based software to visualize the directional information of brain fiber tracts by using a color coding method for DTI data. Also, we examined normal subjects to evaluate the feasibility of our software.

MATERISLS AND METHODS

1. Data acquisition and Subjects

All MR images were obtained from Seoul National University Hospital. Both T1-weighted and EPI (echo planar imaging) scans for anatomical and functional information were performed. Imaging was performed on a 1.5 T MR scanner (GE Signa Horizon, USA) with a conventional quadrature head coil. To acquire diffusion tensor images, we used a single-shot spin-echo EPI sequence. To describe the intensity of diffusion anisotropy and diffusion direction , true axial MR images with 6 non-collinear diffusion gradients, i.e. (Gx,Gy,Gz) = (1,1,0), (-1,1,0), (1,0,1), (-1,0,1), (0,1,1), (0,1,-1) and without diffusion gradient were acquired [2]. As a diffusion encoding gradient strength, b-factor was set to be 500 sec/mm2. Acquisition parameters were as following; FOV = 240 mm, matrix = 128 x 128, slice thickness/ gap= 6mm/0mm, total slice number = 30. TR/TE=10000ms/90ms, scan average=4.

The subjects consisted of normal volunteers with age ranged from 21 to 26 years. Seven MR image sets with each diffusion scheme were converted to ANALYZE format. A total of 7 volumetric data in one subject were obtained and one average volumetric MR image set from them through registration by SPM99 were used to measure the diffusion tensor parameters.

2. Software implementation

1) Calculation of diffusion tensor

We smoothed all diffusion-weighted MR images with Gaussian kernel with a FWHM of 2 pixels to satisfy trade-off condition creasing SNR and keeping not much loss of spatial information. Afterward, from seven diffusion weighted images, we obtained six diffusion tensor components of Dxx, Dyy, Dzz, Dxy, Dxz and Dyz by multiple linear equations.[7] We adopted Vmax, i.e. an eigenvector with maximum eigenvalue of three eigenvectors through eigen-decomposition on diffusion tensor to encode the direction of fiber tracts.

2) Color coding scheme for directional information

In this study, we used a color coding scheme proposed by Pajevic et al.[8]. Brief procedure of their method was as follows.

(1) Color coding by Hue-Saturation-Value (HSV) color system

Let Vmax = [x,y,z], where Vmax are eigenvectors corresponding to the largest eigenvectors in each voxel. HSV color scheme using polar coordinate representation of direction is used for assigning different colors for every different direction. Eigenvector [x,y,z] can be expressed by θ and ϕ that are latitude angle and azimuth angle respectively. H, S, and V is assigned by θ, ϕ, and ΔW, ΔW means the degree of anisotropy in each voxel.

$$H = \phi,\ S = 2\theta/\pi,\ V = \Delta W \qquad (1)$$

Hue, Saturation and Value calculated from this formula (1) can be transformed into RGB color system by a HSV to RGB conversion formula provided by IDL.

(2) Antipodal Symmetry

It is natural to code a color coding scheme for the antipodal direction to have the same color. That is supported by the fact that fiber tract in antipodal direction is consequently the same direction in physical meaning. So even in no symmetry scheme, the antipodal symmetry must be included.

(3) No Symmetry scheme

As we can see from the color table (Figure 1) for no symmetry scheme, we can assign different colors for different orientation. But no symmetry scheme showed much discontinuity in color coding even between adjacent voxels. Of course the antipodal symmetry [8] is included in this scheme.

$$H = \phi,\ S = 2\theta/\pi,\ V = \Delta W \qquad (2)$$

(4) Full Symmetry or Absolute value scheme

With applying full symmetry, i.e. the symmetry for 180o rotation in two parameters,

θ and ϕ (rotation symmetry), and for both hemispheres (mirror symmetry), we have R, G, and B color table as the following equation (3). So we can call this scheme as absolute value scheme. RGB color scheme uses a rectangular three dimensional space

$$R = \Delta W|Vx| \quad G = \Delta W|Vy| \quad B = \Delta W|Vz| \qquad (3)$$

3) Post-processing

For better visualization of fiber tracts, gamma and brightness correction have been done for the reduction of their distortion by specific graphic devices. This is not included in the main software. But we used some conventional image processing softwares.

4) Implemented software

We implemented our software on IDL (RSI, Kodak) platform in window PC environment. We implemented two "no symmetry" and "full symmetry" schemes. Figure 1 shows the color table for each scheme. The color in the circle means the projection of upper hemisphere of the volumetric color coding. So each pixel represents each voxel on the external surface of upper hemisphere. Red color represents the right and left direction, green color does anterior and posterior direction and blue color does inferior and superior direction. Brightness indicates the degree of anisotropy, FA. As we described in the post-processing of the methodology, gamma correction has been applied to overcome the distortion of the ratio of R, G, and B in the color system of the visualizing devices. Our implementation provided additional functions as follows. First, we implemented the separate visualization of x, y and z coordinates of Vmax encoding by FA with various color table. Secondly, an interactive visualization of axial, coronal, and sagittal images were possible with color coding. Lastly our software enabled T1 and DTI images to be overlaid. Our software was compatible for various data formats such as Analyze, DICOM, and raw volume data. Figure 2 shows GUI (graphic user interface) of our software.

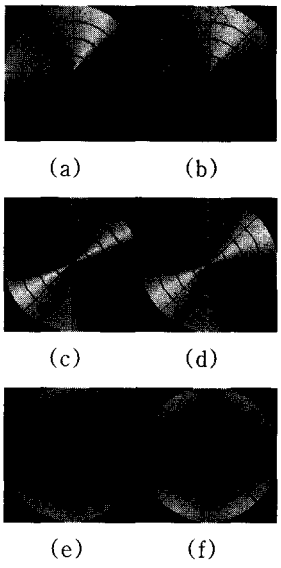

Fig. 1. Color tables for three different schemes;
(1) no symmetry scheme without (a)/with (b) gamma correction
(2) rotation symmetry scheme without (c)/with (d) gamma correction
(3) full symmetry (absolute value) scheme without (e)/with (f) gamma correction

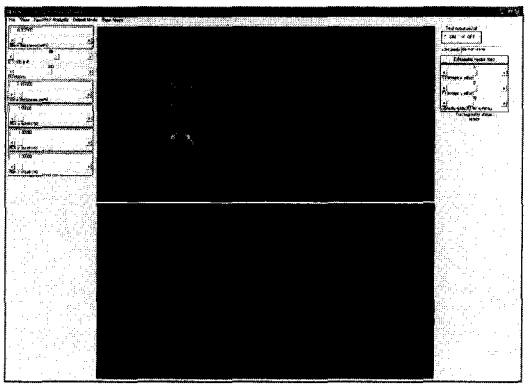

Fig. 2. A graphic user interface of the implemented software

RESULTS

Software development for the visualization of the orientation of brain fiber tracts in diffusion tensor imaging using a 24 bit color coding was successfully done. We found that our software made a good visualization of main fiber tracts such as corpus callosum, internal capsule, pyramidal tract, optic radiation in human brain. Pyramidal tract and pons are more clear in coronal view (Figure 4b).

Color-coded FA images obtained with various schemes showed different color pattern images on the orientation of fiber tracts. The discontinuity artifact in "no symmetry" scheme is shown in Figure 3. With full symmetry (absolute value) scheme considering additional consideration about the symmetry of hemisphere, we can compare fiber tract directions between both right and left hemispheres about the asymmetry of fiber tracts. And continuous direction information can be obtained in this scheme as shown in Figure 4. Figure 4 shows the feasibility of color coding as a methods of visualization of various major fiber tracts in axial view and coronal view. The separate visualization of x, y, z coordinates of Vmax encoding by FA with various color tables showed that we could have more definite information about each component of directional vector and FA (Figure 5).

Fig. 3. Color-coded FA images in "full symmetry" (a) and "no symmetry" (b) schemes; No symmetry scheme shows the discontinuity in colors even in neighbor pixel within yellow circle

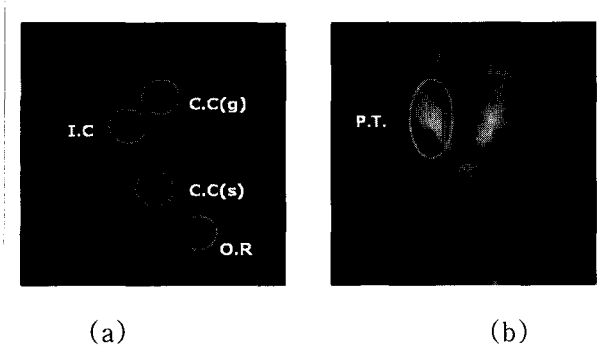

Fig. 4. FA color map images in absolute value scheme for main fiber tract in human brain;
(a) axial view; C.C (g)=corpus callosum (Genu), I.C= internal capsule, C.C (s)= corpus callosum (Splenium), O.R= optic radiation
(b) coronal view; P.T= pyramidal tract

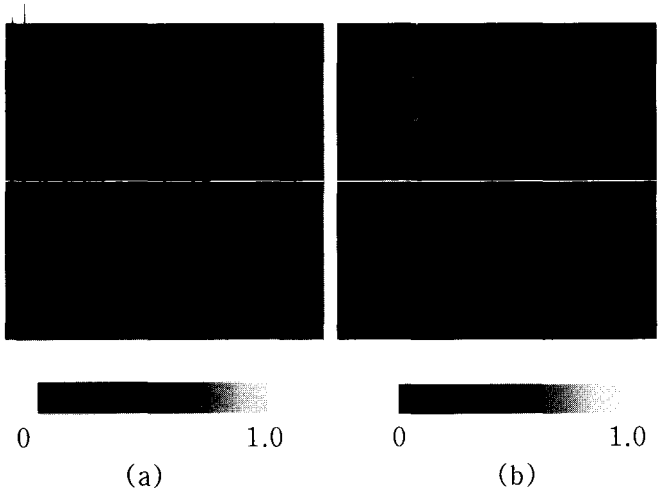

Fig. 5. FA color map images of each directional component; (a) x component (b) z component

DISCUSSION AND CONCLUSION

The visualization of the orientation of the fiber tract in human brain has very important clinical meaning in various diseases of brain related to white matter. This paper aims to implement the visualizing software of the orientations of fiber tracts by using a 24 bit-color coding system. Similar to the results of Pajevic, color-coded FA images showed successful major fiber tracts in brain using our software. Additional feature of the separated views of each x, y and z directional component may be more useful to analyze the fiber tracts. Various color-schemes in our software were shown to have their advantage or disadvantage in visualizing the orientation information on fiber tracts. Also, they had their own values and physical meanings. Therefore, appropriate symmetry schemes were thought to be chosen according to their application.

Our implementation has some limitations to be improved. Firstly, we provided only two dimensional visualization of the color-coded fiber tracts. So we must expand our implementation as three dimensional color coding map. Secondly, color-coding schemes may provide less morphological information than the fiber - tractography method[6][9][10]. Fiber-tractography has been known to visualize the fiber tracts directly. So a new method to combine fiber-tractography and color coding scheme would be thought to be developed.

In conclusion, we made a home-made software for a good visualization of major fiber tracts like corpus callosum, pyramidal tract, optic radiation and corticospinal tract. Because our fiber tract visualization software was developed under windows PC platform and allowed for various data formats like Analyze, DICOM and raw data, most of clinicians are thought to be able to use it easily and routinely. Therefore, our study may contribute a domestic study on clinical or methodological fields about diffusion tensor imaging as a new frontier technique in MR studies under the circumstance that there was no home-made software in domestic area. Also, because there has been no established optimal method to represent the information on fiber tracts, a home-made PC-based software implementation for the visualization of fiber tracts may be a foundation stone for more sophisticated studies on brain fiber tract.

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