Software Development for the Integrated Visualization of Brain Tumor and its Surrounding Fiber Tracts

Jungsu Oh[1], In Chan Song[2], Ik Hwan Cho[4], Dong Gyu Na[2], Kee Hyun Chang[2], Kwang Suk Park[3]

Purpose : The purpose of this study was to implement a software to visualize tumor and its surrounding fiber tracts simultaneously using diffusion tensor imaging and examine the feasibility of our software for investigating the influence of tumor on its surrounding fiber connectivity.

Material and Methods : MR examination including T1-weigted and diffusion tensor images of a patient with brain tumor was performed on a 3.0 T MRI unit. We used the skull-striped brain and segmented tumor images for volume/surface rendering and anatomical information from contrast-enhanced T1-weighted images. Diffusion tensor images for the white matter fiber-tractography were acquired using a SE-EPI with a diffusion scheme of 25 directions. Fiber-tractography was performed using the streamline and tensorline methods. To correct a spatial mismatch between T1-weighted and diffusion tensor images, they were coregistered using a SPM. Our software was implemented under window-based PC system.

Results : We successfully implemented the integrated visualization of the fiber tracts with tube-like surfaces, cortical surface and the tumor with volume/surface renderings in a patient with brain tumor.

Conclusion : Our result showed the feasibility of the integrated visualization of brain tumor and its surrounding fiber tracts. In addition, our implementation for integrated visualization can be utilized to navigate the brain for the quantitative analysis of fractional anisotropy to assess changes in the white matter tract integrity of edematic and peri-edematic regions in a number of tumor patients.

Index words : Brain tumor
Fiber tractography
Diffusion tensor imaging

JKSMRM 9:2-8(2005)

[1]Interdisciplinary Program of Medical and Biological Engineering
[2]Department of Radiology, Seoul National University Hospital
[3]Department of Biomedical Engineering, Seoul National University
[4]Department of Electrical Engineering, Inha University

Received; December 4, 2004, acceepted; February 14, 2005

Address reprint requests to : In Chan Song, Ph.D., Department of Radiology, Seoul National University Hospital, 28 Yeongeon-dong, Chongro-gu, Seoul 110-744, South Korea.
Tel. 82-2-2072-3941 Fax. 82-2-763-0379 E-mail: icsong@radcom.snu.ac.kr

Introduction

Conventional developments in recent image-guided neurosurgery such as Virtual pointer projection of Reinges et al, three-dimensional navigation system of Coenen et al, and Intra-operative Brain Shift system of the surgical planning lab have focused on the integration of functional information and anatomic image data (1-3). However, white matter tractography of such tract as pyramidal tract, optic radiation and corpus callosum were out of consideration in terms of preoperative mapping although it was of great clinical importance in neurosurgical interventions (1, 4). Therefore, these systems show a limitation in the surgical planning due to the lack of a priori knowledge for the estimation of functional connectivity of patient. For now, above all, diffusion tensor imaging (DTI), especially when integrated with tumor, is much focused, where DTI is an in vivo technique to extract information about connectivity and pathology of fiber tracts in brain white matter. Therefore, we implemented software to visualize tumor and its surrounding fiber tracts simultaneously using diffusion tensor imaging and examined the feasibility of our software for investigating the influence of tumor on its surrounding fiber connectivity.

Materials and Methods

Data acquisition and subject

All MR images were obtained from Seoul National University Hospital. Brain MRI and diffusion tensor imaging (DTI) were performed using a 3.0T GE whole body imaging system. A conventional head coil was used for the DTI. A dual-spin echo planar imaging (EPI) sequence was used to acquire diffusion tensor images. To reconstruct the diffusion tensor map images, MR images with 25 non-collinear diffusion gradients and without diffusion gradient were acquired with a b-factor of 1,000 sec/mm^2 (TR/TE = 10000 ms/90 ms, total slice number = 38, scan average = 1, FOV = 240 mm, matrix = 128 × 128, slice thickness/ gap = 3.5 mm/0 mm). One patient with left frontal mass of anaplastic astrocytoma was examined. Contrast-enhanced T1-weighted images (T1 image) were acquired using a 3D SPGR sequence (TR/TE/flip angle = 26 ms/6 ms/40, FOV = 220 mm, matrix = 256 × 160, slice thickness = 1.5 mm, slice = 120) and an administration of 0.2 mmol/kg Gd + agent (Magnevist).

Data processing

Overall procedures for data processing

We conducted sequential procedures for pre-processing for the integrated visualization as in Fig. 1. For DTI map images, we coregisterd diffusion tensor images onto T1 anatomical three-dimensional data by two steps and afterward tensor map images were calculated. Tensorline/streamline-based tractography procedure was implemented as an in-house software on the IDL platform (RSI, Kodak, U.S.A.). On the other hand, we conducted a skull-stripping procedure for T1 images to extract the cortical surface for augmented anatomical information. In addition, we extracted the tumor volume

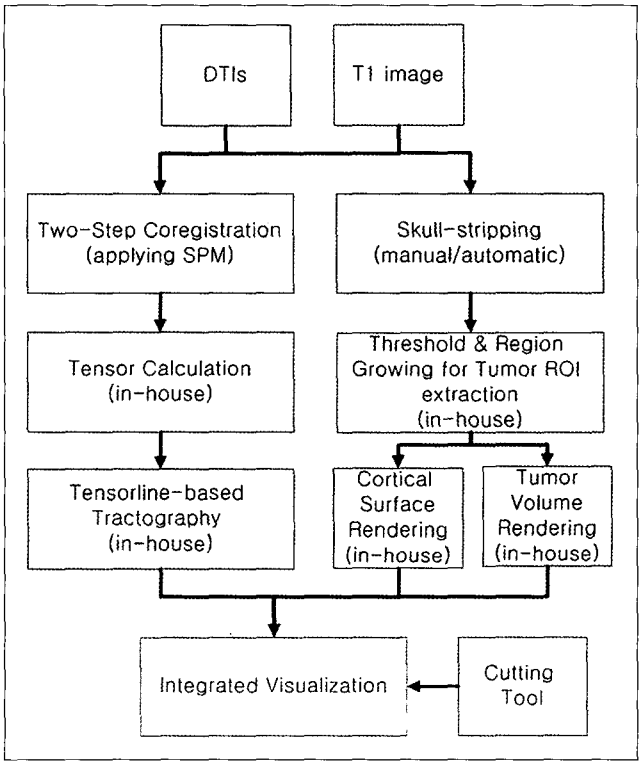


Fig. 1. Overall block diagram of the data processing procedures to the integrated visualization of the tumor and its surrounding fiber tracts. We conducted sequential pre-processing procedures for the integrated visualization. Two-step coregistration of diffusion tensor images onto T1 image and tractography procedure were implemented as an in-house software. For contrast-enhanced T1 image, we conducted a skull-stripping procedure for constructing cortical surface and extracting tumor volume.

with high signal intensities from contrast-enhanced T1 image.

Coregistration of diffusion tensor images and them onto T1 image

We performed a reslicing of each diffusion gradient weighted image using a cubic-spline interpolation and coregistration of it onto the T1 image using a SPM2 (http://www.fil.ion.bpmf.ac.uk/spm).

We used a *two-step* coregistration scheme for minimize the spatial mismatch of diffusion tensor images from the target T1 three-dimensional volume data. The details of the two-step coregistration are illustrated in Fig. 2. We let the image without diffusion gradient (b = 0) as I_0. The first step is the coregistration among diffusion tensor images (notated as Ik in Fig. 2, where k = 1, 2,..., 25), i.e., 25 diffusion gradient weighted images onto I_0. And the second step is the coregistration between coregistered diffusion tensor images onto the T1 image using the coregistration parameter of I_0 onto the T1 image.

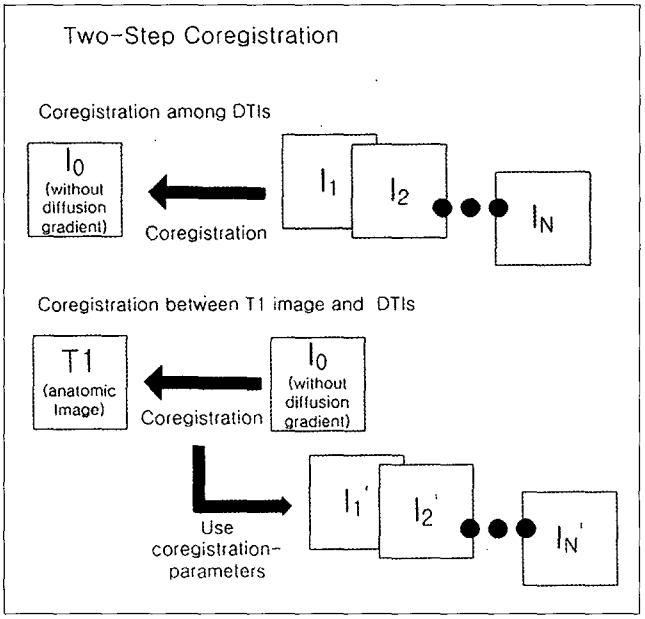


Fig. 2. Two-step coregistration scheme for diffusion tensor images onto T1 three-dimensional anatomical images. We used two-step coregistration scheme for minimizing the spatial mismatch of diffusion tensor images from T1 images. In the first step, we coregistered 25 diffusion gradient weighted images onto an image without diffusion gradient, I_0. In the second step, using the coregistration parameter of I_0 onto the T1 image, we coregistered 25 diffusion gradient weighted images coregistered onto I_0 in step 1.

Calculation of diffusion tensor

We smoothed all diffusion-weighted MR images with a Gaussian kernel with a FWHM of 2 pixels (or 1.94 mm) to reduce noises due to the application of diffusion gradient. Afterward, from 25 diffusion weighted images, we obtained six diffusion tensor components in equation [1]; D_{xx}, D_{yy}, D_{zz}, D_{xy}, D_{yz}, and D_{zx} by multiple linear equations (5), where those six elements is enough to reconstruct the diffusion tensor which is a symmetric 3 × 3 matrix. We adopted the first eigenvector which is corresponding to the maximum eigenvalue in the eigen-decomposition of the diffusion tensor to track fiber pathways.

$$D = \begin{pmatrix} D_{xx}, D_{xy}, D_{zx} \\ D_{xy}, D_{yy}, D_{yz} \\ D_{zx}, D_{yz}, D_{zz} \end{pmatrix} \quad (1)$$

Integrated visualization of brain tumor, cortical surface and fiber-tractography

Tumor volume/surface rendering

We used a simple adaptive threshold method on the contrast-enhanced T1 image to extract the region of tumor. In addition, we smoothed the tumor volume to reduce the stair-like pattern in the tumor volume with a Gaussian kernel with a FWHM of 2 pixels. Both volume-rendering using an alpha-blending and surface-rendering using a marching-cube algorithm were implemented because tumor has volumetric as well as surface features.

Cortical surface rendering

We manually stripped the skull in the T1 image to construct a cortical surface. Construction of cortical isosurface was done by using a marching-cube algorithm.

Fiber-tractography

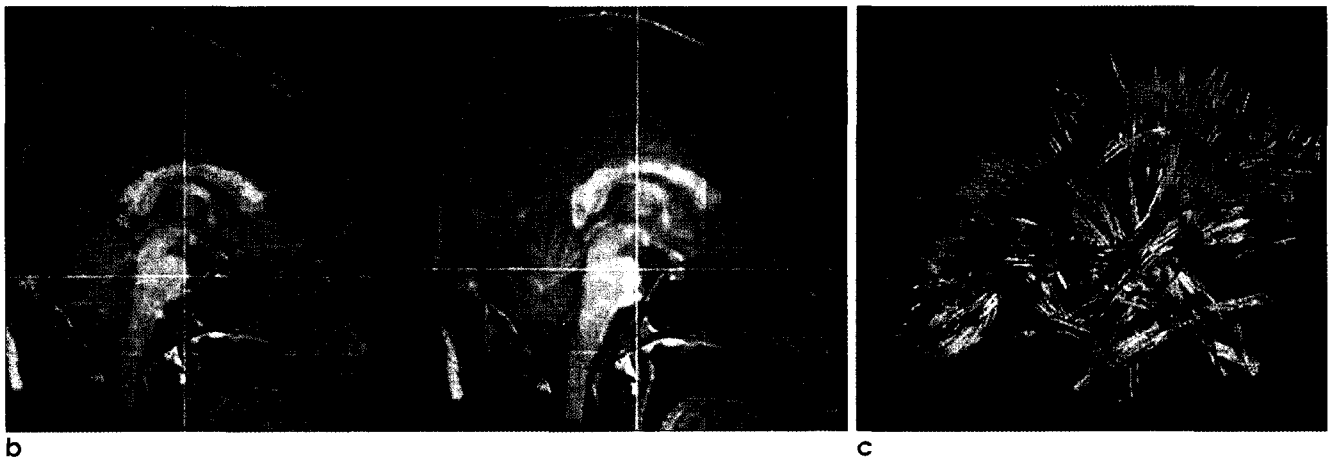
Our implementation offered both streamline method of Susumu et al (6) and tensor-line method of Lazar et al (7) for tractography. Since the stream-line method is generally used as a straightforward tracking algorithm for the principal diffusion direction (PDD) and the tensor-line method uses full information of diffusion tensor itself rather than two methods allow us the trade-off between the straightforward PDD tracking and compatibility in the disk- or sphere-like diffusion distributions in the branching tracts.

Results

Through tumor segmentation procedure, we could also successfully extract the tumor volume (Fig.3a). Through the two-step coregistration, the spatial mismatches of diffusion tensor images from T1 image were successfully corrected. For example, the mismatch in the deformation in the frontal region of the brain and the shape of midsagittal corpus callosum, especially in anterior part were well corrected (Fig. 3b). Tractography reconstructed by tensor-line method was also successful (Fig. 3c).

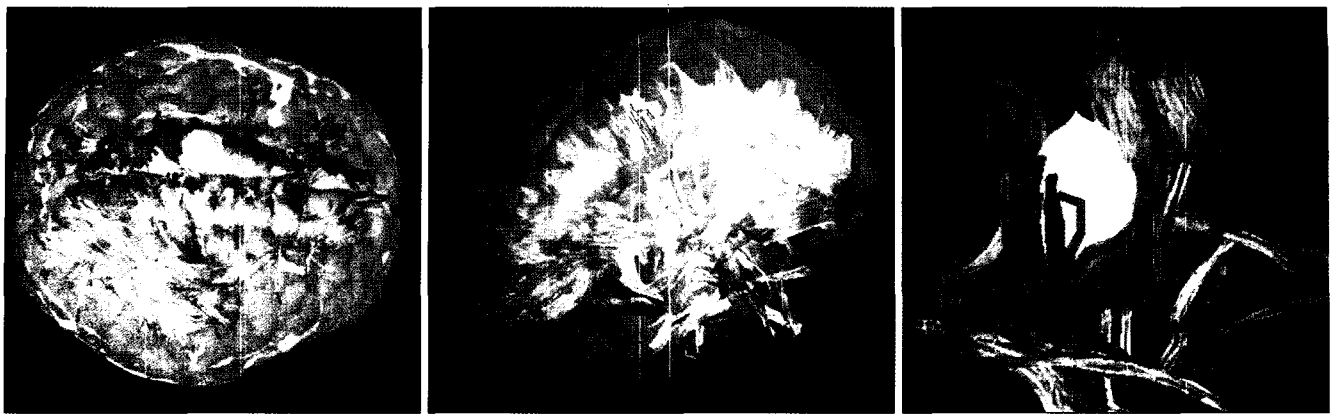
The integrated visualization of the tumor and its surrounding fiber tracts was successful (Fig. 4). In details, tube-like polylines with various colors successfully represented the fiber tracts. In addition, we could investigate the simultaneous visualization of tumor and its related fiber tracts under a guidance of anatomical information of the cortical surface. The color in the tractography means the fractional anisotropy (FA) values of each point on the poly-lines of the fiber tracts. Pure red and black colors mean FA values of 1.0 and 0.0, respectively. Color table is displayed in Fig. 4. In addition, our implementation has a great merit of controllability in the sense that we can use a transparency property which is

a



b c

Fig. 3. Preprocessing for integrated visualization of brain tumor and its surrounding fiber tracts; (**a**) Tumor segmentation by simple threshold method with views of surface rendering before vertices smoothing, after vertices smoothing, volume rendering of it (**b**) Coregistration of the diffusion tensor image onto anatomical T1 image, (**c**) Tractography reconstructed by tensor-line method.



a b c

Fig. 4. Integrated visualization of brain tumor and its surrounding fiber tracts in various aspects; (**a**) Upper view (**b**) Lateral view (**c**) Enlarged view. In each plane, the color of fiber tracts represents the FA values in each point.

adjustable by user, for all the graphic objects, i.e., tube-like tractography, cortical surface and tumor volume/surface.

Discussion and Conclusion

It is needless to say the importance of the visualization of the orientation of the fiber tract in human brain. And in many surgeries for brain tumor, the placement and estimation of region of interest (ROI) concerning the main white matter fiber tracts is very important. For now, DTI is the only way to investigate in vivo fiber tracts in human brain. In this study, thus we implemented integrated visualization of the tumor and fiber tracts to further investigate the influence of the tumor. However, the influence of tumor on its surrounding fiber tracts is out of the scope of this study, we did not conduct it. We successfully visualized both brain mass and its surrounding fiber tracts simultaneously using many graphic objects such as tube-like surface-fashion polylines, surface/volume rendering for the fiber tracts, cortical surface and tumor volume/surface respectively.

Successful implementation and clinical application of integrated visualization of brain tumor and fiber tracts need the same spatial information between anatomical and diffusion tensor images. From this viewpoint, our implementation has some limitations. Firstly, we used SPM for the coregistration of diffusion tensor images onto T1 image. As far as I know, coregistration of brain images with tumoral mass by using a SPM has not been fully evaluated for its precision although our result showed a good coregistration. It would be better to use more sophisticated elastic warping algorithm for the correction of the nonlinear deformation caused by the diffusion gradients and an EPI sequence. Secondly, geometric distortion was known as a result of an EPI sequence sensitive to magnetic susceptibility. Other scan methods may be thought to be an alternative way to reduce spatial distortion. We can use a line scan diffusion imaging (LSDI) technique [8] insensitive to susceptibility rather than our EPI-based sequence. However, there is some trade-off between two sequences, since LSDI costs much more scan time. Also, the advent of parallel imaging technique using a multi-channel coil may provide less distorted images because of shorter TE in EPI, so a spatially more accurate fiber tractography will be obtained (9).

Current our software showed limited performance in handling graphic objects. The order of graphic objects such as tube-like polylines of tracts, cortical surface, tumor volume/surface rendering should be more interactive to show the object of interest in every time. For example, if we want see more prominent tumor volume than other graphic objects, we have to change the order of each object at the stage of loading them. This may cause more time-cost job and result in a non-interactive visualization. Therefore, more convenient interface should be implemented in the future. However, our integration procedures excluding coregistration have great strength over other conventional implementation such as Coenen et al, in the sense of the full visibility of all graphic components such as white matter fiber tractog-

raphy, cortical surface, and tumor volume/surface.

In brief, we implemented integrated visualization software in PC platform which can be used routinely for the investigation of fiber tracts at the surrounding tumor areas in patients with brain tumor. In addition, the current implementation could be applied to the pre-surgical planning if it was integrated with more sophisticated coregistration tool.

Acknowledgment

This study was supported as "Development of New Medical Imaging Techniques in Radiation and Radioisotope" by a grant of the Mid and Long Term Nuclear R/D Plan Program, Ministry of Science and Technology, Republic of Korea.

References

1. Reinges MHT, Krings T, Nguyen HH, et al. Virtual pointer projection of the central sulcus to the outside of the skull using frameless neuronavigation: Accuracy and applications. Acta Neurochir (Wien) 2000;142:1385-1390
2. Schulder M, Maldjian JA, Liu WC, Holodny AI, Kalnin AT, Mun IK, Carmel PW. Functional image-guided surgery of intracranial tumors located in or near the sensory motor cortex. J Neurosurg 1998;89:411-418
3. Coenen VA, Krings T, Mayfrank L, et al. Three-dimensional visualization of the pyramidal tract in a neuronavigation system during brain tumor surgery: first experiences and technical note. Neurosurg 2001;49:86-93
4. Ture U, Yasargil G, Friedman AH, Al-Mefty O. Fiber dissection technique: Lateral aspect of the brain. Neurosurg 2000; 47:417-427
5. Song IC, Chang KH, Moon HH. The software development for diffusion tensor imaging. KSMRM 2001
6. Mori S, Kaufmann WE, Davatzikos C, Stieltjes B, et al. Imaging cortical association tracts in the human brain using diffusion-tensor-based axonal tracking. Magn Reson Med 2002;47:215-223
7. Lazar M, Weinstein DM, Tsuruda JS et al. White matter tractography using diffusion tensor deflection. Human Brain Mapp 2003;18:306-321
8. Mamata H, Mamata Y, Westin CF, et al. High-Resolution Line Scan Diffusion Tensor MR Imaging of White Matter Fiber Tract Anatomy 2002;23:67-75
9. Bammer R, Auer M, Keeling SL, et al. Diffusion tensor imaging using single-shot SENSE-EPI. Magn Reson Med 2002;48:128-136

대한자기공명의과학회지 9:2-8(2005)

뇌종양 및 그 주변 신경다발의 통합적 가시화를 위한 소프트웨어의 개발

[1]서울대학교 대학원 협동과정 의용생체공학전공
[2]서울대학교병원 진단방사선과
[3]서울대학교병원 의공학과
[4]인하대학교 전자공학과

오정수[1] · 송인찬[2] · 조익환[4] · 나동규[2] · 장기현[2] · 박광석[3]

목적 : 뇌종양 및 확산텐서 영상으로 얻어진 그 주변 신경 다발을 동시에 가시화 하는 소프트웨어를 구현하고 그것을 통해 뇌종양이 그 주변 신경다발에 미치는 영향에 대한 조사에의 적용 가능성을 시험해 보고자 하였다.

대상 및 방법 : IDL을 기반으로 뇌종양과 그 주변 신경다발의 통합적 가시화를 구현하였다. 뇌종양을 가진 한 환자에 대한 T1 강조영상 및 확산텐서 영상을 포함하는 자기공명영상이 3.0T 자기공명장치에서 획득되었다. 우리는 해부학적 정보를 위해 두개골을 제거한 뇌 영상과 구획화된 뇌종양을 위한 대조강화 T1 강조 영상을 이용하여 서피스 및 볼륨렌더링을 사용하였다. 대뇌 백질 신경 다발추적을 위해 사용되는 확산텐서영상을 위해서는 25개 방향의 확산경사 자계를 이용하는 SE-EPI 방법을 사용하였다. 신경 다발추적 방법으로는 streamline과 tensorline 방법을 사용하였다. T1 강조 영상 및 확산텐서 영상의 공간적 불일치를 보정하기 위해 SPM을 이용한 정합을 수행하였다. 우리의 소프트웨어는 PC 윈도우 환경에서 작동할 수 있도록 구현되었다.

결과 : 한 명의 뇌종양 환자에 대하여 튜브 모양의 신경다발, 대뇌 백질 서피스 렌더링, 뇌종양의 볼륨/서피스렌더링의 통합적 가시화를 성공적으로 구현하였다.

결론 : 우리의 결과는 뇌종양 및 그 주변 신경다발의 통합적 가시화의 실현 가능성을 보여주었다. 더불어 우리의 구현된 통합적 가시화는 뇌종양 부위 및 그 주변 부의의 대뇌 백질 확산 비등방성의 정량적인 분석에 사용될 수 있을 것으로 기대된다.

통신저자 : 송인찬, (110-744) 서울시 종로구 연건동 28, 서울대학교병원 진단방사선과 MRI실
Tel. 82-2-2072-3941 Fax. 82-2-763-0379 Email: icsong@radcom.snu.ac.kr