

Interactive Three-Dimensional Digital Atlas of the Fiber-tract in Human Brain

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Introduction

Human white matter anatomy has been studied using postmortem specimens. While postmortem approaches can characterize macroscopic features of large white matter bundles, comprehensive description of the 2D and 3D trajectories is very difficult. The understanding of three-dimensional relationships among different tracts and gray matter nuclei is even more difficult because of complex trajectories of the bundles. DTI and DTI-based tractography are excellent tools to study configuration of these large fiber bundles in situ and it has been shown that the macroscopic features of the fiber bundles extracted by tractography agree very well with the postmortem-based studies. However, comprehensive connectivity maps from DTI calculation and fiber tracking may pose neuro-radiologists with some challenges because identifying and quantifying anatomical and functional regions requires detailed knowledge of three-dimensional white matter structures. In addition, various white matter structures and fiber tracts that can be visualized by DTI maps have not been clearly assigned yet. The goal of our work was to create a digital atlas of the human brain white matter based on high-resolution *in vivo* human DTI data. Various white matter tracts and anatomical regions can be visualized and superimposed on MR images (color, FA, and ADC maps, or t1-, t2-, and diffusion-weighted images). The 3D and flexible features of the atlas, such as oblique projection, rotation, zooming and selective visualization of tracts of interest, make this atlas very powerful for the understanding of the white matter architectures.

Methods

All data sets were acquired using a single-shot echo-planar imaging (EPI) sequence with a SENSE parallel imaging scheme on a 1.5T Philips Gyroscan NT scanner. The image matrix was 256x256x55, with a field of view of 246x246 mm² and slice thickness of 2.2mm. A total of 55 axial slices covered the entire hemisphere and brainstem without gaps. The diffusion weighting was encoded along 30 independent orientations using a b-value of 700 mm²/s [1]. Five additional b=0 images were also acquired. To improve the signal-to-noise ratio, the scan was repeated 6 times. Co-registered MPRAGE (Magnetization-Prepared Rapid Gradient Echo) images of the same resolution were recorded for anatomical guidance. The data sets were processed using home-developed diffusion image processing software, DtiStudio (<http://mri.kennedykrieger.org>). Various types of map, such as tensor elements, eigen values, eigen vectors, diffusion anisotropy, diffusion constants, and color maps were calculated. Fiber tracking was performed using the FACT (Fiber Assignment by Continuous Tracking) approach [2] with brute-force strategy (tracking from every single voxel in the whole image matrix). The multi-ROI technique was used to reconstruct the tracts of interest, which exploits existing anatomical knowledge of the tract trajectories. Three kinds of Boolean-based ROI operations, AND/OR/NOT, were employed when multiple ROIs were used for selecting a tract of interest. The choice of the ROI operations depended on the characteristic of each tract [3,4]. All fiber tracts and anatomical regions were stored in a compacted bit-map image format to improve both memory and operation efficiency.

The electronic atlas is implemented on a Windows platform with a graphical user interface providing multiple operations and functions. The software architecture of the atlas is structured in a fully object-oriented manner using the C++ programming language and OpenGL standard. All functional blocks of the software are grouped and encapsulated within C++ class structures with well-defined member functions. The system software is decomposed horizontally into layers and vertically into components. The program is organized in such a way that there are no upward dependencies between layers. Each layer is a container of software components. The components in lowest layer, base layer, have higher reusability, whereas the ones in highest layer, system layer, are more application specific. A complete user interface, as shown in Fig. 1, has a main image panel and a control panel. The main image panel is composed of four views, which are three 2D orthogonal views and a 3D triplanar view. Various fibers of interest are superimposed into the anatomical images or DTI maps with user definable colors. The atlases displayed in the main image panel and the fibers imposed on the images are selected from the image name list and fiber name list, respectively, which are in the control panel. The control panel also contains 2D/3D views, animation, triplanar image opacity and other controls. These controls allow the user to invoke the operations on the atlas by just a few clicks. More tools, such as image enhancing and so on, are accessible by a pop-up menu.

Results and Discussion

A screen shot of the atlas is in Fig. 1, showing three orthogonal views of 2D images and a triplanar view of 3D visualization for the three image slices and selected fibers. The user can interactively do oblique viewing, rotating, zooming in/out, and shifting of the images in real-time. The 3D visualization is synchronized with 2D orthogonal views. The brain atlas database along with MRI images, selected fiber-tracts of interest, and manually defined anatomical regions are encoded on CD-ROM. This electronic atlas CD-ROM provides many features not available in the traditional print brain atlases. The atlas currently works on personal computer with following configuration: Windows-NT, Pentium III, 800MHz, 256M RAM. This work, addressing the construction of the electronic atlas of the white matter tracts in human brain by DTI and DTI-based axonal mapping, presents principles and demonstrates qualitative feasibility. Future work includes building data registry functions to use the atlas as a frame work for informatics of brain white matter anatomy.

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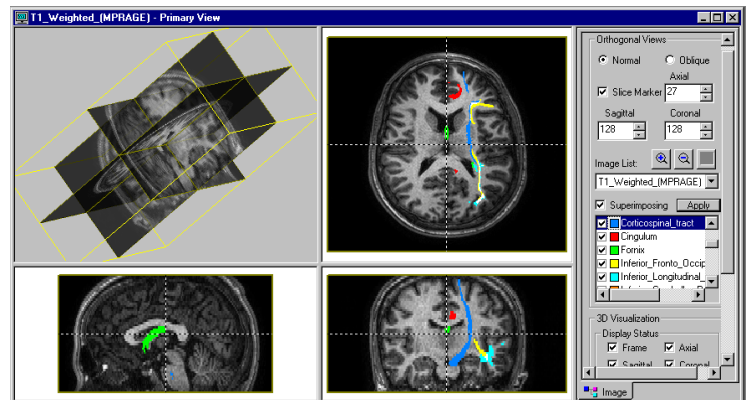


Figure 1. Demonstration of the atlas. The left part includes three orthogonal views and a triplanar view. Multiple fibers of interest are superimposed into the anatomical image, MPRAGE here, with user defined-colors. The right part is the control panel that contains image and fiber lists, 2D/3D views, animation, image opacity and other controls. The user can perform oblique viewing, rotating, zooming in/out, shifting of the images in real-time.