Three-dimensional digital atlas construction of Chinese brains by magnetic resonance imaging

Jianhua Lu, Zhiwei Chen*, Zhong Chen
Department of Physics, Xiamen University
Xiamen 361005, P. R. China
chenzhiwei@xmu.edu.cn

Zhiping Yan*, Yi Yao, Wanneng Luo, Sulian Su
174 Hospital of PLA
Xiamen 361005, P. R. China
yzhip65@126.com

Abstract**—*****This paper describes the construction of an atlas of the human brain by magnetic resonance imaging. The successive steps of the construction were performed with images acquired by three-dimensional fast spoiled gradient-echo recalled acquisition sequences in 1.5T. Data from the young and middle-aged healthy volunteers were spatially normalized into MNI coordinate frame in SPM2 software based on MATLAB. Three-dimensional brain atlas were reconstructed in the MNI coordinate system. There atlases enable efficient structure localization and morphometric comparison, which play important roles in the computer aided surgery, image guide surgery, minimal invasive surgery and other frontier areas.*

Keywords: Brain atlas; spatial normalization; MRI

I. INTRODUCTION

This paper describes the construction of an atlas of the human brain. The atlas has long been recognized as a valuable way of providing a visual interpretation and overview of complex morphological data [1-3]. More recently, the advent of modern computing and digital imaging techniques leverages the development of digital three-dimensional atlases of the brain [4-5]. The digitized atlas of human brain is turned to be very important to the study of brain science and neuroscience, neurosurgery for its precise localization of the target [6,7]. It plays important roles in the computer aided surgery, image guide surgery, minimal invasive surgery and other frontier areas [8].

At the present time, magnetic resonance imaging (MRI) is a non-invasive imaging technique and certainly the most powerful imaging technique to demonstrate brain anatomy in vivo [9]. Clinical brain MRI can produce 3D volumes with spatial resolution of the order of 1 mm or less with 1.5 T instruments. A large number of foreign research institutions dedicated to the brain atlas of construction. These included the Voxel–Man atlas, the Karolinska Brain Atlas project, the Human Brain Atlas, the Digital Anatomist project, the Harvard Brain Atlas, and the Visible Human Project [10,11]. Most of these brain atlases were based on single subjects or on very limited numbers of individuals. However there are some differences in the fine structure of the Chinese brain between the foreigners. So we decided to construct Chinese brain atlas. And we will collate the MRI date information into a database that can be used for surgical and research.

We describe the construction of a digital brain atlas composed of data from young and middle-aged healthy volunteers MRI data. A total of 56 structures were labeled in MRI of 20 healthy, normal volunteers. These atlases will serve as a resource for diverse applications including meta-analysis of functional and structural imaging data and other bioinformatics applications where display of arbitrary labels in probabilistically defined anatomic space will facilitate both knowledge-based development and visualization of findings from multiple disciplines.

II. MATERIALS AND METHODS

A. Subjects and data acquisition

Twenty healthy volunteers were scanned with MRI in the study (7 males and 13 females). The mean age was 25±3.9 years (with a range from 20 to 40 years) and denial of any history of psychiatric or medical illness as determined by clinical interview. Any medical condition or treatment known to affect the brain was excluded. Informed consents were obtained from all volunteers after all of the procedures were fully explained, and the study received the approval of the local ethics committee.

In this study the parameters used to acquire MRI data were as follows: three-dimensional fast spoiled gradient-echo recalled (FSPGR) acquisition sequences, 15.3 kHz bandwidth, TE/TR= 15/12.1 ms, 24×24×24 cm FOV and 256×192×128 acquisition matrix. These acquisition parameters resulted in a nominal spatial resolution of 0.77 mm. The TE value was chosen for optimizing the contrast-to noise ratio and the other parameters are the result of a compromise between the amount of signal, the resolution and the acquisition time. The images with high spatial resolution, integrity, reliability and clarity were peer recognition (see fig. 1).

B. Spatial normalization

Spatial transformations are important before atlas construction. Several techniques are available to perform spatial normalization. The most widely used normalization software in the research literature is Statistical Parametric Mapping (SPM). Spatial normalization involves applying a spatial transformation that moves and warps images into the same standard anatomical space defined by the templates provided by the Montreal Neurological Institute (MNI) [12].

This work was supported by Xiamen Science and Technology Project (3502Z20074028).

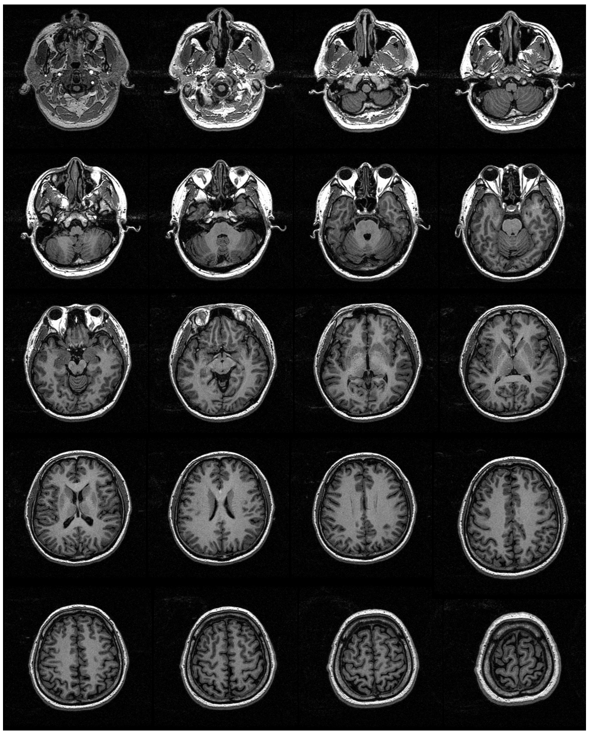

Fig. 1 Some selected 2D slice of 3D T_1 MRI atlases of one brain

The steps involved in the statistical analysis of brain images include: registration, spatial normalization, Gaussian smoothing, and construction of statistical parametric maps. Motion correction was performed to eliminated the head movement before preprocessing image data. The first step in the correction is image registration, which involves determining the parameter values for a rigid body transformation that optimize some criteria for matching each image with a reference image. Following the registration, the images are transformed by re-sampling according to the determined parameters. The standard normalization method in SPM2 minimizes the sum of squared differences between the subject's image and the template, while maximizing the prior probability of the transformation. This spatial normalization begins by determining the optimum nine-parameter affine transformation to account for differences in position, orientation and overall brain size. After affine transformation, a nonlinear transformation is applied to correct for gross differences in head shapes that were not accounted for by the affine transformation. The nonlinear deformations are described by the lowest frequency components of a three-dimensional discrete cosine transform basis functions. For SPM2, the whole-head MRI data is aligned to the atlas target and produces a native-to-atlas transform.

C. Anatomical labeling

One of the most widely used anatomical references is the brain atlas of Talairach. This atlas was seminal for the development of functional neuroimaging by introducing a spatial reference system for the human brain, which is independent of skull landmarks. Stereotaxic locations are then described in coordinates relative to the origin (coordinates 0, 0, 0) defined by the intersection of the AC with the interhemispheric plane. A SPM toolbox named SPM Anatomy enabling the comparison of cytoarchitecture and function was used to provide a routine, standardized application of probabilistic cytoarchitectonic maps as an anatomical reference for functional activations[13]. As a result, the patient’s brain has the same coordinate system as the Talairach brain atlas (see fig.2).

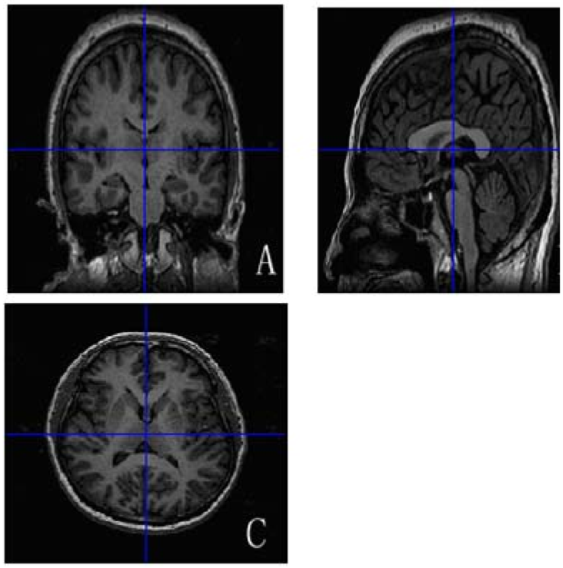

Fig. 2 Atlas data set in the reference frame displayed in SPM2 environment.

D. Three-dimensional visualization

The SPM Anatomy toolbox was developed for the visualization and statistics of cytoarchitectonic probabilistic maps of the human cerebral cortex into the SPM software package. In combination with the freely available probability maps, the SPM Anatomy toolbox handles all of the steps necessary for an integrated analysis of structural and functional data, e.g., the visualization and statistical description of probabilistic maps, the generation of summary maps combining the information of the different probabilistic maps and finally the anatomical interpretation of functional imaging results. Since the functional analysis can be performed entirely within SPM, no specific requirements on the experimental setup or statistical analysis of the functional data are enforced. Fig. 3 illustrates the 3D volumetric nature of the digital map of anatomy. Three orthogonal views are depicted (horizontal, sagittal, and coronal) together with their respective represented through a surface model of the cortex. The image set was then reconstructed into a digital volume and digitally resampled into orthogonal reference planes. Moreover, functional imaging data can be analyzed using all options offered by SPM2 including available toolboxes and extensions. If the functional data have been normalized into the standard MNI space, the SPM Anatomy toolbox automatically applies the linear correction to the anatomical MNI space. All locations are then reported both in standard and anatomical MNI coordinate [14].

III. RESULTS AND DISCUSSION

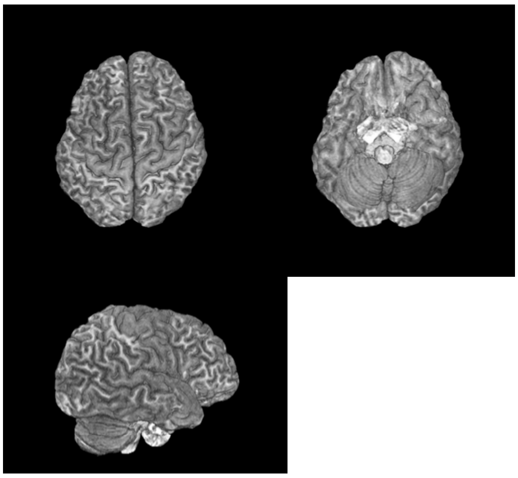

Fig. 3 Three-dimension volumetric nature of the digital map of anatomy.

The 3D MRI data of Chinese young and middle-age healthy volunteers brain were acquired and transferred to a computer workstation for reconstructing the three-dimensional structure and establishing atlas. The novel advantage provided by the present digitlized atlas is that the atlas of which can be changed in any angle or any direction, and displayed in any size or any form, alone or overlay. Through non-invasive imaging technology, we set the Chinese brain digital database, which can use a detailed analysis of deep brain structure and a more accurate understanding of the structure, size, shape, scope and direction of the brain nuclei. The database provided more intuitive, lifelike model of the human brain for clinic and laid a good foundation for the next step for the Chinese virtual brain structure.

Meanwhile, we arranged the correlative information and published MRI anatomy monographs with electronic maps. By promoting, they enriched the anatomy basis theory of the structure of deep brain and changed the traditional anatomy teaching, research and concept relied mainly on the brain specimens. They also made the clinicians more profoundly and truly understand the local anatomy of human brain, which provided a reliable basis for quickly and accurately carrying out brain surgery stereo tactic operation, reduced surgical trauma, avoided major structural damage and improved treatment.

Furthermore, our atlas provided the three-dimensional position of a nucleus of nerve, the various physiological parameters and the adjacent relations. Many aspects of the applications will be practical in the forthcoming research, such as use the atlas to the clinical disease, surgery diagnosis and the operation plan setting. Its major disadvantage, however, is that the 3D Surface of cerebral regions is not clearly and verified. This problem will be studied further.

IV. CONCLUSION

In this paper, we have described the production of a probabilistic atlas of human brain structures. Several digital atlases have been developed using photographic images of cryoplaned frozen specimens [4,5], the data were interfered by external factors and there are some differences between which from normal. In this study we get the images of MRI data based on healthy volunteers, the three-dimensional positioning are more accurate, the information is more complete.

The atlas was generated from a set of T1-weighted MRI volumes collected from 20 healthy volunteers. We hope that high field MR imaging can be scanned in the next step. Finally, manual delineations the atlases of brain structures are our future work.

Presently, our work is only at the laboratory stage and more work has to be done before it becomes practical for widespread clinical use.

REFERENCES

[1] Fischl B, Sereno MI, Tootell RBH, et al. "High-resolution intersubject averaging and a coordinate system for the cortical surface," Hum Brain Mapp, vol 8, pp 272-284, 1999.

[2] Shattuck DW, Mirza M, Adisetiyo V, "Construction of a 3D probabilistic atlas of human cortical structures," Neuroimage, vol 39, pp 1064-1080, 2008.

[3] Hammers A, Allom R, Free SL, et al. "Three-dimensional probabilistic atlas of the human brain," Neuroimage, vol 16, pp S86-S86, 2002.

[4] Schmahmann JD, Doyon J, McDonald D, "Three-dimensional MRI atlas of the human cerebellum in proportional stereotaxic space," Neuroimage, vol. 10, pp 233-260, 1999.

[5] Dimitrova A, Zeljko D, Schwarze F, et al. "Probabilistic 3D MRI atlas of the human cerebellar dentate/interposed nuclei," Neuroimage, vol 30, pp 12-25, 2006.

[6] Maye A, Wenckebach TH, Hege HC, "Visualization, reconstruction, and integration of neuronal structures in digital brain atlases," Int J Neurosci, vol 116, pp 431, 2006.

[7] Nowinski WL, "Human brain atlases in education, research and clinical applications," Complex Medical Engineering, pp 335-349, 2007.

[8] Bejjani BP, Dormont D, Pidoux B, Yelnik J, et al. "Subthalamic stimulation for Parkinson's disease by using three-dimensional stereotactic magnetic resonance imaging and electrophysiological guidance," J. Neurosurg, vol 92, pp 615-625, 2000.

[9] Pautler RG, Silva AC, Koretsky AP, "*In vivo* neuronal tract tracing using manganese-enhanced magnetic resonance imaging," Magn Reson Med, vol 40, pp 740-748, 1998.

[10] Kikinis R, Gleason PL, Moriarty TM, et al. "Computer assisted interactive three-dimensional planning for neurosurgical procedures," Neurosurgery, vol 38, pp 640-649, 1996.

[11] Poirier C, Vellema M, Verhoye M, et al. "A three-dimensional MRI atlas of the zebra finch brain in stereotaxic coordinates," Neuroimage, vol 41, pp 1-6, 2008.

[12] Collins DL, Neelin P, Peters TM, et al. "Automatic 3D intersubject registration of MR volumetric data in standardized Talairach space," J. Comp. Assisted Tomography, vol 18, pp192-205, 1994.

[13] Eickhoff SB, Stephan KE, Mohlberg H, et al. "A new SPM toolbox for combining probabilistic cytoarchitectonic maps and functional imaging data", Neuroimage, vol 25, pp 1325-1335, 2005.

[14] Tsuzuki D, Jurcak V, Singh AK, et al. "Virtual spatial registration of stand-alone MRS data to MNI space," Neuroimage, vol 34, pp 1506-1518, 2007.