Comprehensive digital 3D monkey brain MRI atlas

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Introduction

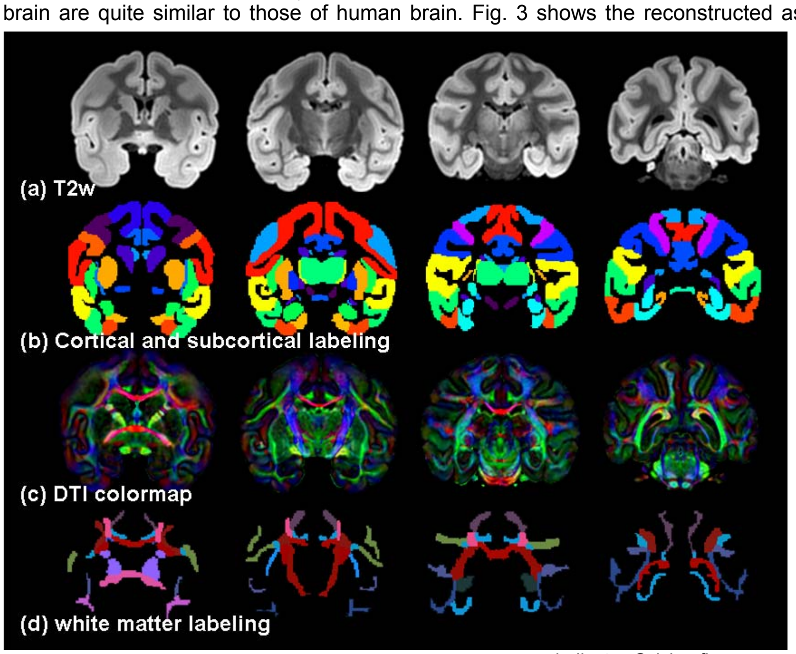
Neuroscientific studies on macaque brains have been playing important roles for understanding neural systems. Due to their close relationship to the human brain, animal models of primates have been unique and irreplaceable in neurobiological studies. Electrophysiological recording directly measures action potentials of individual neurons to learn functions of somatosensory, auditory, visual and other neural systems. Research on these systems [e.g. 1-3] answers fundamental questions about the basic brain mechanism. In these studies, currently available atlases based on histology [e.g. 4-5] and chemical tracing [6] have played central roles as anatomical references. However, few atlases are digital or have 3D presentations. Moreover, none of them are comprehensive, including anatomical information of cortical gyri, subcortical nuclei and white matter tracts. The goal of this study is to establish a 3D digital atlas with comprehensive labeling of all voxels in the brain with DTI and conventional T2 weighted image. To set up this atlas, we acquired very high resolution and high signal-to-noise ratio (SNR) DTI and T2 weighted images with isotropic resolution from a postmortem adult macaque brain with 3D imaging sequences. In this abstract, we show the digital atlas with complete labeling of cortical gyri, subcortical nuclei and white matter tracts. The 3D reconstructed images of the cortical sulci and association tracts traced with DTI tractography are also shown to demonstrate application of our atlas to evolution and brain connectivity study. The digital format of the atlas makes it possible to map the labeling information of the atlas to the experimental monkey brain with image registration.

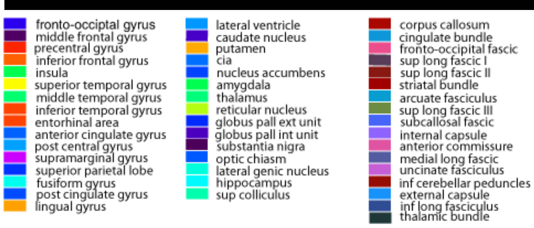
Method

Data acquisition: A 4.7 T Bruker scanner was used. 3D multiple spin echo diffusion tensor sequence was used for DTI imaging. A set of diffusion weighted images (DWI) were acquired in 7 linearly independent directions. DWI parameters were: TE=32.5ms, TR=0.7s, FOV=80mm/58mm/60mm, imaging matrix=160×80×80 (zero filled to data matrix 256×128×128). Co-registered T_2-weighted images with the same FOV were also acquired with the fast spin echo sequence. T_2 weighted imaging parameters were: TE=15ms, TR=1s, imaging matrix=256×160×160 (zero filled to data matrix 256×256×256). *Gray and white matter assignment and reconstruction:* The cortical gyri and subcortical nuclei were manually delineated with ROIEditor [7] following the available atlases [4-5]. The segmentation of white matter tracts was performed by using the information from contrasts of DTI colormap, DTI tractography and chemical tracing results [6]. The 3D reconstruction was visualized by Amira. FACT [8] was used for fiber tractography.

Results

Fig 1 shows the high resolution T2 weighted image (Fig. 1a), complete labeling of cortical gyri, subcortical nuclei (Fig. 1b), DTI colormap (Fig. 1c) and white matter tracts (Fig. 1d). With the isotropic resolution, the labeling is available also in axial and sagittal slices (data not shown due to limited space). From Figs. 1b and 1d, structural labeling has been assigned to all voxels of the brain to get the comprehensive atlas. With 3D reconstruction of the cortical surface (Fig. 2), it is clear that the cortical surface is getting more convoluted from mouse to human. Compared to mouse or marmoset brains, macaque brain has already had many sulci. The two large brain sulci, central sulcus and Sylvian fissure pointed by the blue arrows, are not available in mouse brain and can be clearly seen in the cortical surfaces of the other three species. The limbic, commissural and projection tracts of the macaque brain are quite similar to those of human brain. Fig. 3 shows the reconstructed association tracts of the macaque brain. With inferior fronto-occipital fasciculus (ifo), inferior longitudinal fasciculus (ilf) and uncinate fasciculus (unc) also similar to those of the human brain, the arculate fasciculus (arc) related to language is much smaller in the macaque brain.





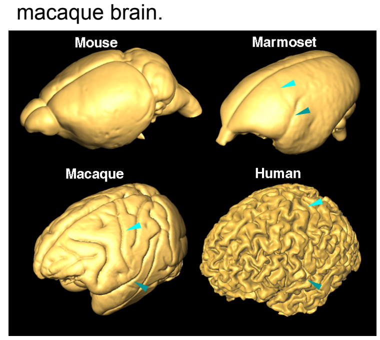


Fig. 1 (upper left): Comprehensive labeling of the macaque brain. The representations of the colors of labeled cortical gyri, subcortical nuclei and white matter are listed in the left, middle and right columns of color legend.

Fig. 2 (upper right): 3D reconstruction of the cortical surfaces of mouse, marmoset, macaque and human brains. The blue arrows point to central sulcus and Sylvian fissure.

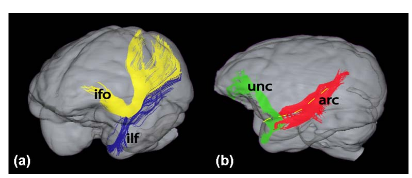


Fig. 3 (lower right): Reconstructed association white matter tracts of the macaque brain. Dashed line in (b) indicates Sylvian fissure.

Conclusion and discussion

With the high resolution and high SNR DTI (resolution about 300μm) and T_2-weighted image (resolution about 200μm), we have constructed a comprehensive digital atlas with all brain voxels labeled. It will be a complementary resource of the histology-based atlas for neural science study. The anatomical information from the digital atlas may be used not only for anatomical guidance for neurobiological research but also for evolution studies. Data acquisition of more macaque brains is underway to finally set up a probabilistic digital and comprehensive monkey brain atlas.

Acknowledgement: This study is sponsored by NIH grant EB009545. **References:** [1] Wang et al (2005) Nature 435: 341. [2] Hendry et al (1994) Science 264: 575. [3] Steinmetz et al (2000) Nature 404: 187. [4] Martin and Bowden (1999) Neuroimage 4: 119. [5] Saleem and Logothetis (2007) Academic Press. [6] Schmahmann and Pandya (2006) Oxford Univ. Press. [7] mristudio.org. [8] Mori et al (1999) Annal Neurol 45: 265.