Toward a comprehensive 3D DT-MRI atlas for marmoset monkey brain

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Introduction

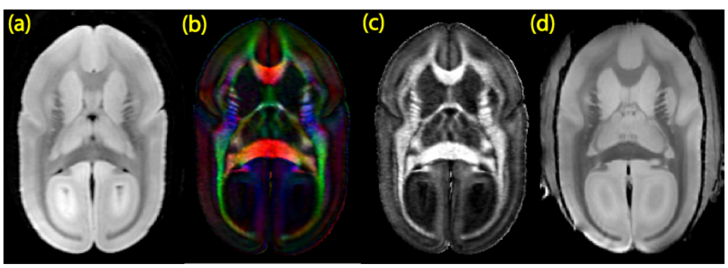
Marmoset has been more and more commonly used as an animal model in neurobiological study (e.g. 1-3). For example, National Human Genome Research Institute (NHGRI) announced the launch of new sequencing of marmoset genome on March 1, 2005. However, there is almost no comprehensive atlas about the brain of this species. The current atlas by Stephan et al (4) is a paper-based 2D atlas and only provides anatomical information of limited slices and orientations. It appears to be an urgent need for the digital 3D comprehensive atlas for marmoset brain. DTI can generate different contrasts of images which provide rich information of not only cortical and subcortical gray matter but also individual white matter fiber bundles. In this study, we acquired ex vivo DTI data of adult marmoset head. Important neural structures were annotated, segmented and reconstructed. This paper demonstrates the current status of our atlas.

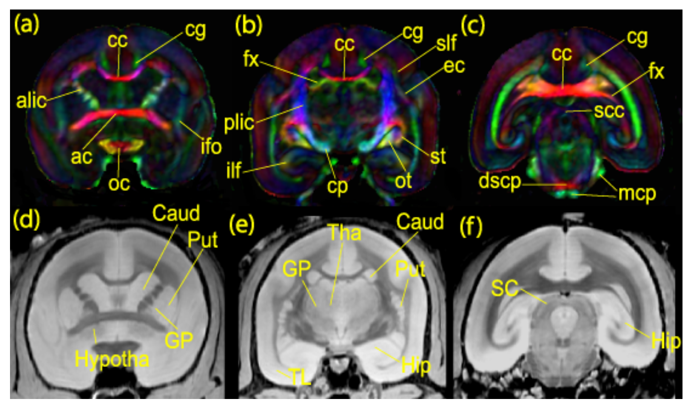
Methods

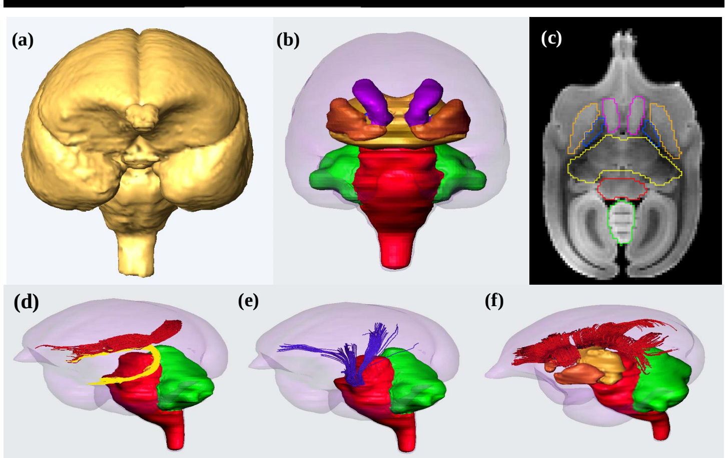
DTI and T2w imaging of postmortem marmoset head: A 9.4 T horizontal bore Bruker scanner was used. For DTI imaging, 3D multiple spin echo diffusion tensor sequence was used. A set of diffusion weighted images (DWI) was acquired in 7 linearly independent directions. DWI parameters were: TE=34ms, TR=0.65s, FOV=40mm/38mm/44mm, imaging matrix=192×96×112 (zero filled to data matrix 256×128×128 with nominal resolution 0.208×0.396×0.393mm^3). b value of DWI is 1000s/mm^2. Co-registered T_2-weighted (T2w) images with the same FOV were also acquired with the fast spin echo sequence. T2w image parameters were: TE=17.4ms (effective TE=21.8ms), TR=1.2s, imaging matrix=256×160×160 (zero filled to data matrix 256×256×256 with nominal resolution 0.156×0.238×0.275mm^3).). ***Gray matter assignment and reconstruction:*** The major gray matter structures were manually segmented and visualized with software Amira (Mercury, Carlsbad, Calif). The segmentation was performed using T_2-weighted images, DTI colormaps and the histology atlas (4). The following major gray matter structures were identified, segmented and reconstructed: ventricle, thalamus, putamen and globus pallidus, caudate, hippocampus and cortex. ***White matter tract tracing and reconstruction:*** For the white matter tracing, FACT [5] was used, with a fractional anisotropy threshold of 0.2 and an inner product threshold of 0.75, which prohibited angles larger than 41 degree during tracking. After fiber tracing, the 3D white matter tracts were visualized also by Amira.

Results

Image contrasts of DTI and T2w: Fig. 1 shows the image contrasts of aDWI (averaged diffusion weighted image), color coded map, fractional anisotropy (FA) map and T2w image. Color coded map carries rich information to differentiate detailed white matter tracts while T2w image has higher resolution to delineate subcortical nuclei. ***Structure annotation:*** White matter fibers and major gray matter structures are annotated on coronal slices of the marmoset brain (Fig. 2). The DTI colormaps are used to delineate white matter fibers and T_2 weighted images are used to differentiate major gray matter structures. Most white matter fiber bundles revealed by DTI in human brain (6) can be found in marmoset brain. However, association fibers, such as superior longitudinal fasciculus (7), are much smaller. ***Segmentation of neural structures:*** Some initial segmentation results are shown in Fig. 3. Compared to human brain, the cortical surface is less convoluted and lateral sulcus is the only major sulcus. The reconstructed subcortical gray matter demonstrates great similarity to that in the macaque brain. ***Diffusion tensor based fiber tractography of marmoset brain:*** Some representative fibers in the limbic system, internal capsule and corpus callosum were reconstructed.







Upper left: Fig. 1 Images with different contrasts. (a) aDWI image; (b) DTI color map; (c) FA map; (d) T2 weighted image.

Upper right: Fig. 2. Annotation of detailed white matter fiber bundles on coronal DTI colormaps and subcortical gray matter on coronal T2 weighted image. ac: anterior commissure, cc: corpus callosum, cg: cingulum, cp: cerebral peduncle, dscp: decussation of superior cerebellar peduncle, fx: fornix, ic: internal capsule, ifo: inferior fronto-occipital fasciculus, ilf: inferior longitudinal fasciculus, mcp: middle cerebellar peduncle, oc: optical chiasm, or: optical radiation, ot: optical tract, scc: superior colliculus commissure, slf: superior longitudinal fasciculus, st: stria terminalis, Caud: caudate nucleus, GP: globus pallidus, Hip: hippocampus, Hypothal: hypothalamus, Put: Putamen, SC: superior colliculus, Tha: thalamus.

Left: Fig. 3. (a) The reconstructed cortical surface. (b) The reconstructed subcortical gray matter, cerebellum and brainstem. (c) The contours of the neural structures in (b) overlaid on the axial slice of marmoset brain. (d), (e) and (f) are reconstructed cingulum and fornix (d), internal capsule (e) and corpus callosum (f). The color scheme is shown as follows. Caudate nucleus: purple; Thalamus: yellow; Putamen: brown; Globus pallidus: blue; Ventricle: cyan; Cerebellum: green; Brain stem: red.

Discussion

Data of more samples, including in vivo brains, will be acquired. Statistical atlas will be set up based on data of multiple samples. After in-ex vivo data registration, the detailed anatomical information from ex vivo data will be mapped into in vivo brain coordinate system. More comprehensive segmentation and annotation, as well as design of interactive viewing system are under way. The 3D statistical digital atlas combined with coordinate system will be freely distributed. We believe that this will be an important resource for stereotaxic operations and for a reporting system of various types of information such as electrode, lesion, or gene expression locations.

References: [1] Wang, X. et al. (2005) Nature 435, 341. [2] Kozorovitskiy, Y. et al. (2006) Nat Neurosci 9, 1094. [3] Schoenemann, P.T. et al., (2005) Nat Neurosci 8, 242. [4] Stephan, H. et al. (1980). The brain of the common marmoset (*Callithrix jacchus*): A stereotaxic atlas. Springer-Verlag, Berlin. [5] Mori, S. et al (1999) Annal. Neurol. 45, 265. [6] Wakana, S. et al. (2004) Radiology 230, 77. [7] Zhang, J. et al. (2007) NeuroImage 38, 239.