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A brain MRI atlas of the common squirrel monkey, *Saimiri sciureus*

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Abstract

The common squirrel monkey, *Saimiri sciureus*, is a New World monkey with functional and microstructural organization of central nervous system similar to that of humans. It is one of the most commonly used South American primates in biomedical research. Unlike its Old World macaque cousins, no digital atlases have described the organization of the squirrel monkey brain. Here, we present a multi-modal magnetic resonance imaging (MRI) atlas constructed from the brain of an adult female squirrel monkey. *In vivo* MRI acquisitions include T2 structural imaging and diffusion tensor imaging. *Ex vivo* MRI acquisitions include T2 structural imaging and diffusion tensor imaging. Cortical regions were manually annotated on the co-registered volumes based on published histological sections.

Keywords

primate neuroanatomy; atlas; magnetic resonance imaging; diffusion tensor imaging

1. INTRODUCTION

The New World squirrel monkey shares many functional organization and microstructural complexities with the human nervous system, although the cortical surface is less gyrated. It is among the most widely used New World primates in biomedical research [1]. The motor cortex, for example, is completely exposed on the brain surface and the cortical connections of the primary motor cortex (M1) are well known from previous studies [2]. Moreover, the smaller brains reduce the time of histological processing and anatomical data analysis. Unlike its Old World cousins, no digital atlas of the squirrel monkey brain has been compiled. The published stereotaxic reference atlases for the squirrel monkey brain provide

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only histological information and predate magnetic resonance imaging (MRI) [3, 4]. Herein, we describe development of a first digital atlas of the squirrel monkey as seen on MRI (Figures 1–4).

2. DATA

The data used to construct the atlas were acquired as a part of longer-term study validating the biological basis of diffusion. Briefly, the brain of a female squirrel monkey was imaged in three sessions on a 9.4 Tesla, 21cm bore Varian scanner (Varian Inc., Palo Alto, CA). The first two sessions were in vivo and had 20 days interval. During each in vivo session, the live squirrel monkey was anaesthetized and then scanned on its head with standard protocols of T2-weighted imaging (gradient echo multi-slice, TR = 404ms, TE = 2.4ms, flip angle = 20°, slice gap = 0mm, voxel size = 300×300×630 μm^3 , data matrix = 128×128×80) and diffusion weighted imaging (pulsed gradient spin echo EPI, TR=5.5s, TE=44ms, number of gradient directions=20, b 1000s/mm², voxel size=630×630×630 μm^3 , data matrix=64×64×80). A month later, under general anesthesia using aseptic techniques, a bidirectional tracer, biotinylated dextran amine (BDA; Molecular Probes Inc., Eugene, OR) was injected (as a 10% solution in phosphate buffer) into left hemisphere M1. The monkey was allowed to recover from the procedure, giving the tracer time to be transported along axons to all regions connected to M1. One week after surgery, the monkey was given a lethal dose of barbiturate, and perfused through the heart. All blood was rinsed out with physiological saline (0.9% NaCl) followed by fixative (4% paraformaldehyde). The brain was removed from the skull and stored in buffered saline overnight. A T2-weighted structural images were acquired by running a standard gradient echo multi-slice sequence with full brain coverage (TR = 963ms, TE = 4ms, flip angle = 20°, slice gap = 0mm, voxel size = 300×300×300 μm^3 , data matrix = 128×128×192, SNR 50).

3. ATLAS CONSTRUCTION

The T2-weighted volume from the second in vivo session was manually rotated to align the inter-hemispheric fissure with the y-axis and the plane of the basal skull plate with the x-y plane. The T2-realigned volume was resampled to 300 μm isotropic voxels to form the T2-target space. All DTI processing was performed in acquired coordinate system, including (1) correction for motion/eddy current distortion, (2) correction of gradient tables, and (3) log-linear tensor fitting. The mean minimally weighted volume was registered with a six degree of freedom transform to the T2-target. The tensor volume was transformed and up-sampled with this transform and the tensors were re-oriented for the rotation matrix [5]. Fractional anisotropy (FA), mean diffusivity (MD), and principle eigenvectors were computed in the re-oriented space and a standard diffusion encoded colormap (red: right/left; green: anterior/posterior; blue: inferior/superior) was created. The first in vivo session was registered to the target session with a 12 degree of freedom transform to correct for distortions. A brain mask was created for the ex vivo session to exclude bright signal due to the PBS buffer solution, and the masked image was co-registered to the mean diffusion weighted signal in the space of the target image; this enable registration of a skull-free brain to a digitally skull-stripped brain. Regions of interest in the motor and frontal cortex were manually labeled by an

experienced neuroanatomist. Transformations, visualization, and file manipulation were performed with FSL FLIRT[6] and MIPAV[7].

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Figure 1. Axial sections of the atlas with 0.3 mm in-plane resolution (radiological view). 1 cm = yellow bar.

Figure 2.
Coronal sections of the atlas with 0.3 mm in-plane resolution (radiological view). 1 cm = yellow bar.

Figure 3. Sagittal sections of the multi-modal atlas with 0.3 mm in-plane resolution. 1 cm = yellow bar.

Figure 4.
Rendering of the manually labeled cortical regions (Table 1).

Table 1

Labeled Cortical Regions of Interest

Abbreviation	Description
PF	Prefrontal Cortex
SMA	Supplementary Motor Area
AC	Anterior Cingulate Cortex
PM	Premotor Cortex
M1	Primary Motor Cortex
PA	Anterior Parietal Cortex
PP	Posterior Parietal Cortex
PVR	Parietal Ventral and Rostral areas (ant. part of upper bank of lateral sulcus)
S2	Secondary Somatosensory Cortex (post. part of upper bank of lateral sulcus)