Postmortem MRI Microscopy for Teaching Neuroanatomy

Sean Miller MD, Julia Goldberg, Mary Bruno, Arline Fausten, MD, Thomas Wisniewski, MD, Laura Crandall, Orrin Devinsky, MD, Timothy Shepherd MD, PhD

NYU Langone Health Medical Center Departments of Radiology, Pathology, and Neurology, NYU School of Medicine & SUDC Foundation

Introduction

- The small nuclei/internal projections of the brainstem, basal ganglia and thalamus function as important relay stations between the cortex and spinal cord to regulate arousal, motor, sensor and autonomic function.
- Learning this subcortical neuroanatomy is a key, but challenging component of medical student and resident education, especially for trainees interested in neurosurgery, neurology, psychiatry & radiology.
- Current practice is to teach brainstem and thalamic anatomy using histology-stained sections and surface anatomy [1]. Trainees then must mentally superimpose this conceptual framework with clinical MRI that lacks sufficient internal detail to directly visualize these structures. We argue this makes it very difficult to learn.

- We have developed a novel postmortem whole brain MRI protocol for an investigation of sudden unexplained death of childhood (SUDC) that produces exquisite internal detail in subcortical structures. This protocol could be used for teaching of the structures as shown in the figure below in Figure 8.

Methods

- After immersion fixation in 4% formaldehyde solution for 2-4 weeks, the whole brain was washed in water for 48 hours, then placed in a custom-built container for an overnight 3 T MRI using a 16 channel head and neck coil (Siemens Healthcare, Erlangen, Germany).
- We have developed a novel postmortem whole brain MRI protocol for an investigation of sudden unexplained death of childhood (SUDC) that produces exquisite internal detail in subcortical structures. This protocol could be used for teaching of the structures as shown in the figure below in Figure 8.

Results/Discussion

- Our novel postmortem protocol does not require advanced technical skills, exotic hardware or MRI expertise – it can be used by anyone with approved access to autopsy specimens and a conventional 3 T MRI system.
- Unlike histology, many clinically important subcortical structures can be observed simultaneously in all three planes with dynamic trainee control of the imaging plane position and angle to emphasize spatial relationships.
- Direct visualization of key subcortical nuclei and pathways using a commonly employed clinical modality (MRI) should facilitate both initial learning of the anatomy by trainees and incorporation of that knowledge into clinical practice.
- Further refinement of these sequences may facilitate generating similar images using routine MRI protocols in patients or animal models of various neurological diseases.

References


Figure 2: Sagittal, axial and coronal images of the corticospinal tract passing through the basis pontis. This is the major pathway for motor control - it can be hard to appreciate in gross specimens that this tract persists and varies in relative compactness as it passes through the brainstem. The motor decussation is show below in figure 8. The anterolateral (2), postero-lateral (1) and central tegmental (3) tracts are traversed by electrode contacts in deep brain stimulation therapy for Parkinson’s disease [2].

Figure 3: Sagittal and axial views of the substantia nigra and ventral tegmental area (VTA) showing the ventralmost boundary of the substantia nigra, the lateral border of the substantia nigra, the VTA ventral tegmental area, as well as the internal globus pallidus. The ventral pallidum is important in several neurological disorders (e.g., essential tremor and tremor associated with Parkinson’s disease) and serves as an important target for DBS.

Figure 4: Sagittal, axial and coronal images of the lateral longitudinal fasciculus (LLF) anterior to the red nucleus. The LLF contains fibers originating in the hippocampus before traveling to the entorhinal cortex. It is also the main output fiber for the fornix. It is a bilateral structure, connecting the entorhinal cortex to the thalamus and subcortical nuclei (Figure 10). Injury to this tract results in amnesia.

Figure 5: Sagittal, axial and coronal images of the area lentiformis. The area lentiformis and lentiform fasciculus are in form the lateral geniculate body. Overall there are three pallidal-glutamatergic pathways connecting the globus pallidus and thalamus, and play prominent role in coordination of movements. Recent evidence demonstrates improved clinical outcomes in Parkinson’s disease when some fibers of the pallidal-glutamatergic tracts are traversed by electrode contacts in deep brain stimulation therapy for Parkinson’s disease [2].

Figure 6: Sagittal, axial and coronal images of the superior cerebellar peduncle (SCP). The SCP is a major efferent pathway from the dentate and fastigial nucleus of the cerebellum. Injury to this structure results in impaired oculomotor function and ataxia.

Figure 7: Sagittal and coronal images of the internal capsule demonstrating the anterior (A), posterior (P) and posterior limbs (PLP) of the external capsule. The anterior limb (A) is a compact, bilaterally oriented pathway that represents the major efferent pathway of the lateral and medial thalamic nuclei to the vertical segmental area of the motor and sensory cortices. This is important both in clinical practice (or malfunctions) and in the thalamus, as shown in Figure 10 (bottom). Injury to this pathway results in atrophy and damage to the internal capsule, and the thalamus.

Figure 8: Sagittal, axial and coronal images of the internal capsule in the left thalamus. Injury to this structure results in impairments of motor control. The internal capsule contains fibers that connect the thalamus to the motor cortex and other cortical areas. Injury to this structure results in hemiplegia and hemisensory loss.

Figure 9: The red nucleus is a rostral midbrain structure that receives input from the substantia nigra and ventral tegmental area. Injury to this structure results in extrapyramidal symptoms and parkinsonism.

Figure 10: The central tegmental tract (CTT) contains descending fibers from the red nucleus that terminate in the inferior olive. The CTT is a part of the Gudden–Molitor triangle, which is a series of tracts connecting the red nucleus, inferior olive, and dentate nucleus. Pathology associated with these areas is associated with movement disorders, tremor, and dystonia.