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Brainstem White Matter Tracts and the Control of Eye Movements

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This article summarizes the anatomy of brainstem tracts and cranial nerves as depicted by magnetic resonance imaging, with special emphasis on the structures that are involved in the control of eye movement. It discusses the anatomical structures that can be observed on conventional magnetic resonance images as well as structures that can only be observed using more advanced imaging techniques such as diffusion tensor imaging and tractography. The basic mechanisms of various kinds of ophthalmoplegia are also discussed.
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Introduction

The brainstem is one of the most important parts of the central nervous system (CNS). In addition to regulating fundamental activities that are vital to human life, the brainstem also controls complex eye movements, and examination of unusual eye movements enables neurologists to estimate the precise location of brainstem lesions. Neuroanatomically, the brainstem is one of the most thoroughly studied regions of the CNS. The brainstem includes the following 3 parts: the medulla oblongata, the pons, and the midbrain. Although the diencephalon can be also included in the brainstem, we chose to exclude it from this article for simplicity.

The brainstem comprises many different nuclei and tracts, each 1 with a different function. The brainstem includes the control centers for autonomic functions, as well as the circuits that control consciousness. There are also major ascending and descending tracts within the brainstem, some of which will be covered in a different article in this edition and are thus not included herein. In this article, we summarize the basic anatomy of the brainstem that can be visualized with magnetic resonance (MR) imaging. The MR imaging techniques discussed include both conventional and more advanced techniques such as diffusion tensor imaging (DTI) and tractography. We have emphasized the depiction of the cranial nerves (CNs) that are important to the control of eye movement.

Tracts Within the Brainstem

Basic Anatomy

The basic anatomical architecture of the brainstem is no different to that of the neural tube. The ventral portion is motor related and the dorsal part is sensory related. The corticospinal tract runs ventrally through the brainstem. The dorsal part of the brainstem is composed of fibers that ascend from the spinal cord. The same rule applies to the nuclei of the CNs. The motor nuclei are located ventral to the central canal (eg, in the aqueduct and the fourth ventricle), and the sensory nuclei are located slightly dorsal or sometimes lateral to the motor nuclei. In this article, we focus on the control of eye movement and discuss the fibers that are related to the control of eye movement and that run in close proximity to the CN, including CNs III, IV, and VI.

Medial Longitudinal Fasciculus

Conjugate eye movement is performed by synchronous activity of CNs III, IV, and VI. Connecting fibers joining the nuclei for these nerves pass through the medial longitudinal fasciculus (MLF). Other CN related to eye movements include

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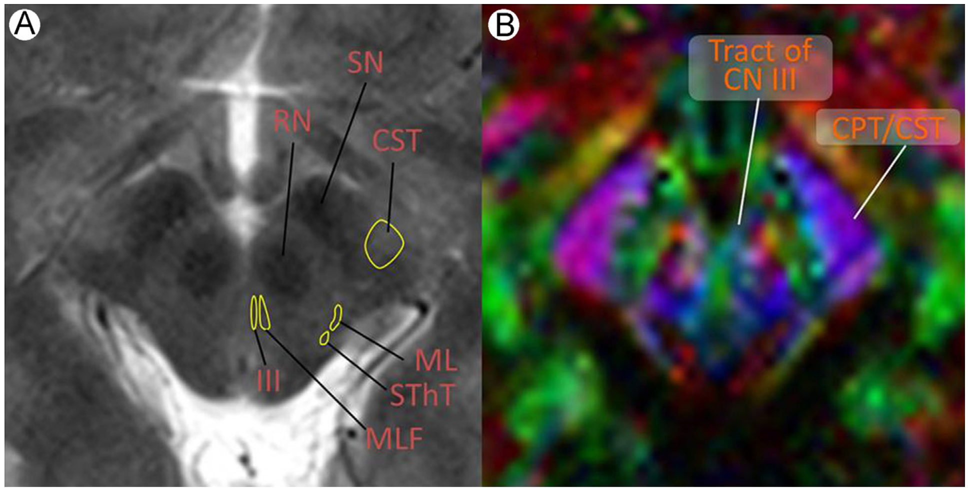

Figure 1 Anatomy at the level of the midbrain including the CN III nuclei: (A) axial T2-weighted image shows labeled structures and (B) vector color map (VCM) shows labeled structures.

CNs V, VII, VIII, and XI, and these are also connected to the MLF. The MLF itself is continuous with the spinal cord and has descending fibers that control head position and posture.

Medial Lemniscus

The medial lemniscus (ML) is the major fiber pathway carrying proprioceptive information. It leads to the thalamus from the dorsal funiculus and passes close to the midline of the brainstem. The ML is horizontally oriented on an axial MR image of the pons, but vertically oriented below and above the pons (Figs. 1-4). It can be easily identified, even on sagittal T1-weighted MR images (T1WIs), as a line of hypointensity between the pontine base and the tegmentum. The ML can sometimes be helpful in determining which part of an atrophied pons is affected.

Spinothalamic Tract

The spinothalamic tract carries information regarding pain, temperature, crude touch, and firm pressure. It extends from the anterolateral funiculus of the spinal cord to the thalamus and passes through the outer edge of the brainstem. In the midbrain and pons, it ascends along with the ML (Figs. 1-4).

Central Tegmental Tract

The rubro-olivary tracts, which connect the red nucleus (RN) and the inferior olivary nucleus, pass through the central tegmental tract (CTT). The CTT forms part of the extrapyramidal system and is involved in augmenting movement, in conjunction with the dentate nucleus of the cerebellum. The circuit between the RN, the inferior olivary nucleus, and the dentate nucleus is called the Guillain-Mollaret triangle.

Superior Cerebellar Peduncle

The superior cerebellar peduncle (SCP) primarily comprises efferent fibers. The tracts originate from the dentate nucleus and travel to the contralateral RN and thalamus, crossing at the midbrain, at the point known as the superior cerebellar decussation. The tracts to the contralateral RN form part of the Guillain-Mollaret

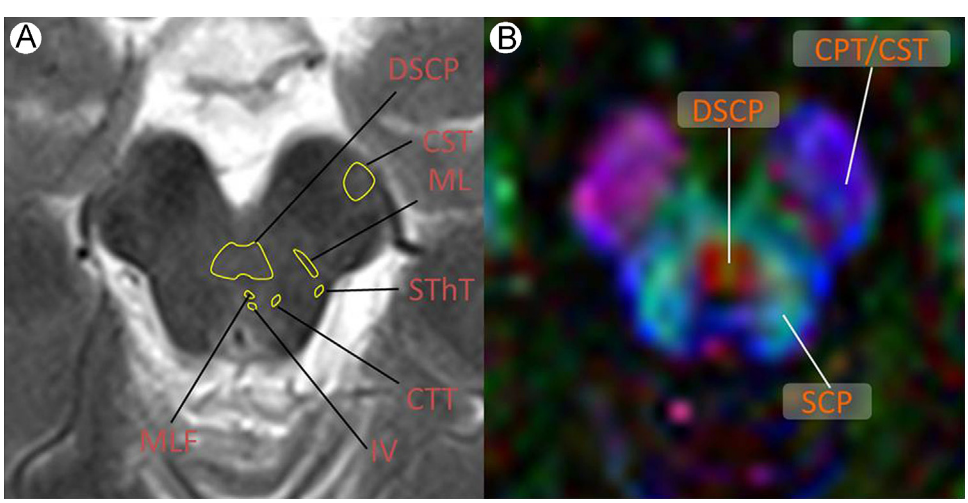

Figure 2 Anatomy at the level of the trochlear (CN IV) nuclei: (A) axial T2 and (B) VCM images with labeled structures.