Diffusion Tensor Tractography of the Somatosensory System in the Human Brainstem: Initial findings using high isotropic spatial resolution at 3.0 T

A. Kamali[1], L. A. Kramer[2], I. J. Butler[3], and K. M. Hasan[2]

[1]Diagnostic and Interventional Imaging, University of Texas Health Science Center at Hosuton, Houston, Texas, United States, [2]Diagnostic and Interventional Imaging, University of Texas Health Science Center at Houston, Houston, Texas, United States, [3]Pediatrics, University of Texas Health Science Center at Hosuton, Houston, Texas, United States

Introduction. The sensory system has been well-described in anatomical literature (1,2). The major sensory pathways include those for pain and temperature (spinothalamic tracts), conscious proprioception (posterior column-medial lemniscus system), unconscious proprioception (dorsal and ventral spinocerebellar tracts) (1). The first two pathways are the main ascending sensory pathways of the body that travel rostrally in close proximity within the brainstem to the thalamus (2). Compared to the motor system (e.g. corticospinal tract), there has been a limited diffusion tensor tractography-based literature on the sensory pathways due to the compact structure of the sensory system in the brainstem. Lack of adequate spatial resolution has impeded depiction of different somatosensory pathways with unique sensory functions such as spinal lemniscus (SL) and medial lemniscus (ML). The purpose of this study is to demonstrate that a reliable delineation of the ML and SL on Diffusion Tensor Imaging (DTI) requires higher spatial resolution combined with accurate ROI placement. This is the first study to demonstrate the feasibility of *in vivo* delineation and reconstruction of the two major somatosensory pathways with unique sensory functions using high spatial resolution DTI data on 3.0 T.

Methods: *Subjects*: Five healthy men (age range 24-37 years) were studied and written informed consent was obtained from all subjects**.** Diffusion tensor tractography (DTT) at 3 T scanner and FACT fiber-tractography method was used within the human brain. *Conventional and DT MRI Acquisition*: Data were using a Philips 3.0 T Intera system using a SENSE receive head coil. The MRI protocol included conventional MRI (dual echo FSE, phase-sensitive, FLAIR & 3D anatomical) in addition to a matching prescription of DT-MRI. Diffusion-weighted image (DWI) data were acquired axially from the same graphically prescribed cMRI volumes using a single-shot multi-slice 2D spin-echo diffusion sensitized and fat-suppressed echo planar imaging (EPI) sequence, with the balanced *Icosa21* tensor encoding scheme (3). The b-factor = 500 sec mm^{-2}, T_R/T_E = 14460/60 msec, FOV = 256 mm x 256 mm and slice thickness / gap/ #slices = 1 mm / 0 mm / 120. The EPI phase encoding used a SENSE k-space undersampling factor of two, with an effective k-space matrix of 112x112 and an image matrix after zero-filling of 256x256. The acquisition spatial resolution for DTI data was ~ 2.29mm x 2.29mm x 1mm, and the nominal resolution after image construction was 1mm x 1mm x 1mm. *Fiber Tracts*: Anterior thalamic radiation (ATR) pathway originates from thalamus and passes through the ALIC to the frontal cortex. Prefronto-caudate originates from prefrontal cortex (frontal pole) and traverses through the caudate head and ends in the thalamus and is located parallel and medially to the ATR. *Fiber Tracking*. We have used a brute force (4) and multiple ROI tracking method and the FACT algorithm (DTIStudio) to reconstruct three white matter tracts: medial lemniscus (ML), spinal lemniscus (SL), and central tegmental tract (CTT) to delineate the sensory pathways within the brainstem, using a fractional anisotropy (FA) threshold of 0.22 and angle threshold of 60 degrees.

Results. A representative tractogram of ML, SL and CTT in one of the subjects on the 1 mm slice thickness acquisition is shown in Fig. 3. ***Medial Lemniscus*:** The medial lemniscus trajectory ascends within the rosteromedial part of medulla oblongata, posterior to the corticospinal tract (Fig. 1a). In the pons, the ML becomes flattened in a more mediolateral direction and ascends dorsal to the pontine nuclei (transverse red area on the DTI color-coded map) (Fig. 1b). These continue upward in pontine tegmentum ventral to the CTT and medial to the spinal lemniscus (Fig. 1b, 1c) At the mesencephalic level, ML lies laterally to the mesencephalic decussation (central red area on the DTI color-coded map) (Fig. 1c). It ascends within the mesencephalic tegmentum lateral to the CTT and more anteromedial to the spinal lemniscus (Fig. 1d). In mesencephalo-diencephalic level, it farther ascends dorsal to the substantia nigra (SN) and lateral to the red nucleus (RN) (Fig. 2a). At the diencephalic level, the ML terminates within the VPM nucleus of the thalamus.

***Spinal Lemniscus*:** The spinal lemniscus course ascends within the rosterolateral part of medulla oblongata dorsal to the principal nucleus of the inferior olivary nucleus and lateral to the ML (Fig. 1a). The SL lies within the anterolateral pontine tegmentum laterally to ML and dorsally to pontine nuclei (Fig. 1b). It shifts slightly dorsolaterally at the level of upper pons. At the mesencephalic level, the SL ascends more dorsolaterally to the ML and CTT within the mesencephalic tegmentum (Fig 1c, 1d) and at the level of diencephalon terminates within the ventral posterolateral nucleus of the thalamus. Thalamocortical pathways of SL propagate from the thalamus, and through the internal capsule toward the post central gyrus and posterior portion of paracentral lobule of the sensory cortical area (Fig. 2b, c).

Discussion and Conclusions: In this report we demonstrated that using higher resolution along with thinner slices reduce the partial volume effect and enabled us to trace the somatosensory pathways within the brainstem in vivo. Using high spatial resolution along with high magnetic field strength improved the detectable anisotropy of gray matter (5) (thalamus) and helped resolve more thalamocortical fibers of the spinothalamic tract. In our observations, the thalamocortical fibers of spinothalamic pathways in all five subjects had the same pattern bilaterally, propagating from thalamus through the posterior limb of the internal capsule toward the post central gyrus of the parietal lobe (Broadman's areas I, II and III) and posterior portion of paracentral lobule, which is consistent with anatomical descriptions (2). Clinical applications of our study include the infarctions that selectively target spinal lemniscus (spinothalamic tract) such as in lateral medullary syndrome and infarctions involving the medial lemniscus preferably, such as medial medullary syndrome and medial pontine syndrome. Other clinical conditions which selectively involve dorsal column medial lemniscus, include vitamin B12 deficiency, neurosyphilis, and Friedreich ataxia.

Figure 1.

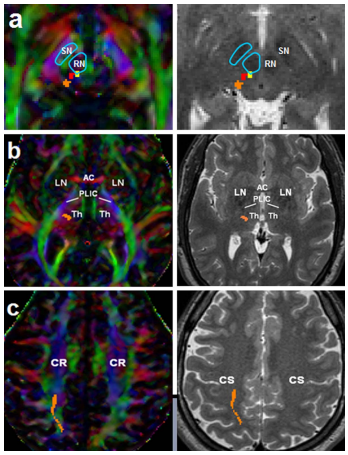

Figure 2.

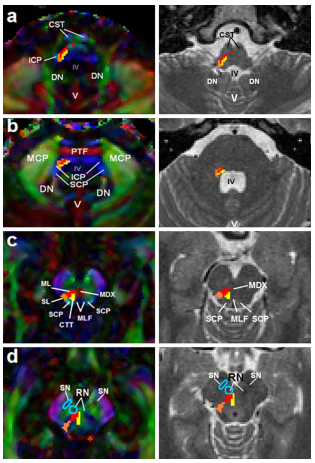

Figure 1, 2. Anatomical parcellation of somatosensory fibers (medial lemniscus [red], spinal lemniscus [orange]) and central tegmental tract (yellow) in telencephalon (Fig. 1c), diencephalon (Fig. 1b), and brainstem (Fig. 1a, Fig. 2)

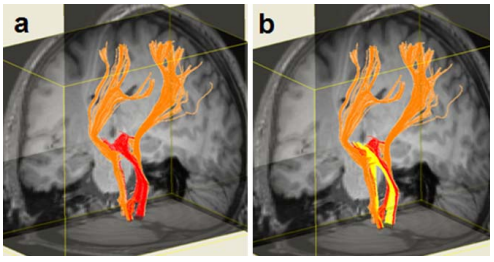

Figure 3. 3D construction of the spinal lemniscus (orange), medial lemniscus (red) , and central tegmental tract (yellow)

References

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