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Technical note

Microstructural mechanisms of analgesia in percutaneous cervical cordotomy revealed by diffusion tensor imaging

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ABSTRACT

The purpose of this study is to demonstrate the potential of diffusion tensor imaging (DTI) to reveal structural mechanisms underlying spinal ablative procedures, including percutaneous radiofrequency cordotomy (PRFC). PRFC is a surgical procedure that produces analgesia through focal ablation of the lateral spinothalamic tract (STT), thereby interrupting the flow of pain information from the periphery to the brain. To date, studies regarding mechanisms of analgesia after PRFC have been limited to postmortem cadaveric dissection and histology. However, with recent advances in DTI, the opportunity has arisen to study the STT non-invasively *in vivo*. In this technical note, an individual with successful pain relief following unilateral STT PRFC was examined using DTI, with the contralateral STT serving as an internal control. PRFC substantially reduced rostrocaudal directional DTI signal in the STT from the lesion in the cervical spinal cord through the pons and mesencephalon. Our findings confirm that focal ablation and anterograde degeneration accompany the analgesic effects of PRFC. *In vivo* imaging of the STT with DTI may contribute to surgical targeting for PRFC procedures, better understanding of the therapeutic and untoward effects of PRFC, and a deeper understanding of spinothalamic contributions to nociception.

1. Introduction

Located in the anterolateral quadrant of the spinal cord, the lateral spinothalamic tract (STT) carries pain and temperature information from the dorsal horn of the spinal cord to synapses in the brainstem and thalamus [1]. Since recognition a century ago that the STT is required for pain and temperature sensation, but not tactile sensation [2], surgical lesioning of the STT has been performed to provide relief from pain [3]. Introduced as an open surgical procedure performed in the thoracic spinal cord, neurosurgical cordotomy has evolved into a minimally invasive, physiologically guided, percutaneous radiofrequency procedure (PRFC). Today, a precise focal thermal lesion in the cervical STT can be placed with the aid of computed-tomographic imaging using a radio-frequency needle electrode [4,5].

Postmortem studies allow some explanation of the mechanisms of pain relief following cordotomy [6–8]. Following cordotomy, anterograde degeneration of the STT from the level of the lesion to the thalamus is observed. Human studies have been performed that document extensive anterograde degeneration as early as 12 days following cordotomy [7]. However, postmortem findings cannot be efficiently translated to the care of living patients without visualization of the involved structures and tracts *in vivo*.

Diffusion tensor imaging (DTI) is an advanced magnetic resonance imaging technique that can noninvasively measure the motion of water molecules in tissue [9]. Using the preferential pattern of motion of the water molecule, DTI can be used to demonstrate neural tract architecture and offers promise in guiding clinical care [10]. In the case of cordotomy, visualization of the spinothalamic tract *in vivo* would be highly advantageous, as the precise position of the STT within the spinal cord varies among individuals [11]. DTI may help to minimize the potential clinical impact of anatomic variability, by establishing the location of the STT in the spinal cord of each patient. In addition, DTI evaluation of anterograde degradation following PRFC may allow better understanding of its therapeutic and adverse effects.

In this technical note, we demonstrate the first application of DTI to examine the STT *in vivo* following PRFC. We find that DTI imaging sharply defines the location of anterograde degeneration throughout the spinal cord and brainstem, consistent with

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previous postmortem studies. Future DTI studies may improve surgical targeting for PRFC procedures, may improve patient selection and broaden indications for PRFC, and may improve our understanding of STT contributions to nociception.

2. Methods

2.1. Study subject

The case under study is that of a 68-year-old male who underwent right C1-2 PRFC in 1968 for left flank and lower extremity pain secondary to an abdominal gunshot wound. Following the PRFC procedure, the patient experienced complete cessation of superficial and deep pain below the T5 dermatome on the left, which persisted for four decades [12]. Our study was performed in accordance with the policies of the Medical Institutional Review Board of the University of Michigan.

2.2. MR imaging and analysis

Anatomical and DTI magnetic resonance imaging was performed on a 3T Philips Achieva imaging system (Philips, Amsterdam, Netherlands). Tractography data sets were acquired with a Stejskal–Tanner sequence with six motion-probing gradient orientations. A b value of 800 s/mm^2 was employed with an average of six images. Data points were recorded using parallel imaging technique for high resolution. Data were transferred to an off-line research workstation for analysis. Anisotropy maps were generated by means of orientation-independent fractional anisotropy. The translation of the vectors into neuronal trajectories was achieved by a technique known as the Fiber Assignment by Continuous Tracking.

3. Results

Anatomical MRI findings demonstrate a focal lesion at C1-2 with otherwise normal spinal-cord anatomy (Figs. 1 and 2). In Fig. 1, sagittal T2-weighted imaging demonstrates focal loss of tissue volume in the ventral spinal cord at the point of needle insertion, between the ring of C1 and the lamina of C2. The diameter and appearance of the spinal cord above and below the lesion is normal. In Fig. 2, axial cross-sectional T1-weighted imaging at the same spinal level demonstrates focal loss of tissue volume in the right anterolateral quadrant. Anatomical axial MR imaging throughout the spinal cord, brainstem, and diencephalon revealed no additional abnormal anatomical findings.

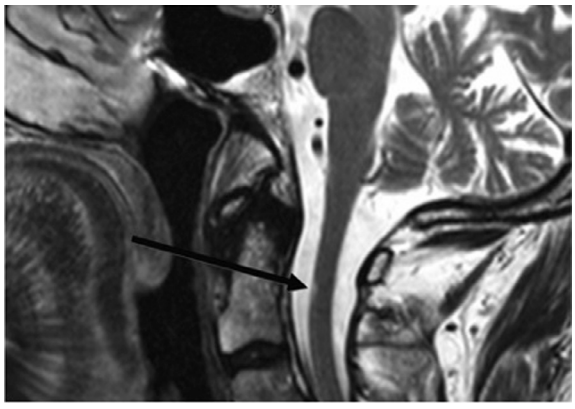

Fig. 1. Sagittal T2-weighted MRI section through the cervicomedullary junction. High T2 signal (arrow) indicates the site of the percutaneous C1-2 cordotomy.

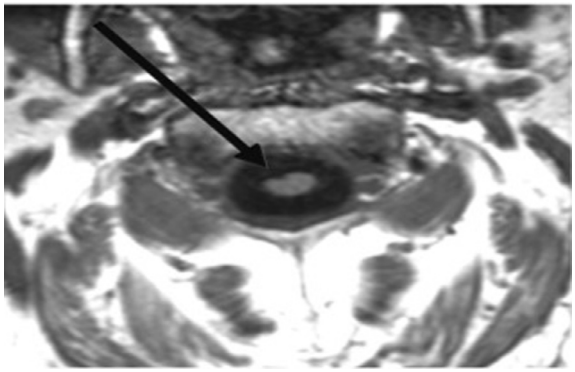

Fig. 2. Axial T1-weighted MRI section through the C1-2 level. Focal contour deformity (arrow) indicates the site of the percutaneous C1-2 cordotomy of the right lateral spinothalamic tract.

By contrast to normal anatomical T1- and T2-weighted MRI findings at all but the level of the PRFC lesion, DTI imaging after PRFC reveals substantially reduced rostrocaudal directional signal in the expected location of the STT from the lesion in the cervical spinal cord through the pons and mesencephalon (Fig. 3). At the level of the lesion at C1-2 (Fig. 3A), there is marked loss of rostrocaudal signal in the right anterolateral quadrant, consistent with focal ablation of the STT. At the level of the pons (Fig. 3B), strong rostrocaudal signal is observed, as expected, for three paired structures: the pyramidal tracts (anterior), the medial lemnisci (middle), and the superior cerebellar peduncles (posterior). The lateral spinothalamic tract is expected lateral to the medial leminiscus. At this location, there is a notable reduction in rostrocaudal signal on the right, consistent with anterograde degeneration of the STT. At the level of the mesencephalon (Fig. 3C), marked focal reduction in rostrocaudal signal is observed on the right, lateral to the cerebral aqueduct and periaqueductal grey matter, corresponding to the STT. By contrast, DTI signal is symmetric for nearby tracts including the medial longitudinal fasciculus, medial lemniscus, and pyramidal tracts.

4. Discussion

4.1. Current PRFC technique and indications

PRFC creates a focal thermal lesion in the STT, thereby providing immediate analgesia. The procedure is percutaneous, image-guided, and may be performed under local anesthesia without sedation using a radiofrequency needle electrode (0.25 mm diameter with 2.0 mm uninsulated tip) [4]. During PRFC, electrical stimulation at the electrode tip allows physiological assessment prior to thermal lesioning [13]. Patients report feelings of contralateral pain and/or warmth at low levels of stimulation (0.2 V, 50–60 Hz) when the PRFC electrode is well located in the STT.

PRFC is effective for the treatment of somatic nociceptive and neuropathic pain [14]. Visceral pain, by contrast, is not well treated with PRFC. Differences in efficacy between somatic and visceral pain may be due to dorsal column fiber transmission of visceral pain signals [15], which are spared during spinothalamic PRFC. Continuous neuropathic pain is also not well relieved by PRFC, while intermittent neuralgic pain responds well [14]. Dorsal column transmission of certain forms of neuropathic pain, including tactile allodynia, may account for these findings of differential efficacy [16].

PRFC is clinically effective. Although prospective randomized trials of PRFC have not been performed, large case series report significant initial pain reduction (~90%) with low complication rates (<3%) [4,17]. However, although the analgesic effects of PRFC