Identification of the Facial Nerve in Relation to Vestibular Schwannoma Using Preoperative Diffusion Tensor Tractography and Intraoperative Tractography-Integrated Neuronavigation System

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BACKGROUND: **Preoperative visualization of the facial nerve could help neurosurgeons to prevent facial nerve injury during vestibular schwannoma surgery. Some studies have addressed diffusion tensor tractography (DTT) for preoperative identification of the facial nerve. However, few studies have focused on tractography-integrated neuronavigation for DTT verification. This study aimed to explore the appropriate DTT tracing parameters and evaluate the effect of intraoperative facial nerve tractography-integrated neuronavigation for verifying the DTT accuracy.**

METHODS: **Patients who underwent vestibular schwannoma surgery between September 2013 and August 2015 were included. Clinical features were recorded. All patients underwent preoperative DTT with 2 seed regions of interest and a variable fractional anisotropy threshold. Intraoperatively, the facial fiber tract guided by the neuronavigation was compared with the real location of facial nerve so that the accuracy of DTT was verified. Postoperative facial nerve function of each patients was followed up.**

RESULTS: **Nineteen patients were enrolled in this study. Successful facial fiber tracts was obtained in 18 patients. In 17 of the 18 patients, intraoperative navigation confirmed DTT accuracy. The facial nerves were located on the anterior middle third of the tumor in 9 patients. Twelve months after surgery, facial nerve function was classified as grade I in 10 patients and grade II in 8 patients.**

CONCLUSIONS: **We consider preoperative DTT with intraoperative tractography-integrated neuronavigation to be a useful method for identifying the location of the facial nerve. This method might improve facial nerve preservation.**

INTRODUCTION

The focus of vestibular schwannoma (VS) surgery is maximum resection of the tumor and maximum preservation of cranial nerve function.[1-3] With the development of microsurgery, postoperative normal or near-normal facial nerve function has been reported to be up to 90%.[3-6] However, the preservation of the facial nerve when removing large or tough VS remains a challenge, even in experienced hands. The difficulty lies in the great variation in the location and the morphologic changes of the facial nerve.[7] Facial nerve paresis can be a devastating complication, leading to a lower quality of life. Preoperative visualization of the facial nerve location is a long-desired wish of neurosurgeons. The application of diffusion tensor tractography (DTT) in VS surgery has turned it into reality. In recent years, many investigators have reported their experience with preoperative identification of the facial nerve in VS surgery using DTT. However, their methods and results have varied.[8-14] In addition, no uniform standard of verifying the accuracy of DTT has been achieved. Few investigators have mentioned the application of a tractography-integrated neuronavigation system for real-time

Key words
- Diffusion tensor tractography
- Facial nerve
- Navigation
- Vestibular schwannoma

Abbreviations and Acronyms
DTI: Diffusion tensor imaging
DTT: Diffusion tensor tractography
FA: Fractional anisotropy
IAM: Internal auditory meatus
MRI: Magnetic resonance imaging
ROI: Region of interest
VS: Vestibular schwannoma

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verification of tractography accuracy. The aim of this study was to determine the appropriate region of interest (ROI) and fractional anisotropy (FA) threshold that influence the successful rates of facial nerve tracing and to evaluate the effect of intraoperative tractography-integrated neuronavigation for verifying DTT accuracy in VS surgery.

MATERIALS

Patient Population and Neuroradiologic Evaluation

Patients admitted to the Department of Neurosurgery at Beijing Tiantan Hospital between September 2013 and August 2015 who were diagnosed with VS and agreed to undergo DTT procedure and tumor resection were included in this clinical study. Patients who had previously received stereotactic radiotherapy or VS surgery were excluded from this study. Those who could not cooperate or made obvious head movements in the procedure of diffusion tensor imaging (DTI) scanning were also excluded. All patients provided written informed consent for this study, and the clinical study was approved by the medical ethics committee of Capital Medical University. The clinical data and surgical records of each case were reviewed. All patients were evaluated with a preoperative contrast-enhanced magnetic resonance imaging (MRI) scan. Tumor size was expressed as the tumor equivalent diameter $(D_1 \times D_2 \times D_3)^{1/3}$. For tumors measured on an axial gadolinium-enhanced T1-weighted image, D_1 represented the greatest diameter perpendicular to the petrous ridge, and D_2 represented the greatest tumor diameter perpendicular to D_1. D_3 represented the greatest vertical height measured on a coronal gadolinium-enhanced T1-weighted image.

DTI Protocol and Analysis

DTI was acquired using a 3.0-T superconducting system (MAGNETOM TRIO TIM [Siemens, Erlangen, Germany]). An 8-channel phased-array body coil was used to obtain high-density diffusion tensor images using 32 diffusion sensing directions with an interleaved echoplanar imaging sequence. The parameters were as follows: repetition time, 4900 milliseconds; echo time, 94 milliseconds; field of view, 230 mm; b value, 1000 seconds/mm^2; bandwidth, 1502 Hz/Px; slice thickness/gap, 1.0/0 mm; voxel size, $1.8 \times 1.8 \times 1.0$ mm.

DTT Tracing Process

The images from the diffusion tensor scan were transferred into Medtronic Stealth Station (Medtronic Planning Station S7, Louisville, Kentucky, USA) in a DICOM (Digital Imaging and Communications in Medicine) file. The StealthViz software mode was adopted for image processing. Two seed ROIs were adopted. The first ROI was on a plane perpendicular to the facial nerve running in the direction of the porus of the internal auditory meatus (IAM). The second ROI was placed at the location where the facial nerve originated from the brainstem around the foramina of Luschka.[15] Because the variation in the mastoid cells in each of the patients might affect the magnetic susceptibility,[8,16] we explored the specific FA threshold for each patient to obtain an accurate fiber tracing result. For each patient, the FA threshold was set at 0 at first and increased by 0.02 every time until an obviously repeatable tract went through both ROIs, extending into the internal auditory canal. Then, we considered the fiber to represent the facial nerve and recorded the FA value as the specific FA for this patient. This process was first performed on the unaffected side and then on the contralateral side and was completed independently by 2 neurosurgeons (H.L. and L.W.) who were not aware of the tracing results of the other. The tracing process was considered successful when a repeatable fiber tract running from the IAM to the location around the foramina of Luschka could be detected.

Classification of Facial Nerve Location

In axial planes of the MRI scans, the facial nerve fiber was evaluated either on the anterior or the posterior tumor surface. In the coronal and sagittal planes, the facial nerve fiber was evaluated on the upper, middle, or lower thirds of the tumor surface. The preoperative three-dimensional model of the facial nerve tract and the tumor was built so that the stereoscopic location of the facial nerve fiber tract and tumor was shown vividly. In general, there were 6 regions: anterior upper thirds; anterior middle thirds; anterior lower thirds; posterior upper thirds; posterior middle thirds; and posterior lower thirds of the tumor surface.

Intraoperative Validation of Tractography

The tractography data were processed by a cranial software mode in which the fiber tract and the routine MRI were merged together. The stereotactic accuracy of DTI merging is submillimetric. The multimodality image with the facial nerve tract was transferred into the neuronavigation planning workstation (Medtronic Stealth Station Treon). The three-dimensional model of the VS and the facial nerve was built to show the spatial relationship between the facial nerve tract and the tumor stereoscopically. The retrosigmoid approach was used for all patients,[5] and all patients were positioned in the lateral position. The same surgeon (J.Z.) performed each operation so that the surgical technique was stable. Intraoperatively, electrophysiologic monitoring was adopted using free facial nerve electromyography. The facial nerve evoked potential was elicited by direct facial nerve stimulation at 0.1—0.2 mA with a duration of 0.2 milliseconds. The real location of the facial nerve was identified by careful visual inspection by the surgeon (J.Z.) with the assistance of electrophysiologic monitoring. We performed the navigation at the beginning of tumor exposure before the release of cerebrospinal fluid. The navigation was performed again when drilling the internal auditory canal. It was performed once more when the location at which the facial nerve originates from the brainstem was exposed. Preoperative tractography of the facial nerve was shown and guided by the tractography-integrated navigation system, which was performed by H.L. It was compared with the real location of the facial nerve to verify the accuracy of the fiber tracing. The verification was performed by J.Z., who was blinded to the preoperative tracing result.

Clinical and Neuroimaging Follow-Up

The neurologic function of the facial nerve was evaluated separately admission, at 2 weeks, and 12 months after the operation according to the House-Brackmann facial nerve grading system.[17-20] An MRI scan was performed in the first postoperative week and then half a year and 1 year later. The extent of resection