Preoperative identification of the facial nerve in patients with large cerebellopontine angle tumors using high-density diffusion tensor imaging

Clinical article

NEIL ROUNDY, M.D., JOHNNY B. DELASHAW, M.D., AND JUSTIN S. CETAS, M.D., PH.D.

Department of Neurological Surgery, Oregon Health & Science University, Portland, Oregon

Object. Facial nerve paresis can be a devastating complication following resection of large (>2.5 cm) cerebellopontine angle (CPA) tumors. The authors have developed and used a new high-density diffusion tensor imaging (HD-DT imaging) method, aimed at preoperatively identifying the location and course of the facial nerve in relation to large CPA tumors. Their study objective was to preoperatively identify the facial nerve in patients with large CPA tumors and compare their HD-DT imaging method with a traditional standard DT imaging method and correlate with intraoperative findings.

Methods. The authors prospectively studied 5 patients with large (≥2.5 cm) CPA tumors. All patients underwent preoperative traditional standard- and HD-DT imaging. Imaging results were correlated with intraoperative findings.

Results. Utilizing their HD-DT imaging method, the authors positively identified the location and course of the facial nerve in all patients. In contrast, using a standard DT imaging method, the authors were unable to identify the facial nerve in 4 of the 5 patients.

Conclusions. The HD-DT imaging method that the authors describe and use has proven to be a powerful, accurate, and rapid method for preoperatively identifying the facial nerve in relation to large CPA tumors. Routine integration of HD-DT imaging in preoperative planning for CPA tumor resection could lead to improved facial nerve preservation.


Key Words • diffusion tensor imaging • vestibular schwannoma • cerebellopontine angle • facial nerve • diagnostic and operative techniques • oncology • skull base

Tumors of the CPA pose a unique problem to the neurosurgeon. As these tumors grow, distortion and compression of other nearby structures including the facial nerve and brainstem can occur, resulting in cranial nerve dysfunction. Therefore, especially in patients with intact facial nerve function, tumor resection should be undertaken with an aim of preserving facial nerve function and completing the resection with no postoperative complications. However, facial nerve paralysis is a potentially devastating complication of surgery for large CPA masses.5,7,9 The rate of intact postoperative facial nerve function decreases significantly with increasing CPA tumor size.2,5,9 Preoperative identification of the facial nerve could help prevent inadvertent injury to the nerve during dissection and removal of the tumor.

Unfortunately, as these tumors enlarge and compress the facial nerve, preoperative identification using standard MR imaging becomes increasingly difficult. The facial nerve becomes stretched thin and can be intimately associated with the tumor, and often the nerve is indistinguishable from the tumor.12

Standard preoperative MR imaging of CPA tumors includes T2-weighted sequences, T1-weighted sequences obtained both before and after contrast administration, and high-resolution 3D cisternography series.6,8,10 Traditionally, these modalities have provided 2D resolution of distinct structures but have lacked the ability to adequately demonstrate spatial relationships.

More recent MR imaging modalities, such as diffusion-weighted imaging and DT imaging, have allowed mapping of the cranial nerves in healthy individuals.4 Taoka et al.11 applied these DT imaging techniques to patients with vestibular schwannomas, and the authors reported that they were able to identify the location of the facial nerve in a subset of patients. Since then, diffusion tractography techniques have evolved with an increase in both the number of diffusion directions and the minimum voxel size. In a recent study in which high-resolution DT imaging was used, standard 6 direction diffusion-weighted imaging was performed with a much

Abbreviations used in this paper: CPA = cerebellopontine angle; DT = diffusion tensor; FA = fractional anisotropy; HD-DT = high-density DT; IAC = internal auditory canal; ROI = region of interest.
smaller voxel size. In the present study, we have applied these advanced diffusion tractography techniques to the preoperative identification of facial nerves that are being compressed by large CPA tumors. In addition to using these high-resolution DT imaging methods, we have combined the use of multiple diffusion sensing directions. We have termed this combination of high-resolution and multiple diffusivity directions as high-density diffusion tensor imaging. We have correlated this with the intraoperative location of the facial nerve. We compare standard DT imaging techniques with HD-DT imaging. In all cases, we studied HD-DT imaging accurately resolved the location of the facial nerve even in cases in which standard DT imaging was equivocal. The techniques we describe can easily be adopted using modern 3-T imagers and readily available freeware.

**Methods**

This prospective study was approved by the Oregon Health & Science University Institutional Review Board. Per our inclusion criteria, patients were between 18 and 80 years of age, healthy other than having a CPA tumor displacing the facial nerve as visualized on MR images, were willing and able to understand and sign informed consent and adhere to protocol requirements and had facial nerve function graded as I–V on the House-Brackmann scale. We studied 1 control individual (to optimize imaging protocols) and 5 patients with large CPA tumors who were undergoing preoperative planning to remove their CPA tumor.

**Imaging Protocol**

Imaging was performed using a single 3-T Philips MR imager (Philips Healthcare) with an 8-channel send/receive head coil.

High-density diffusion tensor images were obtained using 32 diffusion sensing directions, TR 7849 msec, TE 80 msec, b value 1000 sec/mm², field of view 200 × 200 mm, acquired matrix 128 × 128 mm, reconstructed matrix 256 × 256 mm, acquired voxel size 1.6 × 1.6 mm, slice thickness 1.2 mm, number of gaps 0, number of slices 40, duration of imaging time 9 minutes 39 seconds, number of averages 2, and reconstructed voxel size 0.78 × 0.78 × 1.2 mm.

Standard DT imaging was performed during the same imaging session and included the following parameters: number of diffusion sensing directions 6, TR 2026 msec, TE 88 msec, flip angle 90°, b value 1000 s/mm², matrix 128 × 128 mm, field of view 230 × 230 mm, voxel size 1.8 × 1.8 mm, slice thickness 4 mm, number of slices 16, and imaging duration 42 seconds.

Magnetic resonance cisternography was obtained using a balanced fast field echo sequence, TR 5.88 msec, TE 2.4 msec, matrix 560 × 560, and slice thickness 0.58 mm with voxel size 0.6 × 0.6 × 0.58 mm. A second T2-weighted 3D VISTA (volume isotropic turbo spin echo acquisition) whole-brain image was obtained for purposes of overlaying the tractography images using TR 2000 msec, TE 457 msec, matrix 256 × 256, and voxel size of 1 × 1 × 1 mm.

**Data Collection and Analysis**

Diffusion tractography images were reconstructed using 2 methods. The first method used Philips proprietary software available on the MR imaging workstation at Oregon Health & Science University (Philips Interia 3.2.1.1). The second method used a readily available freeware, TrackVis (www.trackVis.org). Two methods of reconstruction were performed to ensure that these techniques could be used with other MR imaging systems. A detailed description of the TrackVis software has been described elsewhere and is summarized here. In TrackVis, the DT imaging data are opened in the graphical user interface. From the ROI menu, “New Hand-Drawn” was selected and, using a sagittal cut through the tumor in a midcisternal location, a free hand ROI is drawn around the circumference of the tumor and the ROI is tracked.

Identification of the facial nerve was considered successful when a continuous bundle of fibers extending from the brainstem into the IAC was identified. To ensure validity of fiber tracking in normal structures, the same procedure for facial nerve reconstruction was performed on the unaffected side. The facial nerve reconstruction procedure was repeated 3 times to ensure reproducibility.

With the Philips proprietary software, the “Fiber Tracking” option was selected. The FA value was set to 0.15, and the DT imaging study was overlaid onto an anatomical sequence acquired during the same imaging session. Using the “ROI” option, a hand-drawn ROI was made in a sagittal cut through the tumor in a midcisternal plane. Successful reconstruction of the facial nerve was such that fiber tracts extended in a continuous fashion from the brainstem to the IAC. This procedure for reconstruction was repeated 3 times to verify accuracy and reproducibility as well as reconstructions of the unaffected VII/VIII complex (data not shown).

**Intraoperative Validation of Tractography**

Each patient participating in the study elected to undergo resection of their CPA tumor. All surgically treated patients underwent intraoperative facial nerve integrity monitoring and nerve stimulation during resection using a Prass probe (Medtronic, Inc.). In 4 of the 5 patients studied, the operating surgeon was unaware of the facial nerve tractography imaging results. In 1 patient (Case 1), the operating surgeon was aware of the predicted location, which was subsequently confirmed by intraoperative visualization and stimulation of the facial nerve. Three patients (Cases 1, 3, and 4) underwent a staged resection, which comprised a retrosigmoid approach followed by a translabyrinthine approach. Two patients (Cases 2 and 5) underwent a single retrosigmoid approach for resection (Table 1).

**Results**

In all 5 patients, a reproducible coherent tract, which coursed from the brainstem around the capsule of the tumor and terminated in the IAC, was identified using the HD-DT imaging method. This fiber tract was confirmed intraoperatively as the facial nerve using electrical stimulation and facial nerve electromyography. In 1
CPA tumors and HD-DT imaging of the facial nerve

<table>
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<th>Case No.</th>
<th>Tumor Size (cm)</th>
<th>Successful HD-DT Reconstruction?</th>
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<th>Verified Intraop?</th>
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</table>

Illustrative Cases

Case 1

This 54-year-old man presented with gradual (over 2 years) left-sided hearing loss with associated facial numbness and pain. Upon presentation, his facial nerve function was normal, with near-complete hearing loss and hypesthesia on the left. Preoperative imaging demonstrated a 5.2 × 3.7 × 4.1–cm mass, which had undergone cystic degeneration and was causing significant brainstem compression. The HD-DT imaging revealed an anterosuperior facial nerve with an origin near the displaced brainstem, which coursed inferiorly as it approached the IAC (Fig. 1A–C and Table 1).

Standard DT imaging did not reveal any useful information regarding the location of the facial nerve, despite lowering the FA value to 0.1.

Case 2

This 46-year-old woman presented with long-standing left-sided hearing loss and tinnitus. Imaging revealed a left-sided 2.5 × 2.5 × 2.5–cm CPA mass, which expanded the IAC consistent with a vestibular schwannoma. The patient’s had a preoperative House-Brackmann grade of I, and she had no serviceable hearing on the left side. Magnetic resonance imaging with diffusion tractography using an FA level of 0.15 was undertaken. Reconstructions of the facial nerve using the 3D seeding technique were successful. The facial nerve was found to originate at the equator of the tumor and course laterally in the same plane toward the IAC (Fig. 1D–F and Table 1).

Standard DT imaging methods were unable to produce a reliable fiber tract, despite reducing the FA value to 0.8. This produced mostly cerebellar fibers and a few fibers through the tumor mass itself.

Case 3

This 54-year-old woman presented with a 2-year history of gradual left-sided hearing loss facial numbness and more recently facial pain. Imaging revealed a 3.5 × 3.1 × 3.3–cm vestibular schwannoma. Using HD-DT imaging and an FA level of 0.15, we were able to successfully reconstruct the facial nerve; it was found to course along the inferior boundary as it traveled toward the IAC. The nerve reconstruction was a continuous tract from brainstem to IAC (Fig. 1G–I and Table 1).

Using standard DT imaging with an FA value of 0.1, we were able to produce a coherent tract of nerve fibers extending from the brainstem to the IAC. There was, however, a significant number of artifact fibers surrounding this tract, bringing into question its reliability.

Case 4

This 61-year-old woman presented with a seizure. The patient reported a several-year history of left-sided hearing loss and a 1-month history of left facial weakness. On examination, her House-Brackmann grade was II on the left, and hearing loss was complete on the left. Imaging revealed a 3.0 × 3.2 × 3.0–cm CPA mass on the left and a right petroclival mass and a left frontal meningioma (Fig. 1J–L and Table 1). High-density DT imaging was performed as described above. Three-dimensional reconstructions of the facial nerve were undertaken. In this patient, a continuous fiber track was not reconstructed. However, we were able to identify 2 portions of the facial nerve using an FA level of 0.15. Using this method, we were able to identify the course of the facial nerve as it originated at the anterosuperior aspect of the tumor and then coursed inferiorly as it rounded the apex of the tumor toward the IAC. The facial nerve was noted to be attenuated as it rounded the anterior-most aspect of the tumor corresponding to the inability to reconstruct a continuous nerve track.

Standard DT imaging was performed initially with an FA value of 0.1, which did not result in any fiber tracks. The FA was reduced to 0.8, which resulted in erroneous cerebellar fibers and a few tracks through the tumor.
Fig. 1. A–C: Case 1. Contrast enhanced T1-weighted MR image (A) showing a large irregular CPA mass causing severe compression of the brainstem and displacement of the normal CPA contents. An HD-DT image (B) with an FA value of 1.5 viewed from left posterior direction, showing anterosuperior displacement of the facial nerve fibers (yellow bands) as they course from the brainstem to the IAC. An HD-DT image (C) again shows a coherent bundle of nerve fibers displaced in an anterosuperior directions coursing toward the IAC. Intraoperatively, this bundle of nerve fibers (yellow bands) correlated exactly with the location of the facial nerve.

D–F: Case 2. An MR cisternography image (D) showing the large left CPA tumor causing compression and deformation of the brainstem and expansion of the IAC. An anterior coronal HD-DT image (E) showing the facial nerve exiting the brainstem and coursing around the equator of the tumor as it courses toward the IAC.

(continued)
that cisternography images are not useful in determining facial nerve injury. One study has previously reported schwannomas, can be marred by postoperative facial paralysis. Knowing the location and the course of the facial nerve complex preoperatively can lead to safer resections by reducing the incidence of inadvertent injury to the nerve. The methods that are described herein have proven to be easily implemented in routine preoperative imaging and reliable in demonstrating the location and the course of the facial nerve in relation to the tumor capsule. In this study, we elected to image large CPA masses partly because of the increased difficulty in resecting and the increased incidence of facial nerve injury in resecting tumors that are larger than 2 cm in size, and partly due to the inability to locate the nerve tract via other means (that is, standard preoperative imaging). Standard preoperative imaging typically comprises T1-weighted images obtained before and after contrast administration, T2-weighted images, and a cisternographic image. One study has previously reported that cisternography images are not useful in determining the location of the facial nerve in tumors greater than 2.5 cm in diameter, due to the fact that the signal characteristics of the nerve and tumor capsule are very similar on T1- and T2-weighted images, as well as the intimate association of the nerve fibers to the tumor capsule.

Diffusion tensor imaging has proven immensely useful in several key areas including diffusion tractography. With technique refinements and improvements in imaging equipment, the boundary of what preoperative imaging is capable of achieving is constantly being pushed. Using our HD-DT imaging method with more diffusion sensing directions and a smaller voxel size, we were able to accurately predict the location of the facial nerve in each of our patients with large CPA tumors. DT imaging reconstruction was considered successful if a continuous tract of fibers was seen to extend from the IAC to the brainstem along the tumor capsule. Additionally, for each patient who underwent imaging, reconstruction reliability was further evaluated by reconstructing the unaffected VII/VIII complex on the opposite side (data not shown). The affected facial nerve was reconstructed 3 separate times to ensure tractography reliability.

This is the first study using these advanced HD-DT imaging techniques to correlate preoperative facial nerve findings with objective intraoperative location of the facial nerve. In this prospective study, we were able to quickly and accurately identify the location of the nerve complex in all patients (100%). In a previous study in which traditional DT imaging was performed in a small cohort of patients with CPA tumors, preoperative identification of the facial nerve was accurately correlated with intraoperative findings in 62% of cases.

Conclusions

Preoperative imaging in patients with large CPA masses (> 2.5 cm) using our method of HD-DT imaging has proven to be a safe, rapid, and easy-to-implement technique when used to identify the facial nerve. We were able to reconstruct the facial nerve in all patients using our HD-DT imaging method. We were unable to identify the facial nerve in 4 of 5 patients using standard DT imaging methods. Routine integration of HD-DT imaging in preoperative planning for CPA tumor resection could lead to improved facial nerve preservation.

Disclosure

The authors report no conflict of interest concerning the materials or methods used in this study or the findings specified in this paper.

Intraoperative Facial Nerve Identification

In all cases the facial nerve was identified by facial nerve stimulation, in exactly the location predicted by preoperative tractography. Intraoperatively, in 1 patient (Case 1), the facial nerve was displaced anteriorly as predicted by preoperative HD-DT imaging methods. In this patient, given the large tumor size, a retrosigmoid approach accomplished significant debulking of the mass, and the location of the facial nerve was verified by stimulation, but not by visual identification. However, during the translabyrinthine approach, the anteriorly displaced facial nerve was clearly identified by both stimulation and visual confirmation. In the patient in Case 2, the facial nerve was located anteriorly and it coursed along the equator of the tumor toward the IAC, as predicted by imaging. In the patient in Case 3, the facial nerve was displaced inferiorly and very slightly anteriorly as predicted by preoperative tractography. In the patient in Case 4, the facial nerve originated anterosuperiorly and traveled inferiorly as it traversed the cistern with significant attenuation of the nerve as it rounded the apex of the tumor. At this location, the nerve was reduced to a thin ribbon. Finally, in the last patient (Case 5), the facial nerve was displaced anterosuperiorly as predicted by the HD-DT imaging methods.

Discussion

Resection of CPA tumors, especially vestibular schwannomas, can be marred by postoperative facial nerve injury. Facial nerve injury can lead to a decreased quality of life postoperatively and ultimately requires other surgical interventions to alleviate the consequences of facial paresis or paralysis. Knowing the location and the course of the facial nerve complex preoperatively can lead to safer resections by reducing the incidence of inadvertent injury to the nerve. The methods that are described herein have proven to be easily implemented in routine preoperative imaging and reliable in demonstrating the location and the course of the facial nerve in relation to the tumor capsule. In this study, we elected to image large CPA masses partly because of the increased difficulty in resecting and the increased incidence of facial nerve injury in resecting tumors that are larger than 2 cm in size, and partly due to the inability to locate the nerve tract via other means (that is, standard preoperative imaging). Standard preoperative imaging typically comprises T1-weighted images obtained before and after contrast administration, T2-weighted images, and a cisternographic image. One study has previously reported that cisternography images are not useful in determining the location of the facial nerve in tumors greater than 2.5 cm in diameter, due to the fact that the signal characteristics of the nerve and tumor capsule are very similar on T1- and T2-weighted images, as well as the intimate association of the nerve fibers to the tumor capsule.

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Author contributions to the study and manuscript preparation include the following. Conception and design: Cetas, Roundy. Acquisition of data: Cetas, Roundy. Analysis and interpretation of data: Cetas, Roundy. Drafting the article: all authors. Critically revising the article: all authors. Reviewed submitted version of manuscript: all authors. Approved the final version of the manuscript on behalf of all authors: Cetas.

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References