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A Systematic Analysis of the Reliability of Diffusion Tensor Imaging Tractography for Facial Nerve Imaging in Patients with Vestibular Schwannoma

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Abstract

Surgeons need to visualize the facial nerve reliably in relation to the vestibular schwannoma (VS) in surgical planning. Diffusion tensor imaging (DTI) tractography has enabled unprecedented in vivo preoperative visualization. We collected data to measure the accuracy of DTI for an accurate location of the nerve in preoperative VS resection planning. A PubMed search for relevant studies was conducted. Inclusion criteria were gross total resection of VS, preoperative DTI identification of the facial nerve, and intraoperative cranial nerve localization by the surgeon. Exclusion criteria were tumors other than VS and unsuccessful preoperative location of the cranial nerve. Accuracy rate was calculated by comparing the intraoperative and preoperative locations detailed by DTI. The query identified 38 cases of VS that fit our inclusion criteria. Overall, 89% had surgical findings that agreed with the DTI location of the facial nerve. Of these cases, 32 patients had a postoperative House-Brackmann grade I or II. Our findings suggest that DTI is a reliable method for facial nerve imaging. Implementation of this technique may help decrease facial nerve injury during surgery. Limitations and further studies are needed to better understand what factors correlate with successful location of the facial nerve and DTI in patients with VS.

Keywords
- facial nerve
- vestibular schwannoma
- diffusion tensor imaging tractography

Introduction

The method of treatment with the best postoperative results[1] for patients with vestibular schwannomas (VSs), which make up 8% of all intracranial tumors,[2–4] is gross total resection.[5] However, a common complication of VS resection is damage caused to the facial nerve during surgery. The facial nerve is often found stretched over the tumor and is often difficult to identify because it is thin and does not have a distinct path.[6] Such damage often leads to paralysis, impaired facial function,[7] corneal scarring, ulceration, conjunctivitis, or psychological issues.[8,9] Thus the goal of VS management is to excise the tumor completely while preserving the facial nerve anatomically, as well as maintaining a maximum level of facial nerve function.[10,11]

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The ability to visualize the facial nerve reliably in relation to the location of the VS is crucial for preoperative surgical planning,[12,13] and it may decrease the risk of facial paralysis due to surgery. Although standard magnetic resonance (MR) techniques are used preoperatively to identify the location of the tumors, standard MRIs are not able to locate the facial nerve accurately if displaced by the tumor,[12,14,15] unlike diffusion tensor imaging (DTI).[16]

DTI tractography is a recently developed MR imaging method that allows for unprecedented in vivo visualization of the seventh cranial nerve, the facial nerve.[12,17–19] It is an imaging modality that utilizes directional anisotropy and measures the water diffusion in tissues to create a visual representation of neural fiber tracts. The visual reconstruction of the fiber tracts in the brain can provide crucial information on the displacement due to tumor or trauma.

DTI tractography is used for preoperative identification of the facial nerve, which can then be used to map its location in relation to VS. This method may allow surgeons to create a preoperative plan to reduce the likelihood of damaging the facial nerve during surgery as a consequence of being unable to directly visualize the nerve intraoperatively.

We conducted a systematic analysis to assess the accuracy of DTI tractography in locating the facial nerve in preoperative VS resection planning, with the goal of determining whether DTI is a reliable tool for facial nerve tractography and preoperative planning that should be more widely used.

Methods

A comprehensive systematic analysis was performed to identity VS patients who underwent DTI tractography prior to their surgical treatment. A PubMed online literature search for "vestibular schwannoma facial nerve tractography," "vestibular schwannoma diffusion tensor tractography," and "diffusion tensor imaging tractography" was conducted in March 2014. An extensive analysis was then performed to extract relevant clinical data including age, sex, tumor size, imaging results, intraoperative findings, and postoperative House-Brachmann (HB) scores.

Inclusion criteria were gross total resection of VS, preoperative identification of the cranial nerve using DTI tractography, and intraoperative localization of the cranial nerve by the surgeon. Exclusion criteria were tumors other than VS and unsuccessful preoperative location of the cranial nerve using DTI tractography. Data on patients with VSs who underwent DTI tractography, as well as data concerning the accuracy of DTI tractography, was collected from three studies.

An overall reliability rate was calculated by comparing the intraoperative location of the facial nerve, as described by the surgeon, with the preoperative location identified by DTI tractography. In all studies included in this article, the surgeon was blind to the results of the preoperative DTI tractography until after locating the facial nerve during surgery. Information on how well the facial nerve functioned for each patient was also collected according to the HB score of grading facial nerve function before and after surgery.

Results

The query identified a total of 38 VS cases that met our inclusion criteria. Eighteen male patients (47%) and 20 female patients (53%) were included in this study. Mean age at presentation was 47 years (range: 19–70 years). Imaging of the facial nerve using DTI tractography was possible in 36 of the 38 cases (94.7%) included in this study. Of the 36 cases in which imaging was possible, 32 (89%) of the imaged locations were accurate. Thus in a large majority of these cases, the intraoperative surgical finding agreed with the location of the facial nerve as predicted by DTI tractography. Of the 38 cases that fit our inclusion criteria, 32 patients (84%) had a postoperative HB grade of I or II compared with 6 patients (16%), with a HB grade of III to IV.

In the first study by Taoka et al, standard MR imaging was used on eight patients; only the patient with the smallest tumor in the cohort at 18 mm had an image in which the facial nerve could not be identified. DTI tractography was then performed on all eight patients, resulting in mapping of the facial nerve for seven of the eight patients (87.5%). The unmapped patient, who had the smallest tumor in the cohort, was excluded from the rest of this study. The seven tumors imaged using DTI tractography were all $>$ 20 mm. DTI was conducted using a Siemens Magnetom Sonata 1.5-T MR scanner (Siemens AG, Erlangen, Germany) with a single-shot echo planar sequence. In five of the seven patients (71%), the surgical findings agreed with the location of the facial nerve as determined by DTI tractography. All patients had their tumors completely excised and had a postoperative HB score of I to II.[20]

In another study by Zhang et al, two men and six women underwent DTI tractography as part of their preoperative planning prior to VS resection. All eight patients had a VS $>$ 30 mm in maximal extrameatal diameter. The average age of the patients in this study was 51 years, with an average tumor size of 38.1 mm (range: 30–55 mm). The patients were imaged using a Siemens Verio 3.0-T MR scanner (Siemens AG). Mapping of the facial nerve was successful for seven of the eight patients (87.5%), and all seven facial nerves that were preoperatively located were accurately correlated to the location of the facial nerve as identified by the surgeon during resection of the tumor. All seven tumors were completely excised, and all facial nerves were preserved with a postoperative HB score of I to II.[21]

In the last study from which data was collected, Gerganov and Samii used DTI tractography to locate the facial nerve of 22 patients, for all of whom imaging was successful. Imaging was conducted using a Siemens Magnetom Allegra 3-T MR imaging scanner. The mean age of the patients was 43.6 years. Intraoperative surgical findings agreed with the DTI mapped location for 20 of the 22 cases (91%). Thus this study shows that DTI tractography can accurately image the facial nerve in a large majority of patients. The surgeon was able to excise all tumors completely while anatomically preserving the facial nerve in all patients. During follow-up of the 20 patients who were accurately imaged with DTI, 14 patients (70%) had a postoperative HB score of I to II, 2 (10%) had a score of III, and 4 (20%) had a score of IV. The two patients whose facial nerves were not accurately mapped by DTI tractography had a postoperative HB score of IV (►**Tables 1** and **2**).[8]

Table 1 Patient characteristics

Study	Mean age (years)	Male:Female	Mean tumor size
Gerganov et al[6,8]	43.6 y (19-62 y)	1:1.4	27 mm
Zhang et al[21]	51 y (40-63 y)	1:3	38.1 mm (30-55 mm)
Taoka et al[20]	69.5 y (27-70 y)	3:5	29 mm (18-47 mm)

Table 2 DTI tractography results and HB scores

Study	Facial nerve mapped with DTI	Accuracy of DTI	HB score
Gerganov et al[6,8]	22/22 (100%)	20/22 (91%)	16 patients had a grade of I-II, while 6 (including the two patients with inaccurate maps) had a grade of IV
Zhang et al[21]	7/8 (87.5%)	7/7 (100%)	All patients had a grade of I-II
Taoka et al[20]	7/8 (87.5%)	5/7 (71%)	All patients had a grade of I-II

Discussion

The goal of VS resection surgery is to excise the tumor completely while maintaining or improving facial function.[22] The preservation of the facial nerve is often influenced by the experience of the surgeon, as well as the size of the tumor.[6,23] Although preservation rates for the facial nerve have been increasing (58% in extra large and 60% in large tumors),[11,23] DTI tractography allows for preoperative in vivo modeling of the facial nerve that could lead to further increases in the rate of facial nerve preservation during surgery.

To resect a VS while maintaining, or improving, the facial function of a patient, surgeons must be aware of the anatomy of the patient's facial nerve to prevent any damage from occurring to the nerve. Facial nerves do not follow a set location pattern and thus exhibit a wide variety of anatomical differences between different patients, which makes them difficult to locate and preserve.[24,25] As VS tumors increase in size, they begin to grow on and around the facial nerve. As such, it becomes increasingly difficult for conventional MRI techniques to locate and provide useful information on the anatomy of the displaced facial nerve.[24,26–29] The facial nerve and the VS are often so closely intertwined that there is little cerebrospinal fluid between the two,[29] which makes it difficult to use standard MR imaging techniques to locate the facial nerve. DTI tractography can be used in these cases to locate the displaced facial nerve preoperatively, as well as the location of the tumor relative to the facial nerve.[12,30,31] Not only does this method have the potential to help increase the rate of preservation of the facial nerve in resection surgeries, it also allows for more of the tumor and its surrounding area to be resected because the location of the nerve and the tumor can be accurately mapped preoperatively.[13,32,33]

The systemic analysis described in this article found that DTI tractography was able to locate the facial nerve accurately 88.9% of the time. This suggests that, with further development and studies, DTI tractography may be a reliable preoperative planning tool that can potentially increase the chance of facial nerve preservation in VS resection surgeries.

Although DTI tractography can accurately image the facial nerve, it does not provide an exact location of the nerve. Rather, it provides a relative location of the facial nerve in relation to anatomical landmarks, as well as the path of the nerve.[34] This may account for the inability of DTI tractography to locate the facial nerve accurately in every patient. Although the accuracy rates between the three studies are extremely similar, differences in parameter settings for the DTI data may lead to a slight variation in rates of accuracy in studies on DTI tractography.[6,29]

Intraoperative neurophysiological monitoring (IONM) is the current standard for cranial nerve imaging during VS resection. This method utilizes electrophysiologic monitoring modalities to help improve functional outcomes of the facial nerve after surgical resection. This technique has been reported to achieve facial nerve preservation in 95 to 100% patients with VSs measuring < 1 cm, 80–92% in patients with VSs measuring 1 to 2 cm, and 50 to 70% in patients with VSs > 2 cm.[35] This can be compared with the 36 tumors using DTI tractography that are presented and all measured > 2 cm. Overall, 89% of these tumors had successful facial nerve tracking, which is higher than the 50 to 70% reported for IONM. Although this suggests an improvement in facial nerve preservation, there are limitations to the study and its comparison with IONM.

Drawbacks of this analysis include a limited number of studies conducted for the accuracy of DTI tractography in locating the facial nerve, as well as the small sample of patient cases included in these studies. Further studies are needed with larger sample sizes to better understand what factors correlate with successful, as well as accurate, DTI of the facial nerve in patients with VS.

Conclusions

Facial nerve function is a major factor in determining quality of life following VS resection.[20,26,36] The goal of VS resection is to remove the tumor completely without compromising the facial nerve.[11,13] Using DTI tractography to determine the exact location of the facial nerve to plan a tumor resection surgery preoperatively can help achieve this goal. This study found a relatively high accuracy rate for DTI tractography in locating the facial nerve, as well as a high rate of patients who maintained normal facial function following surgery.

Our findings suggest that that DTI tractography may be used as an appropriate aid in correctly identifying the facial nerve prior to surgery for most patients. With continued advances in DTI, the use of this imaging modality may one day be standard practice for all patients undergoing VS surgery. However, even in its current state of development, DTI tractography can be used as a valuable tool to potentially improve surgical outcomes.

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