Probabilistic Tractography of the Cranial Nerves in Vestibular Schwannoma

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■ OBJECTIVE: **Multiple recent studies have reported on diffusion tensor-based fiber tracking of cranial nerves in vestibular schwannoma, with conflicting results as to the accuracy of the method and the occurrence of cochlear nerve depiction. Probabilistic nontensor-based tractography might offer advantages in terms of better extraction of directional information from the underlying data in cranial nerves, which are of subvoxel size.**

■ METHODS: **Twenty-one patients with large vestibular schwannomas were recruited. The probabilistic tracking was run preoperatively and the position of the potential depictions of the facial and cochlear nerves was estimated postoperatively by 3 independent observers in a blinded fashion. The true position of the nerve was determined intraoperatively by the surgeon. Thereafter, the imaging-based estimated position was compared with the intraoperatively determined position. Tumor size, cystic appearance, and postoperative House-Brackmann score were analyzed with regard to the accuracy of the depiction of the nerves.**

■ RESULTS: **The probabilistic tracking showed a connection that correlated to the position of the facial nerve in 81% of the cases and to the position of the cochlear nerve in 33% of the cases. Altogether, the resulting depiction did not correspond to the intraoperative position of any of the nerves in 3 cases.**

■ CONCLUSIONS: **In a majority of cases, the position of the facial nerve, but not of the cochlear nerve, could be estimated by evaluation of the probabilistic tracking results. However, false depictions not corresponding to any nerve do occur and cannot be discerned as such from the image only.**

INTRODUCTION

Magnetic resonance imaging has become the mainstay of diagnosis for vestibular schwannoma. However, it traditionally has failed at depicting the facial and cochlear nerve in larger tumors. The position of the nerves has thus remained hidden to the surgeon until the nerve is encountered with an electrode during the surgery. Especially for the facial nerve, preoperative knowledge of the nerve position would be of advantage for the surgeon. Moreover, the position of the facial nerve can be useful for the prediction of postoperative deficits.[1] Therefore, there is strong interest in the preoperative depiction of the nerve. With the emergence of diffusion tensor imaging (DTI), several researchers have attempted to use DTI for the depiction of the facial nerve in vestibular schwannoma. Some groups reported considerable success using the technique,[2,3] and this has inspired other researchers to try implementing similar algorithms in their own work.

In the search for a method more reliable than the standard fiber tracking, we have encountered numerous reports on the superiority of nontensor-based probabilistic tracking in the depiction of smaller fiber bundles.[4-10] The advantages of probabilistic fiber tracking seem to be caused by better extraction of information about fiber direction in areas, where multiple fiber populations occupy the same voxel. In cranial nerves, the situation seems to be similar. Given the size of the facial nerve in its cisternal portion (~0.6 mm in diameter,[11] compared with DTI voxel of approximately 2 mm) and the flattening of the nerve observed in vestibular schwannoma, a large volume of the voxel containing the nerve is occupied by the cerebrospinal fluid and tumor

Key words
- Cranial nerves
- Diffusion tensor imaging
- Probabilistic tractography
- Skull base tumors
- Surgery
- Vestibular schwannoma

Abbreviations and Acronyms
DTI: Diffusion tensor imaging
FA: Fractional anisotropy
FDT: FMRIB's Diffusion Toolbox

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tissue. Both of these elements have completely different diffusion properties, similar to the presence of other fiber tracts.

Therefore, we have hypothesized that probabilistic tractography might yield more accurate results in the depiction of the facial and cochlear nerve compared to standard DTI tracking—without needing to resort to manual fiber selection. We already have tested this hypothesis on a group of healthy subjects obtained from a public database together with a small preliminary patient group[12] and saw an advantage of the probabilistic tracking compared with the standard, deterministic tracking method. To verify our findings on a larger clinical cohort, we decided to evaluate the value of probabilistic tracking in vestibular schwannoma. Therefore, we conducted a prospective cohort study on patients harboring this tumor.

MATERIALS AND METHODS

The institutional ethics committee approved this prospective study on human subjects. Twenty-one patients harboring unilateral large vestibular schwannoma (Hannover grades 3 and 4) were recruited for the study between June 2014 and June 2016. The study group included 7 male and 14 female patients with mean age of 54.6 years, range 28–75 years. None of the patients showed facial palsy before operation, impairment of hearing was noted in all but one patient, and one patient reported deafness preoperatively. Additional variables collected included the presence of cysts in the tumor, tumor size, and postoperative House-Brackmann score, determined at the eighth postoperative day.

In addition to standard preoperative scans, a readout-segmented echo planar imaging DTI was acquired on a Siemens Verio 3T scanner (Siemens, Erlangen, Germany). This special technique was chosen to minimize geometric distortions due to susceptibility artifacts at the skull base. A total of 20 diffusion sampling directions were acquired as a compromise between time requirements (12 minutes) and patient tolerance. The b-value was 800 s/mm^2. The sequence was set up with an isotropic voxel, with both in-plane resolution and slice thickness of 2 mm.

The anatomic images (constructive interference steady state, T1) were coregistered with the DTI scan including a nonlinear step.[13] FMRIB (Oxford Centre for Functional MRI of the Brain) diffusion toolkit software (FDT) was used for the probabilistic fiber tracking by the use of graphics processing unit-accelerated methods.[14,15]

Two regions of interest were used for the initiation of the probabilistic tracking in a network mode, one in the internal acoustic meatus and the second in the brainstem corresponding to the position of the facial/cochlear nerve of the other side. In addition, to speed up the tracking process, the whole processing was restricted to a small volume of interest containing the tumor and an approximately 8 mm (4 voxels) large border of tissue around it. The probabilistic tracking by FDT does not produce fiber depictions in a form of streamlines but rather a cloud of probability values. Therefore, the sagittal oblique images with overlaid results of the tracking in varying probability thresholds were saved. These images were later used for blinded evaluation by independent observers.

For the purpose of this study, we used the Sampath classification used in many previous studies.[16] The Sampath classification describes the position of the nerve by placing it in one of the sixths of the circle represented by the tumor. In addition, the position can be described as being at the upper or lower pole of the tumor. In our analysis, we have allowed the observers to classify the nerve position as "in between" the sixths (**Figure 1**). The surgeon performing the surgery recorded the intraoperative position of the facial and cochlear nerve according to the Sampath classification as described previously. Intraoperatively, the NIM 2.0 stimulator (Medtronic, Minneapolis, Minnesota, USA) with a monopolar stimulation probe was used to identify the location of the nerve. The fiber tracking was run preoperatively; however, for this analysis, 3 independent observers, blinded to the intraoperative findings, evaluated retrospectively the depictions obtained by the probabilistic fiber tracking and classified the visible fiber tracts using the same classification. The median value of the 3 observations was used for further comparison. Up to 2 tracts with the highest

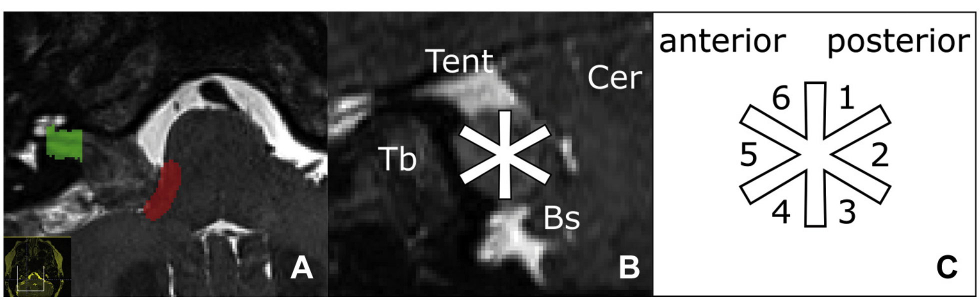

Figure 1. (**A**) Position of the regions of interest used for the tracking. (**B** and **C**) Sampath classification of nerve position in relation to the tumor. (**B**) Sagittal projection of the tumor (*asterisk*) with temporal bone (Tb) to the anterior, brainstem (Bs), and cerebellum (Cer) to the posterior and tentorium (Tent) to the cranial. (**C**) The Sampath classification divides the space around the tumor into sixths, naming them posterior upper (1), middle (2) and lower (3) third and analogically anterior lower (4), middle (5) and upper (6) thirds. In addition, Sampath named the position between 3 and 4 the lower pole and the position between 6 and 1 the upper pole. We have allowed the observers who classified the nerve depictions for comparison with intraoperative findings to mark the position of the nerve as between the sixths (i.e., lower pole would be represented as 3.5), should it be necessary.