Diffusion tensor imaging of the auditory nerve in patients with long-term single-sided deafness

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Audience: Clinicians and researchers interested in imaging the auditory nerve

Introduction: The viability of the auditory nerve in deaf patients is vitally important in successful hearing recovery after cochlear implantation (CI) [1]. However, the nerve typically degenerates following cochlear hair cell loss, and the amount of degeneration may considerably differ between the two ears, also in patients with bilateral deafness [1,2]. A measure that reflects the nerve's condition would help to assess the best of both nerves and decide accordingly which ear should be implanted for optimal benefit from a CI. Diffusion tensor MRI (DTI) may provide such a measure, by allowing noninvasive investigations of the nerve's microstructural properties [3]. In this pilot study, we show the first use of DTI to image the auditory nerve in patients with long-term single-sided deafness (SSD) and normal-hearing subjects. Because the nerve of the deafened ear is expected to be considerably degenerated [1], affecting diffusion, we hypothesize that DTI measures of the auditory nerve differ between the deafened and healthy ears.

Methods: Five patients with SSD and five healthy normal-hearing subjects were included. All control subjects had normal middle ear function, with no acute middle ear infection or tympanic membrane perforations and an air-bone gap <10 dB. Here, normal-hearing subjects were defined as having hearing thresholds ≤20 dB for frequencies of 0.5, 1, 2, and 4 kHz with an average ≤15 dB. Patients were included if one ear had hearing thresholds ≥70 dB and the other ear ≤30 dB for all frequencies.

To image this small nerve bundle, a specialized acquisition protocol was designed for a clinical 3 T MRI scanner, aiming to increase resolution and decrease distortions. A limited field-of-view (FOV) in the AP direction of 79 mm was obtained by placing suppression slabs on both sides of the FOV. Acquisition matrix was 44×128 with 20 axial slices of 1.8 mm thickness to obtain a 1.8 mm^3 isotropic resolution. SENSE 2.1 AP, TE/TR=58/3125 ms resulting in a bandwidth of 48.3 Hz/pixel. A single non-diffusion-weighted image was acquired (6 number of signal averages, NSA) along with 22 gradient directions (3 NSA) with a b-value of 1000 s/mm^2. This set of 23 images was acquired twice to improve SNR, total scan time was 7m49s. Additionally, an axial 3D T2-weighted TSE image was acquired with a FOV of 130x130x25 mm3 (AP×LR×IS) with a reconstructed voxel size of 0.25×0.25×0.50 mm^3. TE/TR=200/2000 ms, scan time was 4m32s.

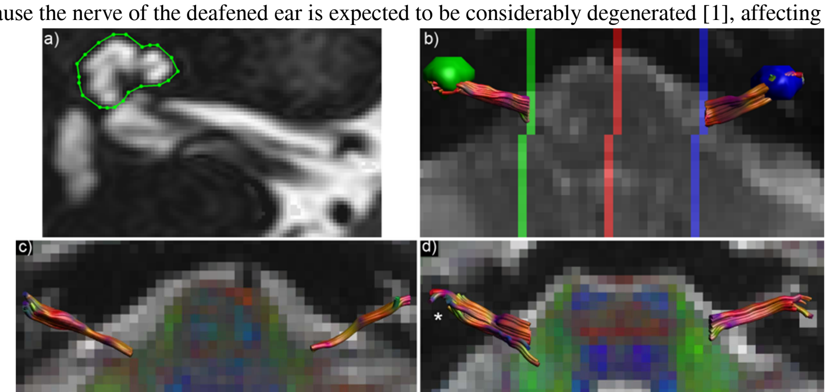

Fig. 1: a) 3D T2 image used to delineate the cochlea and determine the mid-sagittal plane (not shown). These are transformed to the DTI data (b), where the red line is the transformed mid-sagittal plane, the green and blue volumes and lines are right and left cochlear seeding volumes and termination criteria, respectively. c) and d) show tractography results for a control and patient, respectively, with the fiber tract segments shown over an axial slice of the b=0-image and the DEC map. The asterisk in d) indicates the deaf side.

DTI data was corrected for motion and distortions using ExploreDTI and tensors fitted using iterative weighted least squares [4,5]. Manual cochlea delineations and automated mid-sagittal planes [6] were obtained from the 3D T2 (Fig. 1a,b), and transformed onto DTI data by registration. Tractography was seeded from those cochlear volumes and terminated when reaching the brainstem 18 mm lateral of the mid-sagittal plane (Fig. 1b). Fractional anisotropy (FA) and mean diffusivity (MD) were extracted from those fiber bundle segments and compared using repeated measures ANOVA with subject group as a between-group factor and laterality as within-group factor where control subject were split into the left and right bundles and the patients into deaf and healthy-sided bundles. Along-tract investigations were performed as in [7].

Table 1: Bundle-average FA values

	Healthy	Deaf
Patient 1	0.12	0.09
Patient 2	0.10	0.14
Patient 3	0.08	0.09
Patient 4	0.07	0.11
Patient 5	0.13	0.14
Mean	0.10±0.02	0.11±0.03
	Left	**Right**
Control 1	0.14	0.14
Control 2	0.12	0.13
Control 3	0.15	0.13
Control 4	0.12	0.14
Control 5	0.13	0.11
Mean	0.13±0.01	0.13±0.01

Results: Tractography results for three subjects are shown in Fig. 1b-d, demonstrating the ability to reliably reconstruct the auditory nerve. Bundle-average FA values are shown in Table 1. Repeated measures ANOVA showed a significant difference in FA between subject groups with FA values lower in the patient group than the control group (p=0.045). Neither a within-subject difference (p=0.32) nor an interaction of group and laterality (p=0.45) was found. No differences were observed between or within subject groups for MD values. Along-tract investigations did not reveal subtle differences that bundle-average analysis might miss.

Discussion: Our results show the first evidence of possible changes in the microstructure of the bilateral auditory nerves as a result of single-sided deafness. The auditory nerve after leaving the cochlea joins with the vestibular nerve to form the vestibulocochlear nerve, which then runs close to the facial nerve [8]. DTI will not distinguish the different parts of the vestibulocochlear nerve and facial nerve, making out results less specific but nonetheless very informative. The auditory nerve is markedly larger than the facial and vestibular nerves, which means that most of the information captured using DTI comes from the bundle-of-interest. Furthermore, it is more likely that the observed FA differences between deaf and normal-hearing subjects originate from changes in the auditory nerve than from the facial or vestibular nerves. Improvements to these investigations can come through either advancing the spatial resolution – especially beneficial for such a small nerve bundle – or changing to more microstructural diffusion models. Both, however, are complicated by the size and location of the bundle. The area of interest contains soft tissue, air, and bones, making it a region with high susceptibility differences. This means any increases in spatial resolution using single-shot EPI will seriously increase image distortions. Furthermore, this area has intrinsically low SNR because of low soft tissue content, limiting the use of more advanced diffusion MRI models or methods.

References: [1] Seyyedi, M. et al., Otol. Neurotol. 2014;35:1446-50; [2] Spoendlin, H. et al., Hearing Research 1989;43:25-38; [3] Basser, P.J., et al., Biophys J. 1994;66:259-67; [4] Leemans, A. et al., MRM 2009;61:1336-49; [5] Veraart, J. et al., NeuroImage 2013; 81:335-46; [6] Kuijf, H.J., et al., SPIE Medical Imaging 2013:86731K; [7] Colby, J.B., et al., NeuroImage 2012;59:3227-42; [8] Zhang, Y. Et al., Acta Neurochirurgica 2013;155:1857-62.