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Diffusion tensor imaging and MR spectroscopy of microstructural alterations and metabolite concentration changes in the auditory neural pathway of pediatric congenital sensorineural hearing loss patients

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ABSTRACT

Purpose: Our objective was to evaluate age-dependent changes in microstructure and metabolism in the auditory neural pathway, of children with profound sensorineural hearing loss (SNHL), and to differentiate between good and poor surgical outcome cochlear implantation (CI) patients by using diffusion tensor imaging (DTI) and magnetic resonance spectroscopy (MRS).

Materials and Methods: Ninety-two SNHL children (49 males, 43 females; mean age, 4.9 years) were studied by conventional MR imaging, DTI and MRS. Patients were divided into three groups: Group A consisted of children ≤ 1 years old ($n=20$), Group B consisted of children 1–3 years old ($n=31$), and group C consisted of children 3–14 years old ($n=41$). Among the 31 patients (19 males and 12 females, 12 m- 14y) with CI, 18 patients (mean age 4.8 ± 0.7 years) with a categories of auditory performance (CAP) score over five were classified into the good outcome group and 13 patients (mean age, 4.4 ± 0.7 years) with a CAP score below five were classified into the poor outcome group. Two DTI parameters, fractional anisotropy (FA) and apparent diffusion coefficient (ADC), were measured in the superior temporal gyrus (STG) and auditory radiation. Regions of interest for metabolic change measurements were located inside the STG. DTI values were measured based on region-of-interest analysis and MRS values for correlation analysis with CAP scores.

Results: Compared with healthy individuals, 92 SNHL patients displayed decreased FA values in the auditory radiation and STG ($p < 0.05$). Only decreased FA values in the auditory radiation was observed in Group A. Decreased FA values in the auditory radiation and STG were both

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observed in B and C groups. However, in Group C, the N-acetyl aspartate/creatinine ratio in the STG was also significantly decreased ($p<0.05$). Correlation analyses at 12 months post-operation revealed strong correlations between the FA, in the auditory radiation, and CAP scores ($r=0.793$, $p<0.01$).

Conclusions: DTI and MRS can be used to evaluate microstructural alterations and metabolite concentration changes in the auditory neural pathway that are not detectable by conventional MR imaging. The observed changes in FA suggest that children with SNHL have a developmental delay in myelination in the auditory neural pathway, and it also display greater metabolite concentration changes in the auditory cortex in older children, suggest that early cochlear implantation might be more effective in restoring hearing in children with SNHL.

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1. Introduction

High-resolution CT is the primary imaging modality used in the initial workup of patients with profound hearing loss. However, high-resolution CT is not sufficient to evaluate the soft tissue structures of the inner ear, such as the membranous labyrinth and the vestibulocochlear nerve. Magnetic resonance imaging (MRI) can directly assess these soft tissue structures responsible for hearing (Moon et al., 2012). Imaging modalities, such as CT and MRI, can accurately and objectively evaluate sensorineural hearing loss due to the morphological abnormalities present (Jonas et al., 2012). In addition, preoperative magnetic resonance imaging (MRI) can yield valuable information regarding the status of the inner ear in pediatric cochlear implant (CI) candidates, and can improve the success rate of cochlear implants (Hong et al., 2010; Migirov and Wolf, 2013). MRI anomalies in CI patients provide clinically significant information that may be related to poor postoperative outcomes (Moon et al., 2012; Hong et al., 2010). However, a portion of patients with no MRI anomalies have poor postoperative outcomes, indicating a need to identify functional changes or dysfunction of the central auditory pathway itself, which cannot currently be evaluated by conventional imaging (Chang et al., 2004). To further investigate the clinical significance of preoperative brain MRI in pediatric cochlear implant recipients, we investigated whether microstructural changes of white matter tracts and proton metabolites in the auditory cortex could be detected in SNHL patients.

Recent advances in MR imaging provide in vivo tools for studying the microstructure of the CNS. DTI allows one to quantify the integrity of densely packed fiber bundles, such as axonal tracts (Chang et al., 2004). Neural reorganization occurs when the inputs to the sensory system change. Similarly, the pattern of auditory cortical activation becomes altered when the inputs to the auditory system change as a result of peripheral hearing loss. In healthy white tracts, the anisotropy (limited directionality of diffusion) is higher than in less-organized gray matter, enabling myelin development to be detectable by DTI (Chang et al., 2004). In addition, MR spectroscopic studies of hearing loss disorders would be important in understanding how the metabolites listed above are affected in the auditory pathways of the brain during neuronal activity (Nitkunan et al., 2006). In this study, to provide a basis for improving the effectiveness of cochlear implants, we use DTI and MRS to investigate the age-dependent neural integrity of subcortical auditory projections, central to the cochlear nerve, in SNHL children without inner ear malformations.

2. Analysis

Diffusion tensor data was processed and analyzed using DTI-Studio software and an Advantage workstation for Windows (AW4.5, GE Healthcare). After correction for movement and EPI-induced distortion artifacts, the diffusion tensor was calculated for each voxel. The final DTI dataset was fed into Functool software, which automatically computes the FA and ADC maps. The region of interest was about 25 mm^2 and was traced on the superior temporal gyrus and auditory radiation in the original DTI. FA and ADC values for the regions of interest of the control group. Three repeats were acquired and averaged to improve the signal-to-noise ratio. The average value of the data was measured by two experienced radiologists.

For proton MR spectroscopic imaging, a region of interest (ROI) was positioned in the center of an axial T2-weighted scout image positioned in the superior temporal gyrus. Spectroscopic data was processed using SAGE (spectroscopy analysis, GE Medical Systems) for automatic zero-order auto-phasing and two-dimensional discrete Fourier transformation. No spectral or spatial apodization was used to present unmodified raw data to LCModel. A SAGE macro was used to estimate metabolite concentrations using LCModel, a fitting algorithm using a linear combination of model spectra. All spectra were visually inspected to ensure a good fit. Peak area ratios of N-acetyl aspartate (NAA), total choline (Cho), combined glutamate and glutamine and myo-inositol were obtained relative to total creatine (Cr) for each voxel. Since chemical shift artifacts cause a displacement of the excited volume for different metabolites, LCModel concentrations for each voxel were corrected for this effect with an in-house program using information on the RF pulse profiles, the dimensions and position of the ROI, and the resonance frequency of each metabolite. Metabolite ratios calculated from the corrected concentrations for each voxel were exported to a spreadsheet for each subject.