Distortion Product Otoacoustic Emissions for Non-Invasive Intracranial Pressure Assessment

Mian Z Urfy[1], Susan Voss[2] , Chethan PV Rao[1], Jose I Suarez[1], Eusebia Calviillo[1], Alina Pachacek[2], Mary McGrath[2], Alex Fong[1]

Alexandros L. Georgiadis[1] , Eric M Bershad[1]

[1] Baylor College of Medicine, Houston, Texas, [2] Smith College, Northampton, MA.

Background

Currently, there are no reliable non-invasive methods for assessing intracranial pressure (ICP). Distortion product otoacoustic emissions (DPOAE) are evoked sound waves from the cochlea in response to specific externally delivered frequencies. Due to the connection of the cranial subarachnoid space and perilymphatic fluid via the cochlear aqueduct, changes in the ICP may affect DPOAEs.

Methods

This study was approved by the Baylor College of Medicine Institutional Review Board, and written informed consent was obtained from all subjects. We enrolled 20 subjects in this six month prospective pilot study. The inclusion criteria were: age 18-60 years and required LP based on neurological condition. An upper limit for age range was chosen as DPOAE measurements can be affected by hearing loss. The exclusion criteria were: known hearing abnormalities in both ears, excessive wax in the external ear canal, and focal mass lesion. All of the LPs were with the subject in the lateral decubitus position, legs extended. An otoscopic exam was performed to rule out ear canal obstruction. Tympanometry was performed (Earscan, Micro Audiometrics Corp., ES-T) to ensure middle-ear pressure within the range of 0 ± 25 daPa, as outside this range the DPOAEs may be affected. If the pressure was not within this range, the operator instructed the subject to swallow to equalize the pressure. Next, an Etymotic ER-10c ear probe was placed in the subject's ear and connected to hardware and software developed by Mimosa Acoustics (HearID v4.5.15.0). To maximize the DPOAE response at the lower frequencies, we fixed f_2/f_1=1.25 and L_1=L_2=70 dB SPL; DPOAEs were measured at 13 log–spaced frequencies with f_2 approximately 500-4000 Hz. DPOAEs are obtained at the frequency f_{dp}=2 f_1- f_2 from the discrete Fourier transform of the time-domain average of N responses; here the number of responses N varied with noise level, with a maximum N=200. The ICP was averaged over a 5 minute time period observed simultaneously with the DPOAE recordings. After the opening pressure ICP and DPOAE measurements, the CSF was drained as per normal clinical procedures. Then, the closing pressure measurements and DPOAE were repeated again in the same manner. The tympanometry and DPOAE measurements were performed twice in each subject concurrently with the ICP measurements at opening and closing pressures.

Results

Technical success was achieved in 90% (n=18) of patients. For data analysis, we divided subjects into three groups based on small, medium or large changes between opening and closing ICPs. Group A, B and C are subjects with large, medium and small ICP changes respectively from pre to post CSF drainage. For DPOAE magnitudes, we found significant increases between pre and post-LP measurements respectively when comparing groups, mainly at DPOAE F2 frequencies between 700 to 1200 Hz. For the DPOAE phase angles, we found significant negative phase angle shifts of 0.1 to 0.25 cycles when comparing groups with large and medium ICP changes vs. those with small ICP changes, mainly at DPOAE F2 frequencies between 1000 to 2000 Hz. Figures 1 and 2 show the pre and post-LP data from subjects in groups A and C respectively. Figure 3 summarizes the DPOAE magnitude and phase angle changes from pre to post-LP by group combining all data points.

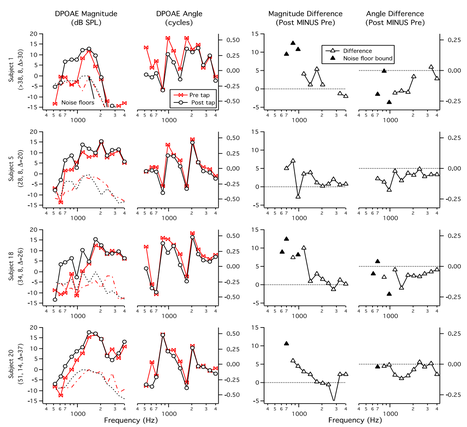

Figure 1

Group A where subjects had pre- and post-LP ICP changes >20 cmH20. Left: DPOAE magnitudes and angles and corresponding noise floors for pre- (red) and post-LP (black) measurements. Right: Differences in DPOAE magnitudes and angles for the post-LP measurement minus the pre-LP measurement. Solid symbols indicate a difference between the post-LP DPOAE magnitude and the pre-LP DPOAE noise floor;

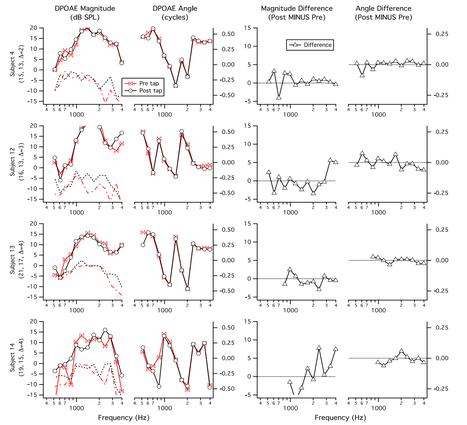

Figure 2

Group C where subjects had pre- and post-LP ICP changes in the range of 7 to 15 cm H20. Left: DPOAE magnitudes and angles and corresponding noise floors for pre- (red) and post-LP (black) measurements. Right: Differences in DPOAE magnitudes and angles for the post-LP measurement minus the pre-LP measurement. Solid symbols indicate a difference between the post-LP DPOAE magnitude and the pre-LP DPOAE noise floor;

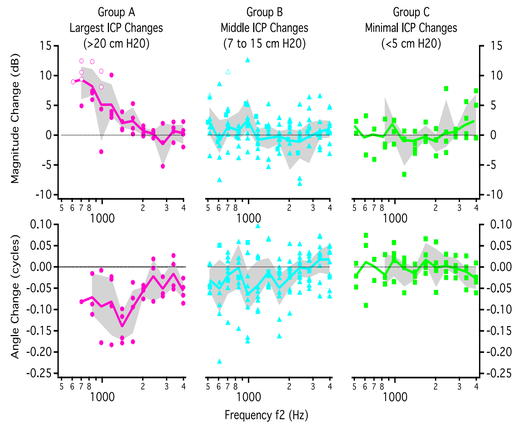

Figure 3

Summary of DPOAE changes in magnitude (upper plots) and angle (lower plots) for the three groups. Solid points represent calculated DPOAE differences and open points represent differences from post-LP DPOAE magnitudes and pre-LP DPOAE noise floors. Solid lines are the mean differences at each frequency. The gray shaded regions represent a 95% confidence interval for the difference in mean DPOAE, as calculated by a bootstrap procedure.

Conclusions

We report for the first time that changes in ICP are associated with significant changes in DPOAE parameters. Specifically, DPOAE magnitudes increased, and phase angles shifted when ICP changed. These findings are consistent with a previous study measuring DPOAE before and after body tilt as an analog for producing ICP changes. Future studies are warranted to develop correlation and ROC curves that relate DPOAE parameters with ICP changes, and further characterize the specific frequencies where ICP modulates DPOAE responses.

Acknowledgments

Susan Voss received funding from the National Science Foundation for this study.