Middle-Ear Impedance Estimation from Wideband Acoustic Immittance Measurements in Ears with Otitis Media with Effusion

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INTRODUCTION

Wideband acoustic immittance (WAI) measurements have been shown to have clinical value in differentiating origins of conductive hearing loss, including both middle- and inner-ear causes. The goal of WAI measurements is to determine the status of the middle ear. However, WAI measures are made by a probe placed at an undetermined location in the ear canal, and variations in probe location and individual patient ear-canal acoustics may add noise and variability to WAI measurements. In an effort to improve these measurements in order to yield better diagnostic sensitivity and specificity, a more direct estimate of middle-ear impedance not influenced by these factors would be beneficial.

METHODS

Measurements: Four representative examples from a recent study of WAI outcomes in ears from children with otitis media with effusion (OME) were utilized (Merchant et al., 2021). Three examples of ears with OME were selected to represent a normal ear without OME, an ear partially full of effusion, and an ear completely full of effusion. A fourth example was selected to represent an age-matched normal ear without OME.

Model: An electric-analog model was used to model WAI responses, and both estimate and model ear-canal and middle-ear impedance from measured ear-canal impedance. The transmission line represents the ear canal while the terminating circuit represents the middle ear. The nonuniform transmission line models acoustic plane-wave propagation through a waveguide consisting of seven concatenated truncated-cone sections. The transmission line is implemented numerically as a two-port transmission matrix (see Lewis and Neely 2015; Merchant et al. 2019). The middle-ear network contains three branches that together represent mechanics of the tympanic membrane coupled to the ossicles (i.e., malleus, incus, and stapes). The model ear-canal input impedance $Z_{in}$ is related to its middle-ear impedance $Z_{me}$ by elements of the ear-canal transmission matrix (Lewis & Neely 2015): $Z_{in} = Z_{me} + Z_{in,m} + Z_{in,c} + Z_{in,e} + Z_{in,p} + Z_{in,n} + Z_{in,g}$. Impedance Estimate: The model middle-ear input impedance $Z_{in}$ may be calculated from the ear-canal impedance $Z_{in}$ by, in effect, inverting the above equation: $Z_{in} = \sum_{n=1}^{n} Z_{in,n}$.

RESULTS

Model results were obtained by fitting parameters values to measured ear-canal impedance and reflectance. The model results appear to fit the measured impedances about equally well for all conditions. Agreement between measured and modeled ear-canal impedance provides a visual indication of the quality of the model fit to the measured data.

As with absorbance, agreement between estimated & modeled middle-ear impedance is better for the normal and empty conditions compared to the partial and full conditions, and the model impedance appears to be a smooth approximation of the estimate.

DISCUSSION

The main effect of increased fluid in the ear full of effusion as compared to the normal ear is an increase in the magnitude of the middle-ear impedance by about a factor of 10.

The two wet conditions (partial and full) appear to be grouped separately from the two dry conditions (normal and empty) by an elevation in magnitude and a shift to lower frequency of the resonant frequency of the cochlear KRM branch. At low frequencies, the modeled middle-ear impedance is dominated by the stiffness of the ossicular branch.

CONCLUSIONS

• Middle-ear impedance estimates calculated by inversion of the ear-canal transmission matrix provides a good description of the measured data.
• The effect of OME effusion volume on ME impedance is to increase its magnitude as effusion volume increases. The impedance magnitude with full effusion is about 10 times normal.
• ME impedance not only helps describe WAI measurements, it may also improve diagnostic predictions of middle-ear status based on those measurements. Further analyses will explore this.

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