Quantitative Assessment of Otitis Media with Effusion with Scanning Laser Doppler Vibrometer - A Preliminary Study

Ethan Soemantri, Ke Zhang, Junfeng Liang, Bin Zheng, Rong Gan, Chenkai Dai

University of Oklahoma, Norman OK 73019

Funding: University of Oklahoma Faculty Fund and LSAMP Grant

ABSTRACT

Otitis media with effusion (OME) is a common middle ear inflammation for preschool-age children, with the presence of fluid in the middle ear cavity (MEC). Although the biomechanical abnormalities induced by OME has been evaluated by many studies through measuring the vibration pattern of the tympanic membrane (TM), the precise and quantitative assessment of severity at different stages of OME is still not fully achieved, and the diagnosis still largely depends on the subjective rating of physicians. To provide reliable and objective evidence for the diagnosis, we developed a new algorithm to process the full-field TM surface motion data acquired by scanning laser Doppler vibrometer (SLDV). The frequency bands and areas on the TM highly sensitive to the effusion amount and viscosity in the MEC were identified.

METHODS

1. The OME was simulated by injecting water of different volume (0.2, 0.4, 0.6 and 0.8 ml) or Intralipid solution of different concentration (1%, 5% and 10%) into the MEC of two human cadaver ears, to separate the influence of volume and viscosity of the fluid. Then, the full-field surface motion of the TM in response to 90 dB sound pressure across the frequency range of 200~8000 Hz was recorded by SLDV.

2. Then we removed the scanning points located on the outermost layer for 2 times successively (Fig. 1), to ensure that most of the scanning points were within the range of the TM.

3. To reduce the noise and recover the deflection shape of the TM, a robust and automatic smoothing algorithm was used to process the displacement data at each frequency. We firstly applied this algorithm on a finite element method computed deflection shape of TM with Gaussian distribution noise. After verifying the effect of smoothing algorithm numerically, we smoothed all the deflection shapes of the TM across all the frequencies (Fig. 2).

4. For the data of experiment with changing fluid volume in the MEC, the mean displacement of the whole TM across the frequency range of 200~8000 Hz was compared with that of the frequency range of 1900~3900 Hz which has high correlation with the fluid volume in the MEC. Similarly, for the data of experiment with changing fluid viscosity, we made a comparison between frequency range of 200~8000 Hz and 600~1000 Hz which has high correlation with the Intralipid concentration.

5. For every sampling point on the TM, we identified the 8 nearest points surrounding it, and calculated the mean displacement of the area consisting of the 9 points, then find out the areas on the TM having greatest variation corresponding to the changing volume and concentration .

RESULTS

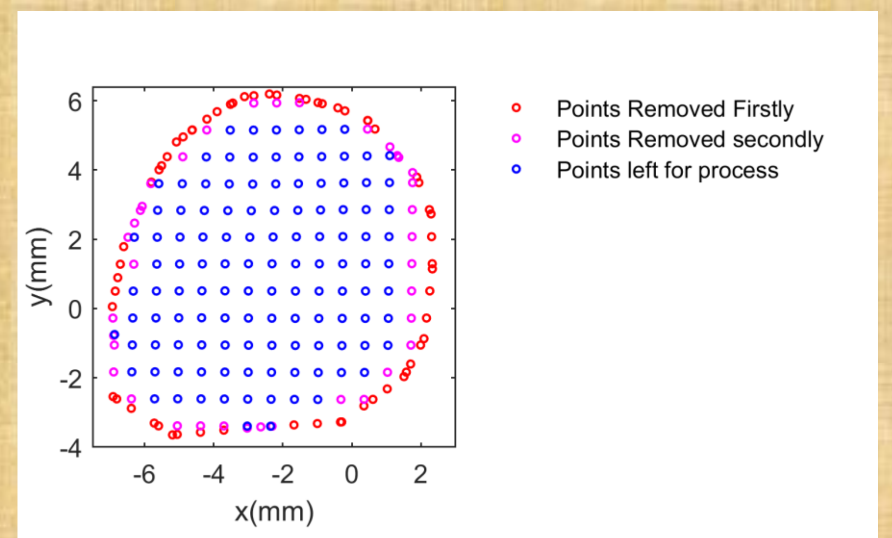

Fig. 1 Illustration of the removing of outermost scanning points for 2 times successively.

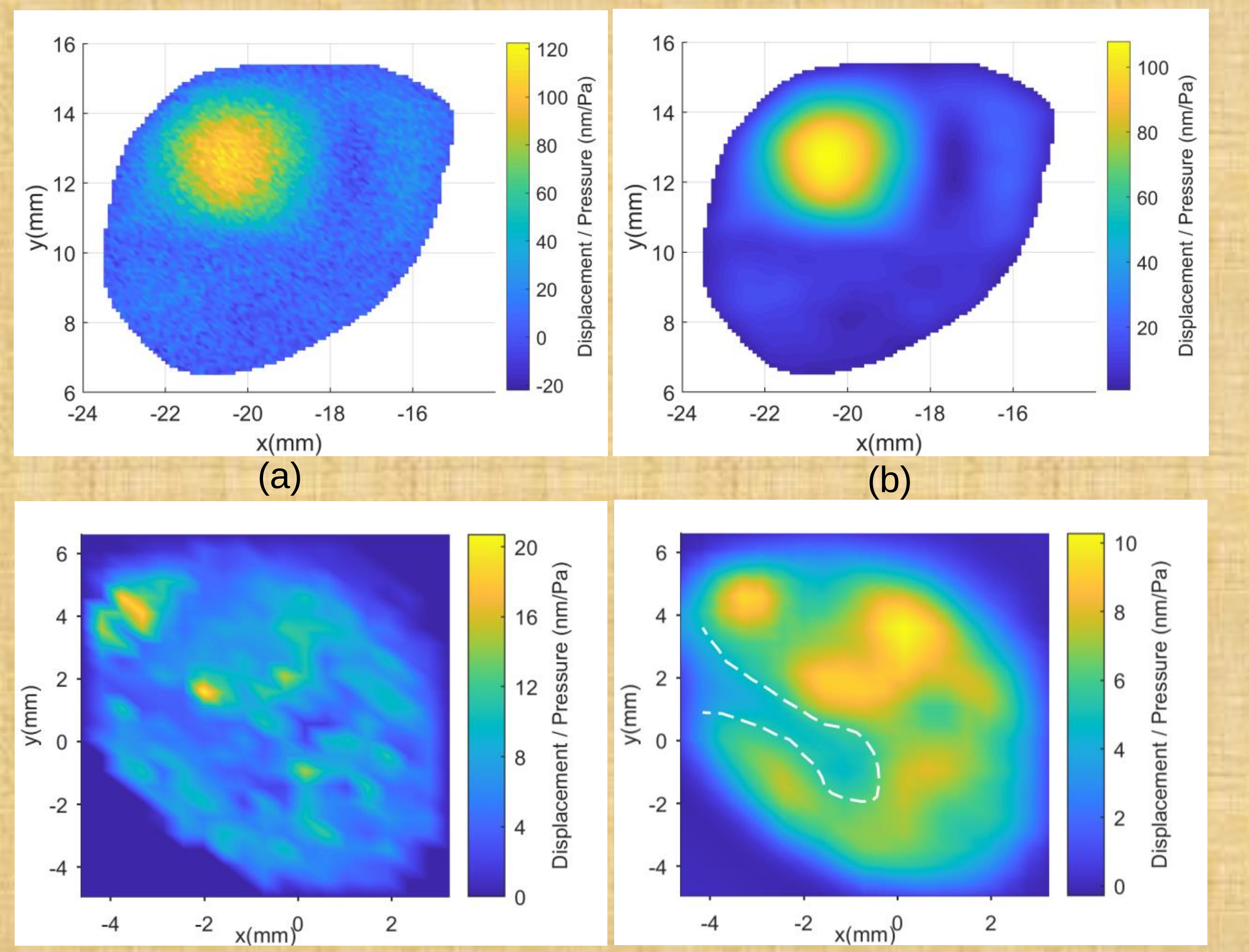

Fig. 2 Illustration of applying a robust and automatic smoothing algorithm on the deflection shapes of the TM, which shows (a) computed defection shape with Gaussian distribution noise, (b) computed defection shape after smoothing, (c) deflection shape of TB-L at 1381.25 Hz before smoothing, and (d) deflection shape of TB-L at 1381.25 Hz after smoothing.

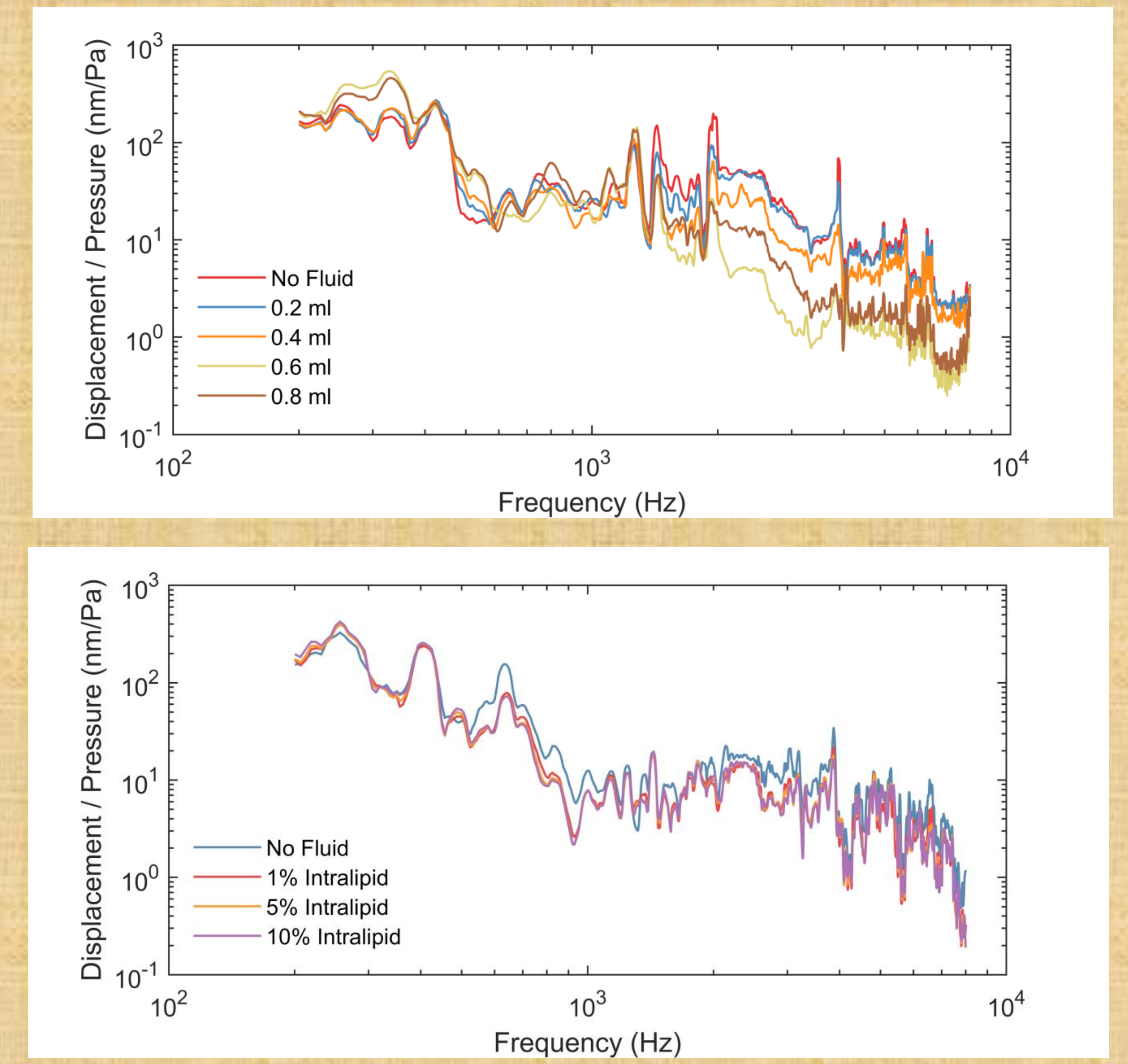

Fig. 3 Averaged whole TM displacement-frequency curves in response to 90 dB SPL sound in the ear canal when (a) the volume of fluid in the MEC changed from no fluid to 0.8 ml and (b) the viscosity of fluid in the MEC changed from 1% to 10% with no fluid condition as reference. It can be seen that the displacement of 1900~3900 Hz has high correlation with the fluid volume in the MEC and the displacement of 600~1000 Hz has high correlation with the Intralipid concentration.

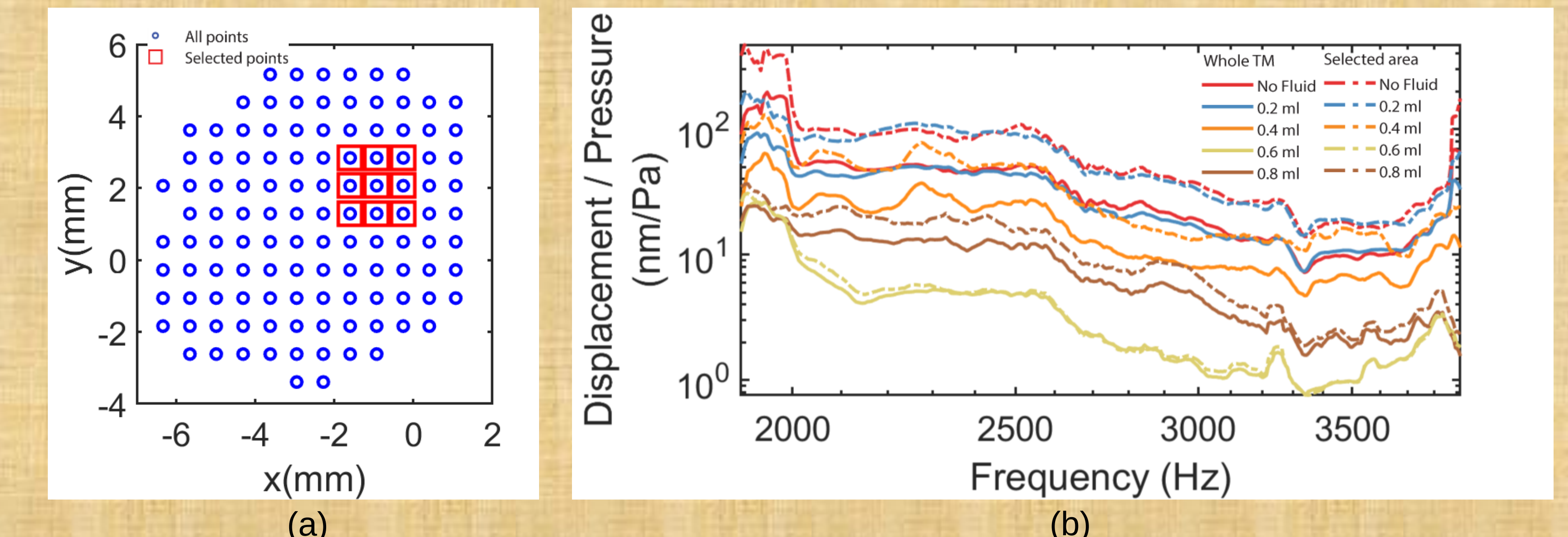

Fig. 4 The position (a) and displacement (b) of the whole TM and selected area which has the greatest variation with respect to the changing fluid volume in the MEC, in the selected frequency range of 1900~3900 Hz.

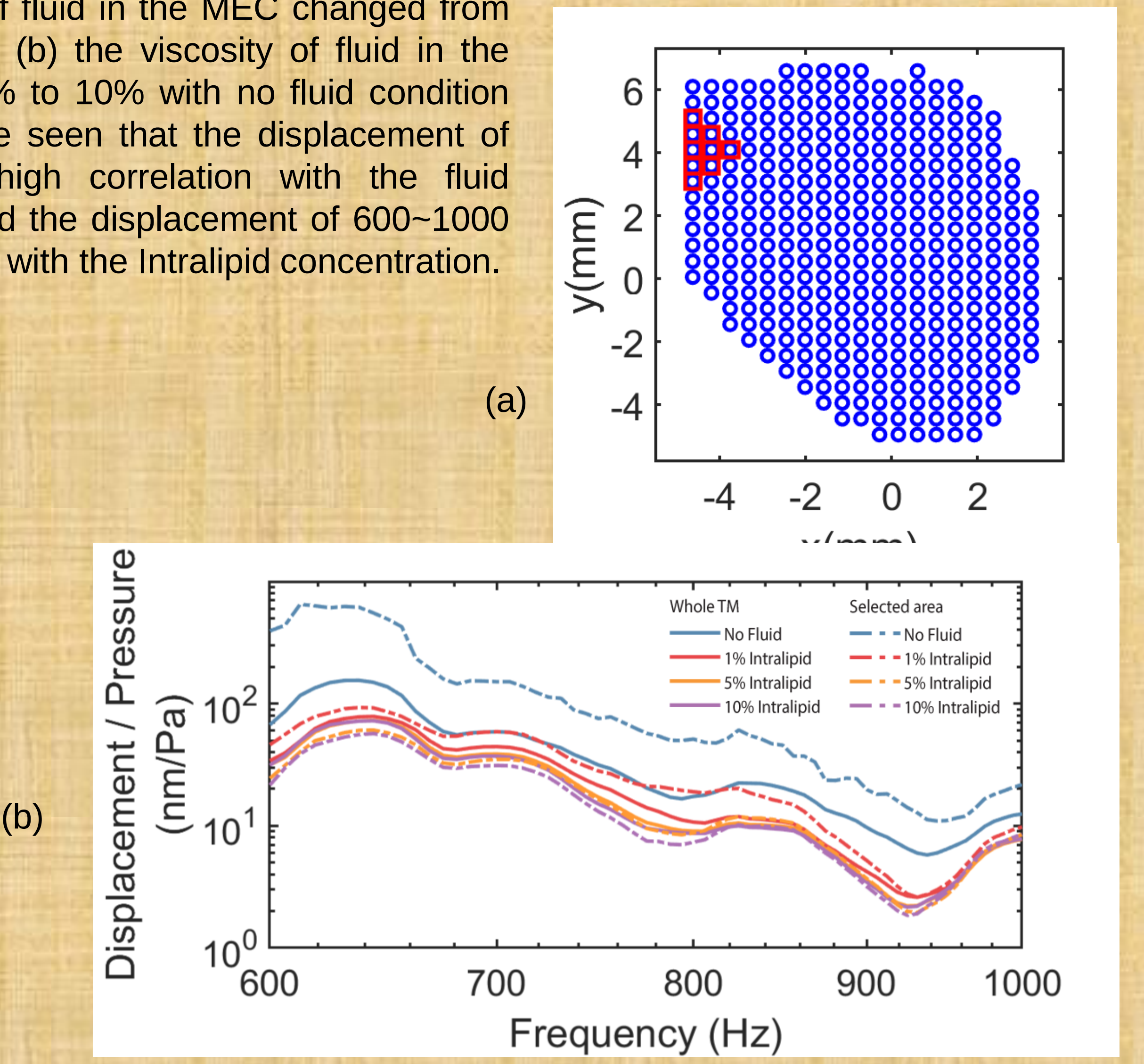

Fig. 5 The position (a) and displacement (b) of the whole TM and selected area which has the greatest variation with respect to the changing Intralipid concentration, in the selected frequency range of 600~1000 Hz.

Table 1 The correlation coefficient between the mean displacement of the TM and the volume of fluid in the MEC.

	Correlation coefficient over 200 to 8000 Hz	Correlation coefficient over 1900 to 3900 Hz
Displacement/Pressure (nm/Pa)	-0.854	-0.994

Table 2 The correlation coefficient between the mean displacement of the TM and the Intralipid concentration of fluid in the MEC.

	Correlation coefficient over 200 to 8000 Hz	Correlation coefficient over 1900 to 3900 Hz
Displacement/Pressure (nm/Pa)	-0.535	-0.650

CONCLUSIONS

1. The smoothing algorithm can reduce the noise level and recover the deflection shape of the TM, which is ready for further processing.
2. The displacements of 1900~3900 Hz and 600~1000 Hz have high correlation with the fluid volume and viscosity respectively.
3. The areas on the TM having higher sensitivity to the volume and viscosity of the fluid in the MEC can be identified by the algorithm.
4. The new algorithm and detection scheme developed in this study are promising to provide a reliable approach to accurately detect and assess OME at different stages with more future measurements and validation analysis.

Acknowledgements

This work was supported by University of Oklahoma faculty startup fund and National Science Foundation OK-LSAMP Program Grant No. HRD-1911370 OK-LSAMP

References

[1]. Zhang X, et al., JARO. 15(6):867-881,2014
[2]. Dai C, Gan RZ, Hear Res. 243(1-2):78-86, 2008
[3]. Gan R, Jiang S,J Biomech Eng. 141(9), 2019