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EFFECTS OF MENIERE'S DISEASE ON THE HEARING SENSITIVITY

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Abstract. *Meniere's disease is a disorder of the inner ear characterized by vertigo, tinnitus and hearing loss especially at low frequency range. The cause of this disease has not been clearly revealed. However, it is known that the increase of endolymphatic pressure due to endolymphatic hydrops is the main cause. In this paper, normal model and Meniere model denoted the Meniere's disease are modeled using a 3D finite element model simulating a human auditory organ and simulate two models in air conduction and bone conduction. The velocity of basilar membrane is compared and analyzed and it is confirmed that hearing loss occurs in the low frequency range.*
Keywords: Meniere's disease, Hearing loss, Basilar membrane, Cochlea, Pre-stress

1. **Introduction.** Meniere's disease is reported by Prosper Meniere for the first time [1,2]. Its symptoms are known as vertigo, tinnitus, hearing loss at low frequency range [3]. The exact cause of Meniere's disease is not known, but scientists believe that it is caused by changes of fluid pressure in the inner ear. In other words, increasing of the endolymphatic pressure in scala media (SM) changes the stiffness of the basilar membrane (BM) so that it affects the hearing sensitivity [4].

Interestingly, there are two types of hearing process, namely air conduction (AC) and bone conduction (BC) [5]. Briefly, sound propagates through the air on air conduction and through the bone vibration on bone conduction. There have been many studies about the Meniere's disease in AC mechanism. However, there has no study about the effect of the Meniere's disease on the BC hearing.

In this paper, hearing loss in low frequency range caused by Meniere's disease will be analyzed using 3D finite element (FE) model in AC hearing as well as BC hearing.

2. Method.

2.1. **Finite element model.** In order to better understand the Meniere's disease, a 3D FE model was developed. The model is composed of the middle ear (ME) and inner ear. The ME is composed of tympanic membrane, ossicles, and ligaments while the inner ear is composed of membrane, fluid, and bony structure.

Specifically, the geometry of the inner ear was assumed to be straight-tapered box shape different from the coiled shape in reality. However, it is known that this simplification does not affect the BM motion [6]. The cochlear fluid is assumed to be perilymph because the SM containing endolymphatic fluid is combined with scala vestibule (SV).

The BM, which is the significant component to hear a sound, was modelled with orthotropic bending stiffness varying along the length from 0.31 GPa to 0.11 GPa. Detailed mechanical properties of the components can be found in the previous study [7].

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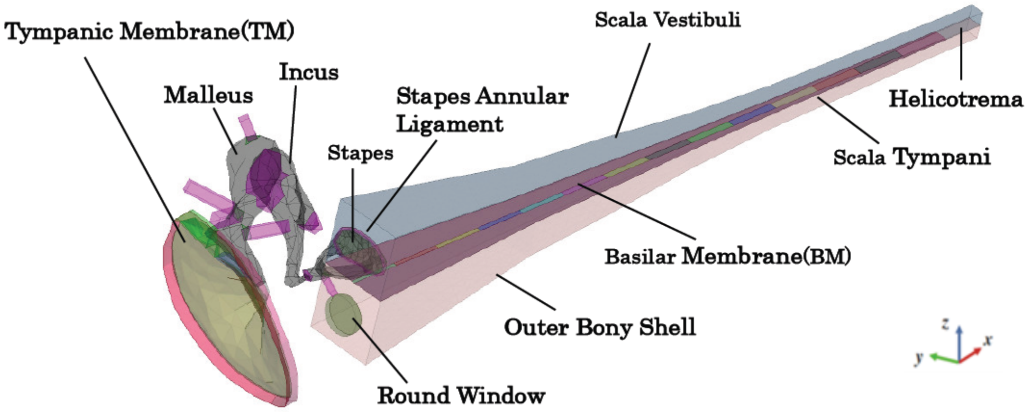

Figure 1. 3D FE model of the middle ear and inner ear. For better visualization, some elements for the fluid are not shown, and bony shell is shown as transparent component.

Figure 2. Deformed shape of the BM due to the pre-stress. The deflection is about 3.2e-6 mm at basal part and 0.188 mm at apical part. The figure has increased scale for better understanding.

2.2. **Simulation of Meniere's disease.** A commercial software, ACTRAN (FFT, Belgium), was used for FE analysis. The simulation was performed in the frequency domain. To make consistent condition with Meniere's disease, the following two steps were carried out.

1) Static pressure (10 Pa) was applied on the top surface of the BM. The static pressure in the frequency domain was implemented by given low frequency such as 1 Hz. This condition is consistent with the pre-stressed BM due to the endolymphatic hydrops in Meniere's diseased patient.
2) The deformed shape of the BM due to the static pressure (step 1) was applied as a new boundary condition for a dynamic simulation. With the displacement boundary condition, AC and BC were simulated by applying dynamic unit pressure on the tympanic membrane, and applying sinusoidal displacement boundary condition on the bony surface and the end of the ligaments attached to middle-ear ossicles, respectively (See Figure 2). The magnitude and direction of displacement for BC stimulation was 1 μm in the z-direction (perpendicular to the BM surface).

The BM velocities corresponding to the input frequency in AC and BC were calculated on 40 nodes on the center of top surface of the BM. The simulated frequency range was specified from 60 Hz to 5000 Hz. On AC, the BM velocities are normalized by stapes velocity (Equation (1)). On BC, the difference between BM velocities and bone velocity is normalized by bone velocity (Equation (2)).

$$\text{Normalized BM velocity (AC)} = \frac{\text{BM velocity}}{\text{Stapes velocity}} \tag{1}$$

$$\text{Normalized BM velocity (BC)} = \frac{(\text{Bone velocity}) - (\text{BM velocity})}{\text{Bone velocity}} \tag{2}$$

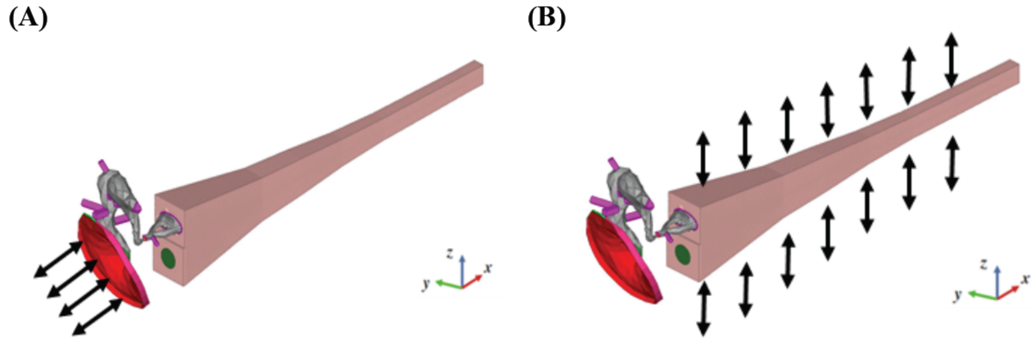

Figure 3. (A) A unit dynamic pressure on a tympanic membrane for AC stimulation and (B) sinusoidal displacement boundary condition for BC stimulation. The magnitude and direction of the displacement were 1 μm in z-direction (normal to the BM surface).

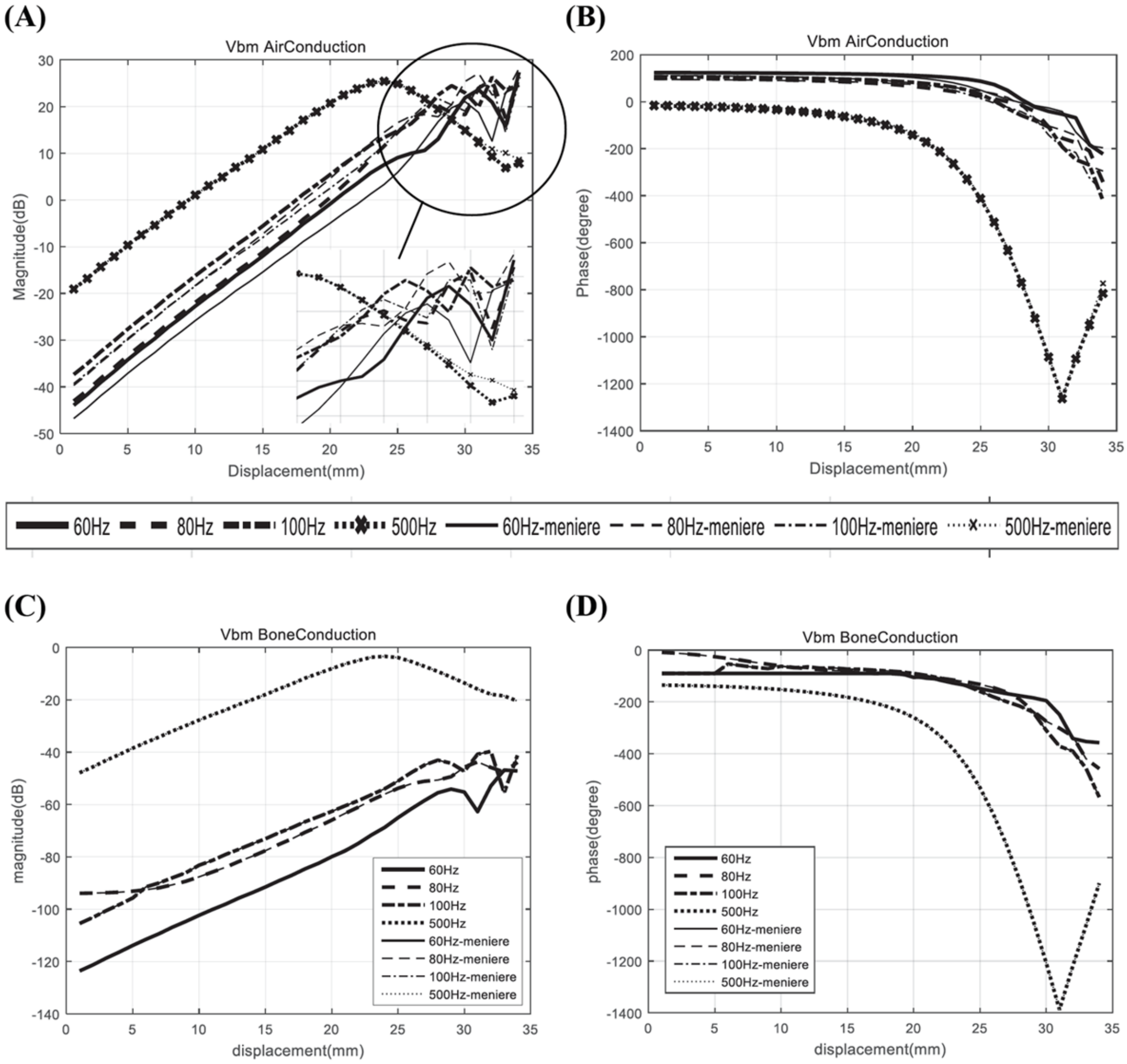

Figure 4. (A) Magnitude and (B) phase of the BM velocities on AC. (C) Magnitude and (D) phase of the BM velocities on BC.

3. **Results.** Using the FE model, both of normal and Meniere conditions were simulated by AC and BC stimulations. Figure 4 shows the comparison of the BM velocity with two different conditions: normal and Meniere. The normal and Meniere conditions were represented by solid and dotted lines, respectively.

As shown in Figure 4(A), up to 100 Hz, pre-stress for Meniere condition decreases the BM velocities in comparison of those of normal condition in AC stimulation. Furthermore, the best frequency (BF) position [8] which has the maximum BM velocity was slightly moved to the basal part up to 100 Hz. Table 1 summarized the movement of BF position. However, from 500 Hz, Meniere condition cannot affect the BM velocity.

On the contrary, as shown in Figures 4(C) and 4(D), the BM velocities with Meniere condition on BC stimulation were consistent with those with normal condition. In other words, there was no movement of the BF position due to the Meniere's disease on BC stimulation.

Table 1. Movement of the BF position on AC stimulation. The BF position is determined by the distance between the basal part and the point where the maximum BM velocity is shown.

Movement of BF position on AC stimulation		
Frequency (Hz)	Normal model (mm)	Meniere model (mm)
60	31	30
80	28	27
100	29	28
500	24	24

4. Discussion.

As shown in Figure 4(A), in AC stimulation, the magnitude of BM velocity was slightly decreased, and the BF position was moved to basal part at low frequencies below 100 Hz. However, the amount of decreased BM velocity was not significant (within 5 dB). Therefore, according to the simulation, a Meniere's disease patient can hear a low frequency sound. However, the frequency is misunderstood by one's brain as a little higher frequency sound.

Moreover, the effect of Meniere's disease on the BM velocity in BC stimulation was not observed. According to Békésy [9], the AC and BC mechanism is the same. Therefore, a specific sound frequency can be recognized the same frequency input by one's brain. However, according to the simulation results, Meniere's patients can hear two different frequencies sound with one specific frequency input. Therefore, they may feel vertigo or tinnitus due to Meniere's disease.

5. Conclusions.

In this study, we analyzed the hearing loss in both AC and BC at the low frequency range caused by Meniere's disease. Using 3D finite element model, Meniere condition was implemented by prestress on the BM corresponding to the increase of the endolymphatic pressure. Simulation results show the hearing loss from the Meniere conditions at low frequencies below 100 Hz in AC stimulation, whereas no effect from the Meniere condition in BC stimulation. Furthermore, there was no effect from the Meniere condition on hearing loss at high frequencies above 500 Hz in both AC and BC stimulations.

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