The study of endolymph flow and hair cell control analysis simulation model through electromagnetic fields

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Abstract

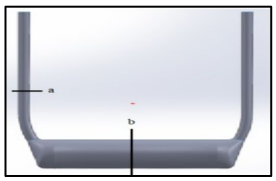
When rotational acceleration occurs in the body, the endolymph moves with velocity owing to rotational inertia, and the cupula is tilted by the force generated by the endolymph. When the cupula is tilted, hair cells are also tilted to create a sense of rotation. At the same time, a rotational signal is transmitted, and if the signal does not match the field of sight, various symptoms such as dizziness, nausea, and headache appear. To resolve the discrepancy between the rotational signal and the sight caused by the tilt of hair cells such as motion sickness, in this study, we developed a vestibular finite element (FE) simulation model to control the angle of hair cells in the cupula. The simulation model consisted of a straight (linear) model and a model identical to the actual shape (curved) model. A fluid velocity of around 0.2 Hz, which is associated with motion sickness, was applied to the model to bend the cupula. [1] A magnetic field was applied by positioning the coil along the three axes based on the cupula and a current is passed to generate a Lorentz force. By increasing or decreasing the current, the displacement moved by the cupula according to the magnetic field was measured. As a result, in both models, the displacement of the cupula tends to decrease when the current is increased.

Introduction

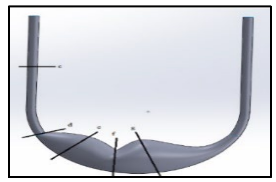
Motion sickness is a symptom of not being able to resolve the imbalance between vision and rotation felt by the vestibular system and causes discomfort or dizziness.[2] And symptoms of motion sickness can be alleviated by reducing the degree of hair cell deflection by causing the flow of the endolymph to act in the opposite direction. Since the endolymph is an ionic liquid, it can change the flow direction of the endolymph by the Lorentz force derived from the strength of the electromagnetic field and the electrode direction.[3] The purpose of this study is to develop a finite element (FE) simulation model of the vestibular system and analyze the endolymph flow pressure, velocity, and hair cell pressure and angle applied by an electromagnetic field through FE simulation to control the angle of hair cells in the cupula.

Methods

A model of the semicircular canal was created to implement the vestibular system. The simulation model consisted of a straight (linear) model and a model identical to the actual shape (curved) model. In the center of this model, cupula is inserted, and endolymph is filled to allow ion liquid to flow in one direction. At this time, the displacement of the cupula slope that occurs was the main focus of this study. The solenoid coil is located on the cupula side at the center of ampulla (Fig.1 (a)-b, (b)-d, e, f, g) and surrounds the ampulla and the utricle. The rotational speed and radius of the solenoid coil were adjusted based on the calculation value of the enamel coil with a diameter of 0.4 mm, and the strength of the internal magnetic field was changed by changing the current from 0 to 15 A. After that, the displacement that the cupula moves with the magnetic field was measured by increasing or decreasing the current.



(a)

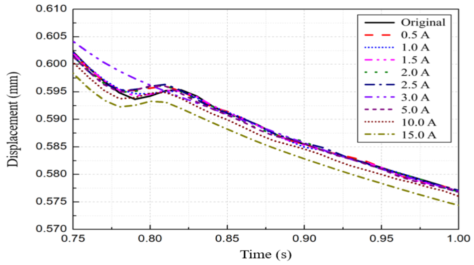


(b)

Figure 1. Linear Semicircular Canal (a) Experiment Optimization Linear Model, (b) Experiment Optimization Curved Model.

Results

In both models, the maximum displacement moved by the cupula decreased when the current increased. As the current increases, the falling pattern has the shape of a decreasing first-order graph. Overall, there was a difference in amplitude in the graph, and the shape was maintained. In the linear model, when the original and 15A currents flowed, the difference was 1.41%. In the case of the curved model, when the original and 15A currents were applied, the difference was 1.719%. When the linear model is compared with the 15A simulation, the reduced displacement of the cupula is 0.02259mm and that of the curved model is 0.0281mm. Both values have an error of 19.69%. The factors that can have an error are the fluid vortex flowing in the above-mentioned curved model and the increase in the flow velocity owing to the rotational moment. Although there is a difference in values, the decrease in cupula displacement according to the increase in current is identical.



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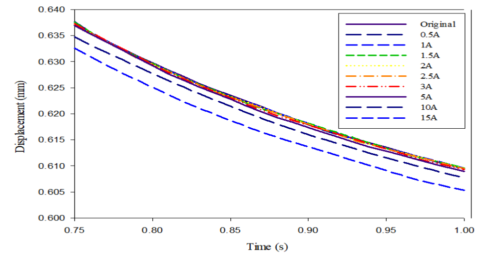

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Figure 2. (a) Linear Model and (b) Curved Model Cupula Displacement due to Magnetic Field Change

Discussion and Conclusions

When the intensity of the magnetic field in the Z-axis direction was increased with an electric current, the inclination angle of the cupula was reduced. The reason for this is gravity and vortex and has the same tendency that the Z axis-oriented magnetic field and increased magnetic field strength most affect the reduction in the displacement. These results can potentially be used for the treatment of vestibular system diseases, such as a non-invasive mechanical motion sickness relief device.

Acknowledgments

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References

[1] Winther, F. Ø., Rasmussen, K., Tvete, O., Halvorsen, U., & Haugsdal, B. (1999). Static magnetic field and the inner ear: A functional study of hearing and vestibular function in man after exposure to a static magnetic field. Scandinavian audiology, 28(1), 57-59. [2] Brainard, A., & Gresham, C. (2014). Prevention and treatment of motion sickness. American family physician, 90(1), 41-46. [3] Ward, B. K., Roberts, D. C., Della Santina, C. C., Carey, J. P., & Zee, D. S. (2015). Vestibular stimulation by magnetic fields. Annals of the New York Academy of Sciences, 1343(1), 69-79.