3D FEM Model of Intact Human Middle Ear Compared to Lumped Mass Model and Experimental Results

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Summary. The human body can be considered by micro biomechanical systems and human middle ear is one of the smallest of those systems. In this abstract, finite elements method model and three degrees of freedom lumped mass model of human middle ear is proposed. Moreover in introduction it contains description of intact human middle ear.

Keywords: middle ear; stapes vibration; relaxation; ligaments modelling

Introduction

The human body can be considered as a set of micro biomechanical systems where human middle ear is one of the smallest of those systems. Human ear can be divided into three basic parts sequentially: external ear, middle ear and internal ear. Through auditory canal sonic waves reaches tympanic membrane which sets in motion three bones of a middle ear – the malleus, the incus and the stapes. The stapes transfers waves to the internal ear. Nest in semicircular canals mechanical vibrations are converted into nerve impulses. Over the years, many attempts have been made to create models of the human ear. The first study in this field was published in 1961 by Möller [1] where the first scheme of middle ear mechanism was proposed. Next, a similar model was investigated by Zwislocki [2]. In both publications, authors used an electrical circuit to analyse middle ear system. Currently, the most popular models of human ear are created by means of finite elements method, rarely as lumped mass models. Due to microscopic structure of human middle ear, examinations are extremely difficult. Moreover experimental studies must be carried out on the human temporal bone, therefore the amount of research is limited. For the above reasons, it is necessary to create models of the middle ear and their validation, because the tests carried out on them are limited only by the computing power of computers. Research on human ear models could lead to breakthroughs in the field of laryngology and otolaryngology.

Results and Discussion

The intact human middle ear lumped mass model is presented on Figure 1(a). There are three masses in the model: m_m, m_i and m_s. Each mass corresponds to one of the bones of the human middle ear: m_m – the malleus, m_i – the incus and m_s – the stapes. All masses are connected to each other by springs and dampers that correspond to joints, ligaments and tendons in s human middle ear. In this case presented here, the human middle ear with the Kelvin–Voigt type of viscoelasticity is used for analysing. Parameters as stiffness and damping coefficients of the middle ear used in numerical simulations were taken both from experimental validation and literature. Figure 1 (b) shows meshed Finite Elements Method (FEM) model of the intact human middle ear to compare numerical results. This model was created by Micro CT scanning of the human middle ear. Three bones: the malleus, the incus and the stapes and the eardrum was separated and then they have undergone a scanning procedure. Parts that were obtained were connected in Computer Aided Design (CAD) software. Moreover simplified ligaments and tendons were created in CAD and were connected to the bones. At the end, a simplified cochlea and oval window was made in order to connect the stapedial annular ligament (SAL). Material data for the Finite Elements Model of intact human middle ear was taken from the literature [4].

(a) (b)

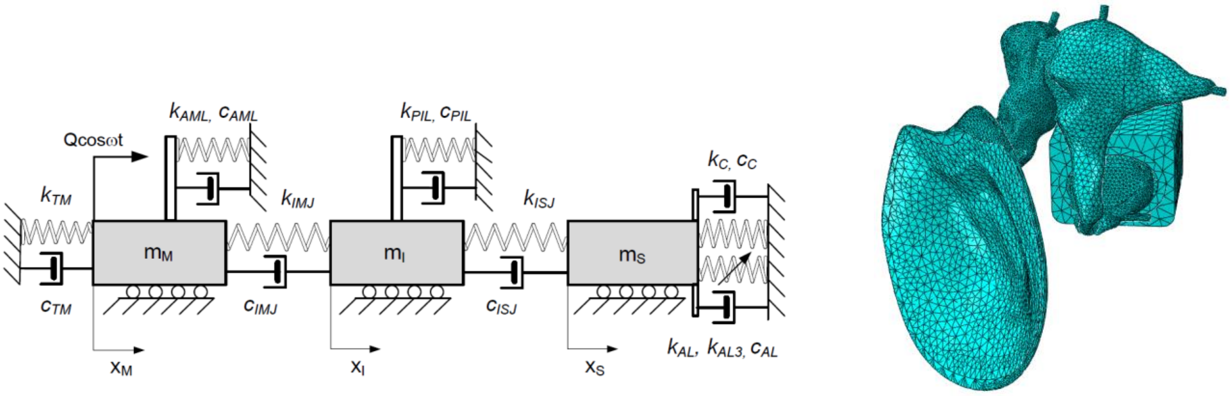

Figure 1: Models of intact human middle ear. (a) 3 degrees of freedom (dof) lumped mass model [3], (b) finite elements method model.

The most demanding aspect of Finite Elements Method modelling was setting the mesh in such a way that the objects do not interpenetrate during the simulation of motion. The next difficulty is determining the time of stabilization for the system. Another demanding task is to set appropriate boundary conditions of the system which allow proper reproduction of the occurring movements in the middle ear as a result of being forced by an acoustic wave onto the eardrum. The FEM model is compared with the experiment results to assess its correctness .

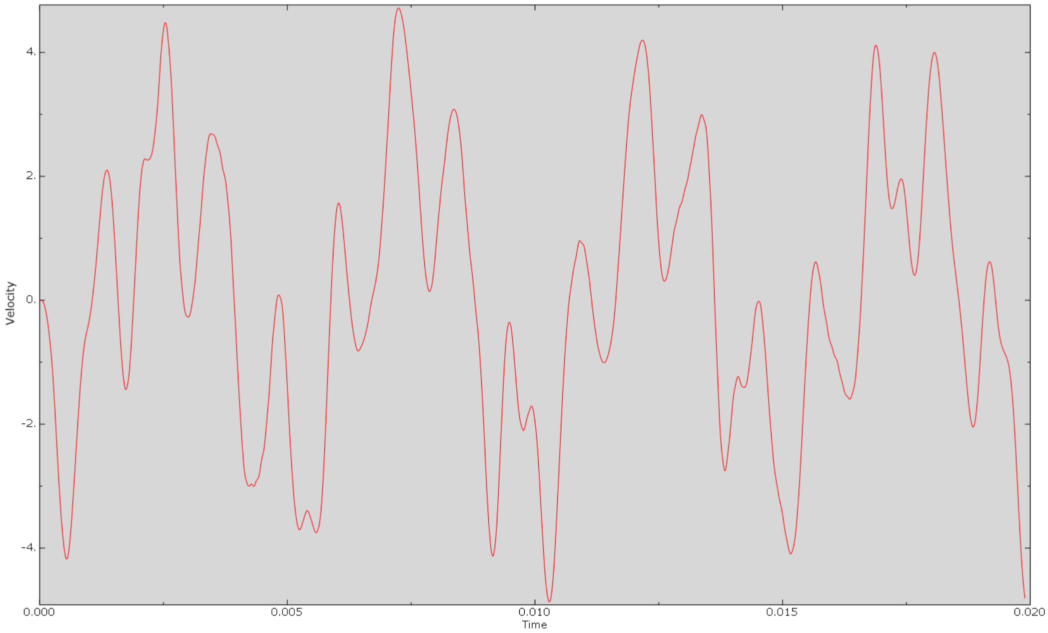

Figure 2:Function of velocity versus time measured on stapes footplate for not-steady state of vibrations in Finite Elements Method model of intact human middle ear for the frequency equal to 200Hz.

In Figure 2, function of velocity versus time for not-steady state of vibrations of human middle ear in FEM model can be observed. For the undefined Rayleigh damping parameters for human middle ear the rumble phenomenon can be observed. By using the appropriate damping parameters velocity of the stapes can be obtained and compared to the experimental data.

Conclusion

A novelty in the Finite Elements Method model is obtaining parts by the Micro CT scanning, which gives an accurate representation of the geometry of the bones of the human middle ear. On the basis of the lumped mass model of intact human middle ear and experimental results, correctness of the FEM model is approved. For the FEM model of the human middle ear, the appropriate material parameters and the Rayleigh's damping parameters allow to shorten the calculation time and obtain results with a similar value to the results obtained experimentally. In the future FEM model will be used to develop model of the middle ear with active implant.

Acknowledgment:

The research was financed in the framework of the project Nonlinear effect in middle ear with active implant, no.2018/29/B/ST 8/01293, funded by the National Science Centre, Poland.

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