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Commentary Open Access

Necessity of Applying Viscoelastic Constitutive Model in Numerical Evaluation of Implantable Hearing Devices

Jing Zhang[1], Jiabin Tian[1], Na Ta[1], Xinsheng Huang[2] and Zhushi Rao[1*]

[1]*Department of Shock and Noise, State Key Laboratory of Mechanical system and Vibration, Shanghai Jiaotong University, Shanghai 200240, China*

[2]*Department of Ear-Nose-Throat, Zhongshan Hospital, Fudan University, Shanghai 200032, China*

[*]**Corresponding author:** Zhushi Rao, Institute of Vibration, Shock and Noise, State Key Laboratory of Mechanical System and Vibration, Shanghai Jiaotong Univesity, Shanghai, China, Tel: 86-13817744008; E-mail: zsrao@sjtu.edu.cn

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Commentary

Middle ear implants (MEIs), a small device that directly stimulate the ossicular chain to provide compensation for hearing impairments, are mainly designed for the patients with moderate to serve sensorineural hearing loss. Compared with conventional hearing aids, MEIs can realize a better compensation performance, such as higher gain at high frequency, better speech recognition and lower acoustic feedback. To better design and optimize MEIs, finite element method has become an important method to study the dynamic response of normal and impaired ears and analyze the characteristic of actuators that are coupled with human auditory system. So it is necessary to develop an accurate finite element model to study the dynamic response of the human ear and evaluate the compensation performance of implantable hearing devices.

Some high quality experiments indicated that the soft tissues in the middle ear exhibit viscoelastic material properties [1]. Unlike purely elastic materials, viscoelastic materials exhibit both elastic and viscous behavior. However, in the previous models, soft tissues were all assumed as linear elastic material and Rayleigh damping was adopted to describe the energy dissipation. As a result, considerable errors exist between the analytical results and experimental data at high frequency. This is because energy dissipation of viscoelastic materials in dynamic analysis is determined by the viscoelastic constitutive relation, which is different from the Rayleigh damping. So several viscoelastic constitutive models have been proposed to describe the stress-strain relation of viscoelastic materials. Among these models, the Wiechert model is applicable to the description of the viscoelastic behaviour of soft biological tissues [2]. And the Wiechert model, which combines many Maxwell models and a Hookean spring in parallel, can adopt the Prony series to express the relaxation modulus of soft tissues in time domain and also easily convert it into frequency dependent complex modulus.

Zhang et al. built an integrated finite element model of the human ear considering viscoelastic properties to investigate the efficiency of the forward and reverse mechanical driving with MEIs [3]. To accurately reflect the biological material properties of soft tissues, viscoelastic properties of soft tissues including tympanic membrane, incudomalleolar joint, incudostapedial joint, stapedial annular ligament and round window were taken into consideration in constructing finite element model of the human ear. Zhang et al. investigated the effects of viscoelastic properties of soft tissues on the dynamic response of the human ear by comparing the Rayleigh damping model and the viscoelasticity model and also studied the change in the performance of implantable hearing devices due to the consideration of the viscoelastic properties [4]. Compared with the displacement response of stapes footplate under the sound excitation of 90 dB SPL derived from Rayleigh damping model, the viscoelasticity model gives a high displacement output above 3000 Hz and shows a better agreement with published experimental data. Furthermore, based on the coupled model of human ear and MEI, the equivalent sound pressure (ESP) and power consumption, which can be chosen as the metrics of MEIs' compensation performance [5], are calculated and the results indicate that the introduction of viscoelasticity would decrease ESP obviously and increase the power consumption of actuator at high frequency.

MEIs are mainly adopted to treat sensorineural hearing loss which usually occurs at high frequency and the frequency range of many products on the market for hearing compensating has reached 10 kHz. What's more, the experimental data have confirmed the viscoelastic properties of soft tissues and analytical results have shown that taking into account of the viscoelastic properties mainly affects the dynamic response of human ear and the evaluation of MEIs at high frequency. So it is suitable and necessary to apply viscoelastic constitutive model to evaluate the performance of implantable hearing devices.

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