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DYNAMIC ANALYSIS OF FLUID–STRUCTURE INTERACTION OF ENDOLYMPH AND CUPULA IN THE LATERAL SEMICIRCULAR CANAL OF INNER EAR*

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Abstract: The semicircular canals, composed of lateral, anterior and posterior canals in the inner ear, are the sensors of equilibrium during head rotation movements in the three-dimensional space. Semicircular canals are filled with endolymph confined by the cupula. The study of the relationship between endolymph flow and cupular deformation is important in revealing the semicircular canals biomechanical behavior. To date, there are few studies focusing on the transient endolymph flow and cupular deformation in response to a head rotation motion. The lateral semicircular canal is mainly responsible for the sense of the horizontal rotation movement. In order to figure out the intricate dynamics in the lateral semicircular canal during the head rotation motion, the time evolutions of both endolymph flow and cupular deformation are analyzed in this article by using a fully coupled fluid–structure interaction model. It is shown that the cupular deformation provides cues for understanding the physiology of sensing the head rotation.

Key words: fluid–structure interaction, endolymph, cupula, finite element method

Introduction

Three semicircular canals are placed orthogonally in the inner ear, with the lateral canal roughly in the horizontal direction and the anterior and posterior canals in vertical directions, and they are the primary sensors for angular motions. The semicircular canals are filled with water-like liquid, endolymph. The endolymph flow used to be considered as a creeping flow in a single uniform toroidal duct[1] or a fully developed Poiseulle flow in a straight tube[2]. The previous findings were mainly related with the semicircular canal fluid mechanics but without considering the importance of cupula.

The cupula is a gelatinous partition sitting on the top of the crista and reaching to the roof of the ampullary wall. The crista is a ridge of neuroepithelial cells that traverse the ampullated end of each membranous semicircular canal. It is shown that the deformation of cupula plays an important role in the perception of the angular motion. Steinhausen (1933) considered the dynamics of the cupula-endolymph system as a highly damped torsion pendulum through a mathematical description for the sensation of the angular motion. However the damping coefficient and the time constants of the model were not determined.

The semicircular canal morphology has a great effect on the endolymph flow dynamics[3].An analysis of the endolymph flow including the effects of the utricle and the cupula was made by Van Buskirk[4]. The fluid interactions between all three ducts and the

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