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Biomechanical study of the vestibular system of the inner ear using a numerical method

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Abstract

The inner ear has two main parts, the cochlea, dedicated to hearing, and the vestibular system, dedicated to balance. Dizziness and vertigo are the main symptoms related to vestibular disorders, which commonly affects older people. In order to eliminate these symptoms a vestibular rehabilitation is performed; this consists in a range of movements of the head, known as maneuvers, performed by a clinical professional. This procedure does not always work as expected. The aim of this work is to contribute to a better understanding on how the vestibular system works. This knowledge will help in the development of new techniques that will facilitate a more efficient rehabilitation. In order to achieve that goal, a three-dimensional numerical model of the vestibular system, containing the fluids which promote the body balance, was constructed. The vestibular components will be discretized using the finite element method and the fluid flow will be analyzed using the Smoothed Particle Hydrodynamics
The results obtained with the numerical model of the semicircular canal built to study the rehabilitation process are presented and compared with other authors. The solution achieved is similar with literature.

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Keywords: Inner ear; vestibular system, numerical methods

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1. Introduction

The vestibular system is located in the posterior region of the inner ear and is a key to our sense of balance and movement. Any changes in this system can cause symptoms such as dizziness, blurred vision, imbalance and nausea, which are vertiginous syndrome indicators. Vertigo is reported as one of the most common symptoms in the world. It is considered the third most frequent complaint in medicine, transmitting a sense of inadequacy and insecurity[1].

1.1. Vestibular System

The vestibular sensory organs are located in the petrous part of the temporal bone, connected to the cochlea, and consists of two labyrinths, the membranous labyrinth and the bony labyrinth. The membranous labyrinth is lodged within the bony labyrinth and they have the same general shape. In order to support the membranous labyrinth there is perilymphatic fluid and connective tissue between both labyrinths. The membranous labyrinth is filled with endolymphatic fluid (resembles intracellular fluid), while the bony labyrinth consists of three semicircular canals (SCCs), the cochlea, and a central chamber called the vestibule. In Fig. 1 it is possible to see five sensory organs of that labyrinth: the membranous portions of the three SCCs (called ampullas) and the two otolith organs, the utricle and saccule[2].

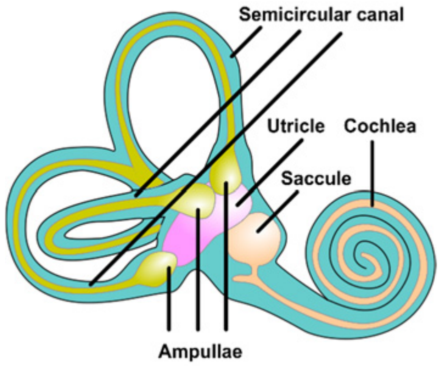

Fig. 1. Vestibular system.

The fluid structure interaction simulation of the endolymph and cupula during head rotation allows the measure of the fluid interactions between the three ducts and the displacement of the cupula during the move. This model could be considered useful to understand the physiological and mechanical aspects of semicircular canal, and it could be described as a band-pass filter relating the displacement of the cupula to the angular velocity of the head[3]. In Fig. 2 it is possible to observe the detailed structure of the hair cells inside the ampulla of the SCC.

The semicircular canals indicate rotational movements, and the otoliths, located inside the utricle and the saccule, indicate linear accelerations.

The mechanical properties of the otolith particles are important to understand and interpret vestibular neurophysiological behavior. The development of a numerical model will permit to calibrate those properties and also will allow to investigate the orientation and shape of the otolith maculae. Another layer of this structure is the specialized hair cells, contained in the gel layer, which are biological sensors that convert displacement, due to head motion, into neural firing.

The hair cells of the saccule and utricle register forces related to linear acceleration. These cells are located on the medial wall of the saccule (related to horizontal movements) and the floor of the utricle (associated to vertical movements)[4].

The vestibular system sends signals primarily to the neural structures that control eye movements and to the muscles that contribute to keep upright position. The projections to the former provide the anatomical basis of the vestibule-ocular reflex (VOR), which is required for clear vision, and the projections to the muscles that control our posture are necessary to keep us standing[2]. Body balance results from a complex interaction between the vestibular system, eyes and gait.