Cupula dynamics under caloric stimulation of the semicircular canal

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Caloric stimulation of the semicircular canal (SC) is widely applied in studies of vestibular impairments. Barany (1906) suggested that caloric response of SC results from mechanism of endolymph convection due to density changes of endolymph and therefore depends on the action of gravity forces. However, the Skylab experiments (1983) showed that the caloric reaction of SC can take place even under microgravity. The studies of Scherer&Clarke (1985), Harada&Ariki (1985), Baumgarten et.al. (1985) considered the thermal expansion of endolymph to be a concurrent mechanism. The model of caloric response based on the buoyancy force due to density change in the endolymph induced by thermal stimulation was proposed by Gentine et al (1990,1991). It should be noted that the first qualitative model that took into account the effect of endolymph thermal expansion under local heating to analyze the properties of primary afferents was proposed by Gusev&Orlov (1977). However, these models failed to answer the question: which of the mentioned effects will be dominant under certain conditions. The purpose of present study was to account for the expansion and convection of endolymph and to determine under which conditions one mechanism dominates over the other. The consideration is based on the following model of SC (Kondrachuk&Sirenko, 1990): an isolated torus filled by a compressible viscous Newton liquid (endolymph); the torus interior is plugged by an elastic body (cupula), the cupula surface in contact with endolymph is supposed to be stretched along the plane of the canal cross-section; temperature (T) variation has a square-wave form; thermal-expansion coefficient of the SC walls is much smaller than that of endolymph; variation of the endolymph density is proportional to T. The analytical solutions of the model and their comparison with experimental data of Harada&Ariki (frog, 1985) resulted in the following. Under the action of heat the mechanics of cupula is governed by two flows caused by thermal expansion and convection of endolymph. Their contributions depend both on parameters of the heat stimulus (such as the heating rate, the size and arrangement of the heating source with respect to SC and the gravity vector), and on the SC parameters (endolymph viscosity, radii of the cross-section and curvature, great time constant, thermal conductivity). Note that direction of the first flow is determined by the temperature of the heater relative to endolymph, whereas direction of the convection flow also depends on orientation of the place of heating with respect to the gravity vector. For certain parameters of the heat stimulus and orientation of the gravity force relative to the SC, the term corresponding to endolymph motion due to its thermoexpansion will be of the same order of magnitude as the convection term. It may also happen that these terms are approximately equal in magnitudes and opposite in their signs; thus, the flow induced by the thermoexpansion of endolymph will be balanced out, in a characteristic compensation time, by the growing convection counterflow. The model demonstrates a good qualitative fit to the experimental data.