Abstract

The caloric test is a generally accepted method of assessing the peripheral vestibular system. Warm and cold water, or air, introduced into the external auditory canal elicits a degree of nystagmus which is recorded. Several mechanisms of action have been postulated to account for the nystagmic response. The earliest, by Barany, suggested a convection hypothesis with column shift of endolymph in response to thermal change.

Aims

We investigated the possibility of a novel mechanism to account for the caloric response: that of a change in the relative specific gravity of the cupula.

Study design

Five cupulae and their surrounding ampullary membranes were successfully harvested under microscopy from fresh wood pigeons, and individually sealed in test tubes filled with Plasmalyte solution. The test tubes were then immersed in a water bath at 21°C, 41°C, 51°C, 60°C and 80°C for 5 minutes. They were then removed from the water bath and inverted.

Methods

Changes in buoyancy of the cupulae were recorded on digital video.

Results

At 21°C, 41°C and 51°C all cupulae were seen to sink. At 60°C the cupulae consistently rose, and remained at the top of their containing test tubes.

Conclusion

We interpret these observations as demonstration that an alternative mechanism for the caloric effect may also be present, dependent on changes in the specific gravity of the cupulae at differing temperatures.

Introduction

The clinical assessment of the vertiginous patient requires a full history, thorough clinical examination and audiovestibular assessment supplemented with appropriate imaging. The caloric test is commonly performed to assess peripheral vestibular function. Water or air irrigated into the external auditory canal is believed to result in endolymph column shift within the lateral semicircular canal (SCC). This results in deflection of the cupula within the ampulla of the SCC, firing of the vestibular nerve and horizontal nystagmus (British Society of Audiology Guidelines 2010). However, studies in micro-gravity would suggest a partial response due to direct thermal stimulation of the ampullary nerve of the lateral SCC (Cohen 1963; Hood 1989; Scherer 1985).

In many species the cupula is an ovoid fibrogelatinous structure housed within the ampullary segment of the semicircular canal. It has been described as consisting of an upper part of dense fibrous tissue and a subcupular space of fibrillar anchoring elements (Tauber 2001). Because of the composition of the cupula, we postulated that a change in temperature may induce an alteration in its specific gravity in relation to endolymph, and that this might in part account for the caloric effect.

Method

All specimens were obtained fresh and not subjected to refrigeration at any stage. A temporal bone dissection was undertaken on 3 wood pigeons (Carnis 1930). The bony labyrinth was skeletonised and subsequently breached in order to harvest the membranous labyrinth. This consisted of the cupula housed within the membrane of the ampulla and semicircular canal in continuity. Five cupulae successfully harvested were maintained in their surrounding membrane and remained structurally intact. The cupula and surrounding ampullary membrane was separated as depicted in Figure 1. This cupula-membrane complex (CMC) was placed in a sealed test tube filled with Plasmalyte physiological solution, which in turn was immersed in a water bath. The temperature of the water bath was incrementally increased from 21°C to 41°C (core body temperature of the wood pigeon, Marsh 1989, Boederer 2005), 51°C, 60°C and 80°C. At each temperature the test tube was immersed for a 5 minute period, removed from the water bath and inverted. The relative buoyancy of the CMC was then recorded.

Results

At 21°C the CMC consistently sank on test tube inversion. At 41°C the CMC was again seen to consistently sink. As the surrounding temperature was increased to 51°C and 60°C the CMC was seen to spontaneously rise and remain at the top of its containing test tube (online resource 1). This was the case each time the tube was inverted. At approximately 80°C the CMC was once again seen to sink repeatedly (Figure 2).

Discussion

Our observations suggest the possibility of an alternative or contributory mechanism for the caloric effect: that of a change in the specific gravity of the cupula in relation to its surrounding endolymph at differing temperatures. An increase in ambient temperature may result in decreased specific gravity of the cupula and increased buoyancy. Similarly a fall in temperature may result in the opposite effect.

We initially anticipated, as with standard bithermal caloric testing, that a temperature change of 7°C would be sufficient to elicit an observable response in this study. This was not the case. Buoyancy was only achieved at the higher temperatures of 51 and 60°C. The additional weight of the surrounding vestibular membrane which was maintained during harvesting may account for this. A greater change in relative specific gravity may have therefore been required to achieve buoyancy. We had hoped to harvest the cupula in isolation however this proved impossible due to its inherent fragility.

At a further increase in temperature, 80°C the CMCs were once again seen to sink rather than rise. Closer inspection under microscopy revealed that the cupulae had entirely dissolved at this temperature, leaving an empty sac of surrounding vestibular membrane. This would account for the observed loss of buoyancy.

We recognise certain limitations arising from our study design. Our methods required exposure of the CMCs to temperatures far beyond normal physiological limits, which would be expected to denature any proteinaceous content of our samples. This would certainly be expected at 80°C; hence our observation of a change in response at this temperature. However with only a short exposure to an ambient temperature 50°C, we suggest that the observed change in buoyancy does indeed support our hypothesis.

References

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