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Experimental round window membrane rupture

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An increase of perilymphatic fluid pressure was found to be an important factor in the aetiology of round window membrane rupture. The critical pressure causing membrane rupture, as determined in anaesthetized cats, was in the range of 10—30 mm Hg (mean, 23.4 ± 17.1). This value was compared to the pressure increases caused by thoracic and abdominal compression, cervical strangulation, forced Trendelenburg position, coughing, and sneezing.

Rupture of the round window membrane is well known to be often in the background of sensorineural hardness of hearing even in children and infants [16]. Although pressure and flow conditions of the perilymphatic space have been investigated from several points of view in the last years, there are hardly any data on the critical perilymphatic pressure causing the round window membrane to rupture.

In the present series of experiments we have investigated the critical range of perilymphatic pressure. The pressure values causing rupture of the round window membrane were compared to those increased perilymphatic pressure values which we could measure under different experimentally induced conditions in the same experimental animals.

Material and Methods

Experiments were performed on 12 female cats weighing 2.3—3.5 kg and anaesthetized with 40 mg/kg pentobarbital intravenously. The trachea was cannulated with a glass cannula, and the bullae osseae were prepared free on both sides from incisions led behind the ears. The round window was exposed by opening the bullae. In a group of 6 cats a 1.5 mm hole was made with a dental drill to the perilymphatic space, through the bony wall of the round window at some millimeter distance from the window. In another group of 6 cats the perilymphatic space was opened by stapedectomy. A metal cannula 1.0 mm in diameter was inserted into the hole and was fixed with Duracryl dental cement. The cannula was connected with a short polyethylene tube filled with Evans-blue stained physiological saline. The tube was connected to a three-way stopcock. The first branch of the stopcock was connected to a mercury manometer, and the pressure read on the manometer was recorded by a Statham P 23 AA pressure transducer in order to have a simultaneous possibility for recording low breakthrough pressure values by a polygraph (Officine Galileo R 105 h, O.T.E. Biomedica, Firenze, Italy). The pressure in the perilymphatic space was elevated slowly and continuously through the third branch of the stopcock with the aid of a syringe filled with Evans-blue stained physiological saline.

Experiments were carried out only in

animals in which the round window membrane was intact under the operation microscope at $\times 32$ magnification. The slowly developing membrane rupture was recorded simultaneously with the pressure measurements, with the aid of a Minolta XG_2 automatic camera combined with an auto-winder. Changes of perilymphatic fluid pressure under the influence of cervical strangulation, forced Trendelenburg position [17], chest and abdominal compression, coughing and sneezing were tested in each experiment before measuring the critical pressure causing rupture.

Cervical, chest and abdominal compression was produced manually, forced Trendelenburg position by lifting the hind limbs to vertical. Coughing and sneezing were provoked by mechanical stimulation of the trachea and the nose with a polyethylene tube. The maximum changes of perilymphatic pressure measured during these model situations were compared to the critical pressure causing round window membrane rupture.

A detailed electron microscopic study of the structure of the round window membrane was published by us previously [15]. Since the situation and the extent of membrane damage were different in each experiment, histologic studies have not been carried out.

Results

Perilymphatic pressure values causing rupture of the round window membrane are summarized in Table I. As it can be seen, the mean pressure causing rupture in 12 ears of 8 cats was 23.4 ± 17.1 mm Hg (SD = 4.9 mm Hg). The upper and lower limits of the critical pressure for intact membranes were 66 mm Hg and 6 mm Hg, respectively. The critical pressure can be quite different in the two ears of the same animal, even when both of the membranes were found healthy under the microscope. We could perform reliable pressure measurements on both inner ears of 4 animals. The mean pressure causing rupture was 17.1 mm Hg on the one side and 35.6 mm Hg on the other side of the same animal, so that there was a 18.5 mm Hg pressure difference between the two ears. The round window membrane was visibly enlarged in 4 inner ears of 4 animals (apart from the 8 healthy cats) in another series of our experiments. Two of these membranes had ruptured at 110 and 186 mm Hg, respectively, while in the other two ears it was not possible to induce a rupture even at 230 mm Hg pressure. In the two last cases, microscopic observation of the enlarged membranes showed an interesting picture: the Evans-blue stained saline had penetrated between the layers of the round window membrane, and a suf-

Table I

Critical perilymphatic pressure causing round window membrane rupture

Number of animal	Body weight, kg	Pressure (mm Hg) causing rupture
1	3.5	18.0
		66.0
2	3.0	26.0
3	3.0	10.5
		22.0
4	3.0	12.5
		6.0
5	3.2	14.0
6	2.3	22.0
7	3.5	42.0
		34.0
8	2.8	8.0

$\bar{x} = 23.4$ mm Hg; SEM = 17.1 mm Hg; S.D. = 4.9 mm Hg; n = 12

TABLE II

Maximum perilymphatic pressure increases (in mm Hg) in test situations

Type of test	Cervical strangulation	Thoracic compression	Forced Trendelenburg position	Coughing	Sneezing
Number of animals inner ears, measurements	5 cats, 8 ears, 9 cases	7 cats, 11 ears, 24 cases	5 cats, 10 ears, 22 cases	5 cats, 7 ears, 36 cases	5 cats, 5 ears, 29 cases
$\bar{x}$	1.09	0.75	1.79	1.14	1.18
SEM $\pm$	0.31	0.11	0.34	0.12	0.15
SD $\pm$	0.93	0.53	1.58	0.72	0.80

fusion of that fluid was seen below the periosteum covering the bone around the window.

The mean pressure values are shown in Table II. As it can be seen, the most significant pressure increase was observed during forced Trendelenburg position. In some of these cases the increase amounted to 5.8 and 4.0 mm Hg values close to the lowest pressure causing round window membrane rupture.

DISCUSSION

The symptoms of round window membrane rupture are serious disturbances of cochlear and vestibular function and ear-noises [1, 2, 5, 7, 8, 10, 11, 13, 18, 19, 21, 22]. The studies published in recent years provided a considerable amount of data on the pathological background of the disfunctions [3, 4, 12, 14, 20, 23].

Simmons et al. [20, 21] and Goodhill et al. [8, 9] have called attention to the significance of perilymphatic pressure changes in the development of perilymphatic fistulas. The aim of the present investigations was to prove the connection of the pressure increase with the rupture of the round window membrane under experimental conditions, and to determine the pressure range at which a rupture of the round window membrane may occur. The results showed clearly that an increased perilymphatic pressure can lead to rupture of the round window membrane. The mean critical pressure was between 20 and 30 mm Hg. The highest and lowest pressure values at which membrane rupture was observed in the experiments were 66 and 6 mm Hg, respectively. In this range of pressure there was no oval window membrane rupture. This fact makes it certain that the tissue of the oval window membrane is more resistant to pressure than that of the round window membrane, in spite of the observation that the tissue layer covering the perilymphatic space from inside appears to be a homogeneous arachnoid structure [6]. According to our results, the pressure causing a rupture of the round window membrane shows considerable individual differences, and significant differences were found in this respect even in the two inner ears of the same animal. The phenomenon is probably due to differences in the structural and mechanical resistance of the membranes. The perilymphatic pressure increase evoked by thoracic and abdominal compression, coughing, sneezing, and forced Trendelenburg position, caused no round window membrane rupture, although the highest pressure values in these situations were close to the lowest pressure causing rupture. Therefore, the possibility that these situations can lead to rupture of the membrane after injuries or in the case of tubal disfunction cannot be excluded and this may explain the observations that physical effort situations may lead to round window membrane rupture.

In the pressure increasing situations investigated by us [17] the pressure usually does not reach the upper limit of the tensile strength of the round window membrane. The resistance of the intact healthy membrane against explosive pressure increases (coughing, sneezing) in the inner ear seems to be high. It seems therefore likely that extreme pressure increases cause rupture only in those cases when the membrane of the round window has been damaged.

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