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AEROMEDICAL REVIEWS

VENTILATION OF THE NORMAL AND BLOCKED MIDDLE EAR

A Review of Mechanisms

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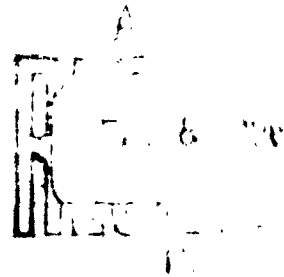
VENTILATION OF THE NORMAL AND BLOCKED MIDDLE EAR

A Review of Mechanisms

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Review 7-62

VENTILATION OF THE NORMAL AND BLOCKED MIDDLE EAR

A Review of Mechanisms

It is essential that personnel subject to flight duty be able to ventilate the middle ear. The Air Force incorporates this ability among the physical standards required of flyers (16). The practicality of this standard was lent additional support recently in a study by Watson (28), in which it was shown that pilots able to ventilate the middle ear successfully had no past history of chronic or recurrent aerotitis media.

The purpose of this study is to compare the advantages and disadvantages of the mechanisms by which the middle ear can be ventilated. Anatomy of the eustachian tube is well described by Graves and Edwards (10). The eustachian tube, about 36 mm. long, extends laterally, posteriorly, and superiorly from the lateral nasopharynx to the middle ear cavity. Its main components are the cartilaginous and osseous portions. The former begins in the lateral nasopharynx at the torus tubarius and extends for about 24 mm. before meeting the osseous portion at the isthmus, the narrowest portion of the tube. The osseous portion extends from the isthmus approximately 12 mm., terminating in the inferomedial aspect of the middle ear cavity.

Because of the different nature of these two tubal components, Schwartzbart (24) has proposed their consideration as separate anatomic structures. He suggests that the term "eustachian tube" be reserved for the cartilaginous portion, and that the osseous portion, being an extension of the tympanic cavity, be called the "protympanum." In addition, he suggests including the protympanum and the current term "hypotympanum" in a new term, the "bitympanum." The divisions are suggested on the basis of sound anatomic and physiologic reasons.

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X-ray studies by Rees-Jones and MacGibbon (22) demonstrate that aerotitis results from blockage of the elastic or cartilaginous portion of the tube. It is primarily the resistance offered by the elastic portion of the tube that must be overcome to ventilate the middle ear successfully. The relaxed elastic portion of the tube has a flutter valve action, allowing increased pressure to escape from the middle ear with little difficulty, but permitting no air to enter the middle ear from the nasopharynx without some muscular act on the part of the subject, such as swallowing.

There is some question as to which muscle or muscles are utilized in opening the eustachian tube. The traditional textbook viewpoint (2, 3, 27) is that the levator veli palatini, the tensor veli palatini, and the salpingopharyngeus all exert an influence. Rich (23), however, gives evidence that the tensor veli palatini is the only muscle active in opening the tube. MacBeth (15) concurs with Rich's findings and cites phylogenetic evidence in the case of whales and porpoises, which have no soft palate but do have well-developed tensor veli palatini muscles. The latter appears to be the sole mechanism for opening the eustachian tubes in these animals.

The tensor veli palatini is involuntarily contracted upon sneezing, swallowing, or yawning (23). These maneuvers adequately serve to ventilate the middle ear of the normal individual subjected to the minor barometric pressure variations existing at ground level. In contrast, a flyer is subjected to rapid changes in barometric pressure upon ascent to and descent from altitude. To assist the flyer in equalization of the middle ear pressures, several maneuvers have been developed.

VALSALVA MANEUVER

The Valsalva maneuver was first described by Antonio Valsalva in his treatise "Tractus de Aure Humana," published in 1704 (25). The procedure consists in forceful expiration while holding the mouth and nose firmly closed, thus forcing air to pass into the tympanum by way of the eustachian tube. Originally, Valsalva suggested this maneuver as a means of expelling pus in cases of

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otitis media with perforated eardrums, but in later years it was employed to replenish the air in the middle ear cavity in cases of eustachian tube obstruction (25).

Since the onset of World War II, the Air Force has recommended the Valsalva maneuver for voluntary middle ear inflation (6). Its incomplete success is attested to, however, by the high incidence of aerotitis media during the war (14). Primary reasons given for its failure were: preoccupation with combat duties, and temporary eustachian tube obstruction due to upper respiratory tract infection (12).

Several physiologic changes occur while the Valsalva maneuver is being performed. Intrathoracic, as well as nasopharyngeal pressure, may be increased to as much as 100 to 200 mm. Hg (8).

As with any other physiologic measure, the pressures required for opening the eustachian tube vary considerably among different subjects and in the same subjects at different times. Chunn (4), in his study of 99 untrained personnel, found that a pressure of 6 to 74 mm. Hg was required (mean pressure 33.4 mm. Hg). Studies by Nordhoff (8) and Perlman (17, 18) agree with Chunn's results in that, with the Valsalva maneuver, mean pressures for opening the eustachian tube were 38 and 30 mm. Hg, respectively.

Perlman (17) demonstrated several environmental influences on opening tubal pressure. Position of the subject was found to affect this markedly. Lying down or bending the head forward increases tubal opening pressure, presumably because of slight venous or lymphatic stasis, with resultant increased turgor of nasopharyngeal tissues. Perlman also found that the eustachian tube is practically impermeable in the horizontal position. In contrast, he demonstrated that exercise would temporarily decrease tubal resistance. A person whose normal opening pressure was 20 mm. Hg, utilizing the Valsalva maneuver, could open his tubes with 10 mm. Hg pressure after mild exercise. Tubal opening pressure returned to 20 mm. Hg after five minutes' rest. No particular correlation of opening pressures with age of subject was noted.

Maximum nasopharyngeal pressures which can be developed with the Valsalva maneuver vary considerably between subjects. In a study by Nordhoff maximum pressures ranged between 50 and 230 mm. Hg and averaged approximately 105 mm. Hg (8). His group of 200 subjects included 100 ground personnel and 100 flyers. He concluded that flying experience was not an important factor in the production of maximum pressures, since there was no significant difference between the pressures produced by the two groups.

The cardiovascular changes occurring during the Valsalva maneuver have suggested its employment as a test of cardiac function (9). Increased intrathoracic pressure produced during the maneuver will result in hypotension in the normal individual. This is due, primarily, to the impairment of venous return to the heart. In addition, pulmonary stretch reflexes have a well-recognized potential for the induction of certain cardiac arrhythmias. A combination of these two influences is probably responsible for the syncope which has been demonstrated frequently upon doing the Valsalva maneuver (5). The catastrophic outcome of such an occurrence in a pilot of a single-seated fighter aircraft is obvious, and this possibility led Armstrong (2) to state that any prolonged Valsalva maneuver should be avoided during flight. In fact, the cardiovascular responses to this maneuver have been implicated in recent aircraft accidents (13).

FRENZEL MANEUVER

A second mechanism of voluntarily ventilating the middle ears, first utilized by the Germans in World War II, is the nasopharyngeal positive pressure maneuver (8). Because of the unwieldy nature of the German translation of this maneuver, and in honor of the man who first described it in literature, it is proposed to call this procedure the Frenzel maneuver (7). Hermann J. Frenzel was a prominent figure in German aviation medicine in World War II, and is presently the Professor of Otolaryngology at the University of Göttingen (11). The Frenzel maneuver consists of voluntarily closing the glottis, closing the mouth and nose, and simultaneously contracting the muscles of the floor of the
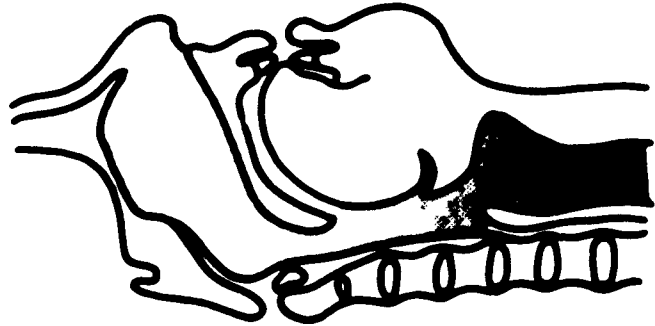
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mouth and the superior pharyngeal constrictors. Subject training for this is more difficult than for the Valsalva maneuver, owing to the involuntary nature of functions normally performed by these muscle groups. However, Chunn (4) demonstrated that with a short practice session, including coaching, the maneuver can be performed successfully by most subjects.

The first step in teaching this maneuver is to give the subject a "feel" for voluntarily closing his glottis. Frenzel suggests teaching this phase of the maneuver by the repeated production of a silent "ah" while expiring after a moderate inspiration. Simulation of either heavy lifting or straining at stool is suggested as an even simpler training aid, since the glottis automatically closes in doing these maneuvers. The second step in teaching the Frenzel maneuver is to have the subject practice moderately rapid elevation and depression of the tongue and of the muscles of the floor of the mouth. As an improvement on this description of Frenzel's, I suggest having the subject close the glottis after a moderate inspiration, and then attempt to make an oral "ka" sound. If the subject partially compresses his nostrils while performing this maneuver, he can feel and hear the rush of air out the anterior nares, thus demonstrating that the maneuver does diminish the volume of the nasopharyngeal space.
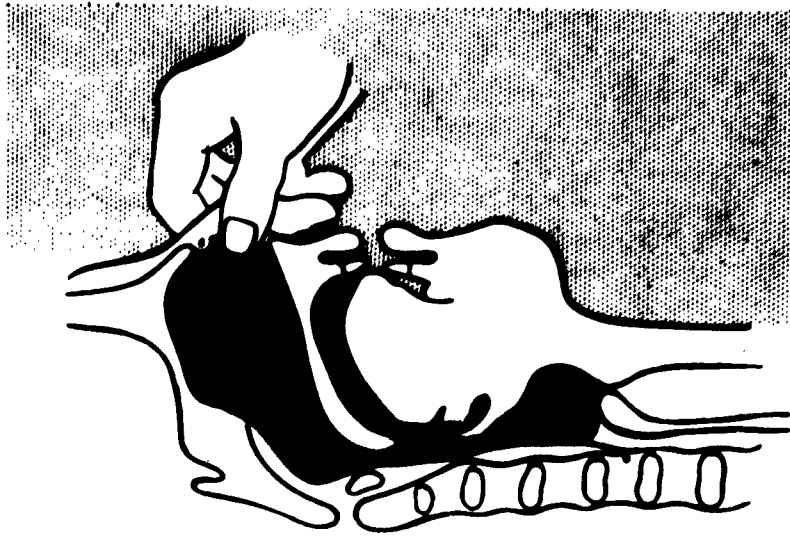
It must be emphasized that the foregoing are merely training steps in teaching the Frenzel maneuver. Once the procedure is learned, the anterior nares are completely closed. In addition, the maneuver can be performed in any phase of respiration and is independent of intrathoracic pressure. Diminution in nasopharyngeal volume during performance of the Frenzel maneuver is illustrated in figures 1 and 2.

Teaching of the Frenzel maneuver can be facilitated by the use of an ordinary aneroid sphygmomanometer gage, coupled to a nasal olive tip through a short length of rubber tubing (fig. 3). The incorporation of a "bleed valve" in this system, as recommended by Nordhoff, will serve to differentiate this maneuver from the Valsalva maneuver (8). If the "bleed valve" is opened during correct performance of the Frenzel maneuver, gage pressure will

FIGURE 2

Diminution of nasopharyngeal volume during performance of the Frenzel maneuver.

FIGURE 1

Normal nasopharyngeal volume (dark-ened area).

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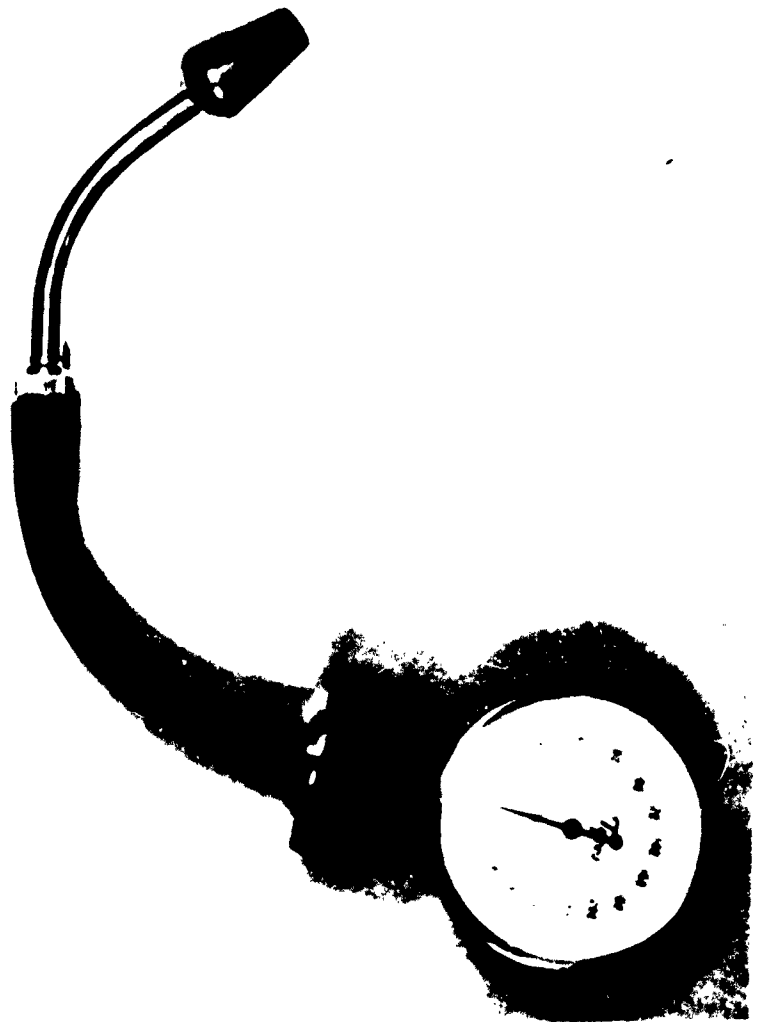
FIGURE 3

Instrument used as teaching aid for Frenzel maneuver.

decline rapidly because of the relatively small volume of the pressurized space. In contrast, if the subject is performing the Valsalva maneuver, such pressure will fall off more slowly because of the large intrathoracic air reservoir and the continued contraction of the diaphragmatic and thoracic musculature.

FIGURE 4

Instrument (see figure 3) with bleed valve added.

Despite the relative difficulty in explaining and teaching the Frenzel maneuver, it appears to warrant consideration in the field of aviation medicine. It has several advantages when compared to the Valsalva maneuver. Chunn (4) found that when the Frenzel maneuver was used the mean eustachian tube opening pressure

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150

100

Maximum [95]

VAL-
SALVA

50
40 Opening [40]
30
20
10
0
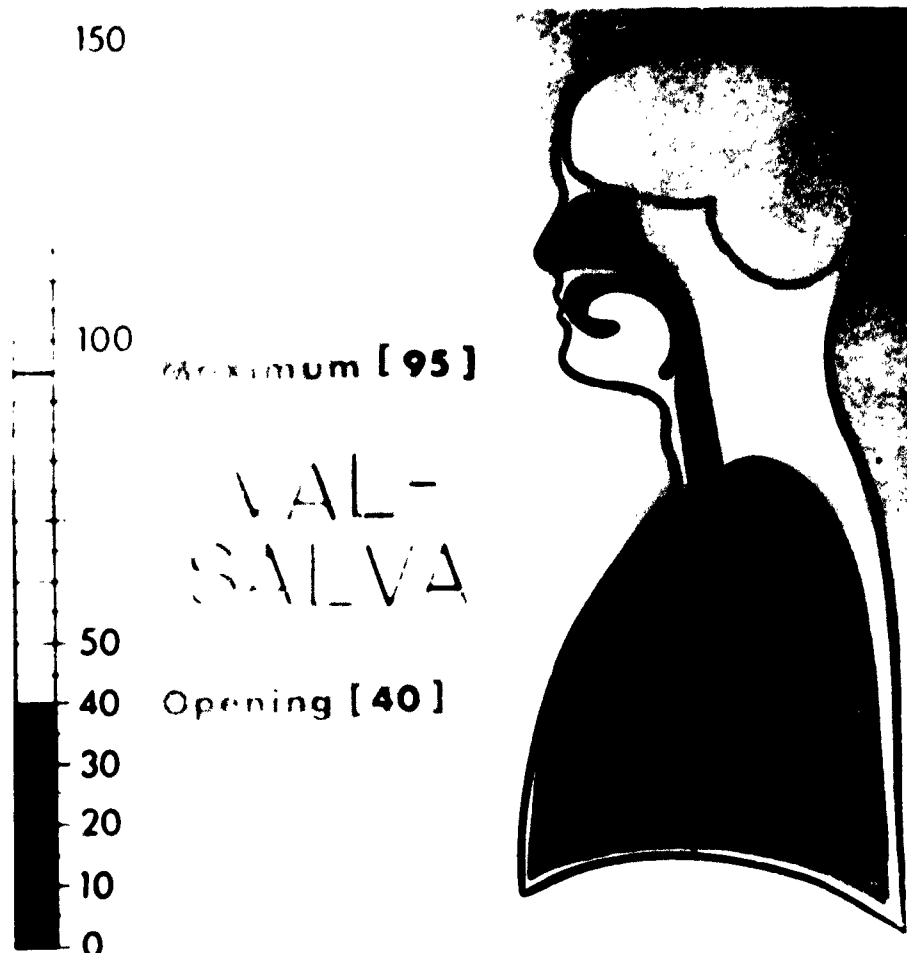
FIGURE 5

Average opening and maximum nasopharyngeal pressures with the Valsalva maneuver.

was approximately 6 mm. Hg in contrast to a mean opening pressure of 38 mm. Hg with the Valsalva maneuver. This finding supports data in studies by Frenzel and Nordhoff (8).

The difference in tubal opening pressure is explainable by several factors. The Valsalva maneuver, by impairing venous return from the head, increases turgor of nasopharyngeal tissue.

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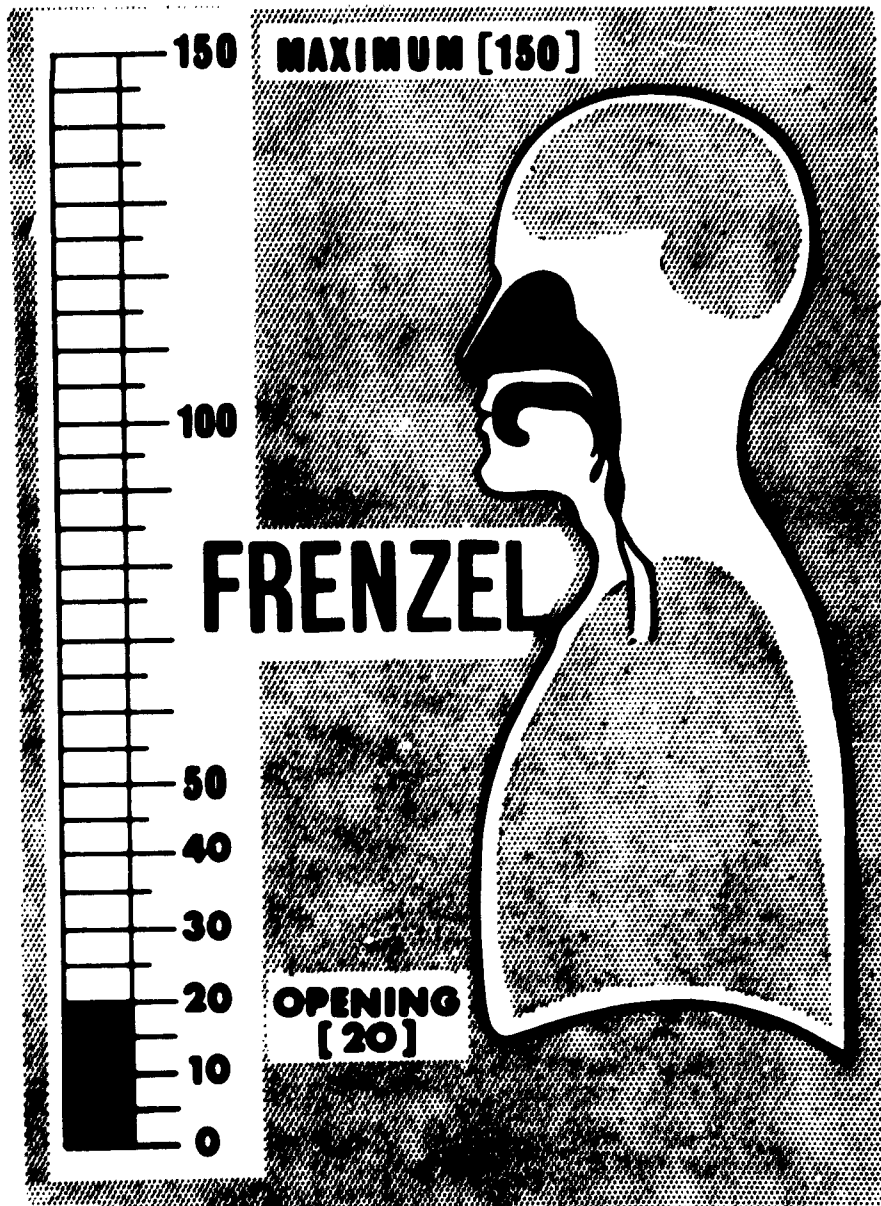
FIGURE 6

Average opening and maximum nasopharyngeal pressures with the Frenzel maneuver.

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Congestion of tissues surrounding the eustachian tube compresses its lumen and suggests that prolonged use of the Valsalva maneuver might lead to an even higher tubal opening pressure. Another factor responsible for the lower opening pressure with the Frenzel maneuver is the contraction of the tensor veli palatini muscle similar to that occurring during the first phase of swallowing. Muscular dilatation of the eustachian tube plays little or no part in performance of the Valsalva maneuver (23).

Performance of the Frenzel maneuver is independent of both intrathoracic pressure and phase of respiration. These features give the Frenzel maneuver a decided advantage over the Valsalva maneuver from an aeromedical standpoint. Independence of intrathoracic pressure obviates the hazards of possible production of syncope. As stated earlier, this has been of some concern with the Valsalva maneuver. Independence of phase of respiration allows middle ear inflation at end-expiration. Poppen (19) suggested this procedure might be of value in reducing the incidence of delayed aerotitis media due to prolonged breathing of 100% oxygen (oxygen absorption barotitis). The procedure is effective because oxygen in the middle ear is replaced by air of alveolar composition (concentrations relatively low in oxygen and high in carbon dioxide). End-expiratory tubal inflation with the Valsalva maneuver is difficult, if not impossible to perform.

In the few studies done on maximal pressures obtainable with the Frenzel maneuver, it was shown that equal or higher positive pressures can be obtained than with the Valsalva maneuver (8). The obvious advantage of this feature is a built-in "safety factor." A flyer with temporary blockage of the eustachian tubes due to an upper respiratory tract infection has a much greater "head of pressure" to call upon with the Frenzel maneuver. In-flight disability due to developing aerotitis media might well be decreased because of this added safety factor.

Additional research is needed to adequately evaluate the Frenzel maneuver. Although pilot studies have been done on flying and nonflying personnel (4, 7, 8), experiments on a larger scale are indicated to evaluate its ease of teaching and efficiency in clearing the middle ear compared to other presently accepted methods.

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Armstrong and Heim (1) have stated that when a negative pressure of 90 mm. Hg or greater develops within the middle ear, no voluntary means of inflation is effective. The pressure differential of 90 mm. Hg is comparable to a change in altitude from 10,000 feet to about 5,750 feet. Such an altitude change occurs with great rapidity during the jet penetration procedures commonly practiced today. It remains for future studies to determine whether the Frenzel maneuver will inflate middle ears subjected to such a pressure differential.

Other applications of the Frenzel maneuver also need to be explored. The efficiency of this method of middle ear clearance on the already-established case of aerotitis media is unknown. Similarly, the qualities of the Frenzel maneuver suggest its use in the treatment of chronic serous otitis media. Voluntary middle ear inflation is a well-established therapeutic measure for this disorder (21). The lower opening pressure and higher available head of pressure characteristic of the Frenzel maneuver would appear to be of definite therapeutic benefit in the treatment of serous otitis media. This can be determined only by large-scale studies on patients with this disorder. The pathologic changes of tubal swelling and middle ear effusion characteristic of serous otitis media might well render the Frenzel maneuver ineffective.

OTHER MECHANISMS

Other mechanisms of eustachian tube inflation are of relatively minor importance for voluntary in-flight use, but will be included in this discussion for the sake of completeness.

Toynbee maneuver

In 1853, Toynbee described a maneuver which opens the eustachian tube at ground level (26). This consists of swallowing with a closed nose. Now known by his name, this maneuver was thought by Toynbee to produce a positive pressure within the middle ear cavity. Politzer subsequently showed, however, that a negative pressure was left in the middle ear (26). In the initial phase of the Toynbee maneuver, a small positive pressure does

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develop in the nasopharynx, but with completion of the maneuver, positive pressure is replaced by negative pressure. The diphasic pressure change is not great, ranging between +4 to −8 mm. Hg (26).

Since egress of air from the middle ear cavity has not been a great problem in aviation medicine, there appears to be little practical application of the Toynbee maneuver. One possible use would be in the prevention of oxygen absorption barotitis. Wash-out of oxygen in the middle ear can be accomplished more rapidly with repeated alternate use of the Toynbee and the Frenzel maneuvers.

Politzerization

This procedure, named after Adam Politzer, the first professor of otology at the University of Vienna, is an instrumented technic for inflation of the middle ear (25). A rubber bag connected to a nasal olive tip serves as a source of compressed air. The procedure consists of insertion of the olive tip in one nostril, occlusion of both nares around the tip, and squeezing the bag while having the subject swallow. Pressures produced with politzerization are of the same magnitude as those produced with the Frenzel maneuver. Because politzerization is accomplished while the subject is swallowing, the dilated elastic portion of the eustachian tube allows easier passage of air to the middle ear. Since the procedure requires an external instrument, however, its application to in-flight voluntary inflation of the middle ear is limited.

Eustachian tube catheterization

One of the oldest means of middle ear inflation is eustachian tube catheterization. This procedure was first described in 1724 by Edme-Gilles Guyot, a French postmaster, using an oral route of passage (25). In 1755, Jonathan Wathen, a surgeon in England, gave the first practical description of nasal passage of a eustachian tube catheter (25). Eustachian tube catheterization is seldom used now, because of the discomfort involved and the tendency to produce tubal orifice trauma. The subsequent inflammation and edema often result in prolongation of the condition for which the

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instrument was originally employed (21). Its limitations for use in flight are obvious.

DISCUSSION

Ventilation of the middle ear will continue to be of concern as long as manned aircraft exist. The introduction of encapsulated aircraft ejection systems presents a new facet of the problem. Loss of cabin pressurization at altitude in aircraft utilizing this equipment requires the aircrewman to activate his capsule, with subsequent rapid repressurization. The rate of capsule repressurization may be as high as 50 mm. Hg per second with a total pressure differential of 500 mm. Hg developing, depending on the altitude at which the cabin is decompressed (20). In such a situation, crew incapacitation due to ear pain is a distinct possibility unless adequate middle ear ventilation is effected.

Aerotitis media and oxygen absorption barotitis are continuing problems in the modern-day practice of aviation medicine. From pilot studies, it appears that the Frenzel maneuver may be of use in the prevention of these maladies. Similarly, it may have therapeutic application in correcting the pathophysiology accompanying chronic serous otitis media. It is hoped that future studies will be conducted to clarify the efficacy of the Frenzel maneuver.

SUMMARY

The middle ear can be ventilated by various methods. The Valsalva maneuver, currently recommended by the Air Force as a method for inflating the middle ear, is described and its shortcomings for use in modern aviation are pointed out. Although the Valsalva maneuver serves adequately to ventilate the blocked ear in most cases, its predisposition to cause syncope and its relative inefficiency warrant re-evaluation of alternate methods.

It is proposed that the rather lengthy name of "nasopharyngeal positive pressure maneuver" be replaced by the shorter term, "Frenzel maneuver," placing it in its rightful category beside the

Valsalva and Toynbee maneuvers. If further studies bear out its greater efficiency, it might be advantageous to the Air Force to adopt the Frenzel maneuver as a recommended means for voluntary middle ear inflation. The reason given for this proposal is three-fold: (1) the eustachian tube opens at a lower pressure with the Frenzel maneuver than with the Valsalva; (2) equal or higher maximum pressures can be developed with the Frenzel maneuver, giving an additional safety factor; and (3) accomplishment of the Frenzel maneuver is entirely independent of intrathoracic pressure and phase of respiration. Thus, there is no tendency for production of syncope during performance of the Frenzel maneuver. In addition, end-expiratory performance of the Frenzel maneuver may facilitate the equilibration of gases within the middle ear with the ambient atmosphere. This is of considerable advantage in the prevention of oxygen-absorption barotitis. The Frenzel maneuver may also be of benefit in the treatment of chronic serous otitis media.

The relative advantages and disadvantages of the Toynbee maneuver, politzerization, and eustachian tube catheterization are also discussed.

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