ORIGINAL ARTICLE

The Deflation (Passive) Opening Pressure of the Eustachian Tube

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OBJECTIVE: To compare the air deflation pressure of the eustachian tubes in patients with tympanic membrane perforations due to various forms of otitis media and those with myringotomy or blast injury perforations.

METHODS: The study group consisted of 321 patients (407 ears) aged 4 months to 91 years with tympanic membrane perforations due to otitis media (318 ears), blast injury (27), and myringotomy (62). Air at 230 cm H2O or less was deflated from the external canal to the nasopharynx in all patients. The deflation opening pressure was measured and compared among groups.

RESULTS: In 1087 measurements (169 ears underwent multiple measurements), the deflation opening pressure was found to be higher in patients with otitis media than in those with normal tympanic membranes (P=.004). Patients with blast-injured tympanic membranes had lower deflation opening pressure than patients with normal ones (P=.002). The deflation opening pressure did not differ between age groups, showed fluctuation in almost all ears, and was not influenced by inflammation or its severity. Deflation opening pressure was higher in patients with otitis media with effusion than with other forms of otitis media (P<.0005). In 17% of the measurements, air did not pass through the eustachian tube: 3% in blast-injured tympanic membranes, 8% in normal tympanic membranes (P=NS), and 20% in inflamed ears (P<.0005 between the last two groups).

CONCLUSIONS: Deflation opening pressure measures the passage of air through the passive eustachian tube. This pressure frequently fluctuates. There is a correlation between various forms of otitis media (especially otitis media with effusion) and higher deflation opening pressure. The high pressure needed for air passage suggests that the eustachian tube transfers air only when actively opened.

The exact role of the eustachian tube (ET) in the pathophysiology of the middle ear cleft is still controversial.[1] Great significance has been given to ET length, angle, and diameter in influencing the occurrence of otitis media as well as outcome of middle ear surgery. Although no measurement has been found to bear prognostic reliability in middle ear pathology, measurements such as tympanometry have been recommended prior to surgery.[2] Surgeons sometimes attach prognostic significance to these values and hesitate to operate on patients whose ears have poor tympanometric measurements. Various parameters of the ET, such as functionality of its lumen,[3] have been measured by sonometry,[4,5] scintigraphy,[6] and endoscopy[7]—all with no significant connection to the diagnosis.

Understanding ET function may contribute to the clarification of two main aspects of middle ear pathophysiology: otitis media and surgery outcome. While its role in middle ear drainage is well known, ET role in ventilation of the middle ear is unclear. Reports on the various methods of measurements and the wide spectrum of frequently contradictory results contribute to the confusion. In general, there is disagreement between the findings and the actual condition of the middle ear.[3,8-14] Even in the studies that found a correlation between pathology and measurement, the relationship has not always been clear.[15,16]

Measuring deflation opening pressure (DOP) is only one parameter investigated in the study of the ET.[8,16,17] Numerous studies report on different pressure tests for the ET.[15,18,19] Longitudinal studies of ET air passage ability are rare.[4,20-22] We examined these pressures, including a series of longitudinal measurements. To the best of our knowledge, this is the largest series of DOP measurements and patients.

MATERIALS AND METHODS

Study design

This was a prospective study of patients with tympanic membrane perforation due to various forms of otitis media compared with patients who had perforated normal and blast-injured tympanic membranes. The study was conducted over several years during which the patients underwent DOP measurement. Longitudinal follow-up was done on 169 ears (41.5%) on which more than one measurement was taken. Forty-three ears (10.6%) were measured more than 5 times. This allowed us to follow DOP changes over time. Time intervals of days or months between measurements were a function of doctor visits. The control group comprised patients with normal tympanic membranes perforated by blast (explosion exposure), trauma, or myringotomy performed by incision or laser before intratympanic application of medicine for sudden sensorineural hearing loss, hyperbaric oxygen treatment, or middle ear endoscopy. All patients' ears were examined under the microscope at each measurement. Patients with normal tympanic membranes had normal otoscopy prior to myringotomy; there was no evidence of middle ear disease. In some patients, we measured DOP in recumbent and seated positions. Patients were very uncomfortable in the seated position; therefore, we discontinued it. In some patients, we also measured the DOP as they swallowed; we found the measurement inaccurate due to technical limitations, mainly head movements.

Measurement technique

All measurements reported were taken when the patients were recumbent (87% of the measurements taken by one investigator). A regulator-controlled tube connected to the hospital air-pressure supply, ending with a Politzer olive (Figure 1), was hermetically sealed against the external auditory meatus. Air was forced through the middle ear and the ET to the nasopharynx. Air pressure, gauged by manometer, did not rise above 230 cm H2O. When air passed through the ET, a low-pitched noise was heard from the patient's nasopharynx; simultaneously, the manometer indicated decreasing pressure. The pressure peak was the DOP. In some patients, air failed to pass. They were designated "not passed." In these patients, we used 250 cm H2O for statistical calculation. In 148 patients, a deflation flow pressure (DFP) was measured. DFP is the pressure level reached 1 to 5 seconds after the beginning of the DOP flow. It was about 10 to 30 cm H2O lower than the

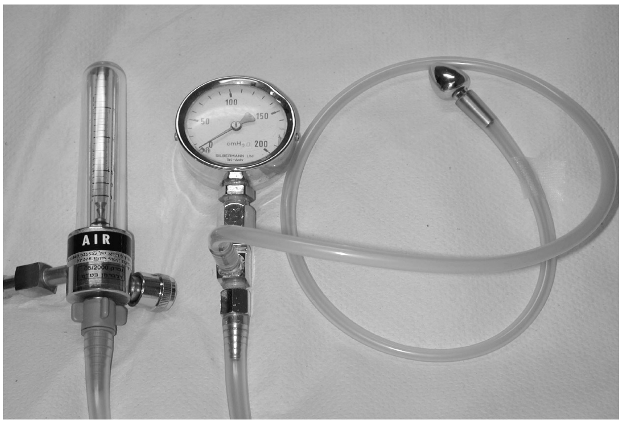


Figure-1: The examination tool: a regulator connected to air pressure supply, manometer, and an olive that adheres to the external ear meatus.

DOP. The DFP remained steady till we ended the test. Measurements that had been taken while the patient was in the seated position were either identical or 10 cm H2O less than those taken while the patient was recumbent.

Statistical analysis

The data were collected and processed by the Epi Info 6.04d epidemiological program (CDC, Atlanta, Ga, USA), using the chi-square and t-tests, and P=.05 was set as significant. SPSS® 11.0 software (SPSS Inc., Chicago, Ill, USA) was used for logistic regression analysis.

Our data comprise a wide spectrum of measured ears; some ears were measured once, others more than 30 times. We felt, therefore, that it was not appropriate to apply the statistical technique of repeated measurements. In order to overcome this problem and at the same time faithfully present our results, we calculated the average DOP of every ear pathology in 4 ways: each DOP measurement was considered a separate, diseased ear; and for each ear measured more than twice, we included the mean, median, and mode of the ear's measurements in the general calculation. We preferred using SEM to SD to determine the limits of the error bars, allowing visual comparison of significance directly from the graphs.

Patients

Three hundred and twenty-one patients (407 ears) aged 4 months to 91 years (178 men and 143 women) underwent ET DOP testing, many on different occasions (Table 1). Two hundred and forty-four patients (318 ears) had otitis media (OM: acute OM [AOM], OM externa [OME] ventilated by tubes, chronic OM [COM]) or cholesteatoma with a perforated tympanic membrane. Twenty-two patients (27 ears) had perforations resulting from blast injury. The DOP results of the inflammation and blast-injury groups were compared with the results of 62 normal tympanic membranes with myringotomy (55 patients, aged 7 to 74 years) who served as controls.

RESULTS

Four hundred and seven ears of 321 patients underwent 1 to 32 DOP/DFP measurements over several years. Table 1 shows overall epidemiologic data as well as DOP pressures by diagnoses. Because of the similarity, the results data are broken down into 3 categories: blast injury, normal, and inflammation. The data show that opening pressures in blast-injured tympanic membranes were significantly lower compared with the normal group (P=.002), while in the inflamed ears, it was significantly higher (P=.004). Figure 2 shows the mean pressures ± SEM of the grouped categories.

The age distribution of the inflammation group extended from infant to elderly. In the blast-injury group, we had children 9-18 years. In the normal group, we had adults only.

The patterns of DOP measurements are presented in Figures 3 and 4. Some similarity is seen in the bilateral comparison (Figure 3). We drew graphs of results for all the ears measured more than 5 times. In all of the graphs, fluctuations were seen, as shown in the normal group (Figure 4).

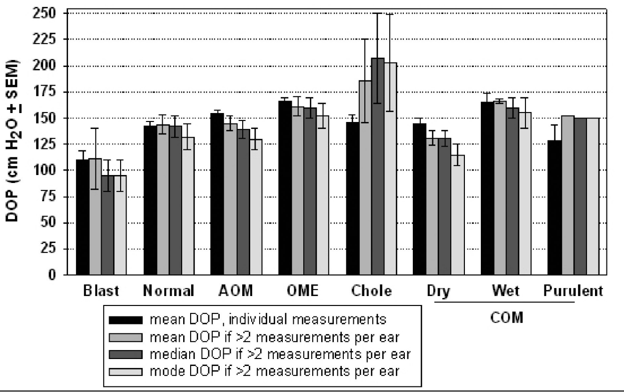
In 17% of the measurements, no air passed through the ET. These results are compiled in Table 1 under the heading "not passed." When we compared "not passed" ears in the OME subgroup, we found that, in the pooled

Table 1. Deflation opening pressure results in various patients and ear conditions.

	Patients	Ears	Measurements	NP
N	321	407	1087	17%
Gender (M:F)	55.5:44.5	54.4:45.6	52.5:47.5	59:41
Age group	**Patients, % (M:F)**	**Ears, % (M:F)**	**Measurements, % (M:F)**	**NP, %**
<3	8.8 (50:50)	12.4 (45:55)	18.5 (39:61)	18
3-8	5.6 (67:33)	6.7 (70:30)	3.2 (74:26)	18
9-15	14.4 (65:35)	13.4 (63:37)	12.5 (62:38)	17
16-60	55.8 (52:48)	52.7 (51:49)	52.6 (51:49)	17
>60	15.4 (55:45)	14.9 (57:43)	13.3 (59:41)	18
Diagnoses: all categories	**N (M:F)**	**n**	**cm H2O, mean ± SD (n)**	**NP, %**
Blast injury	22 (49:51)	27	110 ± 52 (33)	3
Normal	55 (56:44)	62	142 ± 56 (161)	8
AOM	40 (47:53)	66	154 ± 56 (237)	17
OME	122 (54:46)	152	166 ± 66 (423)	25
Cholesteatoma	17 (66:34)	22	146 ± 58 (57)	15
COM total	65 (51:49)	78	159 ± 58 (160)	17
COM dry	41 (45:56)	50	145 ± 49 (99)	7
COM wet	12 (57:43)	14	165 ± 56 (43)	18
COM purulent	12 (67:33)	14	129 ± 63 (18)	11
Diagnoses: 3 main categories	**N (M:F)**	**n**	**cm H2O, mean ± SD (n)**	**NP, %**
Blast injury	22 (49:51)	27	110 ± 52 (33)*	3
Normal	55 (56:44)	62	142 ± 56 (161)*	8
Inflammation	244 (52:48)	318	158 ± 61 (877)*	20

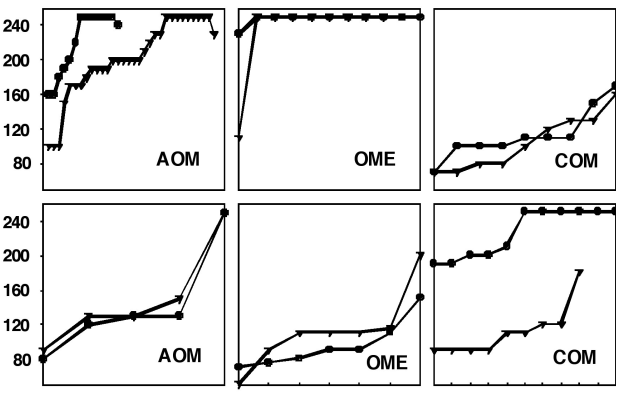
NP = not passed, deflated opening pressure exceeded 230 cm H2O; M:F = male to female; AOM = acute otitis media; OME = otitis media externa; COM = chronic otitis media. .

*P=.004 between inflammation and normal groups; P=.002 between blast-injury and normal groups.



DOP = deflated opening pressure; AOM = acute otitis media; OME = otitis media externa; Chole = cholesteatoma; COM = chronic otitis media.

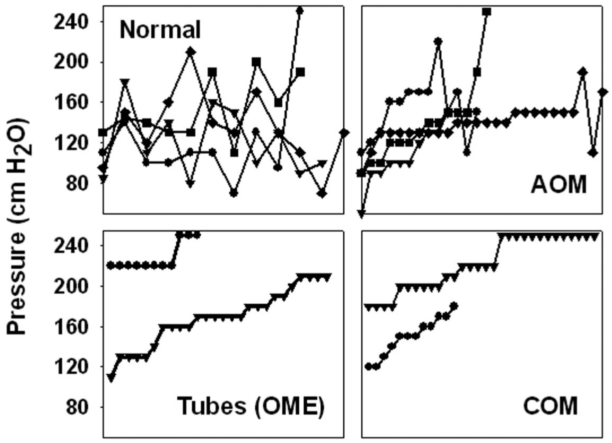
Figure-2: Deflation opening pressure in various diagnoses: analysis of repeated measurements.



AOM = acute otitis media; OME = otitis media externa; COM = chronic otitis media.

Figure-3: Longitudinal deflation opening pressure (repeated measurements on the same patient) by diagnosis in patients with bilateral disease.

data from age groups <8 years, 11.1% did not pass air through the ET, while in the >15years age groups, 26.3% were in the "not passed" category (P=.05). We did not find such a difference in other otitis media subgroups. In the subgroups of blast injury, normal, and dry COM, the percentage of "not passed" was especially low. "Not passed" measurements were a part of the fluctuations in many of the ears that had given measurable DOP values on other occasions.



AOM = acute otitis media; OME = otitis media externa; COM = chronic otitis media.

Figure-4: Longitudinal deflation opening pressure measurements by diagnosis: individual ears (fluctuations do not relate to severity).

DISCUSSION

In this survey, we checked the patency of the ET at rest, not its function. We examined the concept that obstruction of the ET causes middle ear disease, as well as the role of age.

ET patency differed among the 3 major groups (blast injury, normal, and inflammation). The blast-injury group had lower DOP than the normal group, and the inflammation group had higher DOP. In the subgroups (AOM, OME, COM, and cholesteatoma), there was no difference in DOP, but we found a higher "not passed" number in the OME subgroup than in the other subgroups. These differences point to a possible connection between the passive DOP and otitis media. This finding was consistent in all age groups. It seems that in all otitis media forms, air passage in the ET is more difficult than in normal ears and unrelated to the degree of inflammation. It should be noted that due to the fluctuation in results, there was much overlap which gave a confusing picture, and conclusions were drawn only through a thorough statistical work-up.

The "not passed" ears in all groups indicate an obstruction probably difficult to overcome through normal ET active function. This obstruction may contribute to the mechanism that causes OME, and congestion may be the reason for the obstruction. "Not passed" results were extremely high in OME, higher in adults than in children except in cholesteatoma ($P<.05$), and surprisingly low in dry COM. Age did not play a role in COM or other groups. The concept that the angle, length, and diameter of the ET play a role in the pathology of otitis media, as frequently reported in textbooks, was not supported by our results because there was no difference between DOP measurements across age groups.

In the longitudinal follow-up, air passage through the ears was traced repeatedly along time length of days, weeks, and months by numerous measurements (up to 35). We did not find significantly constant values; instead we found fluctuations in results not related to inflammation. Nevertheless, the results for some ears remained within certain levels. Most of the ears demonstrated fluctuations not dependent on the grade of inflammation or the timing of measurement. These fluctuations were also found in short time intervals (hours), and it is unlikely that the patients' condition resolved and reinfected repeatedly within such a short time. This pattern existed in all groups and ages.

We found some similarity between bilateral measurements. Although this similarity was not common, it may indicate the ET reaction to certain causes, such as congestion.

An additional difference was found between the normal tympanic membranes and the blast-injured ones: when we treated patients who were exposed to blast, we noticed that only a minority had tears in their tympanic membranes even when they were all equidistant from the explosion. The lower DOP values in the blast-injury group may point to a possibly easier air escape from the middle ear cavity through the ET, enabling tear of the tympanic membrane.

The difference between DOP and DFP probably indicates clearance of a mucus plug from the ET lumen during the DOP testing, allowing better air passage.

In 5 patients who had a patent ET with normal middle ears and who needed myringotomy for other reasons, we found DOP values similar to the other patients. The DOP was measured in the recumbent position, and tympanic membrane movements during respiration were observed clearly in the minutes prior to the myringotomy.

The DOP represents the resting-passage condition and is much higher than a middle ear can normally withstand. It was uncomfortable for many of our patients even though they had a perforated tympanic membrane. In tympanometry tests, we apply pressures in millimeters of H2O, while in DOP the pressure is measured in centimeters of H2O. This means that the ET at rest cannot passively act as a pressure moderator; to do so, it has to be activated.

In summary, we believe that the DOP indicates variations in the resting condition of the ET. Under this pressure, air or fluid passage is unlikely, and if such passage does occur, active movement is probably necessary. Normally the ET is not exposed to such high pressures, and the difference between DOP and tympanometry requires further clarification.

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