Innovative Use of Tympanometry and Scintigraphy in Preoperative Assessment of the Patients with Chronic Otitis Media

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Abstract Normal middle ear volume indicates the well ventilated middle ear and subsequently the normal function of the Eustachian tube. We carried out preoperative assessment of the middle ear volume by tympanometry and scintigraphic evaluation of Eustachian tube patency in patients with unilateral otitis media. We correlated the middle ear volume and Eustachian tube patency in these patients. Prospective. A total of 58 patients with unilateral otitis media were studied. All patients underwent Eustachian tube scintigraphy. We categorized the patients as Group A with patent Eustachian tube and Group B with blocked Eustachian tube (ET). We assessed the equivalent middle ear volume (VeqME) in all patients and correlated it with ET patency. We also correlated the degree of hearing loss and intraoperative middle ear pathology in two groups. There is strong linear correlation between the ET patency and VeqME of the patients. Degree of hearing loss and the middle ear pathology is also found to be severe in patients with blocked ET and low VeqME. Preoperative assessment of patients with chronic otitis media should include the objective evaluation of middle ear volume and ET patency, as it is the reliable predictor of middle ear pathology.

Keywords Tympanometry · Equivalent middle ear volume (VeqME) · Equivalent external ear volume (VeqEE) · Eustachian tube (ET) scintigraphy · Middle ear pathology

Introduction

The tympanic membrane (TM) serves as a key component of the tympano-ossicular system for sound transmission. Perforation of the TM is common in an otology practice and can result from various causes such as trauma and chronic otitis media. Glasscock and Shambaugh [1] observed that “Seemingly identical perforations in size and location produce different degrees of hearing loss. Hearing loss will vary inversely with the volume of air within the middle ear” [2–4].

The ability to objectively measure and document middle ear function is vital for an otologist to predict the outcome of tympanoplasty. A normally functioning Eustachian tube (ET) is an essential physiologic requirement for a healthy middle ear and normal hearing. Normal mucociliary clearance of ET is required to maintain healthy middle ear. Mucociliary function of the eustachian tube is measured with variety of methods over past 50 years, using methylene blue, saccharin or fluorescein dye. Methylene blue or the fluorescein dye is to be instilled in the middle ear and the dye is seen coming in the nasopharynx by nasal endoscopy. Similar use of saccharin helps to know the Eustachian tube patency when the patient tastes the saccharin as it enters in throat though the nasopharynx. All these methods do evaluate the functional obstruction of ET but fail to evaluate the exact level and the severity of the block (Mechanical obstruction) [5, 6]. We used radioisotope scan to diagnose the Eustachian tube mucociliary clearance capacity as well as the mechanical obstruction (level of obstruction) of the ET.

Second important part of the preoperative assessment is the estimation of middle ear volume. Tympanometry is an established method of measuring the volume contained within a closed air space [7, 8]. We measured the external

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ear-canal volume (VeqEE) in the contralateral ear. As a general rule, values for ear canal volume in both the ears is same. In the ear with perforation of the tympanic membrane, volume measured during tympanometry is the combined volume of the middle ear and the external ear, as the tympanometer measures the entire volume medial to the tip of the sealed probe (VeqEE + VeqME) [7, 8]. We subtracted the VeqEE of the contralateral ear from the combined volume of the perforated ear to get the VeqME of the perforated ear. CT scan of the temporal bone can assess the middle ear volume. But in every patient of otitis media, it is not feasible to do a CT scan as it is expensive and gives radiation exposure also [9]. Tympanometry offers a fast, non-invasive, and cost effective method to assess the middle ear volume.

Materials and Methods

The primary goal of this study was to determine whether the preoperative assessment of middle ear volume and ET patency before tympanoplasty can predict the middle ear pathology so that such patients can be identified and treated accordingly with better outcome of surgery. We prospectively studied 58 patients in the otorhinolaryngology outpatient department (OPD) of our Institute during 2013–2014. Prior to study initiation, the protocol and informed consent documents were approved by the Institutional Ethics Committee.

Inclusion Criteria

Patients with unilateral inactive mucosal chronic otitis media with normal tympanic membrane in the contralateral ear.

Exclusion Criteria

Patients with bilateral chronic otitis media, mixed hearing loss, sensorineural hearing loss, acute otitis media, adhesive otitis media and attic-antral disease. The patients with tinnitus, vertigo and the patients with associated nasopharyngeal pathology like adenoid hypertrophy etc. were also excluded from the study.

All the recruited patients were first examined clinically and under microscope and then their audiological and radiological assessment of mastoid was done. Alongside otoendoscopy, nasal endoscopy, tympanometry and ET scintigraphy were done. In all these cases, other routine investigations were also performed. During the investigations, we ensured that the patient had no ear discharge. In case of active disease, we treated the patient with medication to make the ear dry before investigations.

During ET scintigraphy, 100 µl of MDP (Methyl Diphosphate) labeled with technetium 99 m was instilled in the middle ear cavity under vision. The flow of the dye through the ET was observed by the films at interval of 5 min up to 30 min. In patent ET, there is complete clearance of the dye from the middle ear to the nasopharynx in maximum 30 min. Dye clearance time (DCT) of 30–90 min is considered as partial block of ET. In case of complete obstruction of the tube, the dye remains accumulated in the middle ear. Based on the DCT, we categorized all patients with:

Group A: Patent Eustachian tube.

Group B: Blocked Eustachian tube (partial/complete).

Pure tone audiometry and bilateral tympanometry was done in the patients of both the groups and the results were noted. A Grason-Stadler Incorporated (GSI-61) impedance audiometry machine with a probe tone frequency of 226 Hz was used.

We used the equivalent external canal volume (VeqEE) in the contralateral normal ear to provide an estimate of the VeqEE lateral to the ear drum in the ear with perforation. The equivalent middle ear volume (VeqME) of the diseased ear was calculated as:

“Middle ear volume of the diseased ear = The combined volume of the external ear and the middle ear of the diseased ear – The external canal volume of the healthy ear.” i.e. “VeqME of the diseased ear = (VeqEE + VeqME) of the diseased ear – VeqEE of the contralateral healthy ear.”

Taking the average normal VeqME as 0.6 ml, we noted the number of patients with VeqME < 0.6 ml and those with VeqME 0.6 ml or more.

In addition to demographic data, ET scintigraphy and tympanometry, we also noted the degree of conductive hearing loss and intraoperative middle ear pathology in all the patients.

Middle ear pathology during tympanoplasty was graded as:

Grade I	Normal middle ear mucosa
Grade II	Oedematous middle ear mucosa
Grade III	Oedematous middle ear mucosa with glue and/or ossicular erosion
Grade IV	Granulations and/or Tympanosclerosis

Statistical analysis was performed with SPSS. The Student *t* test was used to compare continuous variables between the two groups. Chi square two tailed test with Yate's correction and Fisher's exact probability test was applied to find statistically significant difference between the variables in the two groups. Two tailed *p* < 0.05 was considered to be statistically significant difference.

Results

58 patients of unilateral chronic otitis media were included in the study. The number of patients in group A was 35 ($n = 35$) and that in group B was 23 ($n = 23$). The ratio of males to females was 15:20 in group A and 14:9 in group B. Patients' age ranged from 18 to 52 years, with a mean age of 44.5 and 42.7 years in the two groups respectively. There was statistically no significant difference between the two groups in terms of demographic data (Table 1).

The mean equivalent volume of external ear (VeqEE) was 1.34 ml in group A and 1.42 ml in group B with the average of 1.38 ml. The mean equivalent volume of the middle ear (VeqME) was 1.28 ml in Group A (Patent ET) and 0.44 ml in group B (Blocked ET). There was statistically no significant difference in VeqEE in two groups ($p = 0.834$); however statistically significant difference was found in the VeqME of the two groups ($p = 0.001$; Table 2).

In group A with patent ET ($n = 35$), 28 had VeqME 0.6 ml or more (80%). While in Group B with blocked ET ($n = 23$), only 9 had VeqME 0.6 ml or more (39%). Chi square value is 8.346 with degrees of freedom as 1 and two tailed p value = 0.0039 (Statistically very significant difference). Two tailed Fisher's exact probability (p) = 0.0022 (Statistically very significant difference; Table 3).

Table 1 Demographic data of patients in the two groups: Group A—patent Eustachian tube (ET), Group B—blocked Eustachian tube (partial/complete)

Variable	Group A Patent ET	Group B Blocked ET (partial/complete)	Statistical analysis (p value)
Number of patients	35	23	NS
Age (years)-mean	44.5	42.7	NS
Sex (M/F)	15/20	14/9	NS

NS not significant, M male, F female

P value <0.05 is significant

In correlating the groups with degree of conductive hearing loss in the form of Air-Bone Gap, Chi square value is 15.58 with two tailed $p = 0.001$ (Graph-I). Severity of middle ear pathology was high in Group B (Blocked ET) with Chi square value 20.32 and two tailed $p = 0.0001$ (Graph II). Thus the degree of conductive hearing loss and the severity of middle ear pathology increases with blocked ET. Middle ear pathologies like tympanosclerosis, granulations, ossicular erosion occurred almost exclusively in the patients with blocked ET.

Of total 58 patients, 28 patients (48.27%) had subtotal perforation, 22 patients (37.93%) had central perforation anterior to handle of malleus, and 8 patients (13.79%) had central perforation posterior to handle of malleus. Subtotal perforation had the highest representation in the study followed by perforation anterior to handle of the malleus.

Discussion

Tympanoplasty has a long history of significant innovations. Changes in operative technique, combined with a better understanding of middle ear pathology, have increased the success of surgery. Success of tympanoplasty depends on securing the graft; thus in turn depends on optimum air pressure on both sides of the ear drum which is possible only with healthy middle ear and patent Eustachian tube. Studies of ET function of the patient with a chronic perforation of tympanic membrane preoperatively helps to determine the potential results of tympanoplasty. Holmquist studied ET function in adults with otitis media, before and after surgery and reported that the operation had high rate of success in patients with good ET function, but in patients with tubal dysfunction, surgery frequently failed to close the perforation [10]. A number of tests of the ventilatory function of the ET have been devised, including tubomanometry, sonotubometry, nine-step inflation-deflation test and pressure chamber tests. At the current time, the equipment these tests require is not widely available, and their accuracy and validity is unclear, but they can be useful research tools [11, 12]. We used radioisotope scan to

Table 2 Comparison of mean VeqEE and mean VeqME in the two groups: Group A—patent Eustachian tube (ET), Group B—blocked Eustachian tube (partial/complete)

	Group A (Patent ET) ($n = 35$)	Group B (Blocked ET) ($n = 23$)	Statistical analysis
Mean VeqEE of the healthy contralateral ear (a)	1.34	1.42	NS ($p = 0.8$)
Mean VeqME + VeqEE of the diseased ear (b)	2.62	1.86	Statistically very significant ($p = 0.001$)
Mean VeqME of the diseased ear (b–a)	1.28	0.44	Statistically very significant ($p = 0.001$)

VeqEE equivalent volume of the external ear, VeqME equivalent volume of the middle ear

Table 3 Comparison of equivalent middle ear volume (VeqME) between two groups: Group A—patent Eustachian tube (ET), Group B—blocked Eustachian tube (partial/complete)

	Group-A Patent ET (n = 35)	Group-B Blocked ET (partial/complete) (n = 23)
<i>Middle ear volume</i>		
<0.6 ml	7	14
0.6 ml or more	28	9
Total	35	23

Chi square test with Yates correction value = 8.346

Degrees of freedom: 1

Two tailed *p* value = 0.0039 (statistically very significant difference)

Two tailed Fisher's exact probability: *p* = 0.0022 (statistically very significant difference)

diagnose in detail the Eustachian tube (ET) mucociliary clearance capacity as well as the mechanical obstruction (Level of obstruction) of the ET. In the normal ET, the velocity of the mucociliary transport is 0.7–1.1 mm/min.

The length of ET is 35 mm. Hence within 30 min the radioisotope completely enters the nasopharynx. Residual radioisotope in the middle ear after 30 min indicates ET block [6]. Rapid and complete clearance of the radioisotope into the nasopharynx was considered to indicate normal drainage function (Fig. 1), whereas its failure to drain from the middle ear into the nasopharynx indicated obstruction of the Eustachian tube (Fig. 2). Eustachian tube function has been the center of focus as a prognostic factor because of its presumed primary role in the pathogenesis of otitis media and clearance of the middle ear cavity [13, 14]. Blocked tube is due to inflammation in the middle ear mucosa especially around the opening of the ET in the middle ear. It usually resolves with medications and the steroid ear drops prior to surgery. Obstruction at the nasopharyngeal end of the tube is diagnosed by nasal endoscopy. ET scintigraphy is an effective method to assess the level of obstruction as well as mucociliary clearance of the ET [15].

Prasad et al. [16] in their study found that the mean value for Saccharin Perception time that correlates with mucociliary clearance time is 17.583 min; In our study, the mean value for Dye clearance time (DCT) is 15.025 min in

Fig. 1 Eustachian tube (ET) scintigraphy showing patent ET

Fig. 2 Eustachian tube (ET) scintigraphy showing blocked ET

group A (Patent ET); and 47.88 min in group B (Blocked ET). The relationship between time of transport and type of perforation was studied by Prasad et al. and Giménez and Marco-Algarra [13, 16]. Mucociliary and equipressive ETF was studied, using saccharin solution (5% sodium saccharinate) and tubal manometry, respectively, in patients with chronic disease undergoing tympanoplasty. The position of the perforation site determines the results as the poorest results are obtained from the posterior ones, having positive cases (47%) and mean transport time (37.7 min), compared to the greater percentage of positive cases (86%) and mean transport time (22.2 min) for anterior perforations. Thus they observed that the mucociliary function was best in ears with anterior perforations and worst in posterior perforations. Subtotal perforations showed intermediate results. Prasad et al. also found same results as described by Giménez and Marco-Algarra [13, 16]. They found that ET function was poor in 52.94% cases among the patients with the posterior perforation. Vallés et al. [17] found contrasting results in their study and their best results corresponded to posterior perforations, whereas worst cases were subtotal

perforations. In our study, in group A (Patent ET) 15 patients (42.85%); and in group B with ET dysfunction, 21 patients (91.30%) had either subtotal perforation or perforation posterior to handle of malleus. Thus mucociliary function is best in the ear with anterior perforation and the results are very similar to those of Prasad et al. [16]. The differences suggest the existence of the relationship between mucociliary transport and the site of perforation. The varying topography of the perforation would thus influence the integrity of the mucociliary system, or also the better or worse condition of the latter would influence the appearance of one type of perforation, or another [13, 16].

In chronic otitis media; in addition to the site of the perforation, equivalent middle ear volume (VeqME) is also a determinant of middle ear pathology and hearing loss. Less middle ear volume is predictive of larger air-bone gaps [4]. Identical perforations in two different ears are predictive of a conductive hearing loss that can differ by up to 35 dB, if the middle ear volumes substantially differ [4, 15]. If there is a large difference between the estimated hearing loss and the actual hearing loss in patients with a

Fig. 3 Tympanometry showing equivalent external ear volume (VeqEE) of healthy ear

Fig. 4 Tympanometry showing combined volume of external ear and middle ear. (VeqEE + VeqME) of diseased ear

perforated ear drum, then we should expect to find additional pathology in the diseased ear [15]. To assess the severity of the middle ear pathology and to plan the medical as well as surgical management, preoperative assessment of the middle ear volume and Eustachian tube patency is of great help to an otologist. Tympanometry estimates the equivalent middle ear volume (VeqME) in case of intact tympanic membrane. But in case of perforated ear drums, it evaluates the combined volume of the external ear and the middle ear i.e. the entire space medial to the sealed probe tip (VeqME + VeqEE) [15, 18]. In unilateral perforated ear drums, it is possible to calculate the VeqME by estimating VeqEE of the contralateral normal ear (Fig. 3) and subtracting it from the combined volume (VeqEE + VeqME) of the diseased ear (Fig. 4).

In our study, the average VeqEE was 1.38 which is consistent with the noted average VeqEE as 1.4 ml in literature [15, 18, 19]. Researchers have found that the

VeqME varies between 0.3 and 1.6 ml with average VeqME for adults and elderly are 0.62 and 0.61, respectively [18, 20]. Taking this average value of 0.6 ml as the cutoff point, the middle ear volumes of the patients in the two groups (according to patency of ET) were compared and we found a very significant linear correlation between the two variables. Patent ET ensures normal middle ear volume and in patients with blocked ET, the middle ear volume is below average.

Our data strongly suggest that there is a linear correlation between middle ear volume and ET patency ($p = 0.0039, 0.0022$; Table 3). Normal middle ear volume indicates the well ventilated middle ear and subsequently the normal function of the Eustachian tube. The degree of conductive hearing loss was significantly high in patients with blocked ET and low middle ear volume. ($p = 0.001$; Fig. 5). Middle ear pathology like tympanosclerosis, granulations or oedematous middle ear mucosa was

Fig. 5 Severity of conductive hearing loss in both groups. Group-A—patent ET, Group-B—blocked ET (partial/complete). Y-axis—number of patients, X-axis—degree of conductive hearing loss, Chi square value is 15.58 with two tailed $p = 0.001$, Statistically very significant difference

Fig. 6 Severity of middle ear pathology in both groups: Group-A—patent ET, Group-B—blocked ET (partial/complete). Y-axis—number of patients, X-axis—middle ear Pathology graded according to severity as: Grade I—normal middle ear mucosa, Grade II—oedematous middle ear mucosa, Grade III—Oedematous middle ear mucosa with glue and/or ossicular erosion, Grade IV—granulations and/or tympanosclerosis, Chi square value is 20.32 with two tailed $p = 0.0001$, Statistically very significant difference

significantly high in patients with blocked ET and low middle ear volume ($p = 0.0001$; Fig. 6).

Although Pure tone audiometry (PTA) is routinely performed in a clinical setting, it has a limitation of being a subjective test. Currently, no single test could be considered a ‘gold standard’ for the diagnosis of ET dysfunction, but there is some evidence that diagnostic accuracy can be improved by combining the results of different objective tests and patient-reported outcome measures [14]. We propose that an objective evaluation of middle ear volume and ET patency is important to ensure the good outcome of tympanoplasty. If the Middle ear volume is <0.6 ml on tympanometry, likely middle ear inflammation is to be suspected and the medical treatment is to be considered prior to surgery. On this basis, we might decide to withhold surgery until the middle ear volume is 0.6 ml or more.

Despite medical management, if middle ear volume is less, the possibility of severe middle ear pathology is to be considered and surgery should be planned accordingly. Tympanometry can estimate middle ear volume only in unilateral chronic otitis media. In case of bilateral disease, ET scintigraphy is to be considered as a predictor of middle ear pathology. This is the primary study to correlate the preoperative assessment and the intraoperative middle ear pathology. In future, we are planning to come up with correlation of preoperative assessment, middle ear pathology and the post operative results too.

Conclusion

Although success rate of tympanoplasty has certainly improved, surgeons must nevertheless maintain a respect for the possibility that unhealthy middle ear can lead to failure of tympanoplasty. Our aim should be to ensure a healthy, well ventilated middle ear prior to surgery.

Based on our data, we recommend the use of tympanometry for evaluation of equivalent middle ear volume (VeqME) in patients with unilateral chronic otitis media. Normal VeqME ensures a healthy middle ear. Tympanometry has the advantages of being an inexpensive, reliable, simple, objective and quick audiological test. As tympanometry has a limitation in bilateral otitis media, Eustachian tube scintigraphy is a reliable investigation for such patients. It evaluates mechanical as well as functional obstruction of Eustachian tube. A patent Eustachian tube is highly predictive of normal middle ear volume and in turn a healthy middle ear.

Compliance with Ethical Standards

Conflict of interest None.

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