The Journal of International Advanced Otology

J Int Adv Otol 2018; 14(2): 255–62 • DOI: 10.5152/iao.2018.4521

Original Article

Eustachian Tube Function in Adults with Ventilation Tubes Inserted for Otitis Media with Effusion

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Cite this article as: Alper CM, Teixeira MS, Swarts JD. Eustachian Tube Function in Adults with Ventilation Tubes Inserted for Otitis Media with Effusion. J Int Adv Otol 2018; 14(2): 255-62.

OBJECTIVE: To investigate the eustachian tube (ET) function (ETF) in adults with ventilation tube (VT) inserted for the treatment of chronic otitis media with effusion (COME).

MATERIALS and METHODS: A total of 17 subjects with at least one VT were enrolled. A detailed history was obtained, and risk factors were assessed with questionnaires. Examination including nasopharyngeal video endoscopy and ETF tests, the forced response test (FRT), inflation–deflation test (IDT), and nasal/nasopharyngeal maneuvers (such as sniffing and Valsalva, Toynbee, and the diver's maneuvers) were performed.

RESULTS: Averages for FRT were 580±333 daPa, 382±251 daPa, and 138±192 daPa for opening pressure, steady-state pressure, and closing pressure, respectively. Most subjects demonstrated minimal or weak active function during the FRT and IDT. While nasopharyngeal maneuvers changed the nasal/nasopharyngeal pressures, they did not significantly change the middle-ear pressures. These results indicated that most subjects had severe obstructive ET dysfunction (ETD) with an ET lumen that required high pressure differences to open and poor active muscular function inadequate for luminal dilation. These results imply that while any treatment to widen the ET, such as balloon dilation of the ET, is not expected to change the voluntary active muscular function, it may reduce the tissue pressures and resistance, thus facilitating luminal opening both passively and actively.

CONCLUSION: Most patients with VT inserted for the treatment of COME appear to have an abnormal ETF with difficulty in passively opening the ET and weak active muscular function. Management of such patients addressing only passive properties may not be sufficient for the resolution of ETD.

KEYWORDS: Eustachian tube, eustachian tube dysfunction, middle ear effusion, ventilation tube, balloon dilation of eustachian tube

INTRODUCTION

Optimal hearing requires a healthy middle ear (ME) with an intact tympanic membrane (TM), an intact and mobile ossicular chain, and an aerated ME near ambient pressure. The sum of the gas partial pressures in the ME is higher than that in venous blood; therefore, the gases gradually equilibrate with blood by diffusion[1]. Similar to any sealed gas pocket within the body, unless there is resupply of such gases, ME pressure (MEP) will reach an unsustainable negative value and the ME will either collapse and/or be filled with fluid. The eustachian tube (ET) is the conduit, which resupplies the ME by periodically opening to deliver a bolus of gas into the ME to compensate for the decrease in MEP due to the diffusion of ME gases through the mucosa. An inadequate ET opening frequency and/or gas bolus volume results in a negative MEP[2]. A sustained negative MEP may facilitate ascending viral and bacterial infections and/or lead to fluid transudation or exudation, thus gradually filling the ME.

Eustachian tube dysfunction (ETD) may manifest itself as a chronic condition or a temporary/intermittent problem arising due to external or internal challenges, such as ambient barometric changes or illnesses and conditions, that affect its function[3]. Both intermittent and chronic ETD may be associated with high tissue pressures that increase resistance to opening or weak active opening function or both[4]. A variety of clinical presentations and underlying causes may represent different phenotypes of ETD. Further research is warranted to delineate the clinical and functional characteristics of each presentation within the spectrum of ETD.

This study was presented in part as an oral presentation at the 19th International Symposium on Recent Advances in Otitis Media, 4-8 June 2017, Convention and Exhibition Centre, Gold Coast, Australia.

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Submitted: 20.10.2017 • **Revision Received:** 14.03.2018 • **Accepted:** 02.07.2018 • **Available Online Date**: 27.07.2018

Historically, ETD was invoked as the cause of many ME diseases including recurrent otitis media, acute or chronic ME effusion, TM retraction, retraction pockets, cholesteatoma, and medical and surgical treatment failures, even though there was no specific therapy for it. Several targeted treatment methods have been recently introduced, including the relatively non-invasive method of balloon dilation of ET (BDET), which provide hope for a cure for ETD and its sequelae[5]. Despite BDET's relatively non-invasive nature, little is known regarding its effect on the ET mucosa, the peritubal tissues, and its mechanism of action[6, 7]. A recent controlled study demonstrated the efficacy of BDET in adults with intact TMs and type B or C tympanograms; however, the severity of ETD was not demonstrated with testing in that population[8]. It remains unclear whether BDET is indicated and has a similar benefit for all manifestations and severities of ETD.

Otitis media with effusion (OME) is defined as inflammation of the ME mucosa with the accumulation of effusion in the normally air-filled ME, without the signs and symptoms of acute otitis media. The pathogenesis of ME effusion is multifactorial, with ETD being the most consistently claimed cause both in children and adults[9]. While relatively more common in infants and young children, most grow out of their ME problems, reflected in the decreasing prevalence of ETD and the resulting OME in older children and adults. Only a small proportion continues to have OME into adulthood. Adults who develop chronic OME and require ventilation tube (VT) insertion probably represent the worst ETD manifestation. Therefore, we conducted a study to describe the history, clinical profile, and ET function (ETF) test results in adults who need VT insertion to treat OME; this cohort is assumed to represent patients with ETD for whom BDET may be indicated.

MATERIAL and METHODS

Otherwise healthy male and female subjects aged 18–50 years with unilateral or bilateral VTs inserted for treatment of OME with suspected ETD were enrolled in this study. Subjects were recruited by referral from adult otology clinics and by advertisement. Potential subjects were screened by phone conversation for eligibility and invited for evaluation and testing at Middle Ear and Eustachian Tube Research Center. This study was reviewed and approved by the University of Pittsburgh Institutional Review Board.

After obtaining written informed consent for participation, subjects underwent a full evaluation, including demographic information, a general health history, a specific ear disease history, questionnaires, physical and otologic examination via otomicroscopy and otoendoscopy, nasopharyngeal video endoscopy, and ETF testing.

Questionnaires for ETD, allergies, sinusitis, and gastroesophageal reflux disease (GERD) were completed by the subjects. The Eustachian Tube Dysfunction Questionnaire-7 (ETDQ-7) was used for the evaluation of ET symptoms[10]. The Allergy Control SCORE™ questionnaire was used for the evaluation of allergic rhino-conjunctivitis symptoms[11-13], and the Sino-Nasal Outcome Test-20 (SNOT-20) questionnaire was used for evaluating the presence of rhinosinusitis[14]. The Gastroesophageal Reflux Disease-Health Related Quality of Life (GERD-HRQL) questionnaire was used for the evaluation of reflux. Tympanometry (Titan Middle Ear Analyzer, Interacoustics, Eden Prairie, MN) was performed to confirm the patency of VTs, and in ears without a VT or perforation, the MEP and compliance were recorded. In ears with a patent VT, the volume was recorded. A 0° endoscope (60×2.7 mm, 1215A Karl Storz Endoscopy, Germany) with a pneumatic sleeve (1215Q, Karl Storz Endoscopy, Germany) attached to a high-speed digital camera (uEye 1220SE, IDS Obersulm, Germany) was used to examine the ear canal and TM. Camera signals were continuously split-routed to an online monitor and to the memory of a PC for storage and analysis.

Only one ear of a subject with bilateral non-intact TMs was included for testing and analysis in the study. A panel of five ETF tests was used to assess the study ears with non-intact TMs; these tests were the forced response test (FRT), the inflation–deflation test (IDT), and the maneuvers, including sniffing, Valsalva, and Toynbee. ETF testing was performed with a custom-made instrument developed by us. Components of this instrument include an ear-canal probe serially attached with a tube to an SDX01D4 differential pressure transducer (Honeywell) with a 3-way valve to a flow sensor (Respiratory Flowhead 1L MLT1l; AD Instruments) and a second 3-way valve to a variable-speed constant-flow pump (Harvard Apparatus Pump 22; Harvard Apparatus) with a syringe pump controller (Syringe Pump Controller version 1.2; National Instruments); a nasal probe was attached with tubing to an SDX01D4 differential pressure transducer. Signals from the transducer were sent to a PowerLab 16/30 data acquisition system connected to a personal computer running Laboratory Chart software, version 7.3.6 (AD Instruments) that displayed the waveforms and data storage in real time.

An ear-canal probe was sealed into the test ear for the FRT. After opening the valves of the test instrument, an airflow of approximately 11 mL/min was delivered by the constant-flow pump to the ME. This continuous delivery of air increased ME pressure to the level at which the ET lumen was forced to passively open (opening pressure [PO]). As the pump continued to deliver an airflow, the pressure and the flow became stable, resulting in a steady system pressure (PS), where the flow (QS) through the ET was almost equal to the applied flow rate by the pump. An air pump delivered a constant flow through the ear canal, non-intact TM, ME, and the ET, which kept the lumen open. After reaching the steady state, the subject was asked to swallow, which contracts the tensor veli palatini (mTVP) and levator veli palatini (mLVP) muscles. Contraction of these muscles is expected to widen the diameter of ET, usually increasing the airflow through the ET (PA, active pressure, at QA, airflow during a swallow). During the steady-state phase, a swallow with active muscular function is expected to widen the lumen, increase the flow rate, and reduce the resistance at the time of the swallow, which should all go back to the baseline flow rate after the swallow. The absence of widening evidenced by lack of increased flow and decreased resistance and system pressure indicates absent muscle strength. The degree of flow change with the change of the ET lumen is measured as dilatory efficiency (DE), a measurement of how weak or strong the tubal musculature is. At the end of the test session, the pump was turned off, thus resulting in a decrease in airflow and pressure, eventually to a level where the ET passively closed. This measured pressure, expected to be equal to the tissue pressures, was the closing pressure (PC). After completion of the first test sequence, the same testing was repeated at an airflow rate of approximately 23 mL/min. Throughout the test, system pressure and flow were continuously

recorded. These waveforms were analyzed, PO, PC, PS, QS, and QA were identified and recorded, and three derived parameters were calculated: passive ET resistance (RS=PS/QS), active resistance (RA=-PA/QA), and ET DE (DE=RS/RA) for both flow rates. The data were reconciled, and the following parameters were entered into the database for analysis: PO, PC, RS, and DE at each airflow rate. Measures of the passive forces that act to maintain a closed ET lumen are PO and PC; the output of the ease of trans-ET air flow is RS, and RS11/RS23 is considered as the output related to ET compliance. All these parameters are related to the structural or passive properties of the ET. Conversely, the active muscular function is measured with DE, which measures the functional effectiveness in the dilation of the ET lumen with active muscle contraction[4].

For the IDT, the test ear was sealed with the ear-canal probe, and after opening the valves, ME pressure was elevated to a pressure of approximately +200 daPa (referenced to ambient pressure), and to reduce system volume, the valves were closed. The subject was then asked to swallow five times at intervals of 3-5 seconds, and the residual pressure (RP) after the 1st and 5th swallow was recorded. MEP was then vented to ambient pressure. The testing was repeated at an applied MEP of approximately −200 daPa. The parameters used in the analysis were the percentage correction of applied ME positive (Infl%Eq) or negative pressure (Def%Eq) after one and five swallows, calculated as applied pressure minus the RP divided by the applied pressure. The ability to open the ET and percentage of equilibration of the positive and negative MEPs were used to evaluate active muscular function, i.e., the efficiency of the muscle-assisted opening of the resting ET lumen[4].

Continuous measurements of the nasal and ME pressures were obtained during the nasopharyngeal maneuvers. Nasal and ME pressures achieved during the sniffing, Valsalva, and Toynbee maneuvers were recorded.

For the endoscopic examination of the nose and nasopharynx, the nasal passages were topically anesthetized and decongested first with a sprayer and then with a cotton gauze (Medtronic Neuray® Neurosurgical Patties, ½ in. x 2 in., Medtronic Xomed, Inc., Jacksonville, FL) comprising a 1:1 solution of 4% lidocaine hydrochloride (Roxane Laboratories Inc., Columbus, OH) and 0.05% Oxymetazoline Hydrochloride (Major® Soothing 12 Hour Nasal Decongestant Spray, Major Pharmaceuticals, Livonia, MI). A 0° endoscope (Hopkins, 2.7 mm. 18 cm, Karl Storz Endoscopy, Germany) attached to a high-speed digital camera was used to examine the nasal passages. The endoscope was then advanced through the experimental side (had the VT and ETF testing) to the level of the nasopharynx. The endoscope was removed; a 45° telescope (Hopkins, 2.7 mm. 18 cm, Karl Storz Endoscopy, Germany) with the attached video camera was inserted into the same side, advanced to the nasopharynx, and focused on the ipsilateral ET orifice. Movements of the ipsilateral ET and associated structures were visualized and captured while the subject performed three sequential swallows. The state of soft palate elevation, degree of rotation of the posterior lamina of the ET cartilage, and degree of widening of ET orifice was assessed at baseline (T1), at the time of maximum elevation of the soft palate during swallow (T2), at the time of maximum widening of the ET orifice (T3), and at the end of swallow (T4).

Statistical Analysis

In the current manuscript, due to small sample size, Excel (2016 for Windows, Microsoft, Redmond, Washington, USA) Data Analysis tool "Descriptive Statistics" was used. The test results and findings were compared to previously reported values of healthy adults with and without a history of ETD[4].

RESULTS

A total of 17 subjects; 11 males and 6 females, all non-Hispanic white, with an average age 31.3±10.2 (range 18.5–45.6) years were enrolled. Thirteen subjects had unilateral VTs (7 right and 6 left), three had bilateral tubes, and one had unilateral (right) perforation after a recent extrusion of a VT. Test results of only one ear per subject were included in the analysis. For subjects with bilateral VTs, test results of the worse ear were included.

Subjects were otherwise healthy, with chronic and/or recurrent middle-ear problems, especially when they did not have VTs. However, some subjects expressed their symptoms and complaints based on their recall because they experienced those during the usually short interval when a tube had extruded until the new one was inserted. Daily pressure in the ears was present in 10 (58.8%), 4 (23.5%) felt popping, and 2 (11.8%) subjects expressed pain; 11 (64.7%) felt symptoms in the test ear with altitude change, 15 (88.2%) with colds. One subject engaged in scuba diving and felt pressure and popping during this activity. All subjects had experience flying; 12 (70.6%) became symptomatic during or after a flight, 5 (29.4%) felt fullness and pressure, 4 (23.5%) popping, and 2 (11.8%) pain. To alleviate the discomfort, 6 (35.3%) performed Valsalva, 6 (35.3%) yawned, 3 (17.6%) moved their jaw, and 3 (17.6%) chewed gum; 5 (29.4%) stated that nothing helped. Ten (58.8%) subjects stated that they heard their own voice and 8 (47.1%) heard their breathing at least sometimes.

The majority of subjects had ear infections since they were a child. During childhood, 14 (82.4%) subjects recalled having an earache, 13 (76.5%) having ear infections or fluid, 15 (88.2%) receiving antibiotics, and 14 (82.4%) having VTs inserted. All subjects experienced ear infections or fluid as adults and received VTs. In the test ear, subjects recalled having had 8.6±5.5 sets of tubes (range from 2 to >23). The last set of tubes was placed at an average age of 29.9±10.5 years (range 17–45). A history of hearing loss was recalled by 13 (76.5%), dizziness by 5 (29.4%), ringing in the ear by 10 (58.8%), and perforation of the TM in the test ear by 5 (29.4%). Past surgical history included adenoidectomy in 8 (47.1%), tonsillectomy in 7 (41.2%), tympanoplasty in 4 (23.5%), and ossicular chain reconstruction in 1 subject (5.9%). A family history of ear infections or fluid and VT insertion was present in 6 (35.3%).

Review of systems revealed a history of nasal allergies in 10 (58.8%) and asthma in 4 (23.5%) subjects. Sixty-five percent of subjects reported having been tested for allergies, 9 (52.9%) reported seasonal allergies, and 3 (17.6%) reported food allergies. Associated symptoms reported by subjects are listed in Table 1. Six (35.3%) were on antihistamines, and 1 subject (5.9%) was on nasal topical steroids. Although 9 (52.9%) reported some symptoms associated with gastroesophageal reflux disease (GERD), only 2 (11.8%) regularly took reflux medications (1 only proton pump inhibitor, 1 both proton pump inhibitor and H2 blocker), and 1 (5.9%) used antacid as needed. High blood pressure was present in 1 subject (5.9%), cough in 3 (17.6),

nervousness in 3 (17.6%), and sleep problems in 4 (23.5%). There was a smoking history in 6 (35.3%) subjects (duration: 3–22 years); 4 (23.5%) reported having quit smoking. Four subjects (24%) reported a recent weight loss.

The mean ETDQ-7 score was 3.4±1.4 (range 1–5.9); 13 (76.5%) were greater than an average score of 2.5 of the total average score of 7, indicating that they experienced moderate to severe ETD problems (Table 2). Responses to the GERD-HRQL questionnaire indicated normal scores for the heartburn indicators in 11 (64.7%), for regurgitation indicators in 15 (88.2%), and QOL indicators in 11 (64.7%). Average total score of the Allergy Control SCORE was 10.9±10.4 (range 0–34). Average total SNOT-20 questionnaire score was 16.4±13.4 (range 0–43), and the mean score was 0.8±0.7 (range 0–2.2).

Table 1. Symptoms potentially associated with nasal allergies reported by subjects (n=17)

	At present		In the past	
	n	%	n	%
Stuffy nose	6	35.3	12	70.6
Sneezing	5	29.4	11	64.7
Itchy eyes	4	23.5	12	70.6
Runny nose	3	17.6	11	64.7
Frequent colds	2	11.8	8	47.1
Mouth breathing	6	35.3	10	58.8
Snoring	7	41.2	10	58.8

n: number

Table 2. Eustachian Tube Dysfunction Questionnaire (ETDQ-7) results (n=17)

SYMPTOMS	avg	std. dev	min	max
Pressure in the ears?	3.9	1.8	1	6
Pain in the ears?	2.9	1.8	1	6
A feeling that ears are clogged or "under water?"	3.8	2.2	1	6
Ear symptoms when you have a cold or sinusitis?	3.0	1.8	1	7
Crackling or popping sounds in the ear?	3.6	1.7	1	6
Ringing in the ear?	2.8	1.8	1	6
Muffled sound?	3.6	1.9	1	7
Mean score	3.4	1.4	1	5.9

avg: average; std. dev: standard deviation; min: minimum; max: maximum

Among the continuous variable ET function tests (Table 3), the FRT at 11 mL/min pump speed revealed an average opening pressure of 580±333 mmH_2O (range 201–1363). The average closing pressure was 138±192 mmH_2O (range 14–755). The average opening pressure and closing pressure on FRT at 23 mL/min were 501±271 mmH_2O (range 196–1023) and 109±156 (range 0–653), respectively. The ratio of steady-state resistance of two pressures (RS 11/RS 23), a measure of compliance calculated in 15 subjects (88.2%) was 2.2±0.8 (range 1–4). The average percent equilibration of the pressure difference between the 1st and total of 5 swallows in IDT for the inflation test phase (Infl%Eq; when ME pressure is high compared to ambient) were 14%±18.9% and 33.8%±29.2% respectively. For the deflation test phase (when ME pressure is low compared to ambient) the average percent correction for the 1st and 5th swallows (Def%Eq) were 7.5%±9.9% and 22.4%±22%, respectively (Table 4).

Pressure measurements of the nose and the ear canal (equal to the ME with the VT) obtained during the nasopharyngeal maneuvers, including the sniffing, Valsalva, and Toynbee, are summarized in Table 5. Sniffing and Valsalva maneuvers were performed in 13 (76.5%) and Toynbee was performed in 12 (70.6%) subjects. With the sniffing maneuver, only one ear pressure changed 33% of the nasal pressure, two ears changed 5% and 3%, respectively, while the remaining showed no changes in ear pressure at all. Three of the six subjects that exceeded nasal pressures of 600 daPa during Valsalva, raised their ME pressure to 77%, 93%, and 98% of the nasal pressure. The other three with nasal pressures reaching 646, 670, and 1054 daPa increased their ME pressures by 0%, 1%, and 0% of those values, respectively. While half of the nasal pressures decreased with Toynbee, the other half either did not change much or increased. The changes in ME pressure with the Toynbee maneuver were minimal.

Table 3. Forced Response Test (FRT) results for continuous variables

	Pump rate at 11 mL/min					Pump rate at 23 mL/min				
FORCED RESPONSE TEST (FRT)	n	avg	std. dev	min	max	n	avg	std. dev	min	max
Opening pressure (PO)	16	580	333	201	1363	17	501	271	196	1023
Steady-state pressure (PS)	15	382	251	118	992	16	345	236	67	912
Steady-state flow (QS)	15	11.3	1.2	8.6	13.2	16	23.1	1.8	18.4	26.3
Steady-state resistance (RS)	15	34	23	9	83	16	14.8	9.9	3.1	39.5
Swallow pressure (PA)	15	380	255	122	988	16	348	233	77	909
Swallow flow (QA)	15	32	38	0.2	108	16	27	32	3	118
Swallow resistance (RA)	15	131	283	1.5	1039	16	27	35	2	148
Closing pressure (PC)	15	138	192	14	755	17	109	156	0	653
Dilatory efficiency (DE)	15	3.2	4.1	0.0	11.3	16	1.2	1.5	0.2	5.7

n: number; avg: average; std. dev: standard deviation; min: minimum; max: maximum

Video recordings of the endoscopic examination of the nasopharynx with the 0° and 45° endoscopes were available for analysis in 15 (88.2%) subjects (two subjects refused the nasal endoscopy after ETF testing). Those documented a mild, moderate, or large degree of lymphoid tissue in the nasopharynx in 11 (73.3%), in the fossae of Rosenmüller in 13 (86.7%), over the ET cartilage in 6 (40%), and within the ET lumen in 6 (40%) of subjects (Table 6). Inflamed mucosa on the torus tubarius was present in 8 (53.3%). Abundant secretions were present in the nasopharynx and over the ET orifice in 13 (86.7%) and 10 (66.7%) subjects, respectively. Frame-by-frame analysis of videos taken during two swallows showed the average total duration of swallows was 3.42±1.55 s, while time to a maximum elevation of the soft palate was a 1.42±0.86 s, with maximum widening of the ET orifice occurring 0.47±0.37 s after the maximum palatal elevation. Mild constriction of the ET orifice during soft palate elevation was seen in 10% of swallows.

Table 4. Inflation–Deflation Test (IDT) results

Test phase	Percent equilibration	n	Avg (%)	Std. dev (%)	Min (%)	Max (%)
Inflation	1st swallow	17	14.0	18.9	1	63
	Sum of 5 swallows	17	33.8	29.2	2	98
Deflation	1st swallow	17	7.5	9.9	0	42
	Sum of 5 swallows	17	22.4	22.0	-1	94

n: number; Avg: average; Std. dev: standard deviation; Min: minimum; Max: maximum

Table 5. Nasal and ear pressure changes from baseline with nasopharyngeal maneuvers: sniffing, Valsalva, and Toynbee

Nasopharyngeal maneuver (n)	Pressure site	Average (daPa)	Std. dev. (daPa)	Minimum (daPa)	Maximum (daPa)
Sniffing (13)	Nasal	-492	197	-1024	-159
	Ear	-13	44	-154	26
Valsalva (13)	Nasal	594	286	197	1214
	Ear	177	327	-15	932
Toynbee (12)	Nasal	-17	107	-166	170
	Ear	1	20	-39	43

Std. dev: standard deviation; daPa: decapascal

Pearson correlation analysis performed on all the quantitative and semi-quantitative variables is summarized in Table 7. Because the full set of associations is impossible to include, variables that have a higher number of significant associations are selected for presentation. Among the questionnaires, SNOT-20 and of the ETF test parameters, DE had the highest number of significant associations with other parameters. However, overall, the low number of significant associations suggest a high degree of variability among the subjects, and may be due to the small number of subjects in the study. It is also possible that conditions the questionnaires assess may not be associated with ETF and ME disease in subjects with a long history of ETD.

DISCUSSION

Previously, ETD was a presumptive diagnosis assigned, without any testing, to ears with symptoms of pressure pain, an uncomfortable degree of popping, an inability to tolerate pressure variations resulting in middle-ear effusion, or hemotympanum and to patients diagnosed with recurrent otitis media, acute or chronic ME effusion, TM retraction, retraction pockets, cholesteatoma, and medical and surgical treatment failures. Most practitioners do not use the various published tests to verify this diagnosis because results do not guide the management of ETD or the resulting clinical condition. Moreover, the fact that these testing methods are not readily available or easily performed, their sensitivity and specificity are not fully documented, and their interpretation requires expertise, compounds this situation.

This situation changed after the discovery of a non-invasive presumably effective treatment, the BDET[5, 15]. Clinicians then felt it challenging to identify the correct indications for this procedure and assess and document its effects. Naturally, reimbursement and medico-legal concerns were among the main driving forces in seeking clarity with respect to defining abnormal ETF. In the absence of the broadly utilized accurate test methods, elements of history, symptoms, questionnaires for symptom scores, and ability to perform Valsalva were used as substitutes for the tests[16]. Tympanometry and tubomanometry results were also added to the ETD test batteries [17, 18] creating scoring systems that go from a simple questionnaire (ETDQ-7) to one that requires a test machine (Tubomanometer) and is only available in a few centers (ETS-7). Recognizing the limitations of these diagnostic criteria, an alternative approach was proposed by the manufacturers of the recently approved balloon dilation device: evidence of negative ME pressure and endoscopic verification of inflammation on and around the ET orifice were added to abnormal ETDQ-7 scores

Table 6. Endoscopic findings of the nasopharynx, on the torus tubarius, and around the Eustachian tube orifice

		None		Mild		Moderate		Large	
Endoscopic findings (n=15)		**n**	**%**	**n**	**%**	**n**	**%**	**n**	**%**
Lymphoid tissue involving	Nasopharynx	4	27	7	47	4	27	0	0
	Fossa of Rosenmüller	2	13	5	33	7	47	1	7
	Over the ET cartilage	9	60	1	7	5	33	0	0
	ET orifice	9	60	4	27	2	13	0	0
Inflamed mucosa on Torus Tubarius		7	47	2	13	5	33	1	7
Secretions on	Nasopharynx	2	13	8	53	4	27	1	7
	ET orifice	5	33	6	40	2	13	2	13

ET: Eustachian tube

Table 7. Pearson correlation coefficients between selected variables

			Questionnaire Scores				Video Analysis		
Selected Pearson Correlation Analysis Results			**ETDQ-7 Score**	**GERD Score**	**Allergy Control Score**	**SNOT-20 Score**	**All Questionnaire Scores**	**Change in angle between T2 and T3**	**Orifice opening at T3**
Video Analysis	Degree of ET cartilage rotation at T2	Slope	−0.61	0.07	−0.07	−0.17	−0.41	0.21	0.03
		p	0.026*	0.81	0.82	0.57	0.16	0.48	0.92
		n	13	13	13	13	13	13	13
	Degree of lumen opening at T2	Slope	0.04	−0.18	−0.67	−0.08	−0.33	−0.36	0.58
		p	0.89	0.55	0.012*	0.79	0.27	0.22	0.04*
		n	13	13	13	13	13	13	13
	Degree of soft palate relaxation at T3	Slope	−0.13	0.06	−0.06	−0.23	−0.16	0.64	−0.08
		p	0.66	0.83	0.84	0.45	0.61	0.018*	0.81
		n	13	13	13	13	13	13	13
	Degree of constriction at T3	Slope	−0.18	−0.18	0.17	−0.21	−0.13	0.54	−0.62
		p	0.56	0.55	0.58	0.49	0.67	0.06	0.02*
		n	13	13	13	13	13	13	13
ETF Test Results	Steady-state resistance at 11 mL/min	Slope	0.50	0.28	0.15	0.54	0.57	−0.53	−0.10
		p	0.06	0.31	0.59	0.039*	0.028*	0.08	0.75
		n	15	15	15	15	15	12	12
	Dilatory efficiency at 11 mL/min	Slope	0.65	0.44	0.08	0.68	0.71	−0.12	−0.11
		p	0.008*	0.10	0.78	0.005*	0.003*	0.71	0.74
		n	15	15	15	15	15	12	12
	Opening pressure at 23 mL/min	Slope	0.42	0.22	0.08	0.50	0.48	−0.61	−0.02
		p	0.10	0.41	0.77	0.041*	0.05	0.028*	0.96
		n	17	17	17	17	17	13	13
	Inflation % equilibration at 1st swallow	Slope	0.22	0.49	0.02	0.24	0.32	0.14	0.12
		p	0.39	0.047*	0.93	0.35	0.21	0.66	0.69
		n	17	17	17	17	17	13	13

ETDQ: Eustachian tube dysfunction questionnaire; GERD: gastroesophageal reflux disease; SNOT: sino-nasal outcome test; ETF: Eustachian tube function
*Correlation coefficients with $p<0.05$; T2: time of maximum elevation of soft palate during swallow; T3: time of maximum widening of the ET orifice

for indication to perform balloon dilation. This approach was based on the claim that the role of balloon dilation is not via the structural changes it causes but via the elimination of the mucosal inflammatory changes at the orifice and in the lumen.[7] Irrespective of the mechanism of action, there is an ongoing need for more sensitive and specific methods for measuring ETF.

In this study, all 17 ears had abnormal ETF as per the previously reported values and ranges of normal and abnormal test results[4]. Of these 17 ears, all had an abnormality in the ET pressure-equalizing function. Fourteen (82.4%) had abnormal passive function properties, i.e., very high-pressure differences between the ME and ambient were needed to passively open the ET. The active function was abnormal in 16 (94.1%), i.e., even when there was a sufficient ME-nasopharynx pressure gradient, the muscle activity was unable to sufficiently widen the ET to equilibrate the pressure difference. Thirteen (76.5%) ears with both abnormal passive and active functions were categorized as having severe ventilatory dysfunction. Three (17.6%) ears with normal passive but abnormal active properties were assigned as having moderate ventilatory dysfunction. The only subject with abnormal passive but normal active function was considered to have mildly abnormal ventilatory ET function.

The protective function of the ET was assessed through the opening and closing pressures. None of the subjects had low opening pressure; however, 7 ears (41.2%) had a low closing pressure, indicating an abnormality in the protective function. Six of the seven ears with abnormal protective function had a severely abnormal pressure-equalizing function, indicating that although those ETs had difficulty in opening passively and actively, once opened, they closed at low pressures, making them prone to regurgitation of nasopharyngeal secretions possibly containing the virus and/or bacteria.

Questionnaires to identify the presence of risk factors for OM and ETD in the study population, such as nasal allergy, sino-nasal symptoms, and GERD, were used to identify potential risk factors for inflammation in and around the ET. However, despite reports in the literature suggestive of these associations, only a few subjects in this study appeared to have relatively high scores.

Current evidence suggests that there may be different ETD phenotypes and that a testing algorithm that produces relevant discriminations is necessary to identify a specific phenotype. Our Center has developed a number of tests, including the FRT and IDT, applicable to ears with a VT or a perforation[4]. In our recent publication, we compared ETF tests between 15 normal ears of 15 adult subjects who received experimental myringotomy with 23 ears of 19 subjects with ventilation tubes inserted for ETD[4]. This study demonstrated that the 4 ETF test parameters (Valsalva, ET opening pressure, DE, and percentage of positive pressure equilibrated) together correctly identified ears with ET dysfunction with a sensitivity of 95% and a specificity of 83%. The 19 subjects in that study had unilateral or bilateral VTs inserted by their physician for the diagnosis of ETD. However, only 20 of the 23 ears had a history of COME, and of the 20, 10 also had a history of acute and/or recurrent acute otitis media, representing a variability in the ETD profile. Conversely, the current study was conducted on a separate more uniform group, defined by having VT insertion for COME, as a distinct group with worse anticipated ETD, not reported previously. The average opening pressure on the FRT in this study was much higher (580±333 daPa at 11 mL/min and 501±271 daPa at 23 mL/min) compared with both study and control groups in the previous publication (approximately 300 daPa for both groups, both pump speeds). Similarly, closing pressures were higher for a similar comparison. These parameters represent a much higher tissue pressure resistance to open and close the ET lumen in the ears with a more severe ETD. Dilatory efficiencies of 3.2±4.1 and 1.2±1.5 for the 11 and 23 mL/min pump speeds, respectively, in the current study, were not different from the results of the ETD group (3.2±3.1 and 2.5±2.2 for 11 and 23 mL/min, respectively) in the previous study. However, DE in the control group from the previous publication was higher (8.7±7.4 and 4.5±2.8 for 11 and 23 mL/min, respectively) compared to the test results of both ETD groups. DE, the measure of active muscular dilation that widens the ET lumen is apparently abnormal in all forms of ETD. The difference between the current study group and the ETD group in the previous publication was more apparent in the inflation–deflation test results. The percent equilibration of positive pressure and negative pressure after 5 swallows were 33.8%±29.2% and 22.4%±22% for this study versus 57%±36% and 33%±38% for the ETD group, respectively. This suggests that ETD was more severe in this population, with its more stringent enrollment criteria, VTs for the indication of COME as an adult, compared with the more diverse cohort reported previously. The current study population with a history of VT insertion as a child in 82%, and an average of 8.6±5.5 sets of tubes (range from 2 to >23) is also clearly different from the study that served to obtain FDA approval for the balloon dilation device on adults with no history of prior VT insertion 39.4%, and only one set of VT in 41.3%, implying very small overlaps between the two study populations[8].

Of these tests, it appears that abnormal passive test results from ETF (opening and closing pressures) are more consistently associated with more severe forms of ETD, similar to those ears with persistent effusion when a VT is not inserted. Of the active function tests, DE is abnormal in most forms of ETD, and the ability to equilibrate positive and negative pressures is worse in ears with VT insertion for chronic effusion.

Results of this study indicate that most subjects had severe obstructive form to ETD, with an ET lumen that required high-pressure differences to open and poor active muscular function inadequate for luminal dilation. These results imply that while any treatment to widen the ET, such as balloon dilation of ET, is not expected to change the voluntary active muscular function, it may reduce the tissue pressures and resistance, thus facilitating luminal opening both passively and actively.

CONCLUSION

Currently, to the best of our knowledge, no test is widely available, easy to use, objective, and reproducible for testing ET function. Sophisticated test methods are still under investigation with respect to their sensitivity and specificity and are used in few centers of the world. Lack of objective and reliable tests leads to the use of surrogate and mostly subjective criteria for diagnosing ETD and determining the best treatment method. The current study suggests that the presence of VTs in adulthood inserted in response to the development of ME effusion indicates severe ETD, and most patients appear to have abnormal ETF with difficulty passively opening the ET and with a weak active muscular function. An effort should be made to address the extrinsic contributors to ETD, such as inflammation, adenoid, and lymphoid tissue, prior to treatment of the ET itself. However, management of such patients addressing only passive properties may not be sufficient for the resolution of ETD. Therefore, such patients with relatively worse ETD should be warned that the severity of their dysfunction may limit the benefit of the available treatment methods.

Ethics Committee Approval: Ethics committee approval was received for this study from University of Pittsburgh Institutional Review Board.

Informed Consent: Written informed consent was obtained from the patients who participated in this study.

Peer-review: Externally peer-reviewed.

Author Contributions: Concept - C.M.A; Design - C.M.A; Supervision - C.M.A., M.S.T., J.D.S.; Resource -C.M.A.; Data Collection and/or Processing - C.M.A., M.S.T., J.D.S.; Analysis and/or Interpretation - C.M.A., M.S.T., J.D.S.; Literature Search - C.M.A.; Writing - C.M.A.; Critical Reviews - C.M.A., M.S.T., J.D.S.

Acknowledgements: The authors would like to thank Late Willam J. Doyle Ph.D. for contributions to design, Ellen N. Mandel MD, for review and editing of the manuscript.

Conflict of Interest: No conflict of interest was declared by the authors.

Financial Disclosure: This study was supported by NIH (NIDCD R21DC013167).

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