Published in final edited form as:
Acta Otolaryngol. 2011 November ; 131(11): 1150–1154. doi:10.3109/00016489.2011.603137.

A Pilot Study of the Ability of the Forced Response Test to Discriminate Between 3-Year-Old Children with Chronic Otitis Media with Effusion or with Recurrent Acute Otitis Media

Margaretha L. Casselbrant, MD, PhD, **Ellen M. Mandel, MD**, **James T Seroky, MS**, **J. Douglas Swarts, PhD**, and **William J. Doyle, PhD**
Division of Pediatric Otolaryngology, Children's Hospital of Pittsburgh and the University of Pittsburgh School of Medicine, Pittsburgh, PA

Abstract

Conclusions—The Forced Response Test (FRT) when used to test 3-year-old children within 3 months of tympanostomy tube placement for recurrent acute otitis media (rAOM) or chronic otitis media (cOME) showed relatively minor differences in the active and passive functions of the Eustachian tube. While the sample size was small, the high variability in all test parameters suggests that the FRT alone is not capable of distinguishing between children with different otitis media expressions.

Objective—The FRT was designed to measure the passive and active properties of the Eustachian tube. We evaluated the ability of that test to discriminate groups of children with rAOM or cOME.

Methods—Twenty-two ears (15 children) with a confirmed history of rAOM and 24 ears (17 children) with a confirmed history of cOME were tested at 3 years of age within 3 months of ventilation tube placement. The parameters of the FRT were compared between these groups using a two-tailed Student's t test and the frequencies of ears evidencing Eustachian tube dilation with swallowing were compared between groups using a Chi-square test.

Results—Passive resistance and one measure of active function were significantly higher in the rAOM group. The frequency of tubal dilation was not significantly different between groups. There were no differences in any of the FRT measures between cOME ears that did and did not have acute otitis media by history.

Keywords

Eustachian Tube Function; Middle Ear Disease; Diagnostic Utility; Forced Response Test

INTRODUCTION

Otitis media is a disease characterized by inflammation of the middle ear mucosa with or without the presence of an effusion within the normally air-filled middle ear and can present as an acute bacterial infection (acute otitis media, AOM) or as otitis media with effusion (OME). Past studies suggest that poor Eustachian tube function (ETF) contributes to the pathogenesis of these disease expressions with Eustachian tubes that passively open at

Correspondence To: Ellen M. Mandel, MD, Department of Otolaryngology, Children's Hospital of Pittsburgh of UPMC, One Children's Hospital Drive, 4401 Penn Avenue, Pittsburgh, PA 15224, Phone: 412 692-6214, FAX: 412 692-6074, mandele@pitt.edu.

CONFLICT OF INTEREST STATEMENT
None of the authors have a conflict of interest to declare regarding this manuscript.

relatively small nasopharyngeal pressures promoting the development of recurrent AOM (rAOM) and those with poor muscle-assisted Eustachian tube openings promoting the development of chronic OME (cOME) (1).

There are a variety of tests available to assess the function of the Eustachian tube. For ears with an intact tympanic membrane, these include the inflation-deflation test within a pressure chamber (2), the Valsalva (3) and Sniffing (4) maneuvers and the 9-step test (5). However, the predictive value of these tests for assessing surgical results or discriminating populations “at risk” for different disease expressions is inconsistent and less than optimal.

The Forced Response Test (FRT) was developed to provide measures of both the passive and active functions of the Eustachian tube in ears with a non-intact tympanic membrane. The passive functions include the ease of opening the Eustachian tube by middle ear over-pressure, the pressure at which the Eustachian tube passively closes and the intra-luminal airflow required to maintain a dilated Eustachian tube lumen. The active functions include the ability of the paratubal muscles to further dilate a pre-dilated Eustachian tube lumen as well as the extent of that dilation (6).

To date, no study concurrently evaluated the capabilities of that test to discriminate groups of children (or adults) with different disease expressions despite the 30 years since its description. The purpose of this pilot study was to compare the results of the FRT in 3-year-old children with ventilation tubes placed for either cOME or rAOM. Based on the pathogenic mechanisms outlined by Bluestone, we expect that the active function will be poorer in the cOME group and that the passive function measures will be less in the rAOM group (1).

MATERIALS AND METHODS

The study was approved by the University of Pittsburgh Institutional Review Board (IRB). Parents of potentially eligible children were recruited from the ENT clinics and from other sources. The design, parental obligations and procedures were explained to those parents expressing interest, and, if in agreement, signed informed consent was obtained. In this report, we present FRT test results for subjects at 3 years of age. To avoid bias in the presentation of results, only those tests with complete FRT data for at least one ear were included.

The FRT requires the presence of a patent ventilation tube (or a non-intact tympanic membrane) with no evidence of otorrhea. All subjects in this report had bilateral ventilation tubes inserted for unilateral or bilateral rAOM or cOME and were tested within 3 months of tube placement. The diagnosis was confirmed by examination of the records from the child’s primary care physician and/or from the Children’s Hospital of Pittsburgh ENT clinic. A child was classified as having rAOM for a history of ≥3 episodes of AOM in 6 months or ≥4 episodes in 12 months. cOME was defined as the presence of middle ear effusion for ≥3 months bilaterally or ≥6 months unilaterally. Children classified as cOME could also have had AOM episodes. Children were excluded from the study if they had cleft palate or other craniofacial syndromes with a predisposition to otitis media, cholesteatoma, or other past ear surgery other than ventilation tube insertion. For children with a unilateral history of cOME or rAOM, only the ear with documented disease was included in the data analysis.

On presentation for testing, otoscopy was done by a study physician to document a lack of otorrhea and ventilation tube patency. Tympanometry was also done. For FRT testing, the child was seated either in the parent’s lap and gently restrained or by him/herself in the testing chair. A hermetically sealed plastic probe was introduced into the ear canal. The probe was coupled to a flow sensor, pressure transducer and, via a valve, to a variable-speed,

constant flow pump as described by Cantekin and colleagues (6). The constant flow pump was set to deliver ≈23 ml/min of air-flow to the system and middle ear. This application of air-flow increased middle ear pressure to a point where the Eustachian tube passively opened (Opening pressure-PO). Continued delivery of air-flow usually resulted in a semi-stable system pressure (PS) with the flow rate through the Eustachian tube being equal to that delivered by the pump (QS). The child was induced to swallow by drinking liquid from a cup causing activity of the two paratubal muscles, the tensor veli palatini and levator veli palatini muscles, which is associated with either further dilation or constriction of the pre-dilated Eustachian tube lumen. Such events were measured by recording the pre-swallow system pressure (PA) and air-flow (QA) during the swallow. The pump was then turned off, allowing the Eustachian tube to passively close (PC). The FRT variables analyzed for this report are those representing the passive characteristics of the Eustachian tube (PO, PC and passive Eustachian tube resistance [RS=PS/QS]), and those representing the active, muscle-assisted function of the Eustachian tube (Eustachian tube constriction/dilation, active Eustachian tube resistance [RA=PA/QA] and Eustachian tube dilatory efficiency [DE=RS/RA]). We also calculated the active Eustachian tube resistance (RA*) and dilatory efficiency (DE*) for the subset of tests where the Eustachian tube was noted to dilate on swallowing as was described previously (6). Where possible, this test protocol was done bilaterally. For some ears, the FRT was not done because the ventilation tube was occluded or displaced, or otorrhea or AOM was observed. The results for a number of the bilateral testings were not complete usually because the child failed to cooperate and the test session was interrupted before the contralateral ear could be tested.

The data are summarized as the average and standard deviations of PO, PC, RS, RA and DE for all tests, and those for RA* and DE* when Eustachian tube dilation was observed. RA and DE were highly skewed and therefore a log transformation was done on the data for these parameters. Each parameter of the FRT was compared between groups using a Students two-tailed t test evaluated at $p<0.05$. Also, the percent of tests evidencing an increase in airflow for the pre-dilated Eustachian tube lumen (Eustachian tube dilation) was compared between groups using a Chi-Square test evaluated at $p<0.05$. We also tested for independent contributions of sex, race, and the parameters of the FRT as predictors of group assignment using logistic regression. Finally, these comparisons were made between those ears with cOME that did and did not also have AOM recorded in their medical records.

RESULTS

A total of 22 rAOM and 24 cOME ears were tested. For rAOM, these tests were based on 15 children (5 left ears only, 3 right ears only, 7 both ears tested) and for cOME on 17 children (7 left ears only, 3 right ear, 7 both ears tested). For the 22 ears in the rAOM group, 8 of the ears were from males and 14 were from females (18 white, 2 black and 2 mixed race) and for the 24 ears in the cOME groups 10 were from males and 14 from females (18 white, 2 black, 4 mixed race). Of the 24 ears with cOME, 12 ears were from children who also had AOM episodes noted in their medical records. The average and standard deviations of the days between ventilation tube insertion and testing was 45.2±21.2 and 45.3±12.3 ($t=-0.02$, $p=0.98$) for the cOME and rAOM groups, respectively.

For the two groups, the summary data for each of the FRT variables are presented in Table I along with the associated t-values and p-levels. Of the FRT parameters, only 2 were statistically different between groups, with RS and DE* being lower in the OME group when compared to the rAOM group. Of the 22 tests in the rAOM group, 9 (41%) evidenced tubal dilation with swallowing, as opposed to 11 (46%) of the 24 tests in the cOME group (ChiSquare=1.11, $p=0.74$). Logistic regression did not identify any of the possible predictor variables as significant contributors to group assignment.

These data for the two subgroups of cOME defined by the absence and presence of AOM recorded in the study charts are reported in Table II. There were no significant differences in any of the measured FRT parameters. Of the 12 tests in the cOME subgroup, 7 (58%) evidenced tubal dilation with swallowing as opposed to 4 of the 12 tests (33%) in the cOME +AOM subgroup (ChiSquare=1.51, p=0.22).

DISCUSSION

In this pilot study, the sample sizes were rather small allowing for the possibility of failure to identify significant between-group discriminators. However, we chose to limit our analyses to these two groups because the ears were well characterized with respect to disease assignment and similar for sex, race, age, and the time between ventilation tube insertion and FRT testing. Our results were not impressive with only 1 parameter of the passive function parameters and one highly selected parameter of the active function parameters showing relatively small but significant differences between groups.

It should be noted that low values for the passive function parameters directly reflect the ease of tubal opening by passive processes such as sniffing, the Valsalva or Toynbee maneuver or the application of middle ear or nasopharyngeal overpressures. In contrast, two of the active function parameters (DE and Eustachian tube dilation) directly reflect the relative efficiency of muscle-assisted Eustachian tube opening while the frequency of tubal constriction with swallowing and higher RA values indicate poor muscle assisted tubal opening.

In that regard, we had expected that the passive function parameters would be significantly lower in the rAOM group as was demonstrated by studies in Apache Indians who are characterized by rAOM and/or persistent drainage through a tympanic membrane perforation (7) and in chinchillas that have a low passive resistance (8) and are susceptible to experimentally induced AOM (9). In contrast, we expected that the cOME group would be characterized by poor active function but relatively normal passive function as was reported previously in cleft palate patients who are characterized by persistent, cOME into childhood (10) and in monkeys when the muscles that open the Eustachian tube are debilitated (11). If we accept the validity of our results, these predictions were not realized but rather they were in direct opposition to these expectations.

The diagnostic utility of a variety of ETF tests is not well established and the results of different studies have been contradictory. For example, those tests may or may not predict the outcome of tympanoplasty (12, 13), do not predict the development of effusion during hyperbaric O2 therapy (5), and had no value in predicting which ears would develop recurrence of cOME after ventilation tubes, inserted for cOME, were displaced (14). In contrast, ETF tests did show abnormalities during a cold-like illness (15), predicted which subjects would develop middle ear underpressures during upper respiratory infection (16), discriminated the subset of ears susceptible to “sniffing” induced middle ear underpressures (4), and predicted the risk for barotrauma in divers (3). Nonetheless, for most of the studies listed above, the literature contains others with opposing conclusions.

In summary, a role for ETF has not been clearly established for most otologic diseases. One problem that affects this capability is the variety of ETF tests published in the literature and the use of different methods in different studies. In this study, the FRT was used because it is believed to be the most sensitive test for assessing the passive and active functions of the Eustachian tube (6). From our results, we question whether or not the FRT can discriminate between groups of 3-year-old children with two different disease presentations presumably caused by different pathogenic mechanisms. Moreover, given the high variability in all of

the test parameters, we dismiss the possibility that an individual can be assigned to a particular disease expression based on the results of that test.

Acknowledgments

Supported in Part by NIH grant DC005832. The authors would like to thank Kathleen Tekely, RN, for assistance with subject recruiting, and Juliane Banks, BA, Maria Swarts, BA and Jenna El-Wagga for assistance with data abstraction and formatting.

References

1. Bluestone CD. Pathogenesis of otitis media: role of eustachian tube. Pediatr Infect Dis J. 1996 Apr; 15(4):281–91. [PubMed: 8866795]
2. Bylander A. Upper respiratory tract infection and eustachian tube function in children. Acta Otolaryngol. 1984 Mar-Apr;97(3–4):343–9. [PubMed: 6539043]
3. Uzun C. Evaluation of predive parameters related to eustachian tube dysfunction for symptomatic middle ear barotrauma in divers. Otol Neurotol. 2005 Jan; 26(1):59–64. [PubMed: 15699720]
4. Sakakihara J, Honjo I, Fujita A, Kurata K, Takahashi H. Eustachian tube compliance in sniff-induced otitis media with effusion. A preliminary study. Acta Otolaryngol. 1993 Mar; 113(2):187–90. [PubMed: 8475734]
5. Karahatay S, Yilmaz YF, Birkent H, Ay H, Satar B. Middle ear barotrauma with hyperbaric oxygen therapy: incidence and the predictive value of the nine-step inflation/deflation test and otoscopy. Ear Nose Throat J. 2008 Dec; 87(12):684–8. [PubMed: 19105143]
6. Cantekin EI, Saez CA, Bluestone CD, Bern SA. Airflow through the eustachian tube. Ann Otol Rhinol Laryngol. 1979 Sep-Oct;88(5 Pt 1):603–12. [PubMed: 573980]
7. Beery QC, Doyle WJ, Cantekin EI, Bluestone CD, Wiet RJ. Eustachian tube function in an American Indian population. Ann Otol Rhinol Laryngol Suppl. 1980 May-Jun;89(3 Pt 2):28–33. [PubMed: 6778327]
8. Doyle WJ. Eustachian tube function in the chinchilla. Arch Otolaryngol. 1985 May; 111(5):305–8. [PubMed: 3985851]
9. Giebink GS. Otitis media: the chinchilla model. Microb Drug Resist. 1999 Spring;5(1):57–72. [PubMed: 10332723]
10. Doyle WJ, Cantekin EI, Bluestone CD. Eustachian tube function in cleft palate children. Ann Otol Rhinol Laryngol Suppl. 1980 May-Jun;89(3 Pt 2):34–40. [PubMed: 6778343]
11. Doyle WJ. Functional eustachian tube obstruction and otitis media in a primate model. A review. Acta Otolaryngol Suppl. 1984; 414:52–7. [PubMed: 6398609]
12. Bluestone CD, Cantekin EI, Douglas GS. Eustachian tube function related to the results of tympanoplasty in children. Laryngoscope. 1979 Mar; 89(3):450–8. [PubMed: 431249]
13. Takahashi H, Sato H, Nakamura H, Naito Y, Umeki H. Correlation between middle-ear pressure-regulation functions and outcome of type-I tympanoplasty. Auris Nasus Larynx. 2007 Jun; 34(2): 173–6. [PubMed: 17055205]
14. Straetemans M, van Heerbeek N, Schilder AG, Feuth T, Rijkers GT, Zielhuis GA. Eustachian tube function before recurrence of otitis media with effusion. Arch Otolaryngol Head Neck Surg. 2005 Feb; 131(2):118–23. [PubMed: 15723942]
15. Miura M, Takahashi H, Honjo I, Hasebe S, Tanabe M. Influence of the upper respiratory tract infection on tubal compliance in children with otitis media with effusion. Acta Otolaryngol. 1997 Jul; 117(4):574–7. [PubMed: 9288215]
16. Doyle WJ, Seroky JT, Angelini BL, Gulhan M, Skoner DP, Fireman P. Abnormal middle ear pressures during experimental influenza A virus infection--role of Eustachian tube function. Auris Nasus Larynx. 2000 Oct; 27(4):323–6. [PubMed: 10996490]

TABLE I

The Sample Size (N), Average (AVG), Standard Deviations (STD), t-value and p-level for the 5 Forced Response Variables; opening pressure (PO), closing pressure (PC), passive resistance (RS), log active resistance (Log RA) and the log dilatory efficiency (Log DE) and the active resistance (RA*) and dilatory efficiency (DE*) when calculated for those ears exhibiting Eustachian tube dilation in the cOME and rAOM groups.

	cOME			rAOM				
	N	**AVG**	**STD**	**N**	**AVG**	**STD**	**T-value**	**p-level**
PO	24	309.0	119.5	22	309.5	102.6	−0.01	0.99
PC	24	102.0	44.5	22	99.4	37.4	0.22	0.83
RS	24	6.9	2.8	22	8.6	2.7	−2.11	0.04
Log RA	24	0.9	0.5	22	1.1	0.7	−0.65	0.52
Log DE	24	−0.1	0.5	22	−0.2	0.7	−0.02	0.98
RA*	11	3.3	1.6	9	2.0	0.9	2.04	0.06
DE*	11	2.5	1.1	9	5.2	3.9	−2.22	0.04

TABLE II

The Sample Size (N), Average (AVG), Standard Deviations (STD), t-value and p-level for the 5 Forced Response Variables; opening pressure (PO), closing pressure (PC), passive resistance (RS), log active resistance (Log RA) and the log dilatory efficiency (Log DE) and the active resistance (RA*) and dilatory efficiency (DE*) when calculated for those ears exhibiting Eustachian tube dilation in the cOME and cOME+AOM groups.

	cOME			cOME+AOM				
	N	**AVG**	**STD**	**N**	**AVG**	**STD**	**T-value**	**p-level**
PO	12	282.7	128.4	12	335.4	108.8	−1.09	0.29
PC	12	95.7	30.4	12	108.4	55.9	−0.69	0.49
RS	12	6.6	2.7	12	7.2	3.0	−0.53	0.60
Log RA	12	0.8	0.5	12	1.0	0.5	−0.95	0.35
Log DE	12	−0.1	0.6	12	−0.2	0.4	0.79	0.44
RA*	7	3.1	1.5	4	3.5	2.1	−0.32	0.75
DE*	7	2.8	1.3	4	1.9	0.5	1.24	0.25