Middle Ear Barotraumas in Commercial Aircrew

Oskari H. Lindfors; Kimmo S. Ketola; Tuomas K. Klockars; Tuomo K. Leino; Saku T. Sinkkonen

BACKGROUND: Middle ear (ME) barotraumas are the most common condition in aviation medicine, sometimes seriously compromising flight safety. Considering this and the ever-increasing amount of commercial aviation, a detailed overview is warranted.

METHODS: In this survey study, an anonymous, electronic questionnaire was distributed to commercial aircrew of the three major commercial airlines operating in Finland ($N = 3799$), covering 93% of the target population (i.e., all commercial aircrew operating in Finland, $N = 4083$). Primary outcomes were self-reported prevalence, clinical characteristics, and health and occupational effects of ME barotraumas in flight. Secondary outcomes were adjusted odds ratios (OR) for frequency of ME barotraumas with respect to possible risk factors.

RESULTS: Response rate was 47% ($N = 1789/3799$), with 85% ($N = 1516$) having experienced ME barotraumas in flight. Of those affected, 60% had used medications, 5% had undergone surgical procedures, and 48% had been on sick leave due to ME barotraumas (40% during the last year). Factors associated with ME barotraumas included a high number of upper respiratory tract infections [≥3 URTIs/yr vs. 0 URTIs/yr: OR, 9.02; 95% confidence interval (CI) 3.99–20.39] and poor subjective performance in Valsalva ("occasionally" vs. "always" successful: OR, 7.84; 95% CI 3.97–15.51) and Toynbee ("occasionally" vs. "always" successful: OR, 9.06; 95% CI 2.67–30.78) maneuvers.

CONCLUSION: ME barotraumas were reported by 85% of commercial aircrew. They lead to an increased need for medications, otorhinolaryngology-related surgical procedures, and sickness absence from flight duty. Possible risk factors include a high number of URTIs and poor performance in pressure equalization maneuvers.

KEYWORDS: ENT, epidemiology, Eustachian tube, Eustachian tube dysfunction, health surveys, survey, Valsalva maneuver.

Lindfors OH, Ketola KS, Klockars TK, Leino TK, Sinkkonen ST. *Middle ear barotraumas in commercial aircrew.* Aerosp Med Hum Perform. 2021; 92(3):182–189.

Middle ear (ME) barotraumas in flight are the result of inadequate Eustachian tube (ET) function during atmospheric pressure changes,[13,17] which is generally considered to be the mildest form of ET dysfunction.[28] This condition can cause significant discomfort for both passengers and aircrew, but more importantly, pose a serious risk to flight safety. ME barotraumas can cause a variety of symptoms, including hearing loss and pressure sensations, pain, or ringing in the ears. Less frequently, facial baroparesis[1,6,8] or inner ear damage[14] can occur, sometimes causing serious incapacitation.[9,14]

Prevalence estimations vary significantly. The lowest numbers, 1.5–2.4%, have been reported in pressure chamber measurements of Italian military personnel,[16,20] while a prevalence of 4.1% has been reported in Japanese pilots.[23] In contrast, 37.6–55.5% of Danish commercial pilots have reported at least one ME barotrauma during their career[5,25] and in other publications, 41.0–84.0% of airline passengers have reported similar symptoms.[18,30] The symptoms have, in some instances, led to permanent groundings of aviation staff[9,14] and are, in fact, considered the most common medical condition encountered in all aviation medicine.[7]

Considering both the ever-increasing amount of commercial aviation[2,3] (with the exception of the still-ongoing COVID-19 era) and the relative commonness of ME barotraumas, a detailed examination on the matter is most definitely warranted. To this end, the primary objectives of our study were to

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This manuscript was received for review in July 2020. It was accepted for publication in December 2020.

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DOI: https://doi.org/10.3357/AMHP.5738.2021

determine the frequency, clinical characteristics, and both health and occupational effects of ME barotraumas in flight. The secondary objective was to elucidate possible risk factors, the tertiary to examine whether repetitive exposure to rapid changes in atmospheric pressure might gradually lead to an increase in these problems.

METHODS

Subjects

The study was conducted in accordance with the Declaration of Helsinki and approved by the Ethics Committee of the Hospital District of Helsinki and Uusimaa (§6164/HUS/2508/2018). The need for informed consent was waived as the study was conducted anonymously.

Questionnaire

The literature for questionnaires regarding ME barotraumas in flight was reviewed. As none of the published questionnaires could be used to meet the objectives of the study, a new questionnaire was developed by the research group with the support of previous literature.

The questionnaire consisted of 18–58 questions (depending on the answers of each individual respondent) designed to best determine the respondents' aviation and medical histories as well as their frequency of ME barotraumas in flight. Moreover, the respondents were asked about the possible pressure-chamber testing, clinical characteristics, and occupational health effects of these symptoms, such as their need for medications, otorhinolaryngology-related surgical procedures, and sickness absence from flight duty. The anonymous Finnish questionnaire was twice piloted with selected aircrew personnel (the English translation is presented in **Appendix A**, https://doi.org/10.3357/AMHP.5738sd.2021).

The questionnaire was electronically sent via company e-mail to all Finnish-speaking aircrew of the three major commercial aviation companies operating in Finland. The study population was considered nationally representative as the questionnaire covered a total of 93.0% of Finnish commercial aircrew. Data acquisition was carried out between November 2018–May 2019, consisting of the primary e-mail and repeated reminder e-mails at approximately 1-mo intervals (full details of data acquisition presented in **Appendix B**, https://doi.org/10.3357/AMHP.5738sd.2021).

Statistical Analysis

All statistical analyses were performed using SPSS Statistics for Windows, version 25.0, released 2017 (IBM Corp, Armonk, NY, USA). A two-tailed *P*-value of < 0.05 was interpreted to indicate statistical significance.

Descriptive statistics are presented as numbers and percentages for categorical variables and as medians and interquartile ranges for continuous variables. Categorical data were analyzed using Fisher's exact test (two-tailed) and, when there was insufficient memory to do so, using the Chi-squared test. Continuous variables were analyzed using the Mann-Whitney *U*-test or the Kruskal-Wallis test as appropriate. In order to counter the multiple comparisons, Bonferroni correction was used when appropriate.

Multivariable binary logistic regression analyses were performed to identify factors associated with ME barotraumas in flight. Variables included in the models were sex, profession, number of flight years, age, body mass index (BMI), pollen allergies, smoking, number of upper respiratory tract infections (URTIs) per year, and subjective Valsalva and Toynbee performances. The results are presented as adjusted odds ratios (OR) with 95% confidence intervals (CI), where the frequency of ME barotraumas was dichotomized at two different cutoff points. The first cutoff point was set between "never" and at least "sporadically" suffering from ME barotraumas during one's career, the second between suffering from ME barotraumas only "sporadically" and at least "occasionally". These two separate cutoff points were chosen to gain a better overall understanding of factors associated with the condition.

RESULTS

The questionnaire yielded a response rate of 47.3% (1798/3799) and after deletion of nine technically unsuccessful responses, a final response rate of 47.1% (1789/3799). An overview of the study sample is presented in **Table I**.

In total, 38.3% of the respondents were pilots and 61.7% were cabin crew. A significant majority of pilots were men (95.2%), while women (88.6%) made up the majority of cabin crew ($P < 0.001$). Median (IQR) age was 40 (34–48) yr in pilots and 44 (33–53) yr in cabin crew ($P < 0.001$), while height, weight, and BMI broadly conformed to the sex distributions of the two profession groups ($P < 0.001$ for all variables, respectively). Further characteristics of the study sample are presented in Table I.

URTIs were less frequent in the pilot group. The proportion of respondents with 0 URTIs per year was the same in both groups, but a larger proportion of pilots reported having only one URTI per year compared to cabin crew (37.8% vs. 30.2%, $P = 0.003$). The proportion of respondents with two URTIs per year was the same, but a smaller proportion of pilots reported having ≥3 URTIs per year compared to cabin crew (23.0% vs. 31.3%, $P = 0.003$).

Subjective Valsalva and Toynbee performances also differed between the profession groups. With regard to the Valsalva maneuver, 23.9% of pilots reported succeeding in the maneuver "always" (even when having an URTI), while 11.7% of cabin crew reported the same ($P < 0.001$). Conversely, 6.7% of pilots reported succeeding in the maneuver "occasionally" or "never", as opposed to 23.8% of cabin crew. Similar findings were observed with respect to Toynbee performance, albeit it was generally considered the harder one to succeed in of the two maneuvers.

ME barotraumas in flight had affected 84.7% of the respondents. A total of 62.0% reported symptoms "sporadically", another 20.7% "occasionally", and a further 2.0% "almost always" or "always" when flying. The proportion of respondents

Table I. Overview of the Study Sample and Middle Ear Barotraumas in Flight.

VARIABLE	ALL (N = 1789)	COCKPIT (N = 686)	CABIN (N = 1103)	P-VALUE
Sex				
Female	1010 (56.5%)	33 (4.8%)	977 (88.6%)	<0.001
Male	779 (43.5%)	653 (95.2%)	126 (11.4%)	
Age (years)	42 (34–51)	40 (34–48)	44 (33–53)	<0.001
Height (cm)	173 (168–180)	180 (176–185)	170 (166–174)	<0.001
Weight^{x} (kg)	74 (64–83)	82 (75–89)	67 (60–75)	<0.001
BMI^{x} (kg/m^2)	24 (22–26)	25 (23–27)	23 (21–26)	<0.001
Flight years	13 (3–24)	13 (5–23)	12 (3–25)	0.360
Flight times^{y}	3000 (1000–5500)^{y}	3000 (1200-6000)^{y1}	2000 (500–4400)^{y2}	<0.001
Smoking				
Never	1521 (85.0%)	605 (88.2%)$_a$	916 (83.0%)$_b$	<0.001
Occasionally	198 (11.1%)	69 (10.1%)	129 (11.7%)	
Regularly	70 (3.9%)	12 (1.7%)$_a$	58 (5.3%)$_b$	
Allergies				
Any allergy	539 (30.1%)	202 (29.4%)	337 (30.6%)	0.634
Pollen	384 (21.5%)	155 (22.6%)	229 (20.8%)	0.375
Animal	137 (7.7%)	59 (8.6%)	78 (7.1%)	0.236
Food	96 (5.4%)	20 (2.9%)	76 (6.9%)	<0.001
Other	93 (5.2%)	23 (3.4%)	70 (6.3%)	0.006
Surgical procedures (ORL-related)				
Any procedure	719 (40.2%)	288 (42.0%)	431 (39.1%)	0.234
Adenoidectomy	505 (28.2%)	195 (28.4%)	310 (28.1%)	0.914
Myringotomy	220 (12.3%)	99 (14.4%)	121 (11.0%)	0.032
Tympanostomy	83 (4.6%)	33 (4.8%)	50 (4.5%)	0.818
BET	7 (0.4%)	3 (0.4%)	4 (0.4%)	>0.99
Myringoplasty	11 (0.6%)	5 (0.7%)	6 (0.5%)	0.758
FESS	91 (5.1%)	30 (4.4%)	61 (5.5%)	0.320
Septoplasty	37 (2.1%)	20 (2.9%)	17 (1.5%)	0.059
RFA (inf. turbinates)	14 (0.8%)	9 (1.3%)	5 (0.5%)	0.055
Cleft palate	2 (0.1%)	0 (0.0%)	2 (0.2%)	0.527
URTI per year				
0	120 (6.7%)	46 (6.7%)	74 (6.7%)	0.003†
1	592 (33.1%)	259 (37.8%)$_a$	333 (30.2%)$_b$	
2	574 (32.1%)	223 (32.5%)	351 (31.8%)	
≥ 3	503 (28.1%)	158 (23.0%)$_a$	345 (31.3%)$_b$	
Subj. Valsalva performance				
Never/Occasionally	308 (17.2%)	46 (6.7%)$_a$	262 (23.8%)$_b$	<0.001
Almost always (not when URTI)	1188 (66.4%)	476 (69.4%)$_a$	712 (64.6%)$_b$	
Always	293 (16.4%)	164 (23.9%)$_a$	129 (11.7%)$_b$	
Subj. Toynbee performance				
Never/Occasionally	709 (39.6%)	215 (31.3%)$_a$	494 (44.8%)$_b$	<0.001
Almost always (not when URTI)	906 (50.6%)	395 (57.6%)$_a$	511 (46.3%)$_b$	
Always	174 (9.7%)	76 (11.1%)	98 (8.9%)	
Pres. equalization test before flight				
No	1397 (78.1%)	519 (75.7%)	878 (79.6%)	0.053
Yes	392 (21.9%)	167 (24.3%)	225 (20.4%)	
Middle ear barotraumas in flight				
Never	273 (15.3%)	101 (14.7%)	172 (15.6%)	<0.001
Sporadically	1109 (62.0%)	485 (70.7%)$_a$	624 (56.6%)$_b$	
Occasionally	370 (20.7%)	92 (13.4%)$_a$	278 (25.2%)$_b$	
Almost always	33 (1.8%)	7 (1.0%)$_a$	26 (2.4%)$_b$	
Always	4 (0.2%)	1 (0.1%)	3 (0.3%)	

Data missing in ^{x}2, ^{y}968, ^{y1}48, and ^{y2}920 cases. Categorical data is presented as numbers (%) and continuous data is presented as medians (IQR). Categorical data was analyzed using Fisher's exact (two-tailed) or Chi-squared tests (when there was insufficient memory to conduct Fisher's exact test, marked as †) and continuous data was analyzed using the Mann-Whitney U-test. Bonferroni correction was used when carrying out multiple comparisons. Each subscript letter denotes a subset of categories whose column proportions do not differ significantly from each other at the 0.05 level.

BET, balloon Eustachian tuboplasty; BMI, body mass index; FESS, functional endoscopic sinus surgery; ORL, otorhinolaryngology; RFA, radiofrequency ablation; URTI, upper respiratory tract infection.

experiencing symptoms "sporadically" was significantly larger in the pilot group (70.7% vs. 56.6%), while the proportion of those who responded "occasionally" or "almost always" was significantly larger in cabin crew (14.4% vs. 27.6%, $P < 0.001$).

Factors associated with the frequency of ME barotraumas in flight are presented as ORs and 95% CIs in **Table II**. Both the number of URTIs per year and subjective Valsalva and Toynbee performances were strongly associated with the frequency of

Table II. Multivariable Logistic Regression Analyses of Factors Associated with Middle Ear Barotraumas in Flight.

VARIABLE	OR (95% CI)	OR (95% CI)
	(N = 273 vs. 1516)	(N = 1382 vs. 407)
FREQUENCY OF MIDDLE EAR BAROTRAUMAS IN FLIGHT	NEVER vs. SPORADICALLY, OCCASIONALLY, ALMOST ALWAYS, ALWAYS	NEVER & SPORADICALLY vs. OCCASIONALLY, ALMOST ALWAYS, ALWAYS
Age	0.95 (0.93–0.98)	1.01 (0.97–1.04)
Flight years	1.06 (1.04–1.09)	1.02 (0.99–1.04)
BMI[x]	1.03 (0.98–1.09)	1.00 (0.96–1.04)
Sex		
Male	1.00	1.00
Female	1.05 (0.64–1.74)	1.96 (1.21–3.17)
Profession		
Cockpit	1.00	1.00
Cabin crew	0.68 (0.41–1.14)	0.79 (0.49–1.30)
Allergies (pollen)		
No	1.00	1.00
Yes	1.17 (0.81–1.69)	1.23 (0.92–1.66)
Smoking		
Never	1.00	1.00
Occasionally	1.32 (0.81–2.13)	1.06 (0.71–1.59)
Regularly	1.15 (0.53–2.50)	1.80 (1.01–3.21)
URTI per year		
0	1.00	1.00
1	1.96 (1.22–3.15)	2.47 (1.09–5.61)
2	2.58 (1.58–4.22)	3.76 (1.67–8.51)
≥ 3	5.25 (2.99–9.23)	9.02 (3.99–20.39)
Valsalva		
Always	1.00	1.00
Almost always (not when URTI)	3.71 (2.50–5.51)	2.32 (1.21–4.43)
Occasionally/Never	5.49 (3.13–9.64)	7.84 (3.97–15.51)
Toynbee		
Always	1.00	1.00
Almost always (not when URTI)	1.48 (0.94–2.36)	4.26 (1.25–14.54)
Occasionally/Never	2.00 (1.22–3.28)	9.06 (2.67–30.78)

Data missing in [x]2 cases. An adjusted OR over 1 indicates an increase in the odds of experiencing middle ear barotraumas in flight. CI, confidence interval; OR, odds ratio; URTI, upper respiratory tract infection.

the symptoms, while no clear association was found with sex, profession, number of flight years, age, BMI, pollen allergies, or smoking status.

Concerning URTIs, respondents with ≥3 URTIs per year had an adjusted OR of 5.25 (95% CI 2.99–9.23) for experiencing ME barotraumas at least "sporadically" compared to respondents with 0 URTIs per year, and an OR of 9.02 (95% CI 3.99–20.39) for experiencing them at least "occasionally". Generally, the OR for experiencing ME barotraumas increased as the number of URTIs per year increased.

Valsalva and Toynbee performances were both strongly associated with the frequency of ME barotraumas in flight. Respondents who succeeded in Valsalva and Toynbee maneuvers only "occasionally/never" had respective adjusted ORs of 5.49 (95% CI 3.13–9.64) and 2.00 (95% CI 1.22–3.28) for experiencing ME barotraumas at least "sporadically", and ORs of 7.84 (95% CI 3.97–15.51) and 9.06 (2.67–30.77) for experiencing them at least "occasionally". Overall, the ORs for experiencing ME barotraumas increased as the subjective Valsalva and Toynbee performances of the respondents decreased.

Characteristics of ME barotraumas are presented in **Table III**. The table consists of questionnaire results from respondents affected by ME barotraumas (N = 1516) and is divided into three categories based on the respondents' subjective Valsalva performance (as it was shown to be highly associated with the condition in Table II).

With regard to frequency, 53.4% of respondents had experienced ME barotraumas 1–9 times, a further 21.1% 10–19 times, and the final 25.5% ≥20 times during their career. The number of ME barotraumas generally increased as subjective Valsalva performance decreased ($P < 0.001$).

Correlation between ME barotraumas and URTIs varied. A majority of respondents, 63.8%, had had an URTI 100% of the times they had experienced ME barotraumas, another 14.3% >50% of the times, and the remaining 19.3% ≤50% of the times. The correlation of ME barotraumas to URTIs decreased as subjective Valsalva performance decreased ($P < 0.001$).

Symptoms predominantly appeared at the descending phase of the flight. Almost all (97.7%) respondents reported symptoms when descending, 20.3% when ascending, and smaller minorities when cruising (4.1%) or when experiencing a sudden problem with cabin pressurization (4.0%). The proportion of respondents with symptoms at atypical flight stages (i.e., other than descending) increased as subjective Valsalva performance decreased ($P = 0.041$, $P = 0.002$, and $P = 0.001$, respectively).

Table III. Characteristics of Middle Ear Barotraumas in Flight and the Effect of Subjective Valsalva Performance.

VARIABLE	ALL ($N = 1516$)	SUBJECTIVE VALSALVA PERFORMANCE: ALWAYS ($N = 174$)	ALMOST ALWAYS (NOT WHEN URTI) ($N = 1060$)	OCCASIONALLY OR NEVER ($N = 282$)	*P*-VALUE
Symptoms[x]					
1-9 times	809 (53.4%)	144 (82.8%)$_a$	571 (54.0%)$_b$	94 (33.3%)$_c$	<0.001†
10-19 times	319 (21.1%)	19 (10.9%)$_a$	236 (22.3%)$_b$	64 (22.7%)$_b$	
≥20 times	386 (25.5%)	11 (6.3%)$_a$	251 (23.7%)$_b$	124 (44.0%)$_c$	
% of symptomatic times related to URTI[y]					
>100% (= erroneous)	38 (2.6%)	8 (5.4%)	23 (2.2%)	7 (2.6%)	<0.001†
100%	923 (63.8%)	113 (76.4%)$_a$	681 (66.2%)$_b$	129 (47.8%)$_c$	
51–99%	207 (14.3%)	11 (7.4%)$_a$	146 (14.2%)$_{a,b}$	50 (18.5%)$_b$	
≤50%	279 (19.3%)	16 (10.8%)$_a$	179 (17.4%)$_a$	84 (31.1%)$_b$	
Symptoms during flight					
When ascending	308 (20.3%)	25 (14.4%)$_a$	215 (20.3%)$_{a,b}$	68 (24.1%)$_b$	0.041
When cruising	62 (4.1%)	0 (0.0%)$_a$	47 (4.4%)$_b$	15 (5.3%)$_b$	0.002
When descending	1481 (97.7%)	169 (97.1%)	1035 (97.6%)	277 (98.2%)	0.685
Cabin pres. problem	60 (4.0%)	3 (1.7%)$_a$	34 (3.2%)$_a$	23 (8.2%)$_b$	0.001
Symptoms manifested as					
Ear pressure	1426 (94.1%)	149 (85.6%)$_a$	1002 (94.5%)$_b$	275 (97.5%)$_b$	<0.001
Ear pain	857 (56.5%)	71 (40.8%)$_a$	592 (55.8%)$_b$	194 (68.8%)$_c$	<0.001
Ear ringing	194 (12.8%)	14 (8.0%)$_a$	126 (11.9%)$_a$	54 (19.1%)$_b$	0.001
Hearing loss	514 (33.9%)	38 (21.8%)$_a$	353 (33.3%)$_b$	123 (43.6%)$_c$	0.001
TM perforation	49 (3.2%)	0 (0.0%)$_a$	35 (3.3%)$_b$	14 (5.0%)$_b$	0.004
Vertigo	94 (6.2%)	8 (4.6%)	67 (6.3%)	19 (6.7%)	0.663
Nausea	38 (2.5%)	2 (1.1%)	25 (2.4%)	11 (3.9%)	0.177
Other	43 (2.8%)	5 (2.9%)	30 (2.8%)	8 (2.8%)	1.000
Symptoms manifested in					
One ear	202 (13.3%)	17 (9.8%)	147 (13.9%)	38 (13.5%)	<0.001†
Both ears	772 (50.9%)	50 (28.7%)$_a$	543 (51.2%)$_b$	179 (63.5%)$_c$	
Not sure	542 (35.8%)	107 (61.5%)$_a$	370 (34.9%)$_b$	65 (23.0%)$_c$	
Symptoms lasted for					
≤2 min	526 (34.7%)	114 (65.5%)$_a$	356 (33.6%)$_b$	56 (19.9%)$_c$	<0.001†
≤2 h	679 (44.8%)	47 (27.0%)$_a$	494 (46.6%)$_b$	138 (48.9%)$_b$	
≤2 d	241 (15.9%)	10 (5.7%)$_a$	162 (15.3%)$_b$	69 (24.5%)$_c$	
>2 d	70 (4.6%)	3 (1.7%)$_a$	48 (4.5%)$_{a,b}$	19 (6.7%)$_b$	
Symptoms before flight					
Yes	447 (29.5%)	33 (19.0%)$_a$	342 (32.3%)$_b$	72 (25.5%)$_{a,b}$	<0.001
No	1069 (70.5%)	141 (81.0%)$_a$	718 (67.7%)$_b$	210 (74.5%)$_{a,b}$	
Symptom progression over the years					
Less symptoms	279 (18.4%)	35 (20.1%)	201 (19.0%)	43 (15.2%)	<0.001†
Same amount of symptoms	1004 (66.2%)	130 (74.7%)$_a$	712 (67.2%)$_a$	162 (57.4%)$_b$	
More symptoms	233 (15.4%)	9 (5.2%)$_a$	147 (13.9%)$_b$	77 (27.3%)$_c$	

Data missing in [x]2 and [y]69 cases. Categorical data is presented as numbers (%) and was analyzed using Fisher's exact (two-tailed) or Chi-squared tests (when there was insufficient memory to conduct Fisher's exact test, marked as †). Bonferroni correction was used when carrying out multiple comparisons. Each subscript letter denotes a subset of categories whose column proportions do not differ significantly from each other at the 0.05 level.
TM, tympanic membrane; URTI, upper respiratory tract infection.

Symptoms of ME barotraumas were numerous. Of the respondents, 94.1% reported pressure sensations in the ears, 56.5% pain, and 12.8% ringing in the ears, with a further 33.9% reporting hearing loss as a symptom. Among less frequent symptoms, 3.2% had experienced tympanic membrane perforations, 6.2% vertigo, and 2.5% nausea. Generally, the frequency of all symptoms increased as subjective Valsalva performance decreased.

Symptoms were most often bilateral. Half (50.9%) of respondents reported symptoms in both ears and 13.3% in only one ear, with the remaining 35.8% being unsure as to how many ears had been affected.

Symptom duration varied substantially. The symptoms lasted for ≤2 min in 34.7% of cases, 2 min–2 h in 44.8% of cases, 2 h–2 d in 15.9% of cases, and >2 d in 4.6% of cases. The duration of symptoms significantly increased as subjective Valsalva performance decreased ($P < 0.001$).

Symptom development over the years was also examined. A majority (66.2%) of the respondents reported no symptom development in any direction, while 18.4% reported having less symptoms compared to previously during their career. The final 15.4%, however, reported currently having more symptoms and, as the respondents' subjective Valsalva performance decreased, the proportion of respondents with symptom progression during their career increased ($P < 0.001$).

Treatment and occupational health effects of ME barotraumas are presented in **Table IV**. The table consists of questionnaire results from respondents affected by the ME barotraumas

($N = 1516$) and is divided into three categories based on the respondents' subjective Valsalva performance.

Medication due to ME barotraumas had been used by 60.0% of the respondents. Of the respondents who reported "always" succeeding in the Valsalva maneuver, only 29.3% had needed medication, as opposed to 62.0% of those who "almost always" succeeded and 71.6% of those who succeeded in Valsalva only "occasionally/never" ($P < 0.001$). The same general rule applied with both prescribed and nonprescribed medications: their use increased as subjective Valsalva performance decreased.

Surgical procedures due to ME barotraumas had been resorted to by 4.9% of the respondents. Of these, 4.2% had undergone myringotomies, 0.7% tympanostomies, and 0.5% balloon Eustachian tuboplasties. The proportion of respondents having undergone procedures increased as subjective Valsalva performance decreased, reaching statistical significance in myringotomies ($P < 0.001$).

Sickness absences due to ME barotraumas are also presented. During their career, 47.6% of respondents (46.2% of pilots, 48.4% of cabin crew) had been on sick leave, the proportion increasing as subjective Valsalva performance decreased: a total of 23.0% of respondents in the best Valsalva group had been on sick leave as opposed to 55.7% in the worst Valsalva group ($P < 0.001$). The same general rule applied when looking at sickness absences from the previous 12 mo ($P < 0.001$).

DISCUSSION

In our study, ME barotraumas were highly associated with both URTIs and subjective Valsalva and Toynbee performances. While the connection to URTIs has been widely reported,[5,14,25] no previous studies have investigated the role of URTIs as a possible risk factor (Table II) or the proportion of ME barotraumas connected to them (Table III). Surprisingly, the association to Valsalva and Toynbee performance has not been previously examined in aviation, despite the widespread use of the maneuvers as pressure equalization techniques. The association between (objective) Valsalva/Toynbee performance and (otoscopic) barotraumas has been previously reported in diving conditions,[31] but this is not necessarily generalizable to an aviation environment. Although no clear association to smoking or pollen allergies was detected, a connection to pollen allergies has been previously demonstrated by Ohrui et al.[24] This contrast most likely reflects the fact that while Ohrui et al. investigated the association to active, symptomatic allergic rhinitis, we simply investigated an association to a patient-reported

Table IV. Treatment and Occupational Health Effects of Middle Ear Barotraumas in Flight and the Effect of Subjective Valsalva Performance.

VARIABLE	ALL ($N = 1516$)	SUBJECTIVE VALSALVA PERFORMANCE: ALWAYS ($N = 174$)	ALMOST ALWAYS (NOT WHEN URTI) ($N = 1060$)	OCCASIONALLY OR NEVER ($N = 282$)	*P*-VALUE
Medication due to symptoms					
All medication					
All	910 (60.0%)	51 (29.3%)$_a$	657 (62.0%)$_b$	202 (71.6%)$_c$	<0.001
All, last 12 mo	644 (42.5%)	28 (16.1%)$_a$	467 (44.1%)$_b$	149 (52.8%)$_c$	<0.001†
All, earlier	382 (25.2%)	26 (14.9%)$_a$	279 (26.3%)$_b$	77 (27.3%)$_b$	0.004†
Prescribed					
Prescribed, all	664 (43.8%)	31 (17.8%)$_a$	480 (45.3%)$_b$	153 (54.3%)$_c$	<0.001
Prescribed, last 12 mo	449 (29.6%)	19 (10.9%)$_a$	321 (30.3%)$_b$	109 (38.7%)$_c$	<0.001
Prescribed, earlier	254 (16.8%)	14 (8.0%)	186 (17.5%)	54 (19.1%)	0.002
Nonprescribed					
Nonprescribed, all	699 (46.1%)	37 (21.3%)$_a$	495 (46.7%)$_b$	167 (59.2%)$_c$	<0.001
Nonprescribed, last 12 mo	489 (32.3%)	19 (10.9%)$_a$	347 (32.7%)$_b$	123 (43.6%)$_c$	<0.001
Nonprescribed, earlier	255 (16.8%)	21 (12.1%)	176 (16.6%)	58 (20.6%)	0.059
Surgical procedures due to symptoms					
All procedures	74 (4.9%)	1 (0.6%)$_a$	45 (4.2%)$_a$	28 (9.9%)$_b$	0.001
Myringotomy	64 (4.2%)	1 (0.6%)$_a$	36 (3.4%)$_a$	27 (9.6%)$_b$	<0.001
Tympanostomy	10 (0.7%)	0 (0.0%)	8 (0.8%)	2 (0.7%)	0.772
BET	7 (0.5%)	0 (0.0%)	5 (0.5%)	2 (0.7%)	0.697
Sick leave due to symptoms					
During career					
Yes	721 (47.6%)	40 (23.0%)$_a$	534 (49.4%)$_b$	157 (55.7%)$_b$	<0.001
No	795 (52.4%)	134 (77.0%)$_a$	536 (50.6%)$_b$	125 (44.3%)$_b$	
During last 12 mo					
0 d	912 (60.2%)	142 (81.6%)$_a$	622 (58.7%)$_b$	148 (52.5%)$_b$	<0.001†
1–5 d	370 (24.4%)	28 (16.1%)$_a$	258 (24.3%)$_{a,b}$	84 (29.8%)$_b$	
6–10 d	148 (9.8%)	2 (1.1%)$_a$	115 (10.8%)$_b$	31 (11.0%)$_b$	
≥11 d	86 (5.7%)	2 (1.1%)$_a$	65 (6.1%)$_b$	19 (6.7%)$_b$	

Categorical data is presented as numbers (%) and was analyzed using Fisher's exact (two-tailed) or Chi-squared tests (when there was insufficient memory to conduct Fisher's exact test, marked as †). Bonferroni correction was used when carrying out multiple comparisons. Each subscript letter denotes a subset of categories whose column proportions do not differ significantly from each other at the 0.05 level.
BET, balloon Eustachian tuboplasty.

allergy, regardless of its activity. To the best of our knowledge, no previous studies have reported a connection to one's smoking habits.

The majority of respondents (84.7%) had suffered from ME barotraumas in flight. These numbers broadly conform to reports given by commercial airline passengers[18] and slightly exceed those reported by Boel and Klokker,[5] possibly reflecting the inclusion of cabin crew (who suffer from ME barotraumas more often than pilots due to more URTIs per year and poorer subjective Valsalva/Toynbee performances, see Table I and Table II) in our study as well. The details regarding the symptoms, their laterality, or their duration have not been previously reported, but the flight phase in which the symptoms took place has been, aligning with our results.[5,25] Notably, as much as 29.5% of the respondents reported symptoms of poor pressure equalization before flying, while only 2.4–3.2% have reported so previously.[5,25] A majority of symptomatic respondents (60.0%) had resorted to the use of medication due to the symptoms and, again, these numbers are somewhat larger than the ones reported by Boel and Klokker[5] and Rosenkvist et al.[25] No previous studies have reported surgical procedures or the amount of sickness absences caused by these symptoms.

Considering the scope of these problems, the aviation community would greatly benefit from a tool that could be used in both predicting and preventing ME barotraumas in flight. As the means currently in use for prediction, such as tympanometry, tubomanometry,[11] the 9-step inflation/deflation test,[10,29] and others[19,21,27] are not applicable for everyday use in aircrew, better options to assess one's ET function before flying are needed. Moreover, preventive measures have been found either ineffective (e.g., pressure-regulating earplugs[12,15] and external ear canal moisturization[22]) or effective,[4,26,32] but unsuitable for routine use in aviation staff (e.g., nasal balloon inflation[30] or modified tympanostomy tubes[33]), leaving the community with no tools to fight the problem. It is our suggestion that the Valsalva and/or Toynbee maneuvers might be used both in predicting the problems and, with appropriate training, preventing them as well. We suggest this to be the focus of future research on ME barotraumas in flight.

Concerning external validity, the study population can be considered fairly representative as it covered a total of 93.0% of the target population. Questionnaire responses were obtained from 47.1% of the study population and so a considerable nonresponse error is, in theory, a possibility. However, based on our demographic analyses, the study sample broadly conforms to the study population and can therefore be considered representative of the study and target populations (Appendix B, https://doi.org/10.3357/AMHP.5738sd.2021). With caution, the results can be considered representative of all commercial aircrew operating similar aircraft, given a roughly similar demographic composition and distribution of possible risk factors.

Concerning internal validity, the results on the frequency, clinical characteristics and health and occupational effects of ME barotraumas can be considered reliable but results on the possible risk factors are subject to several biases, predominantly confounding. To limit such errors, multivariable logistic regression analyses were performed, in which the number of URTIs per year and poor subjective Valsalva and Toynbee performances independently associated with ME barotraumas in flight. With these precautions in place, we consider the effect size larger than the possibly remaining, undetected confounding, and therefore the association genuine. Moreover, application of the Bradford Hill guidelines broadly agrees with these hypotheses (**Appendix C**, https://doi.org/10.3357/AMHP.5738sd.2021), further establishing the findings. Further research is, nevertheless, needed to establish the role of URTIs and poor Valsalva/Toynbee performance as risk factors for ME barotraumas in flight.

Other strengths of the study include its considerable sample size and the level of detail regarding questions submitted to the respondents: no studies to date have investigated the characteristics, progression, or health and occupational effects of ME barotraumas on such a detailed level. Furthermore, the anonymity of the questionnaire increases its reliability: eliminating the possibility of respondent identification also eliminates the reason for dishonesty when submitting one's response.

The limitations mainly include the use of patient-reported and, therefore, completely subjective estimations of all collected data. While this is certainly a limitation, many of the outcomes the study was intended to examine were in themselves subjective, so such a limitation could not be entirely avoided.

Overall, ME barotraumas were reported by 84.7% of the study sample and cause a significantly increased need for medications, otorhinolaryngology-related surgical procedures, and sickness absence from flight duty. Possible risk factors include a high number of URTIs per year and poor performance in pressure equalization techniques, such as Valsalva and Toynbee maneuvers. Further research is still needed to better establish these findings.

ACKNOWLEDGMENTS

The views expressed in the manuscript are solely those of the authors and do not reflect the official policy or position of either Aava Co., Finnair Co., or the Finnish Defence Forces.

Financial Disclosure Statement: The authors have no competing interests to declare. This study was funded by Research Grants from the Department of Otorhinolaryngology – Head and Neck Surgery, Head and Neck Center, Helsinki University Hospital, grant code Y1014KN014. The funding sources had no role in the design and conduct of the study; collection, management, analysis, or interpretation of the data; preparation, review, or approval of the manuscript; or decision to submit the manuscript for publication.

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Appendix A. English Translation of the Questionnaire.

The questionnaire consisted of 18–58 questions, depending on the answers of each individual respondent.
Questions related to smoking directed only to those who reported being smokers (based on the answer to question 2.9).
Questions related to pressure chamber testing directed only to those having been to a pressure chamber (3.1).
Questions related to ME barotraumas directed only to those having experienced ME barotraumas in flight (4.4).
Questions related to increase of ME barotraumas directed only to those with an increase in symptoms over the years (5.11).
In addition, some questions were directed at pilots only (e.g., flight permit type).

1) Aviation history

1.1) Profession
☐ Pilot
☐ Cabin Crew

1.2) Aircraft type (select one or more)
☐ Jet engine plane
☐ Turboprop plane
☐ Military fighter jet
☐ Military training jet
☐ Other

1.3) Flight permit type (pilots only)
☐CPL (commercial pilot license)
☐ ATPL (airline transport pilot license)

1.4) Number of flight years

1.5) Number of flights during career (pilots only)

1.6) Number of flight hours during career (civilian pilots only)

1.7) Number of flights per year during last 5 years (pilots only)

1.8) Number of flight hours per year during last 5 years (civilian pilots only)

1.9) Employer
☐ Civilian airline 1 (not disclosed here)
☐ Civilian airline 2 (not disclosed here)
☐ Civilian airline 3 (not disclosed here)
☐ Finnish Defense Forces

2) Medical history

2.1) Sex
☐ Female
☐ Male

2.2) Age (years)

2.3) Height (cm)

2.4) Weight (kg)

2.5) Allergies
☐ Pollen
☐ Animals
☐ Food
☐ Other
☐ No allergies

2.6) Number of upper respiratory tract infections (URTIs) per year

2.7) When suffering from URTI I tend to not fly as planned (select one or more):
☐ Yes, when suffering from URTI with fever and significant congestion.

☐ Yes, when suffering from URTI with no fever and mild congestion.
☐ Never

2.8) Previous otorhinolaryngology-related (ORL-related) surgical procedures (select one or more):
☐ Adenoidectomy
☐ Myringotomy
☐ Myringoplasty
☐ Tympanostomy tubes
☐ Balloon Eustachian tuboplasty
☐ Functional endoscopic sinus surgery
☐ Septoplasty
☐ Radiofrequency ablation of inf. turbinates
☐ Cleft palate repair
☐ None of the above

2.9) Smoking
☐ Never
☐ Occasionally
☐ Regularly

2.10) Number of active smoking years

2.11) Number of cigarettes per day

3) Questions related to pressure chamber testing and middle ear (ME) barotraumas

3.1) I have been to hypobaric pressure chamber testing to evaluate my pressure equalization ability.
☐ Yes
☐ No

3.2) I have experienced ME barotraumas during hypobaric pressure chamber testing.
☐ Yes
☐ No

3.3) I have experienced ME barotraumas during hypobaric pressure chamber testing in my:
☐ Right ear
☐ Left ear
☐ Both ears
☐ Not sure

3.4) I have experienced ME barotraumas during hypobaric pressure chamber testing X times.

3.5) I have had concomitant URTI symptoms X times together with ME barotraumas.

3.6) The ME barotraumas have mainly occurred when (select one or more):
☐ Decreasing the chamber pressure
☐ Increasing the chamber pressure

3.7) The ME barotraumas have manifested as (select one or more):
☐ Ear pain
☐ Ear pressure
☐ Ear ringing
☐ Hearing loss
☐ Tympanic membrane perforation
☐ Vertigo
☐ Nausea
☐ Other

3.8) Other, how?

3.9) The symptoms have typically dissipated in:
☐ 2 minutes
☐ 2 hours

☐ 2 days
☐ >2 days

3.10) I had had symptoms of poor pressure equalization preceding the symptoms during the hypobaric pressure chamber test.
☐ Yes
☐ No

3.11) I have had to ask for my pressure chamber test to be rescheduled due to my inability to equilibrate my middle ear pressure.
☐ Yes
☐ No

3.12) I have had to ask for my pressure chamber test to be aborted due to my inability to equilibrate my middle ear pressure.
☐ Yes
☐ No

4) Questions related to pressure equalization of the ears

4.1) I can equalize the pressure in my ears by exhaling into my nasopharynx while pinching my nose and keeping my mouth closed (the Valsalva maneuver).
☐ Never
☐ Occasionally
☐ Almost always (but not when having an URTI)
☐ Always (even when having an URTI)

4.2) I can equalize the pressure in my ears by swallowing while pinching my nose and keeping my mouth closed (the Toynbee maneuver).
☐ Never
☐ Occasionally
☐ Almost always (but not when having an URTI)
☐ Always (even when having an URTI)

4.3) I have a habit of testing my pressure equalization ability before undertaking a flight.
☐ Yes
☐ No

4.4) I have experienced ME barotraumas in flight.
☐ Never
☐ Sporadically
☐ Occasionally
☐ Almost always
☐ Always

5) Questions related to ME barotraumas in flight

5.1) I have experienced ME barotraumas in my:
☐ Right ear
☐ Left ear
☐ Both ears
☐ Not sure

5.2) I have experienced ME barotraumas X times.

5.3) I have had concomitant URTI symptoms X times together with ME barotraumas.

5.4) The ME barotraumas have appeared (question intended for military pilots only):
☐ With the head in a neutral position (straight forward)
☐ With the head turned to either right or left
☐ Not a military pilot

5.5) The ME barotraumas have mainly occurred (select one or more):
☐ When ascending
☐ When cruising
☐ When descending

☐ With a sudden problem in cabin pressurization

5.6) The ME barotraumas have occurred at an altitude of X ft.

5.7) The ME barotraumas have manifested as (select one or more):
☐ Ear pain
☐ Ear pressure
☐ Ear ringing
☐ Hearing loss
☐ Tympanic membrane perforation
☐ Vertigo
☐ Nausea
☐ Other

5.8) Other, how?

5.9) The symptoms have typically dissipated in:
☐ 2 minutes
☐ 2 hours
☐ 2 days
☐ >2 days

5.10) I had had symptoms of poor pressure equalization preceding the symptoms during the flight.
☐ Yes
☐ No

5.11) The ME barotraumas have X during the years:
☐ Decreased
☐ Remained unchanged
☐ Increased

6) Questions related to the increase of ME barotraumas in flight

6.1) The increase in the symptoms started:
☐ 0–4 years (after start of career)
☐ 5–9 years
☐ 10–14 years
☐ 15–19 years
☐ 20–24 years
☐ 25–29 years
☐ 30–34 years
☐ 35–39 years
☐ 40–44 years
☐ 45–50 years
☐ Not sure

6.2) The increase in the symptoms started:
☐ During an URTI
☐ During a middle ear infection
☐ During active allergies
☐ Gradually without an apparent cause
☐ Other

6.3) Other, how?

7) Questions related to the treatment of ME barotraumas in flight

7.1) I have had to use nonprescribed medications due to my ME barotrauma symptoms (select one or more):
☐ Yes, during the last 12 months
☐ Yes, earlier than during the last 12 months
☐ No

7.2) Name of the nonprescribed medication:

7.3) I have had to use prescribed medications due to my ME barotrauma symptoms (select one or more):
❒ Yes, during the last 12 months
❒ Yes, earlier than during the last 12 months
❒ No

7.4) Name of the prescribed medication:

7.5) I have had one of the following ORL-related surgical procedures due to my ME barotrauma symptoms (select one or more):
❒ Myringotomy
❒ Tympanostomy
❒ Balloon Eustachian tuboplasty
❒ None of the above

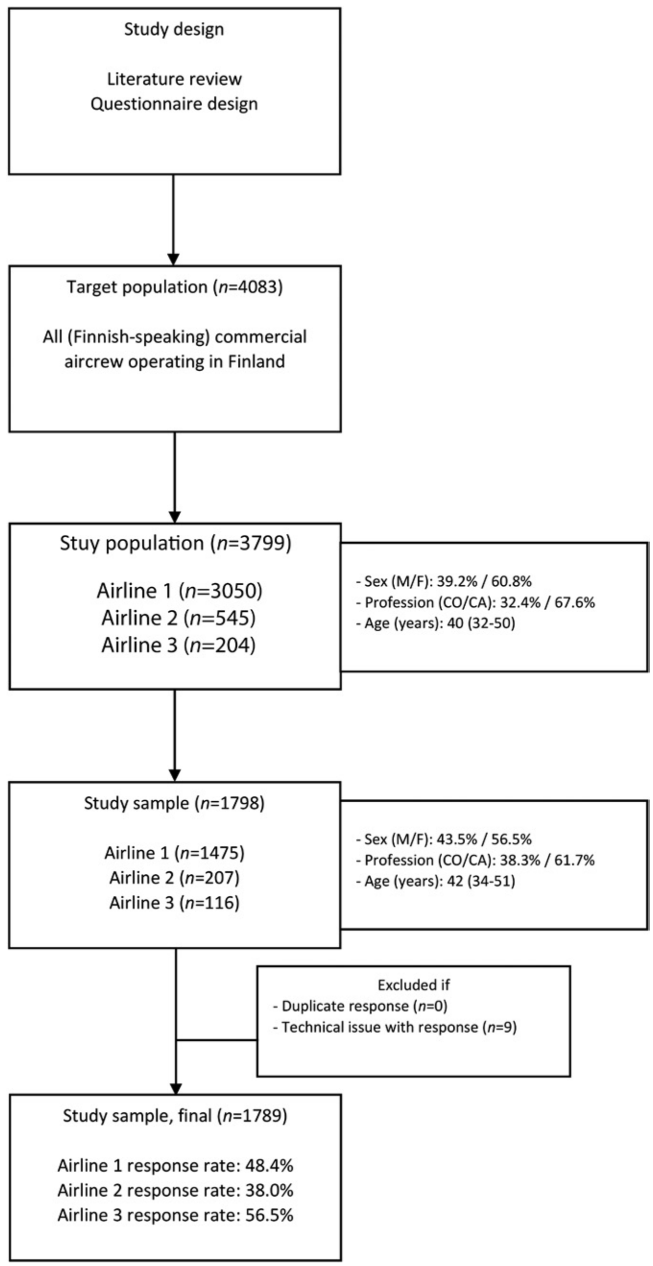
7.6) I have been on sick leave due to my ME barotrauma symptoms (select one or more):
❒ Yes, an independently taken sick leave
❒ Yes, a mandatory sick leave
❒ No

7.7) I have been on sick leave for X days during the last 12 months due to my ME barotrauma symptoms.

7.8) I have tried to manage my ME barotrauma symptoms by (open response):

Appendix B. Details of Data Acquisition.

Details of data acquisition are presented below. Study population and study sample data are both presented as percentages for categorical data (i.e., data on sex and profession) and as medians and IQRs for continuous data (i.e., data on age).



CA, cabin; CO, cockpit; F, female; M, male

Appendix C. Application of the Bradford Hill Guidelines for Observational Data: Middle Ear Barotraumas in Flight and the Condition's Possible Risk Factors.

VARIABLE	URTIs/YEAR	VALSALVA PERFORMANCE	TOYNBEE PERFORMANCE
1) Temporality	No No temporal relations to detect as the study design was cross-sectional.	No No temporal relations to detect as the study design was cross-sectional.	No No temporal relations to detect as the study design was cross-sectional.
2) Strength	Yes ORs 5.25 & 9.02 Adjusted	Yes ORs 5.49 & 7.84 Adjusted	Yes ORs 2.00 & 9.06 Adjusted
3) Experiment	No No prospective studies with similar association (as patients with URTI are often excluded from studies).	No No prospective studies with similar association.	No No prospective studies with similar association.
4) Biological plausibility	Yes The URTI-associated mucosal inflammation of the ET orifice is generally considered to impede ET opening and hence middle ear equalization.	Yes The inability to successfully perform the Valsalva maneuver (i.e., to adequately raise one's nasopharyngeal pressure leading to a passive opening of the ET) is generally considered to impede middle ear equalization.	Yes The inability to successfully perform the Toynbee maneuver (i.e., to adequately contract one's LVP and TVP muscles leading to an active opening of the ET) is generally considered to impede middle ear equalization.
5) Biological gradient	Yes The frequency of the outcome consistently increases as the number of URTIs increase. No reversibility to detect as the study design was cross-sectional.	Yes The frequency of the outcome consistently increases as the subjective Valsalva performance decreases. No reversibility to detect as the study design was cross-sectional.	Yes The frequency of the outcome consistently increases as the subjective Toynbee performance decreases. No reversibility to detect as the study design was cross-sectional.
6) Consistency	No No previous studies have investigated URTI as a risk factor for ME barotraumas.	No No previous studies have investigated Valsalva performance as a risk factor for ME barotraumas.	No No previous studies have investigated Toynbee performance as a risk factor for ME barotraumas.
7) Coherence	Yes Several case reports of ME barotraumas when having an URTI. Nothing to contradict the hypothesis.	Yes Several mentions of alleviated ME barotrauma symptoms when performing the Valsalva maneuver. Nothing to contradict the hypothesis.	Yes Several mentions of alleviated ME barotrauma symptoms when performing the Toynbee maneuver. Nothing to contradict the hypothesis.
8) Specificity	No URTIs not specific for ME barotraumas.	Yes Poor subjective Valsalva performance not generally considered to result in other adverse effects than ME barotraumas.	Yes Poor subjective Toynbee performance not generally considered to result in other adverse effects than ME barotraumas.
9) Analogy	Yes Other conditions causing mucosal inflammation of the ET orifice also associated with ME barotraumas (e.g., active allergic rhinitis).	No No other conditions causing an inability to adequately raise one's nasopharyngeal pressure.	Yes Other conditions causing an inability to adequately contract one's velopharyngeal muscles also associated with ME pathology (e.g., cleft palate).

Application of the Bradford Hill guidelines for observational data presented above.
ET, Eustachian tube; LVP, levator veli palatini; ME, middle ear; OR, odds ratio; TVP, tensor veli palatini; URTI, upper respiratory tract infection.