Middle ear barotrauma in diving

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Key words
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Abstract
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Introduction: Middle ear barotrauma (MEBt) is the most common medical complication in diving, posing a serious risk to dive safety. Given this prevalence and the continuing growth of the diving industry, a comprehensive overview of the condition is warranted.
Methods: This was a survey study. An anonymous, electronic questionnaire was distributed to 7,060 recipients: professional divers of the Finnish Border Guard, the Finnish Rescue Services, and the Finnish Heritage agency; and recreational divers registered as members of the Finnish Divers' Association reachable by e-mail (roughly two-thirds of all members and recreational divers in Finland). Primary outcomes were self-reported prevalence, clinical characteristics, and health effects of MEBt while diving. Secondary outcomes were adjusted odds ratios (OR) for frequency of MEBt with respect to possible risk factors.
Results: A total of 1,881 respondents participated in the study (response rate 27%). In total, 81% of the respondents had experienced MEBt while diving. Of those affected, 38% had used medications and 1% had undergone otorhinolaryngology-related surgical procedures due to MEBt. Factors most associated with MEBt were poor subjective success in Valsalva ('occasionally' versus 'always' successful: OR 11.56; 95% CI 7.24–18.47) and Toynbee ('occasionally' versus 'always' successful: OR 3.51; 95% CI 1.95–6.30) manoeuvres.
Conclusions: MEBt is common in both recreational and professional divers, having affected 81% of the respondents. The main possible risk factors include poor success in pressure equalisation manoeuvres.

Introduction

Middle ear barotrauma (MEBt) while diving is considered to result from inadequate Eustachian tube (ET) function during rapid ambient pressure changes,[1,2] this being generally considered the mildest form of ET dysfunction (ETD).[3] The symptoms typically include pressure sensations or pain in the ears, hearing loss or muffled hearing and sometimes tinnitus.[4–7] Rarely, the condition may manifest as alternobaric vertigo,[8,9] perilymphatic fistula[10] and even less frequently, in the case of a dehiscent cranial nerve VII, as facial baroparesis.[8,11–16] A further, extremely rare complication is a temporal bone fracture[17] (most likely resulting from a dehiscent *tegmen tympani*), leading to subsequent intracranial sequelae.[17] These symptoms are widely considered to be the most prevalent disorder in all diving and subaquatic medicine,[4–7] sometimes seriously compromising dive safety.

Reports on the prevalence vary. While an incidence of 10.1% has been documented in hyperbaric pressure chamber testing of Taiwanese Navy recruits,[18] numbers as high as 23.2% have been reported in military divers in more representative, open-water conditions.[19] Moreover, even higher prevalences (45.0%) have been reported[20] among recreational divers with numbers increasing further (71–72%)[21,22] when considering otoscopic/tympanometric diagnoses instead of symptom reporting alone.

Given the large scale of the diving industry, the high prevalence of MEBt while diving and its potentially hazardous consequences and complications, a thorough examination of the condition is justified. With this in mind, the primary objective of the study was to determine the frequency, clinical characteristics, and the short-term health effects of MEBt while diving. The secondary goal was to examine possible risk factors. The tertiary goal was to examine whether repetitive exposure to barometric stress might lead to an increase in MEBt over the years.

Methods

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.

STUDY DESIGN

Previous literature describing questionnaires on MEBt while diving was reviewed. None of the published questionnaires were directly applicable to the objectives of the study, so a new questionnaire was developed by the research group, utilising previous literature.

The questionnaire consisted of 22–55 questions (depending on answers) designed to examine the respondents' diving and medical histories and frequency of MEBt while diving. Furthermore, the respondents were asked about possible pressure-chamber testing, clinical characteristics and their need for medications and otorhinolaryngology-related (ORL-related) surgical procedures due to MEBt. The English translation of the questionnaire is presented in Appendix 1*.

The questionnaire was electronically sent via e-mail to 7,060 recipients: professional divers of the Finnish Border Guard, the Finnish Rescue Services, and the Finnish Heritage agency; and recreational divers registered as members of the Finnish Divers' Association reachable by email (roughly two-thirds of all members and all recreational divers in Finland). Data acquisition was carried out between November 2018 and September 2019, consisting of the primary email and repeated reminder emails at approximately 1–2 month intervals. Full details of data acquisition are presented in Appendix 2*.

STATISTICAL ANALYSIS

All statistical analyses were performed using SPSS Statistics for Windows, version 25.0, 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 (IQR) for continuous variables. Categorical data were analysed using Fisher's exact test (two-tailed) or where appropriate, the Chi-Square test. Continuous variables were analysed using the Mann-Whitney U test or the Kruskal-Wallis test as appropriate. The Bonferroni correction was applied to account for multiple comparisons.

Multivariable binary logistic regression analyses were performed to identify factors associated with MEBt while diving. Variables included in the models were sex, number of diving years, age, body mass index (BMI), pollen allergies, smoking, number of upper respiratory tract infections (URTI) per year and subjective success in Valsalva and Toynbee manoeuvres. The results are presented as adjusted odds ratios (OR) with 95% confidence intervals (CI). The frequency of MEBt was dichotomised at two different cut-off points: between "*never*" and at least "*sporadically*" suffering from MEBt during one's life; and between suffering from MEBt only "*sporadically*" and at least "*occasionally*". These two separate cut-off points were chosen to gain a better overall understanding of factors associated with the condition.

Results

OVERVIEW OF THE STUDY SAMPLE AND MIDDLE EAR BAROTRAUMA WHILE DIVING

The survey achieved a final response rate of 26.6% (1,881/7,060). Details of the study sample and the frequency of MEBt while diving are presented in Tables 1 and 2, respectively.

In total, males made up the majority of the study sample, comprising 79.8% of the respondents. A quarter (23.2%) of the respondents were professional divers, the other three quarters (76.8%) recreational ones. Most respondents reported being scuba divers (91.9%), some reporting technical diving (18.3%) and some free diving (15.6%) as their respective diving types. Median (IQR) age was 43 (35–52) years, 44 (36–53) in males and 41 (33–50) in females. Further characteristics of the study sample are presented in Table 1.

Subjective success in Valsalva and Toynbee manoeuvres was also aksed for (see Table 2). A small minority (6.3%) reported succeeding in the Valsalva manoeuvre "*occasionally*" or "*never*", while 51.9% reported "*almost always*" (but not during an URTI) succeeding in the manoeuvre. The final 41.7% reported success "*always*", even during an URTI.

Subjective success in Toynbee manoeuvre was generally poorer among the respondents, compared to success in Valsalva. A total of 47.2% of the respondents reported succeeding "*occasionally*" or "*never*", another 35.8% "*almost always*", the final 17.0% reporting "*always*" succeeding in the manoeuvre.

MEBt while diving had affected 80.7% of the sample. More than half (61.2%) of the respondents reported symptoms "*sporadically*", another 15.5% "*occasionally*" and the final 4.0% "*almost always*" or "*always*" while diving. The proportion of respondents having never experienced symptoms was 20.5% in males and 14.7% in females, while the proportion of those having experienced symptoms at least "*occasionally*" was 17.4% in males and 27.8% in females.

Footnote: * Appendices 1–3 are available on DHM Journal's website: https://www.dhmjournal.com/index.php/journals?id=83

Table 1

Overview of the study sample. Categorical data presented as *n* (%) and continuous data presented as median (IQR). * Data missing in two cases. BET – balloon eustachian tuboplasty; BMI – body mass index; FESS – functional endoscopic sinus surgery; ORL – otorhinolaryngology; RFA – radiofrequency ablation; URTI – upper respiratory tract infection

Variable	All (*n* = 1881)	Female (*n* = 380)	Male (*n* = 1501)
Age (years)	43 (35–52)	41 (33–50)	44 (36–53)
Height (cm)	178 (172–183)	167 (163–171)	180 (175–184)
Weight (kg)	83 (74–91)	68 (62–75)	85 (78–94)
BMI ($kg \cdot m^{-2}$)	26 (24–28)	24 (22–27)	26 (25–28)
Diving years	10 (4-17)	6 (3–11)	10 (4–20)
Number of dives*	200 (80–550)	150 (50–400)	200 (100–600)
Diving type			
Professional	436 (23.2%)	30 (7.9%)	406 (27.0%)
Recreational	1,445 (76.8%)	350 (92.1%)	1,095 (73.0%)
Diving mode			
Free diving	293 (15.6%)	53 (13.9%)	240 (16.0%)
Scuba diving	1,728 (91.9%)	359 (94.5%)	1,369 (91.2%)
Technical diving	344 (18.3%)	46 (12.1%)	298 (19.9%)
Smoking			
Never	1,542 (82.0%)	318 (83.7%)	1,224 (81.5%)
Occasionally	242 (12.9%)	37 (9.7%)	205 (13.7%)
Regularly	97 (5.2%)	25 (6.6%)	72 (4.8%)
Allergies			
Any allergy	629 (33.4%)	157 (41.3%)	472 (31.4%)
Pollen	451 (24.0%)	96 (25.3%)	355 (23.7%)
Animal	226 (12.0%)	64 (16.8%)	162 (10.8%)
Food	151 (8.0%)	54 (14.2%)	97 (6.5%)
Other	99 (5.3%)	42 (11.1%)	57 (3.8%)
Surgical procedures (ORL-related)			
Any procedure	696 (37.0%)	127 (33.4%)	569 (37.9%)
Adenoidectomy	492 (26.2%)	93 (24.5%)	399 (26.6%)
Myringotomy	198 (10.5%)	43 (11.3%)	155 (10.3%)
Tympanostomy	93 (4.9%)	19 (5.0%)	74 (4.9%)
BET	14 (0.7%)	4 (1.1%)	10 (0.7%)
Myringoplasty	22 (1.2%)	2 (0.5%)	20 (1.3%)
FESS	84 (4.5%)	12 (3.2%)	72 (4.8%)
Septoplasty	60 (3.2%)	2 (0.5%)	58 (3.9%)
RFA (inf. turbinates)	16 (0.9%)	4 (1.1%)	12 (0.8%)
Cleft palate	2 (0.1%)	0 (0.0%)	2 (0.1%)
URTI per year			
0	313 (16.6%)	52 (13.7%)	261 (17.4%)
1	958 (50.9%)	193 (50.8%)	765 (51.0%)
2	424 (22.5%)	96 (25.3%)	328 (21.9%)
≥ 3	186 (9.9%)	39 (10.3%)	147 (9.8%)

FACTORS ASSOCIATED WITH THE FREQUENCY OF MIDDLE EAR BAROTRAUMA

Factors associated with the frequency of MEBt while diving are presented as odds ratios (OR) and 95% confidence intervals (CI) in Table 3. Poor subjective success in Valsalva and Toynbee manoeuvres were both strongly associated with the frequency of MEBt, while female sex and a high number of URTIs per year were somewhat associated with the condition. Factors such as allergies, smoking, or the

Table 2
Middle ear barotrauma in 1,881divers. Data presented as *n* (%). URTI – upper respiratory tract infection

Variable	All (*n* = 1,881)	Female (*n* = 380)	Male (*n* = 1,501)
Subjective success in Valsalva			
Never/Occasionally	119 (6.3%)	39 (10.3%)	80 (5.3%)
Almost always (not when URTI)	977 (51.9%)	222 (58.4%)	755 (50.3%)
Always	785 (41.7%)	119 (31.3%)	666 (44.4%)
Subjective success in Toynbee			
Never/Occasionally	887 (47.2%)	199 (52.4%)	688 (45.8%)
Almost always (not when URTI)	674 (35.8%)	130 (34.2%)	544 (36.2%)
Always	320 (17.0%)	51 (13.4%)	269 (17.9%)
Pressure equalisation test before dive			
No	648 (34.4%)	166 (43.7%)	482 (32.1%)
Yes	1,233 (65.6%)	214 (56.3%)	1,019 (67.9%)
Middle ear barotrauma in diving			
Never	363 (19.3%)	56 (14.7%)	307 (20.5%)
Sporadically	1,151 (61.2%)	218 (57.4%)	933 (62.2%)
Occasionally	292 (15.5%)	75 (19.7%)	217 (14.5%)
Almost always	64 (3.4%)	26 (6.8%)	38 (2.5%)
Always	11 (0.6%)	5 (1.3%)	6 (0.4%)

number of diving years had no association with frequency of MEBt while diving.

Poor success in Valsalva was the variable most strongly associated with the frequency of MEBt while diving. Respondents who reported succeeding in the Valsalva manoeuvre only "*occasionally*" or "*never*" had an adjusted OR of 4.80 (95% CI 2.44–9.44) for experiencing MEBt at least "*sporadically*" and an OR of 11.56 (95% CI 7.24–18.47) for experiencing such symptoms at least "*occasionally*", compared to respondents who reported "*always*" succeeding in the manoeuvre.

Poor success in Toynbee was also associated with MEBt. Respondents who reported succeeding in the manoeuvre "*occasionally*" or "*never*" had respective ORs of 1.83 (95% CI 1.32–2.53) and 3.51 (95% CI 1.95–6.30) for experiencing MEBt at least "*sporadically*" and "*occasionally*", compared with those who reported "*always*" succeeding in the manoeuvre. Overall, the ORs for experiencing MEBt more often increased as subjective success in Valsalva and Toynbee manoeuvres decreased.

CHARACTERISTICS OF ME BAROTRAUMAS

Characteristics of MEBt and its circumstances are presented in Table 4. The table reports questionnaire results from respondents affected by MEBt (n = 1,518) and is divided into three categories based on the respondents' subjective success in Valsalva (as it was shown to be highly associated with the condition in Table 3).

Half (54.6%) of the respondents had experienced MEBt 1–9 times, the other half either 10–19 times (19.1%) or 20 or more times (26.3%) throughout the years. The number of MEBt events experienced while diving increased as subjective success in Valsalva decreased ($P < 0.001$).

Symptoms predominantly appeared when descending, 94.6% of the respondents reporting symptoms mainly on descent and a minority of 14.3% mainly on ascent. Furthermore, the symptoms most often manifested in relatively shallow waters (where the relative pressure differentials are the largest). In total, 38.4% of respondents reported symptoms at a depth of 0–4 metres' seawater (msw), a further 43.1% at a depth of 5–9 msw and the last 18.4% at a depth ≥ 10 msw.

Symptoms of MEBt varied. Symptoms such as pain (80.0%) and pressure sensations (52.2%) of the ears were by far the most prevalent, others such as hearing loss (5.9%) and ringing in the ears (4.7%) appearing less frequently. Among other symptoms, tympanic membrane perforations had been experienced by 3.0% of the respondents, whereas vertigo and nausea had affected proportions of 10.7% and 1.7%, respectively. Of note, vertigo (34.1% versus 6.5%, $P < 0.001$) and nausea (6.0% versus 1.0%, $P < 0.001$) were more often reported by those who reported symptoms mainly on ascent.

Symptom laterality was also examined. Symptoms were reported in both ears in 43.4% of cases and in one ear in 22.8% of cases. The remaining 33.8% of the respondents were unable to specify the number of affected ears, the proportion of which decreased as subjective success in Valsalva decreased ($P < 0.001$).

Table 3

Multivariate logistic regression analyses of factors associated with middle ear barotrauma while diving. An adjusted OR over 1 indicates an increase in the odds of experiencing MEBt in diving. BMI – body mass index; CI – confidence interval; OR – odds ratio; URTI – upper respiratory tract infection

Variable	Frequency of middle ear barotrauma in diving	
	Never (n = 363) versus Sporadically, Occasionally Almost always, Always (n = 1,518)	Never, Sporadically (n = 1,514) versus Occasionally, Almost always, Always (n = 367)
	OR (95% CI)	**OR (95% CI)**
Age	1.00 (0.98–1.01)	1.01 (1.00–1.02)
Diving years	1.03 (1.01–1.04)	0.99 (0.98–1-01)
BMI	1.00 (0.97–1.04)	0.98 (0.95–1.02)
Sex		
Male	1.00	1.00
Female	1.36 (0.97–1.91)	1.43 (1.07–1.92)
Allergies (pollen)		
No	1.00	1.00
Yes	1.11 (0.82–1.50)	1.30 (0.99–1.71)
Smoking		
Never	1.00	1.00
Occasionally	1.27 (0.86–1.86)	0.93 (0.64–1.36)
Regularly	0.88 (0.51–1.49)	0.91 (0.51–1.60)
URTI per year		
0	1.00	1.00
1	1.08 (0.78–1.48)	0.97 (0.66–1.44)
2	1.34 (0.90–2.00)	1.37 (0.89–2.10)
≥ 3	1.37 (0.81–2.32)	2.11 (1.30–3.42)
Subjective success in Valsalva		
Always	1.00	1.00
Almost always (not when URTI)	4.22 (3.14–5.66)	3.13 (2.25–4.36)
Occasionally/Never	4.80 (2.44–9.44)	11.56 (7.24–18.47)
Subjective success in Toynbee		
Always	1.00	1.00
Almost always (not when URTI)	1.53 (1.08–2.16)	1.98 (1.08–3.63)
Occasionally/Never	1.83 (1.32–2.53)	3.51 (1.95–6.30)

Symptom duration was highly variable. The symptoms typically dissipated in ≤ 2 min in 67.3% of cases, between 2–120 min in 22.7% of cases and between 2 h–2 d in 6.7% of cases. In the remaining 3.2% of cases, the symptoms typically lasted for > 2 d and generally, the duration of symptoms increased as subjective success in Valsalva decreased ($P < 0.001$). Symptoms typically lasting for > 2 h were more often reported by those who reported symptoms mainly on ascent.

Changing vulnerability to MEBt concerned a minority of respondents. The majority, 56.1%, reported no change in either direction, whereas 37.9% reported experiencing less MEBt than previously throughout their diving careers. Conversely, the remaining 5.9% reported currently experiencing more symptoms than previously, and the proportion of such respondents increased as subjective success in Valsalva decreased ($P < 0.001$).

HEALTH EFFECTS OF MIDDLE EAR BAROTRAUMA

Health effects of MEBt are presented in Table 5. The table consists of questionnaire results from affected respondents (n = 1,518) and is divided into three categories based on the subjective success in Valsalva. Medication use in response to symptoms was reported by 37.5% of affected divers. A total of 27.5% reported having used prescribed medications and 22.3% the use of nonprescribed ones. The use of all medications increased as subjective success in Valsalva decreased ($P < 0.001$).

Table 4

Characteristics of middle ear barotrauma while diving and the effect of subjective success in Valsalva manoeuvre. Data are presented as *n* (%) and analysed using Fisher's exact (two-tailed) or Chi-Square tests*. The Bonferroni correction was applied to multiple comparisons. Each subscript letter (a, b, and c) denotes a subset of categories whose column proportions do not differ significantly from each other at the 0.05 level. [xx] data missing in 582 cases. TM – tympanic membrane; URTI – upper respiratory tract infection

Variable	All (*n* = 1,518)	Subjective success in Valsalva manoeuvre			*P*-value
		Always (*n* = 519)	Almost always (not during URTI) (*n* = 890)	Occasionally or never (*n* = 109)	
Symptoms					
1–9 times	829 (54.6%)	357 (68.8%)$_a$	439 (49.3%)$_b$	33 (30.3%)$_c$	< 0.001*
10–19 times	290 (19.1%)	84 (16.2%)	187 (21.0%)	19 (17.4%)	
≥ 20 times	399 (26.3%)	78 (15.0%)$_a$	264 (29.7%)$_b$	57 (52.3%)$_c$	
% of symptomatic times related to URTI[xx]					
100%	355 (37.9%)	123 (46.6%)$_a$	220 (35.4%)$_b$	12 (23.5%)$_b$	0.005
51–99%	137 (14.6%)	31 (11.7%)	96 (15.5%)	10 (19.6%)	
≤ 50%	444 (47.4%)	110 (41.7%)	305 (49.1%)	29 (56.9%)	
Symptoms during dive					
Mainly ascending	217 (14.3%)	67 (12.9%)	139 (15.6%)	11 (10.1%)	0.175
Mainly descending	1,436 (94.6%)	487 (93.8%)	843 (94.7%)	106 (97.2%)	0.396
Symptoms manifested at:					
0–4 msw	583 (38.4%)	190 (36.6%)	355 (39.9%)	38 (34.9%)	0.550*
5–9 msw	655 (43.1%)	227 (43.7%)	375 (42.1%)	53 (48.6%)	
≥ 10 msw	280 (18.4%)	102 (19.7%)	160 (18.0%)	18 (16.5%)	
Symptoms manifested as:					
Ear pressure	793 (52.2%)	254 (48.9%)	483 (54.3%)	56 (51.4%)	0.153
Ear pain	1,215 (80.0%)	384 (74.0%)$_a$	733 (82.4%)$_b$	98 (89.9%)$_b$	< 0.001
Ear ringing	71 (4.7%)	21 (4.0%)	43 (4.8%)	7 (6.4%)	0.483
Hearing loss	90 (5.9%)	27 (5.2%)	56 (6.3%)	7 (6.4%)	0.688
TM perforation	46 (3.0%)	12 (2.3%)	32 (3.6%)	2 (1.8%)	0.361
Vertigo	162 (10.7%)	44 (8.5%)	110 (12.4%)	8 (7.3%)	0.042
Nausea	26 (1.7%)	6 (1.2%)	16 (1.8%)	4 (3.7%)	0.140
Other	31 (2.0%)	12 (2.3%)	15 (1.7%)	4 (3.7%)	0.280
Symptoms manifested in:					
One ear	346 (22.8%)	101 (19.5%)	213 (23.9%)	32 (29.4%)	< 0.001*
Both ears	659 (43.4%)	174 (33.5%)$_a$	428 (48.1%)$_b$	57 (52.3%)$_b$	
Not sure	513 (33.8%)	244 (47.0%)$_a$	249 (28.0%)$_b$	20 (18.3%)$_b$	
Symptoms lasted for:					
≤ 2 min	1,022 (67.3%)	384 (74.0%)$_a$	577 (64.8%)$_b$	61 (56.0%)$_b$	0.001*
≤ 2 hours	345 (22.7%)	93 (17.9%)$_a$	219 (24.6%)$_b$	33 (30.3%)$_b$	
≤ 2 days	102 (6.7%)	27 (5.2%)	67 (7.5%)	8 (7.3%)	
> 2 days	49 (3.2%)	15 (2.9%)	27 (3.0%)	7 (6.4%)	
Symptoms before dive					
Yes	446 (29.4%)	126 (24.3%)$_a$	292 (32.8%)$_b$	28 (25.7%)$_{a,b}$	0.002
No	1,072 (70.6%)	393 (75.7%)$_a$	598 (67.2%)$_b$	81 (74.3%)$_{a,b}$	
Changing vulnerability over the years					
Less	576 (37.9%)	233 (44.9%)$_a$	316 (35.5%)$_b$	27 (24.8%)$_b$	< 0.001
Same	852 (56.1%)	272 (52.4%)$_a$	509 (57.2%)$_{a,b}$	71 (65.1%)$_b$	
More	90 (5.9%)	14 (2.7%)$_a$	65 (7.3%)$_b$	11 (10.1%)$_b$	

Table 5

Health effects of middle ear barotraumas while diving and the effect of subjective success in Valsalva manoeuvre. Medication refers to use of medication as a result of MEBt symptoms. Data are presented as *n* (%) and analysed using Fisher's exact test (two-tailed) (Bonferroni correction applied). Each subscript letter (a and b) denotes a subset of categories whose column proportions do not differ significantly from each other at the 0.05 level. BET – balloon eustachian tuboplasty; URTI – upper respiratory tract infection

Variable	All (*n* = 1,518)	Subjective success in Valsalva manoeuvre			*P*-value
		Always (*n* = 519)	Almost always (not during URTI) (*n* = 890)	Occasionally or never (*n* = 109)	
All medication					
All	570 (37.5%)	138 (26.6%)$_a$	377 (42.4%)$_b$	55 (50.5%)$_b$	< 0.001
All, last 12 months	294 (19.4%)	57 (11.0%)$_a$	214 (24.0%)$_b$	23 (21.1%)$_b$	< 0.001
All, earlier	329 (21.7%)	92 (17.7%)$_a$	201 (22.6%)$_a$	36 (33.0%)$_b$	0.001
Prescribed					
All	417 (27.5%)	94 (18.1%)$_a$	279 (31.3%)$_b$	44 (40.4%)$_b$	< 0.001
Last 12 months	213 (14.0%)	40 (7.7%)$_a$	152 (17.1%)$_b$	21 (19.3%)$_b$	< 0.001
Earlier	231 (15.2%)	61 (11.8%)$_a$	145 (16.3%)$_{a,b}$	25 (22.9%)$_b$	0.005
Non-prescribed					
All	338 (22.3%)	76 (14.6%)$_a$	229 (25.7%)$_b$	33 (30.3%)$_b$	< 0.001
Last 12 months	168 (11.1%)	30 (5.8%)$_a$	127 (14.3%)$_b$	11 (10.1%)$_{a,b}$	< 0.001
Earlier	184 (12.1%)	48 (9.2%)$_a$	113 (12.7%)$_a$	23 (21.1%)$_b$	0.003
Surgical procedures due to symptoms					
All	19 (1.3%)	5 (1.0%)	11 (1.2%)	3 (2.8%)	0.285
Myringotomy	6 (0.4%)	1 (0.2%)	4 (0.4%)	1 (0.9%)	0.387
Tympanostomy	2 (0.1%)	0 (0.0%)	2 (0.2%)	0 (0.0%)	0.599
BET	14 (0.9%)	4 (0.8%)	8 (0.9%)	2 (1.8%)	0.503

Surgical procedures due to the symptoms were reported by 1.3% of affected divers. In total, six respondents (0.4%) had undergone a myringotomy, two (0.1%) a tympanostomy tube insertion and 14 (0.9%) a balloon Eustachian tuboplasty. The proportion of respondents having undergone procedures seemed to increase as subjective success in Valsalva decreased.

Discussion

COMPARISON WITH PREVIOUS RESEARCH

In this study, subjective success in Valsalva and Toynbee manoeuvres were the factors most strongly associated with MEBt while diving. Even though tympanometric measurements before and after the Valsalva manoeuvre (and measurements before and after swallowing, i.e., effectively the Toynbee manoeuvre) have been investigated as predictors of (otoscopic) MEBt,[23,24] no studies exist examining *subjective* success in Valsalva or Toynbee in relation to MEBt symptoms specifically. Additionally, in this study, female sex and a high number of URTIs per year were associated with MEBt (ORs of 1.43 and 2.11 respectively); both have been previously noted as possible risk factors.[9,25] While no connection was detected to smoking or pollen allergies, a connection between allergic rhinitis and alternobaric vertigo has been previously reported in patients with ETD (hypothesised to occur via the Toynbee phenomenon).[26]

MEBt while diving has been experienced by 80.7% of the sample, more or less aligning with previous reports: 23.9–52.1% of recreational divers have reported similar symptoms in other surveys,[27,28] and a prevalence of 36.5–72.0% has been reported on multiday-diving courses,[22,29] and even after a single dive[21] (although these numbers mostly reflect otoscopic barotrauma, not necessarily symptomatic MEBt). As the present study examined the *lifetime* (to date) prevalence of MEBt in diving, the numbers not surprisingly surpass those of the studies spanning shorter time periods.

The findings relating to conditions in which the symptoms arose (diving phase, depth) or how they manifested (symptoms, laterality, duration) have not been previously investigated, making this the first publication to comprehensively present such findings. Moreover, to the best of our knowledge, no studies on the health effects of MEBt while diving have been published.

STRENGTHS AND LIMITATIONS

The external validity of the results is certainly the study's largest limitation. As our study population did not consist of the entire target population (i.e., all recreational and professional divers in Finland) and the study sample was comprised of only 26.6% of the study population, the results can hardly be considered representative of all divers operating in Finland. However, the study is (by far) the

largest survey on ME barotraumas while diving to date, and therefore a valuable contribution to the diving and medical communities.

Regarding internal validity, the data describing the frequency, clinical characteristics, and health effects of MEBt can be considered reliable, whereas the data relating to possible risk factors are vulnerable to several biases, predominantly confounding. To minimise this, multivariate logistic regression analyses were carried out, in which poor success in Valsalva and Toynbee manoeuvres was associated with the frequency of symptoms. These associations are further supported by application of the Bradford Hill guidelines for observational data, presented in Appendix 3*.

The main strengths of the study are its large sample size and level of detail regarding the questions submitted to the respondents: no previous studies have examined MEBt while diving on such a large scale and a detailed level. Moreover, the anonymity of the questionnaire is an additional strength: with no risk of identification, the reason for dishonesty disappears when submitting one's response.

Limitations include the use of diver-reported data with its inherent subjectivity. While this is a limitation, many of the outcomes the study was designed to investigate were in themselves subjective, so such a limitation could not be avoided. Moreover, the health effects of MEBt covered by our questionnaire failed to include their long-term effects, such as any permanent ear and hearing disorders resulting from the repeated MEBt. In addition, there is a possibility that a proportion of the symptoms, here attributed to MEBt, were in fact the result of other pathologies such as inner ear barotrauma or inner ear decompression sickness. Finally, given the ~27% response rate, the possibility of a reporting bias among respondents cannot be excluded.

Given the high prevalence and sometimes hazardous sequelae of MEBt while diving, a reliable method for evaluating a diver's middle ear equalisation is needed. While predictors such as tympanometry,[23,24] the 9-step-test[20,30,31] and mastoid pneumatization volume[20,32] have been studied previously, most of these studies have either had relatively small sample sizes or have mainly focused on otoscopic (instead of symptomatic) barotraumas. Moreover, previous studies examining success in Valsalva or Toynbee manoeuvres have demonstrated poor predictive value, albeit these studies have also investigated the ability to predict otoscopic barotraumas, not symptomatic ones.

The diving community would most benefit from a predictive tool that is quick and easy to perform in a wide range of environments (e.g., on a multi-day boat dive) and which can reliably predict symptomatic MEBt (or its absence) while diving. While future research should focus on discovering such a tool, most MEBt seems to arise in relatively shallow depths and therefore, in some instances, the diver can simply test his/her ET function at the start of the dive, and discontinue if problems in middle ear equalisation arise. The association of MEBt to one's success in pressure equalisation could suggest that practicing these techniques might be an effective way of preventing MEBt while diving.

Conclusions

MEBt is common in both recreational and professional divers affecting 80.7% of a sample of over 1,800 divers, and is most often manifest when descending at relatively shallow depths. MEBt is most strongly associated with poor success in pressure equalisation techniques, but women and those with a high number of URTIs per year also seem to be at an increased risk. More research is needed to establish whether the practicing of pressure equalisation techniques could prevent MEBt while diving. This could offer an effective way to reduce the burden of MEBt to both recreational and professional divers around the world.

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List of appendices

Appendix 1. English translation of the questionnaire
Appendix 2. Details of data acquisition
Appendix 3. Application of the Bradford Hill guidelines for observational data: middle ear barotraumas while diving and the condition's possible risk factors

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