

## CLINICAL COMMUNICATION

**Proposal of a new scoring system for equalization problems during freediving**

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CORRESPONDING AUTHOR: Antonio Giunta – [antoniogiunta.ork@gmail.com](mailto:antoniogiunta.ork@gmail.com)**ABSTRACT**

**Objective:** Scuba diving and freediving are popular activities around the world, and their growth has increased the frequency of related pathology. A good ability to equalize is of paramount importance for diving. This is especially true for freediving, during which dive time is limited to just one breath. Even though equalization disorders are quite common in divers, a scoring system does not exist to date. In this paper we propose a new scoring system for equalization problems of freedivers: the EP score – shorthand for “equalization problems.”

**Methods:** We administered the EP score assessment to 40 Italian freediving spearfishermen who were divided in two groups: Group A comprised 20 freedivers complaining of equalization problems and multiple barotraumas but totally asymptomatic in their everyday lives. These individuals had already received medical treatment and nasal surgery without improvement and then had undergone Eustachian tube balloon dilation. Group B comprised 20 healthy freedivers without any history of equalization disorders.

We performed a statistical analysis to evaluate the reliability of this scoring system and to evaluate its usefulness in diagnosis and follow-up.

**Results:** Our data show substantial statistical differences between healthy freedivers and freedivers complaining of equalization disorders ( $Z$ -Score = -5.396 at  $p < 0.05$ ); data do not show any statistical difference between healthy freedivers and patients successfully treated by Eustachian tube balloon dilation ( $U$ -value = 152.5 and  $Z$ -Score = -1.271 at  $p < 0.05$ ).

**Conclusion:** The EP score assessment seems to be a reliable tool to quantify equalization disorders during freediving and to evaluate how the difficulty varies over time and after treatment. Since equalization disorders could be present in different populations, the EP score assessment could be applicable to a wider group. ■

KEYWORDS: score; ear barotrauma; Eustachian tube; equalization; diving; freediving

**INTRODUCTION**

Middle ear pressure regulation is a complex mechanism controlled primarily by the Eustachian tube [1-3], a structure connecting the middle ear to the nasopharynx. It is approximately 44 mm in length and includes a medial cartilaginous portion (two-thirds) and a lateral bony part (one-third) [4]. At rest the cartilaginous portion of the tube is collapsed; it opens for about 0.4 seconds 1.4 times each minute during swallowing [5]. This is thanks to the paratubal muscles, primarily the tensor veli palatini and secondary levator veli palatini [6,7].

When a rapid change in atmospheric pressure occurs – such as during scuba diving, freediving, flying, hyperbaric chamber therapies – Eustachian tube equalization capability is very important to avoid injuries to the middle or inner ear [8-11]. These injuries are referred to as barotraumas. This is particularly true in underwater diving and particularly in freediving, which is performed while breath-holding, because of the limited time available for equalization.

Many maneuvers have been developed to equalize the middle ear pressure during diving. The following are the most popular.

- **Valsalva maneuver**, first described by Antonio Maria Valsalva in 1704 [12], increases nasopharyngeal pressure and creates an active air flow through the Eustachian tube by a forced exhalation against closed nose and mouth.
- **Toynbee maneuver**, described in 1853, produces nasopharyngeal hypertension by swallowing with the nose closed off [11].
- **Marcante-Odaglia maneuver**, also termed the **Frenzel maneuver**, described in 1959 by Duilio Marcante and Giorgio Odaglia [13], creates the same air flow by a nasopharyngeal air compression achieved by moving the tongue upward and backward.

Equalization failures expose the diver to barotraumatic damage of the middle and/or inner ear. At least three middle ear barotrauma staging systems have been proposed: the Teed, the Modified Teed, and the O’Neill

**Table 1: Equalization Problems (EP) score**

perfect equalization	0
equalization possible and effective but slight difference between the ears (no middle ear barotrauma reported even after many dives and/or many days of diving)	1
equalization possible but ineffective (middle ear barotrauma after few dives)	2
equalization not possible	3

grading systems, with the TEED as the most popular [14-18]. Inner ear barotrauma occurs when pressure variations in the middle ear cleft are transmitted to inner ear structures with the occurrence of a perilymph fistula, intralabyrinthine membrane tear, inner ear hemorrhage and other rarer pathologies.

Differently from barotrauma, a specific staging system for equalization efficiency and disorders does not exist even though equalization problems are very common in divers, with a prevalence of 4.1-91% [16]. In 2012 an English-language questionnaire to assess Eustachian tube dysfunction was validated by McCoul, et al.: the Eustachian Tube Dysfunction Questionnaire (ETDQ-7) [19]. The ETDQ-7 is made of seven questions about more common Eustachian tube dysfunction symptoms, with a score ranging from 1 to 7 for each question [19]. Even though the ETDQ-7 seems to be a good tool to assess Eustachian tube dysfunction in the general population, it is not as useful for assessing problems in diver equalization since it considers symptoms that are present in everyday life and not just during a particular activity such as diving. When administered to divers the ETDQ-7 is therefore inconclusive.

Normally divers are categorized as “good” or “effective” equalizers when they did not report barotrauma and as either “bad” or “ineffective” equalizers or as affected by Eustachian tube dysfunction when they do report it. We think it is useful to divide equalization efficiency into different levels in order to connect each level to a specific risk of barotrauma and evaluate treatment efficacy in improving equalization capability. For this reason, we propose a new scoring system to categorize and assess diver equalization problems and aim to evaluate its reliability. We have termed it the EP score assessment (for equalization problems).

## METHODS

From October 2016 through May 2018 we considered a population of 40 Italian freediving breath-holding spearfishermen. All patients were amateurs who had made dives at least twice a week all year long. Exclusion criteria were age younger than 18 and older than 65, clinical evidence or history of ENT pathology and impossibility to follow up with the patient and/or to collect a detailed diving and medical history.

We subdivided our population in two groups: Group A comprised 20 freedivers affected by middle ear equalization disorders (equalization not possible or laborious, impossibility of performing more dives during the day or of diving for more days in row, etc.) on one side and a history of multiple middle ear barotrauma requiring medical treatment for at least one year but without any symptom (hearing loss, fullness, tinnitus, pressure or ear pain, cracking or popping sounds during swallowing, etc.) in everyday life. Group B was composed of 20 healthy freedivers without any history of equalization difficulties or barotrauma. After receiving traditional medical therapies (oral and/or intravenous antibiotics and steroids) and insufflation therapy (Politzer, catheter insufflation, Otovent®) without improvement of equalization difficulties, all the patients in Group A underwent surgery by balloon dilation of the cartilaginous portion of the Eustachian tube of the affected side. Both groups of patients were evaluated with a very detailed interview and a complete ENT examination.

The study participants had various tests performed, including: hearing, tympanometry, acoustic reflexes, tympanometric assessment of Eustachian tube function via nine-step inflation/deflation, as well as completing an ETDQ-7 questionnaire.

The patients were administered the EP score assessment and, concerning Group A patients, just the EP score of the affected side was considered. The EP score was rated as:

- 0 when equalization was perfect and no barotrauma was reported;
- 1 when equalization was possible and effective (no barotrauma reported even after many dives and/or many days of diving) but there was a slight difference between the ears;
- 2 when equalization was possible but ineffective with multiple middle ear barotrauma reported;
- 3 when equalization was not possible (Table 1).

Table 2

	GROUP A				GROUP B		
	Age	Sex	Pre-op EP score	Post-op EP score	Age	Sex	EP score
1	43	M	2	0	29	M	1
2	38	M	2	0	57	M	0
3	28	M	3	3	25	M	1
4	46	M	2	1	30	M	1
5	52	M	2	1	39	M	0
6	46	M	2	0	44	M	0
7	42	M	2	2	43	M	0
8	37	M	2	0	53	M	0
9	38	M	2	2	52	M	1
10	26	M	3	1	25	M	0
11	36	M	2	0	42	M	0
12	38	M	2	1	39	M	1
13	60	M	2	0	28	M	0
14	48	M	2	0	46	M	0
15	25	M	2	1	44	M	1
16	48	M	2	2	38	M	0
17	27	M	2	0	23	M	1
18	22	M	3	0	37	M	0
19	29	M	2	2	29	M	0
20	37	M	2	0	23	M	0

Group A: Freedivers affected by equalization problems  
Group B: Freedivers without any history of equalization problems

A statistical analysis was performed using the Statistical Package for the Social Sciences (SPSS) package (version 24.0). Continuous variables were expressed as mean and standard deviation. Comparisons between groups were performed by means of the Mann-Whitney U test. The strength of the correlation was tested using the Spearman's rank correlation test. The level of significance accepted was  $p < 0.05$ .

## RESULTS

Group A comprised 20 male freedivers with a mean age of 38.3 years, with a standard deviation of 10.06; Group B comprised 20 male freedivers with a mean age of 37.3 years with a standard deviation of 10.4. Data are homogeneous regarding sex and age. All subjects of both groups showed no pathology at clinical evaluation and audiological tests (nothing to report at clinical examination, bilateral type "A" tympanogram, acoustic reflexes normally present, no dysfunction at the nine-step inflation/deflation test). The ETDQ-7 questionnaire scored in a range of 7-14.4, a normal value, without statistically significant differences between the two groups.

EP score values were very different between the two groups, however. In Group A three patients scored 3 and 17 patients scored 2, while in Group B seven patients scored 1 and 13 patient scored 0 (Table 2). The mean score in Group A was 2.5, while in Group B it was 0.35. The statistical analysis of the data using the Mann-Whitney U test

showed a statistically significant difference among the two groups (Z-Score = -5.396 at  $p < 0.05$ ). Group A patients underwent balloon dilation of the Eustachian tube. Fifteen showed improvement or resolution of their equalization problems, with stable results up to three years. Ten patients reported a complete disappearance of the problem, showing a postoperative EP score of 0, and five patients reported an improvement, with persistence of a slight equalization delay on the treated side and showing a postoperative EP score of 1. Five patients did not report any improvement: four of them had a preoperative EP score of 2, and one had a preoperative EP score of 3. The EP scores of these non-responders did not change.

The statistical analysis performed by the Mann-Whitney U test showed a statistically significant difference between EP score before and after surgery (U-value = 42.5 and Z-Score = 4.247 at  $p < 0.05$ ). No statistically significant difference was found between the EP scores of Group A patients who reported good results after balloon dilation and Group B patients (U-value=152.5 and Z-Score=-1.271 at  $p < 0.05$ ). The result, therefore, is not significant.

## DISCUSSION

Underwater diving has become increasingly popular around the world, and with its growth the frequency of related pathology has increased. A good equalization technique and capability is the prerequisite for every dive. This is especially true for freedivers who have just a one breath per diving time. For them equalization is performed very quickly, without the possibility to stop the dive temporarily and repeat a failed equalization maneuver. Moreover, freedivers dive multiple times each day for many hours in a row and stress their equalization apparatus considerably.

Equalization disorders are common in divers and are very difficult to assess, especially in freedivers. In the majority of the cases, patients complaining of this problem are completely asymptomatic in everyday

life and do not show any signs at clinical examination, conventional audiological tests or through the ETDQ-7 questionnaire. Regarding the ETDQ-7, normal values in divers with equalization problems and multiple barotraumas in their history are explained by the fact that this questionnaire assesses steady symptoms present in the last month and not just during or after a particular activity such as diving. A diver with equalization problems is usually forced to reduce the frequency of his diving: It is therefore clear that if he did not have a barotrauma in the last month, he is symptom-free with a normal ETDQ-7. This at least was the case with our patients.

A scale specifically suited for equalization disorders that, to the best of the authors' knowledge is not found in medical literature, is therefore needed to allow separation of divers in different groups and to evaluate the success of medical and/or surgical treatment in those individuals complaining of difficulties in equalization.

Even if our study considers a relatively small population of spearfishermen and if additional studies in different and larger populations are necessary to definitely validate the usefulness of our scoring system, the EP score assess-

ment we describe in this paper seems to be a good tool since our data show substantial statistical differences between healthy freedivers and freedivers complaining of equalization disorders and do not show a statistical difference between healthy freedivers and patients treated successfully.

## CONCLUSION

This work, even with its limits, demonstrates that the EP score assessment could be a reliable tool to quantify equalization disorders during freediving and to evaluate how the difficulty varies over time and after treatment. Since equalization disorders could be present also in different populations such as scuba divers, fliers, patients undergoing hyperbaric therapy, and others, the EP score could be applicable not only to freedivers but to other populations as well. ■

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## Conflict of interest

The authors declare no conflict of interest exists with this submission.

## REFERENCES

1. Wang TC, Lin CD, Shih TC, Chung HK, Wang CY, Tsou YA, Huang CH, Tsai MH. Comparison of balloon dilation and laser Eustachian tuboplasty in patients with Eustachian tube dysfunction: a meta-analysis. *Otolaryngol Head Neck Surg.* 2018; Apr;158(4):617-626.
2. Feldmann H. Physiology and pathophysiology of the ventilation of the middle ear. 2. Methods of examination of the eustachian tube. Pathophysiology of typical ventilation disorders of the middle ear. *Z Laryngol Rhinol Otol.* 1973 Aug;52(8):555-572.
3. Pau HW. Eustachian tube and middle ear mechanics. *HNO.* 2011 Oct;59(10):953-963.
4. Tysome JR, Sudhoff H. The role of the Eustachian tube in middle ear disease. *Adv Otorhinolaryngol.* 2018; 81:146-152.
5. Mondain M, Vidal D, Bouhanna S, Uziel A. Monitoring eustachian tube opening: preliminary results in normal subjects. *Laryngoscope.* 1997 Oct;107(10):1414-1419.
6. Poe DS, Pyykkö I, Valtonen H, Silvola J. Analysis of eustachian tube function by video endoscopy. *Am J Otol.* 2000 Sep;21(5):602-607.
7. Alper CM, Swarts JD, Singla A, Banks J, Doyle WJ. Relationship between the electromyographic activity of the paratubal muscles and eustachian tube opening assessed by sonotubometry and videoendoscopy. *Arch Otolaryngol Head Neck Surg.* 2012 Aug;138(8):741-746.
8. Swarts JD, Alper et al. Eustachian tube, middle ear, and mastoid--anatomy, physiology, pathophysiology, and pathogenesis. *Otolaryngol Head Neck Surg.* 2013 Apr;148(4 Suppl): E26-36.
9. Kouwen H1, van Balen FA, Dejonckere PH. Functional tubal therapy for persistent otitis media with effusion in children: myth or evidence? *Int J Pediatr Otorhinolaryngol.* 2005 Jul;69(7): 943-951.
10. Uzun C Evaluation of pre-dive parameters related to eustachian tube dysfunction for symptomatic middle ear barotrauma in divers. *Otol Neurotol.* 2005 Jan;26(1):59-64.
11. Hidir Y, Ulus S, Karahatay S, Satar B. A comparative study on efficiency of middle ear pressure equalization techniques in healthy volunteers. *Auris Nasus Larynx.* 2011 Aug;38(4):450-455. doi: 10.1016/j.anl.2010.11.014.
12. Stangerup SE1. Autoinflation: historical highlights and clinical implications. *Ear Nose Throat J.* 1998 Sep;77(9):737, 740-742.
13. Marcante D, Odaglia G. *Scendete sott'acqua con me.* Casa editrice Ceschina. 1972.
14. Schmitt D, Akkari M, Mura T, Mondain M, Uziel A, Venail F. Medium-term assessment of Eustachian tube function after balloon dilation. *Eur Ann Otorhinolaryngol Head Neck Dis.* 2017 Dec 27. pii: S1879-7296(17)30159-X.

15. Meyer MF, Boor M, Jansen S, Pracht ED, Felsch M, Klünter HD, Hüttenbrink KB, Beutner D, Grosheva M. Influence of repetitive diving in saltwater on pressure equalization and Eustachian tube function in recreational scuba divers. *Diving Hyperb Med.* 2017 Dec;47(4):214-215.

16. Owen J. O'Neill; Anthony J. Frank. *Diving, Ear Barotrauma.* StatPearls Publishing; 2018 Jan-. Last Update: May 13, 2018

17. O'Neill OJ, Weitzner ED. The O'Neill grading system for evaluation of the tympanic membrane: A practical approach for clinical hyperbaric patients. *Undersea Hyperb Med.* 2015 May-Jun;42(3):265-271.

18. Lima MA, Farage L, Cury MC, Bahamad F. Update on middle ear barotrauma after hyperbaric oxygen therapy-insights on pathophysiology. *Int Arch Otorhinolaryngol.* 2014 Apr;18(2):204-209.

19. McCoul ED, Anand VK, Christos PJ. Validating the clinical assessment of eustachian tube dysfunction: The Eustachian Tube Dysfunction Questionnaire (ETDQ-7). *Laryngoscope.* 2012 May;122(5):1137-41.

