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Main Article

Prevalence and severity of external auditory exostoses in breath-hold divers

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Abstract

Objective: To explore the prevalence and severity of external auditory exostoses in a population of experienced breath-hold divers, and to compare these to the same parameters within surfing and self-contained underwater breathing apparatus diving populations.

Design: A stepwise, multiple regression analysis of cross-sectional data examining the relative contributions of sea surface temperature, latitude of exposure and years of exposure to the prevalence and severity of stenosis due to external auditory exostoses. A chi-square analysis of the prevalence and severity of external auditory exostosis stenosis in the breath-hold divers was compared with previously published data for surfers and self-contained underwater breathing apparatus divers.

Subjects: Seventy-six male and thirty-five female breath-hold divers attending an international 'freedive' competition completed a questionnaire describing aquatic sports habits, geography of participation and symptomatology. Those completing the questionnaire (111/154 attendees) were examined otoscopically for evidence of external auditory exostoses. Images were digitally recorded, scored and graded.

Results: Exostoses were evident in 87.7 per cent of the 204 ears scored and graded for severity of stenosis due to external auditory exostoses. The prevalence of exostoses was no different from that found in previous studies of surfers and self-contained underwater breathing apparatus divers ($p = 0.101$). However, the pattern of affliction was more similar to that found in surfers. The severity of exostoses was significantly less than that found in surfing populations ($p \leq 0.001$ to 0.007), but greater than that found in self-contained underwater breathing apparatus diving populations ($p \leq 0.001$). Sea surface temperature at the location of open-water exposure was the most significant predictor of the prevalence and severity of external auditory exostoses in breath-hold divers ($p = 0.019$).

Conclusion: The prevalence and severity patterns of stenosis due to external auditory exostoses in breath-hold divers are more similar to previously published results for surfing populations than to previously published results for self-contained underwater breathing apparatus diving populations. In breath-hold divers, sea surface temperature is the strongest predictor of severity of stenosis due to external auditory exostoses.

Key words: Apnoea; Diving; Auditory Canal, External; Exostoses

Introduction

External auditory exostoses, defined as discrete, bony lesions of the outer ear canal, have been shown to be unusually prevalent in various contemporary, historic and prehistoric communities. Mid-twentieth century animal studies conducted by Fowler and Osmun[1] and by Harrison[2] demonstrated that repeated cold water exposures precipitate the development of new bony tissue in the outer ear canal. In the current study, the bony inclusions of interest are of the dome-like, layered exostosis type described by Fowler and Osmun[1] and by Harrison,[2] as opposed to the less regularly shaped osteomata that may be regarded as secondary to local infection.[3]

Kennedy's comprehensive review[4] of archaeological and anthropological data on external auditory exostoses concluded that the latitude of open-water exposure was a fundamental component in the onset and severity of external auditory exostoses in prehistoric societies. This link to latitude was examined in the present study in the light of changes in diving equipment following the industrial revolution;

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in particular, the availability of neoprene wetsuits and hoods. In the past two decades, studies on surfers[5–10] and military compressed gas divers,[11,12] and a study which briefly discussed breath-hold divers,[13] have concurred in their conclusion that cold water exposure is an initial element in external auditory exostosis development, but that it is the duration of participation, measured in hours or years, that determines the severity of stenosis.

Personal observations of breath-hold divers (i.e. sub-aquatic athletes who with a single breath attempt to dive as deep as possible below the water surface) and their training practices suggest that they may have a similar aquatic history to the communities of surfers and military divers who have been shown to exhibit increased prevalence and severity of external auditory exostoses.[5–12] To test this hypothesis, a survey and otological examination of competitive breath-hold divers was undertaken. The aims of the study were (1) to determine whether the rates of prevalence and severity of breath-hold divers' external auditory exostoses differed from those observed in previous studies of other populations, and (2) if such findings existed, to determine the best predictor of external auditory exostosis prevalence and severity in breath-hold divers, considering the effect of latitude,[4] and temperature and duration of exposure.[5–13]

Materials and methods

Divers competing in an international freediving competition (in Ibiza, Spain) were invited to participate in the study. The study procedures had previously been granted ethical approval by the local internal review board, and all participants provided written informed consent. Participants completed an aquatic history questionnaire regarding their watersports activities, participation patterns, symptomatology and the geographical location of their diving exposure.

Immediately following the completion of the questionnaire, participants underwent otological examination of their external auditory canals to determine the presence or absence of external auditory exostoses. An examiner viewed the left ear then the right. Examiner one was an American Board certified ENT consultant experienced with aquatic sports populations; examiner two was the lead author. All ear canals were examined using a digital otoscope (Jedmed 70-6001, St Louis, Missouri, USA), with the image projected onto a liquid crystal display screen (Sharp LC10A3UBK, Camas, Washington, USA) and recorded via a digital photo printer (Sony DPP MS-300, New York, New York, USA.)

Images were later scored, following the system of Umeda *et al.*,[5] according to the percentage stenosis of the external auditory canal caused by external auditory exostoses, in 5 per cent increments. Images were then graded, following the system of Ito and Ikeda,[12] according to the following percentage obstruction: grade zero, 0 per cent; grade one, <30 per cent; grade two, 30–59 per cent; grade three, 60–90 per cent; and grade four, >90 per cent (Figures 1 and 2).

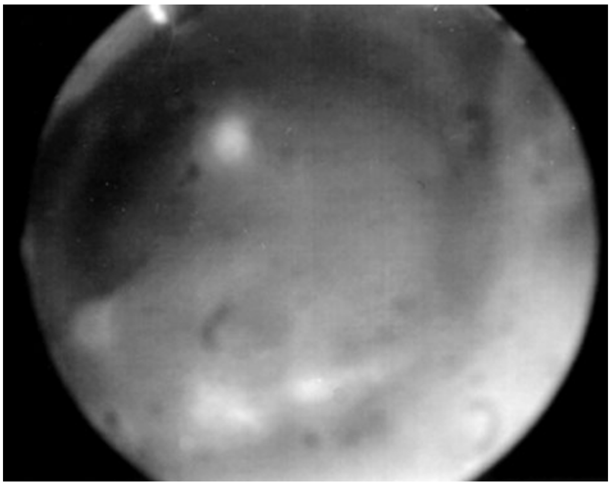

FIG. 1
Example of an external auditory canal unaffected by exostoses (i.e. grade 0; 0 per cent stenosis).

Divers were asked to indicate their three most common breath-hold dive sites by marking a global map included in the questionnaire and writing the name of each location marked; they were also asked to record an estimate of the number of breath-hold diving days spent at each location in each of the last three years. The primary dive location was considered to be the place where ≥60 per cent of total diving days was spent; where this was not the case, the two most dominant dive locations were pooled. From this, sea surface temperatures were determined by calculating the average temperature at the diver's primary open-water site, for the period 1992 to 2001, according to monthly data collated by the National Oceanographic Data Center.[14] Where two dominant dive sites were pooled, the weighted averaged temperature for the two sites was determined.

A diver's total number of aquatic years was transformed into 'adjusted years' by taking the lesser of two figures: either aquatic years per se, or aquatic years minus 16. This was done for two reasons. Firstly, in both anthropological and clinical studies, evidence of external auditory exostoses in sub-adult populations is largely absent. Kennedy[4] argues that, in anthropological studies, the exploitation of aquatic resources is an almost exclusively adult, male occupation and that it is this social phenomenon which accounts for the absence of external auditory exostoses in the skeletal remains of younger individuals. Di Bartolomeo[15] confirms that in clinical observations there is almost no evidence of external auditory exostoses in children or adolescents. He relates this finding to the incomplete osteological development of the tympanic and surrounding bones in adolescents and children, which acts to mediate external auditory exostosis remodelling. Once adult morphology has been attained, external auditory exostoses are free to develop in a relatively stable environment. Secondly, as many breath-hold divers come to the sport via

FIG. 2

Example of an external auditory canal with grade 3 (60–90 per cent) stenosis due to external auditory exostoses.

self-contained underwater breathing apparatus (SCUBA) diving, for which the generally accepted minimum age for certification is 16 years,[16] an age of 16 years has been adopted as defining 'adulthood.'

Six of the subjects were examined via both digital equipment and a manual otoscope (Welch-Allyn 25020, Skaneatles, New York, USA), in order to validate agreement of observations between the two devices and between the two examiners. Validation was confirmed using typical error measures and coefficients of variation.[17] Four of the participants were re-examined using the hand-held otoscope on three occasions, and a further three participants were re-examined on two more occasions to determine intra-tester reliability, also using typical error measures and coefficients of variation.[17]

Extreme Studentised deviate analyses[18] was used to identify outliers in the external auditory exostosis prevalence data, comparing the current cohort and those of previous studies. Chi-square tests were used to identify differences in severity between the current participants and previously studied populations. Multiple linear regression (stepwise inclusion) was used to determine the relative contributions of sea surface temperature, exposure latitude and exposure years to the breath-hold divers' observed stenosis due to external auditory exostoses. Analyses were carried out using the Statistical Package for the Social Sciences version 12.0.1 software (SPSS Inc, Chicago, Illinois, USA). Statistical significance was determined when $p = 0.05$.

Results

The validity of the study's manual testing procedure was compared against the observations of the ENT consultant examiner, using digital imaging. Repeated observations were made of six participants: typical error ($n = 6 \times 2$ trials) = 2.67 per cent stenosis (95 per cent confidence limits (CL) = 1.89 to 4.52 per cent stenosis). These values indicate that observations were consistent enough between observers and equipment not to impact on the percentage stenosis values assigned within the study group (<5.00 per cent).[17] The internal reliability of the study observations were then confirmed through repeated observations of seven participants four of whom were examined on three occasions, and three, on two occasions: typical error ($n = 4 \times 3$ trials) = 1.89 per cent stenosis (95 per cent CL = 1.25 to 3.58 per cent stenosis); typical error ($n = 3 \times 2$ trials) = 2.18 per cent stenosis (95 per cent CL = 1.58 to 3.51 per cent stenosis). These values indicate that the observations were consistent enough between data collection sessions not to impact on the percentage stenosis values assigned within the study group (<5.00 per cent).[17]

The response rate was 72 per cent (111/154). Of the 111 divers examined (Table I), four male and five female participants were not scored and graded due to inconclusive imaging or obstruction by waxy cerumen. As such, 204 ears were included in the analysis. Of these 204 examined ears, 179 (87.7 per cent) showed some degree of stenosis; 25 (12 per cent) appeared unaffected. Five participants (5 per cent) exhibited unilateral external auditory exostoses, 13 (13 per cent) showed bilateral external auditory exostoses with equal stenosis in each ear, and 84 (82 per cent) had bilateral external auditory exostoses with differing degrees of stenosis in each ear. Following the procedures for scoring external auditory exostoses established by Umeda *et al.*,[5] and the grading system for external auditory exostoses (by percentage stenosis) established by Ito and Ikeda,[12] the hemispheric distribution of external auditory exostosis growths observed in the participants was determined, as shown in Table II.

Classic 'V-sign' stenosis was unilaterally present in seven participants, all of whom exhibited an overall stenosis of >30 per cent in the affected ear. Current otitis externa was observed in one participant, who also showed signs of previous severe infection in the opposite ear, with evidence of deformation and scarring of the tympanic membrane. Unilateral scarring was also evident on the tympanic membrane of one participant whose eardrum had ruptured during a competition seven months earlier.

TABLE I

SUBJECTS' CHARACTERISTICS

Sex	Age (y)	Height (m)	Weight (kg)	BMI (kg/m^2)	Diving exp (med (IQR); y)	EAE (% ears)
Male*	32.8 ± 6.8	1.82 ± 0.07	78.3 ± 7.2	23.64 ± 1.72	18 (9, 23)	91.6
Female†	30.8 ± 7.1	1.65 ± 0.09	67.1 ± 8.9	24.64 ± 2.31	10 (6, 25)	68.3

Data are presented as mean ± standard deviation unless otherwise specified. *$n = 76$; †$n = 35$. y = years; BMI = body mass index; exp = experience; med = median; IQR = interquartile range; EAE = external auditory exostoses

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TABLE II

DISTRIBUTION OF EXTERNAL AUDITORY EXOSTOSES BY EAR AND STENOSIS SEVERITY

Stenosis (grade (%))	L ear	R ear	Combined
0 (0)	12	13	25
1 (<30)	36	34	70
2 (30–59)	35	36	71
3 (60–90)	19	19	38
4 (>90)	0	0	0

L = left; R = right

Previous studies[5,7–13] have found a prevalence of exostoses ranging from 25 to 80 per cent, as compared with the 88 per cent prevalence rate found in the current cohort of divers (Table III). When comparing these values, no significant difference was found between the current cohort's prevalence of external auditory exostoses and the overall distribution of the reference data ($z = 1.276$; $p = 0.101$). When the previous studies were subdivided into surf studies[5,7–10] ($z = 1.062$; $p = 0.144$) and dive studies[11–13] ($z = 1.341$; $p = 0.089$) and each subgroup compared with the current cohort, again, no significant difference in the prevalence of external auditory exostoses was seen.

Due to the format in which data were presented in the previous literature, comparisons of the distribution of severity of external auditory exostoses were only possible with four previous surfing populations[5,7–9] and two previous diving populations.[11,12] Chi-square tests for differences in the distribution of severity of external auditory exostoses showed significant differences in the current study population, compared with all reference cohorts (Table IV).

We tested a multiple regression analysis model determining the contribution of sea surface temperature, latitude and duration of breath-hold diving exposure to the development and severity of external auditory exostoses. It was determined that both sea surface temperature and duration of diving exposure were significant contributors to the prediction of the development and severity of external auditory exostoses, where latitude of exposure was a non-significant contributor (Table V). Coefficient analysis of the multiple regression model derived the following results: sea surface temperatures, $\beta = -2.452$, $p = 0.019$; adjusted years, $\beta = 0.641$, $p = 0.031$; and latitude, $\beta = -0.315$, $p = 0.519$. This suggests that sea surface temperature and adjusted years had a significant magnitude of impact on stenosis development, while latitude had no statistically significant impact. There follows the implication that for every 1°C drop in sea surface temperature, there is an increase of 2.45 per cent in stenosis development, and for every year of exposure to these temperatures, there is an increase of 0.64 per cent in stenosis development.

In a secondary analysis following the regression analysis, the participant with the highest hemispheric difference in external auditory exostosis severity (left − right = 25 per cent) produced a covariance ratio of 0.79 from the cohort data against his left ear external auditory exostoses (stenosis = 70 per cent). Review of this participant's history revealed him to be an avid surfer based in Cornwall (south-west England). Following Umeda and colleagues'[5] and Chaplin and Stewart's[7] attribution of external auditory exostosis asymmetry to surfers' stance on their boards, it is not surprising that this subject used a 'goofy-foot' stance (i.e. left foot lead); the implication is that a surfer's lead ear is subject to more rapid evaporative cooling.[5,7]

TABLE III

PREVALENCE OF EXTERNAL AUDITORY EXOSTOSES IN PREVIOUS AND CURRENT COHORTS

Study	Cohort	Subjects (n)	EAE* prevalence (%)
Kroon *et al.*[9]	Surf	202	38
Hurst *et al.*[10]	Surf	300	63
Chaplin & Stewart[7]	Surf	92	73
Wong *et al.*[8]	Surf	307	74
Umeda *et al.*[5]	Surf	51	80
Karegeannes[11]	SCUBA	87	26
Ito & Ikeda[12]	SCUBA	97	54
Fabiani *et al.*[13]	Breath-hold	24	25
Current study	Breath-hold	102	88

*Note that none of the previous studies found an EAE (external auditory exostoses) prevalence which differed significantly from that of the current study. Surf = surfers; SCUBA = self-contained underwater breathing apparatus divers; breath-hold = breath-hold divers

TABLE IV

DIFFERENCE IN EAE SEVERITY BETWEEN CURRENT COHORT AND PREVIOUS STUDIES

Study	Cohort	Difference in EAE severity		
		χ^2	p	Direction*
Umeda *et al.*[5]	Surf	9.09	0.003	More
Chaplin & Stewart[7]	Surf	12.04	0.007	More
Wong *et al.*[8]	Surf	32.37	<0.001	More
Kroon *et al.*[9]	Surf	106.82	<0.001	Less
Karegeannes[11]	SCUBA	35.99	<0.001	Less
Ito & Ikeda[12]	SCUBA	134.03	<0.001	Less

*More = more severe; less = less severe. EAE = external auditory exostoses; surf = surfers; SCUBA = self-contained underwater breathing apparatus divers

Discussion

While a broad range of prevalence of external auditory exostoses was seen across the previous studies, and the prevalence in the current cohort was the

TABLE V

MULTIPLE REGRESSION MODEL FOR PREDICTION OF EAE SEVERITY IN BREATH-HOLD DIVERS

EAE predictor	Cumulative R^2	Change in R^2	p
Sea surface temp	0.503	0.503	<0.001
Exposure years	0.555	0.052	0.017
Exposure latitude	0.556	0.001	0.568

EAE = external auditory exostoses; temp = temperature

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highest yet reported, no single study stands apart from the group as being significantly different regarding the reported prevalence of external auditory exostoses. However, when ranked by prevalence, surf studies appear to have a higher mean prevalence (65.6 per cent) than dive studies (35.0 per cent) (Table III). This might be best explained by the hypothesis of rapid ear cooling due to evaporation from surfers' ears, as proposed by previous studies,[5,7,12,13] based on the evidence of increased external auditory exostosis severity in the surfer's lead (i.e. windward) ear (which catches more wind than their leeward ear). This may be compared with the decreased volume of cold water exchange within the external auditory canals of divers wearing hoods[11,12,17] or helmets.[11]

Three[5,7,8] out of four of the previous surf studies found more severe stenosis due to external auditory exostoses than that observed in the current breath-hold diver cohort (Table IV). As with the prevalence of external auditory exostoses, it may be hypothesised that evaporative cooling elicits more severe external auditory exostosis growth. Kroon and colleagues' surf study[9] showed less severe external auditory exostosis stenosis. Examination of this cohort revealed that, of those participants with external auditory exostoses, 83.6 per cent (169/202) were predominantly 'warm water' surfers (p. 500) and 16.3 per cent (33/202) were predominantly 'cold water' surfers (p. 500), 60°F (16°C) being the threshold temperature between cold and warm water. This preponderance of warm water exposure may explain why this particular surfer cohort had both the lowest prevalence and the lowest severity of external auditory exostoses, within the surfer sub-group. No distinction was made between cold and warm water divers in the current breath-hold diver cohort, as this was not part of the original design.

Both SCUBA diving reference populations[11,12] showed less severe external auditory exostosis stenosis than the breath-hold cohort (Table IV). This may be attributable to the above-mentioned use of hoods or helmets and to the absence of exacerbation by cooling due to evaporation. When the short-duration, repeated immersions of a typical breath-hold diving session are compared to the sustained, single- or double-immersion exposures of SCUBA diving, the breath-hold divers' in-water sessions may be more comparable to the multiple 'dunkings' and/or sea-spray exposures experienced by surfers, in terms of repeated evaporative cooling of the external auditory canal.

The multiple regression model suggests that, at the time of study in the current cohort, sea surface temperature was the strongest predictor of external auditory exostosis severity, accounting for 50.3 per cent of the total 55.6 per cent prediction by the model. Years of exposure added a further 5.2 per cent to the strength of the model. Latitude of exposure added a non-significant ($p = 0.568$) 0.1 per cent prediction of external auditory exostosis severity to the overall model.

The regression model proposed supports assertions in the literature that, in susceptible individuals,[2,15] there is a threshold temperature[1–3,6,9,15] below which external auditory exostosis development is accelerated, and that the rate of acceleration observed in the current cohort represents an increase of 2.5 per cent external auditory exostosis stenosis for every 1°C drop in sea surface temperature. Kennedy's[4] model of exposure latitude as a predictor for external auditory exostosis development in prehistoric populations has been masked by its high collinearity ($6.387 > 1.000$) with sea surface temperature. With the advent of wetsuits, latitudes of exposure, particularly those of the northern European divers in the current cohort, have been expanded beyond those exploited by pre-industrial societies.

- **The formation of external auditory exostoses following repeated cold-water irrigation has been well reported**
- **This paper presents data on the prevalence and severity of stenosis due to external auditory exostosis in breath-hold divers, a group not previously examined in the literature**
- **Breath-hold divers appear to have a similar prevalence but a reduced severity of external auditory exostosis stenosis compared with surfer populations, and a similar prevalence but an increased severity compared with SCUBA diving populations**
- **The strongest predictor of external auditory exostosis stenosis severity was sea surface temperature at the primary dive site (2.5 per cent increase in stenosis per 1°C decrease in temperature); years of exposure was a secondary predictor (0.6 per cent increase in stenosis per year of exposure)**

It should be noted that a correlation between sea surface temperature at depth during dives has not been established in this study, nor in the previous literature. Personal observations at breath-hold diving competitions suggest that a diver will be in the water for a total of approximately 45 minutes while preparing for and executing their dive. Of this time, approximately 2 minutes 30 seconds will be spent submerged at depth. As such, the influence of the temperature at depth has only a brief, transient influence on overall external auditory canal cooling. Of greater importance is the moderating impact of sea surface temperature on the air temperature close to the water surface. This, in turn, has an apparent effect on the rate of evaporative cooling of the external auditory canal.

Whilst the number of competitive breath-hold divers in the UK is at present limited (to approximately 100), the International Association for the Development of Freediving (in French, Association Internationale pour le Development du Apnée) suggests that participation in the sport has been

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doubling every three years since 1992 (M Harris (British Freediving Association Press Officer and Association Internationale pour le Development du Apnée liaison officer), personal communication).[19] The Association further suggests that registered competitors reflect less than 20 per cent of serious recreational participants (M Harris, personal communication).[19] Spearfishing represents another avenue for serious recreational breath-hold divers. Spearfishing divers are estimated to outnumber freedivers by two to one (M Harris, personal communication).[19] It may, therefore, be speculated that approximately 1000 to 1500 serious recreational breath-hold divers are active in UK waters. As such, they represent a small but important clinical sub-population at risk of external auditory canal stenosis due to external auditory exostoses.

Conclusion

The prevalence of external auditory exostoses in the current cohort was similar to that of previously studied surf populations,[5,7–10] and worse than that of previously studied SCUBA diving populations.[11,12] The severity of stenosis due to external auditory exostoses was less severe in the current cohort than in previously studied surf populations, but more severe than in previously studied SCUBA diving populations. In the current breath-hold diver cohort, declining sea surface temperature was the strongest predictor for occurrence and severity of stenosis due to external auditory exostoses; years of exposure was also a limited but significant contributor.

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