

Acute otitis externa in divers working in the North Sea: a microbiological survey of seven saturation dives

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SUMMARY

Saturation diving is an important and widely used technique in the Offshore Oil Industry. During 1974–5 two saturation dives in the North Sea were terminated because of outbreaks of incapacitating otitis externa, and others were disrupted. *Pseudomonas aeruginosa* was consistently isolated from the ears of affected divers. Because complex work schedules were threatened seven subsequent dives were subjected to microbiological monitoring and control. Colonization of the ear canal with *P. aeruginosa* or with other gram-negative bacilli occurred in 39 (67%) of the 58 divers studied, usually within 7 days of starting the dive. Data obtained by serotyping the isolations of *P. aeruginosa* suggested that a single infected diver may be the source of organisms which rapidly spread to his colleagues and throughout the living chambers, that the living chambers may constitute a reservoir of infection during and between dives, and that certain serotypes of *P. aeruginosa* are more likely than others to colonize the ear canal in the conditions of a saturation dive. The control measures used during the dives were only partially effective, but none of the divers suffered severe pain and all the dives were an operational success.

INTRODUCTION

The effective working time of a deep sea diver is severely curtailed because a slow and carefully controlled ascent is necessary to prevent decompression sickness. A saturation dive overcomes this problem by establishing a uniform pressure system between the diver's living quarters and the depth at which he works. In a typical saturation dive a team of divers live on the surface in a complex of several linked pressure chambers (Fig. 1, T or R). A detachable, pressurized diving bell transports them to and from the sea bed as required. A diver may live for several weeks within the complex before his eventual decompression. The environment in such a system is unique. Typically the atmosphere is mainly pressurized helium, the partial pressure of oxygen is about 400 millibars and the partial pressures of carbon dioxide and nitrogen are nominal. The high thermal conductivity of helium requires an ambient temperature of 30–35 °C. The relative humidity is controlled at about 55%, but sometimes exceeds 90%. The living space provides all life-support facilities for 6–8 divers over several weeks, and is very cramped.

Otitis externa is known to be strongly associated with swimming and diving

(Sperati & Pefumo, 1967; Hoadley & Knight, 1975). It is a major cause of morbidity during saturation dives, and in this environment the symptoms are frequently incapacitating (Cobet, Wright & Warren, 1970; Summitt, Kelley, Herron & Saltzman, 1971; Thalman, 1974).

Local trauma, the removal of lipid from the skin, and prolonged exposure to high humidity and temperature are all thought to predispose to otitis externa; high humidity is particularly important (Senturia & Liebman, 1956; Taplin, Zaias & Rebell, 1965; Wright & Dineen, 1972). A critical factor in the pathogenesis of the disease appears to be the ratio of gram-positive to gram-negative bacteria in the ear canal. The normal flora is predominantly gram-positive, mainly staphylococci and corynebacteria; that in otitis externa is predominantly gram-negative mainly Enterobacteriaceae and *Pseudomonas aeruginosa* (Hardy *et al.* 1954; Wright & Alexander, 1974). Hydration of the skin of the ear canal probably predisposes to this change (Wright & Dineen, 1972; Hojyo-Tomaka, Marples & Kligman, 1973). *P. aeruginosa* is the gram-negative species most often implicated in overt disease (Wright & Alexander, 1974).

During 1974–5 two saturation dives in the North Sea were terminated because of outbreaks of incapacitating otitis externa, and others were disrupted. *P. aeruginosa* was consistently isolated from the ears of the divers with otitis. In the terminated dives, two entire teams, each of six divers, became infected a few days after entering saturation. Because complex work schedules were threatened, subsequent dives were subjected to microbiological monitoring and control. This paper describes the data obtained during seven of these dives, involving two different saturation complexes.

MATERIALS AND METHODS

Chamber complexes

Two complexes (Fig. 1, T & R) situated on different ships were studied at different times. The divers lived on the surface inside the steel pressure chambers. These were named after their diameter in millimetres and linked together via air locks, which usually remained open during a dive. Each chamber had an 'S.A.S.' area which contained the lavatory, wash basin and shower for that chamber and was very cramped. In the R complex this area was separated from the rest of a chamber by an air lock (again, usually kept open during the dives). In the T complex, there was no separation in the 1500 and a loose-fitting screen and door was fitted in the 2500 (Fig. 1, A). The detachable diving bell keyed onto the 2500 'S.A.S.' area in the T complex and the 1800 I 'S.A.S.' area in the R complex. In both complexes the 2500 was the main living chamber and housed 6–7 divers. The smaller chambers were used to allow compression and decompression of divers without disturbing the environment of the 2500. In the R complex excess personnel sometimes lived for short periods in 1800 II. In all the chambers a false floor overlay heating elements needed to maintain the high ambient temperature. The oxy-helium atmosphere was recycled over 7–8 min through a gas regeneration plant consisting of separate tanks of silica gel, carbon particles, and soda lime.

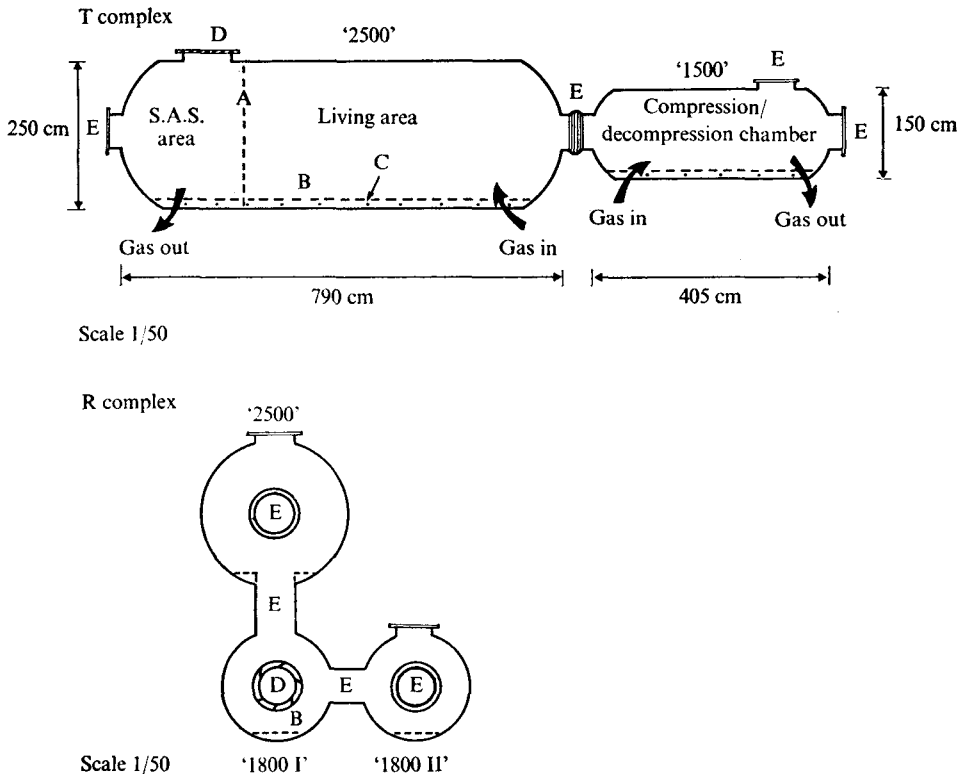


Fig. 1. Arrangement of pressure chambers in the T and R living complexes. A, T complex: partition with loose-fitting door; B, false floor; C, heating elements; D, diving bell keys on here; E, air locks.

Dive monitoring and control

Four dives lasting 10, 5, 9 and 30 days, in which a total of 25 divers participated, were monitored in the T complex (T_1 – T_4); three dives lasting 26, 9 and 30 days and involving a total of 33 divers were monitored in the R complex (R_1 – R_3). The term 'dive' in this context denotes only the discrete period during which the main living area of a complex was pressurized. During any such period the diving personnel were frequently changed, e.g. in dives T_4 , R_1 and R_3 the teams of divers at the end of the dive were entirely different from those at the beginning. At any one time, in both T and R systems, from 5–8 divers were housed in a complex. The chambers were decompressed for less than 24 h between T_3 and T_4 , and between the three dives in the R complex.

Work was at a depth of 75–85 m (7.5–8.5 atm gauge pressure). Divers spent from 4–8 h each day on the sea bed, for about 9 out of every 14 days spent in saturation. Decompression of divers at the end of their period in saturation occupied 50 h. In the R system only, divers routinely used prophylactic ear drops containing boric acid, alcohol and glycerol.

The divers' ears and the chamber complex were swabbed before each dive and at least every 2 days thereafter, with 'Exogen' plain swabs moistened with sterile

distilled water. Divers were not admitted to the dives if gram-negative bacilli were isolated from their ears in the pre-dive screen. In T_1 , however, one diver, from whose ears *P. aeruginosa* had been grown, was inadvertently allowed into the complex and not removed for 3 days.

During a dive those divers from whose ears gram-negative bacilli had been isolated were treated every 8 h with ear drops containing gentamicin sulphate 0.3% (w/v) and polymyxin B sulphate 0.5% (w/v). In the dive T_1 , a cream was used containing the same antibiotics at the same concentration. Infected divers were decompressed as soon as operational needs allowed, particularly if *P. aeruginosa* had been isolated.

A high standard of personal and chamber hygiene was enforced during the dives. During T_1 and T_2 'Savlon' (I.C.I.) 1/200 was used to disinfect the chamber, thereafter 'Panacide' (dichlorophen B.D.H.) 200 parts/10⁶ was used. Surfaces were scrubbed with, then washed clear of, detergent, before the use of 'Panacide'. The lavatory, wash basin and shower area were washed out and disinfected several times daily, the 'S.A.S.' area of the chamber once a day, and the whole chamber complex in the periods between dives. In all the dives except T_1 sheets and towels were changed every 2 days.

Bacteriological techniques

Swabs from the T complex were processed within 24 h, having been stored at 4 °C and then flown to the shore. Swabs from the R complex were processed immediately by a mobile laboratory set up on the ship which housed the chamber complex. Swabs were plated out, before and after incubation for 12 h in thioglycollate broth, using heart infusion agar ('Difco') + 10% horse blood, and MacConkey agar ('Oxoid'). Only swabs from T_1 were examined culturally for fungi. Pseudomonads were identified after Cowan & Steel (1965), with additional tests for growth on milk agar (Brown & Scott Foster, 1970), 6% sodium chloride, and 1% tetrazolium chloride (Phillips, 1969). Non-pseudomonad isolations were fully identified in T_1 , but thereafter were classified on the basis of colonial appearance and growth characteristics. All non-lactose fermenting gram-negative bacilli were treated as putative pseudomonads, and were screened on milk agar and by the oxidase and catalase tests. Antibiotic sensitivities were determined by the disk method on Mueller Hinton agar of calcium and magnesium content 75 and 32 mg/l respectively (Reller, Schoenknecht, Kenny & Sherris, 1974; Ericsson & Sherris, 1971). 'Oxoid' disks containing 10 µg of gentamicin or colomycin were used, and a zone of inhibition of less than 2 mm diameter on either side of the disk was taken to indicate resistance.

RESULTS

The pattern of data illustrated in Fig. 2 is representative of that obtained from the divers in all of the dives studied. Conditions (e.g. in terms of the divers present in the chamber complex and their ear floras) varied throughout any one dive. Thus divers F and G (Fig. 2) entered a different environment from divers A-E and, unlike them, could remain in the complex for only 5 days before the dive ended.

Divers	Ear	Duration of saturation (days)									
		Pre-dive	1	2	3	4	5	6	7	8	9
A	L	+		+		+	Treat*	●	N		Out
	R	+		+		Δ	Treat	●	N		
B	L	+		+		+	Treat	N		Out	
	R	N		+		●	Treat	+			
C	L	+		+		●	Treat	N		Out	
	R	+		+		●	Treat	N			
D	L	+		+		+		+		Out	
	R	+		+		+		+			
E	L	+		+		+Δ	Treat			Out	
	R	+		+		+●	Treat				
F	L					+	In		+	Treat	Out
	R					+			+		
G	L					N	In		●	Treat	out
	R					N			+		

Fig. 2. Ear flora of divers during the dive, R₂. +, Normal gram-positive flora; Δ, non-pseudomonad gram-negative bacilli; ●, *P. aeruginosa*; N, no bacteria isolated. L, left; R, right. * Begin 7 days of treatment with antibiotic drops.

To minimize the problems presented by such variations, the results are presented more in terms of the experiences of different groupings of divers than as an analysis of each dive as a whole.

Divers' ear flora before and during saturation

The ear flora of 57 divers just before entering saturation is shown in Table 1. Staphylococci predominated, and all 29 isolations from men sampled before T₁-T₃ were coagulase negative. Many of the divers had used prophylactic and/or antibiotic ear drops during previous dives. Most had been subjected to earlier bacteriological studies, and divers were not considered for saturation work whilst gram-negative bacilli could be isolated from their ears.

Table 2 shows the frequency with which gram-negative bacilli were isolated from the ears of a group of divers who lived in either the T or R complex for at least 7 days, or who were decompressed within this period because of abnormal ear flora.

Table 1. Ear flora of 57 divers swabbed before entering saturation

Bacterial genus	Isolation rate*
<i>Staphylococcus</i>	60 %
<i>Corynebacterium</i>	6 %†
<i>Pseudomonas</i>	2 %‡
No detectable flora§	38 %

* Expressed as a percentage of the number of swabs cultured (114).

† Mixed growth with staphylococci.

‡ One diver admitted to T₁ in error.

§ No colonies observed after plating out swabs incubated in thioglycollate broth for 12 h.

Table 2. The frequency of isolation of abnormal ear flora in divers exposed to a saturation environment for at least 7 days*

Saturation complex	Time of entry into the complex (B or D)†	Number of divers	Percentage who at any time yielded:		
			Gram-negative bacilli	<i>P. aeruginosa</i>	<i>P. aeruginosa</i> as the only gram-negative bacillus
T	B	18	72	67	28
	D	6	50	50	50
R	B	10	70	50	20
	D	20	80	60	35

* Divers removed from saturation after less than 7 days because of ear infection are included in the data.

† B, Divers entering the chamber complex at the beginning of the dives; D, divers entering the chamber complex during the dives.

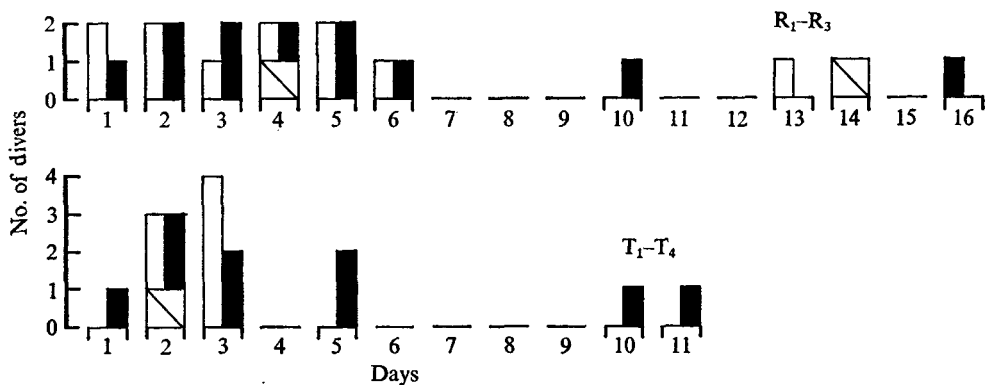


Fig. 3. Number of days spent by divers in saturation before taking ear swabs from which gram-negative bacilli were first isolated. Divers in whom the first isolation was: ■, *P. aeruginosa*; □, non-pseudomonad gram-negative bacilli; ▨, *P. aeruginosa* and other gram-negative bacilli.

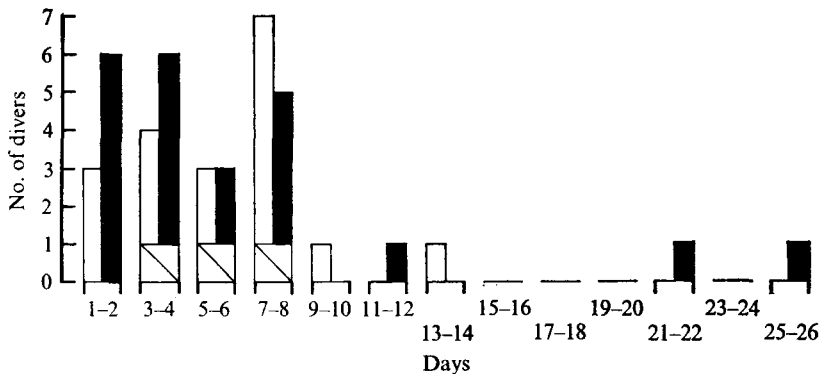


Fig. 4. Number of days spent by divers in saturation after taking ear swabs from which gram-negative bacilli were first isolated. Combined T and R data. Divers in whom the first isolation was: ■, *P. aeruginosa*; □, non-pseudomonad gram-negative bacilli; ▨, *P. aeruginosa* and other gram-negative bacilli.

Within this group, gram-negative bacilli were isolated from the ears of 67% of divers living in the T complex and 77% of those living in the R complex. (The corresponding figures if all divers are considered, irrespective of their time in saturation are 64% (T) and 70% (R).) *P. aeruginosa* was isolated at some time from 15 (94%) of infected divers using the T complex and 17 (74%) of infected divers using the R complex. There appeared to be no significant difference in the frequencies of colonization between divers using the two complexes, and between divers entering the chambers at the beginning of a dive and those who entered during a dive. Divers in whom a normal gram-positive ear flora was detected before entering saturation usually retained this during the dive, irrespective of subsequent colonization with gram-negative bacilli.

The ears of 87% (T complex) to 83% (R complex) of infected divers became colonized with gram-negative bacilli within the first 6 days of the dive. The first isolation of gram-negative bacilli was *P. aeruginosa* in about 50% of all cases (Fig. 3). In 46% of infected divers the first isolations were made from both ears, and in 89% of these the two ears were colonized with similar microorganisms.

Seven divers never entered the water but remained in the chambers as tenders. Three became infected, two with *P. aeruginosa*. Actual diving with direct wetting of the ear canal is thus not essential for infection, although the numbers are too small to determine if it is a contributory factor.

Consequences of the changes in ear flora observed during saturation

Five (25%) of the divers using the T complex and five (15%) of those using the R complex developed ear pain. Gram-negative bacilli were isolated from the ears of all these divers, and *P. aeruginosa* from eight of them. The pain developed within 0-4 days of taking the ear swab from which gram-negative bacilli were isolated for the first time, and only affected two divers already under treatment, both within 24 h of starting therapy. It was managed by mild analgesics, antibiotic ear drops and prompt decompression; it was never incapacitating.

For operational reasons many infected divers were not decompressed promptly

(Fig. 4). Twenty-one divers (54 % of all infected divers) did not start decompression for 5 or more days after taking the ear swabs from which gram-negative bacilli were first isolated. All but two of them were treated, and only one (who was treated) suffered pain. These data, combined with the finding that only two of all treated divers suffered pain, suggest that, with treatment, infected divers can remain in saturation and incur little risk of pain.

Effect of treatment on ear flora

Thirty-five (90 %) of the infected divers were treated, 34 within 12–48 h of taking the diagnostic swab. Most were treated for 8–10 days and decompressed within 2–8 days. No bacteria were isolated from 28 of 34 swabs taken about 24 h after beginning treatment and 7 h after an application of antibiotic ear drops. A similar result was obtained from swabs taken throughout the courses of treatment. (All these swabs were probably contaminated with antibiotics from the ear canal.) Sampling thereafter was unsatisfactory, but data from 19 divers suggested that after treatment, and without further diving, ears remained free of detectable gram-negative bacilli. Treatment appeared to have no effect on infection patterns in subsequent dives, but the number of observations is insufficient for adequate assessment.

The high percentage of divers who entered saturation with no detectable bacteria in one or both of their ears (Table 1) may reflect previous treatment; the frequency with which such ears subsequently became colonized with gram-negative bacilli was similar to that for ears from which normal flora had been isolated.

In all the dives except T₁, antibiotics were administered as ear drops. During these dives none of the 66 isolations of *P. aeruginosa* from ear swabs were resistant to gentamicin or colistin, when tested by the disk method. All the 47 ear strains of other gram-negative bacilli were sensitive to gentamicin, and 39 were sensitive to colistin. In T₁, where the same antibiotics were administered as a cream, three of the 25 ear strains of *P. aeruginosa* were resistant to gentamicin, and of the 13 isolations of other gram-negative bacilli all were sensitive to gentamicin, and 10 were sensitive to colistin. In both cases no gentamicin-resistant strains of *P. aeruginosa* were isolated from the chamber complexes, and all the colistin resistant ear strains were members of the proteus group.

The gentamicin-resistant pseudomonads were isolated from two divers; and were all of serotype 11. In one diver, the first resistant isolation was made after 2 days of treatment for an ear infection with *P. aeruginosa*, also of serotype 11 and originally sensitive to gentamicin. The other had had no previous isolations of *P. aeruginosa*, but had been treated for 5 days for a non-pseudomonad ear infection.

Divers whose ears remained clear of detectable gram-negative bacilli during the dives

Gram-negative bacilli were not isolated from the ears of 9 divers using the T complex and 10 using the R complex. None of these divers suffered pain. The ear floras identified in these divers before they entered saturation were similar to the

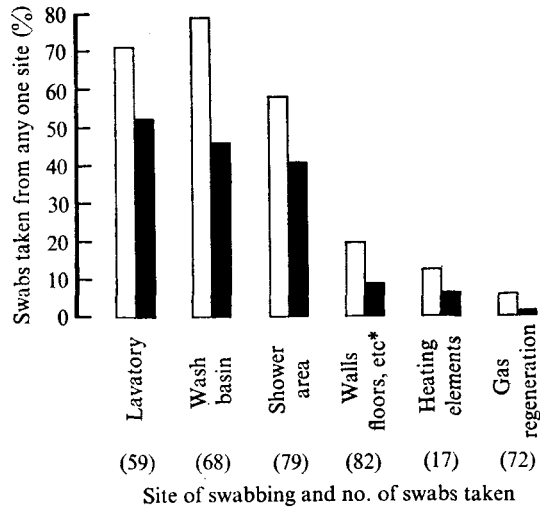


Fig. 5. Isolations of gram-negative bacilli from the '2,500' chambers of the T and R complexes. □, All gram-negative bacilli; ■, *P. aeruginosa*, * Excludes swabs from the 'S.A.S.' area.

pre-dive floras of those who subsequently became infected, and did not change during the dives. The absence of detected gram-negative colonization was not due to unusually short periods of exposure to the saturation environment – 12 divers spent 9 or more days, and 8 spent 14 or more days in saturation.

Chamber contamination

During the dives 377 swabs were taken from the main living (2500) chambers of the T and R complexes. The pattern of contamination of those chambers with gram-negative bacilli is shown in Fig. 5. The 'S.A.S.' regions of the chambers (lavatory, wash basin, shower, and the adjacent chamber) showed heavy contamination with *P. aeruginosa* and other gram-negative bacilli within 1–2 days of starting a dive, and continuously thereafter. Elsewhere only scattered isolations were made, the gas regeneration systems remaining particularly clear. The same pattern was observed in the main chambers of the T and R complexes, and in the smaller chambers when divers were living in them. In dive T₁, the men's bedding showed a mixed flora of gram-negative bacilli after 4 days in saturation, in subsequent dives bedding was changed every 2–3 days.

Throughout any one dive either 'Savlon' or 'Panacide' was used to disinfect the chambers. The quoted killing concentration of 'Panacide' for *P. aeruginosa* is 80 parts/10⁶ (B.D.H. Ltd.). Neither regime reduced contamination of the 'S.A.S.' areas of the chambers to acceptable levels. When only a few hours separated the periods of saturation, contaminated chambers could not be cleared of gram-negative bacilli between the dives. Limited data suggested a better result if chambers were left unused for a few days after decompression and disinfection; this was done before T₁, when bacteria were not isolated from 29 of 30 swabs taken from the chamber 3 days after cleaning and disinfection.

Table 3. *Gram-negative bacilli other than Pseudomonas aeruginosa isolated from divers and saturation chambers*

Saturation complex and dive	Site swabbed	No. of isolations	Distribution of isolations according to family and genus (%)					Unidentified N.L.F.
			Enterobacteriaceae					
			<i>Escherichia</i>	<i>Klebsiella</i>	<i>Proteus</i>	<i>Enterobacter</i>	<i>Alcaligenes*</i>	
T ₁ †	Divers' ears	13	0	8	23	0	61‡	8
	Chamber	30	13	13	7	30	3	33
R ₁ -R ₃ §	Divers' ears	37	24	19	22	—	—	35
	Chamber	74	38	26	3	—	—	34

N.L.F., Non-lactose fermenting organism.

* As defined by Cowan & Steel (1965).

† Identified culturally and biochemically as described in Methods.

‡ Isolated from the ears of four of the six divers who participated in T₁.

§ Identified by growth and colonial characteristics only.

Scattered isolations of staphylococci and, less commonly, aerobic spore bearers were made at all sites in the chambers throughout the dives. In T₁, only, swabs were examined culturally for yeasts and fungi, and occasional isolations were made from the chamber walls and the divers' bedding. Bacteria were not isolated (no colonies observed after plating out swabs incubated in thioglycollate broth for 12 h) from 37% of all the swabs taken from the chamber complexes and from 18% of those taken from the S.A.S. areas.

The water supply to the R complex and the heated sea water pumped through water-jacketed diving suits had a presumptive coliform count of 0/100 ml when tested by the Multiple Tube Method (Cruickshank, Duguid & Swain, 1969). *P. aeruginosa* was never isolated from such samples. Limited sampling of diving suits and hoods showed scattered contamination with *P. aeruginosa* and other gram-negative bacilli; washing with 'Panacide' did not eliminate this.

Non-pseudomonad gram-negative bacilli

The non-pseudomonad gram-negative bacilli isolated from both the divers' ears and the chambers contained a high percentage of members of the Enterobacteriaceae (Table 3). The data are limited but demonstrate the variety of bacteria which can colonize the ear canal during saturation, and the importance of enterobacteria, both in this context and as a cause of chamber contamination.

Serotypes of Pseudomonas aeruginosa

The strains of *P. aeruginosa* from dives T₁ and R₁-R₃ were serotyped by the method of Habs (1957), and were phage typed (Asheshov, 1974) at the Central Public Health Laboratory, Colindale.

Chamber contamination with *P. aeruginosa* was not detected by swabbing before dive T₁. One diver (H) entered with two strains (of serotypes 11 and 2b/5c)

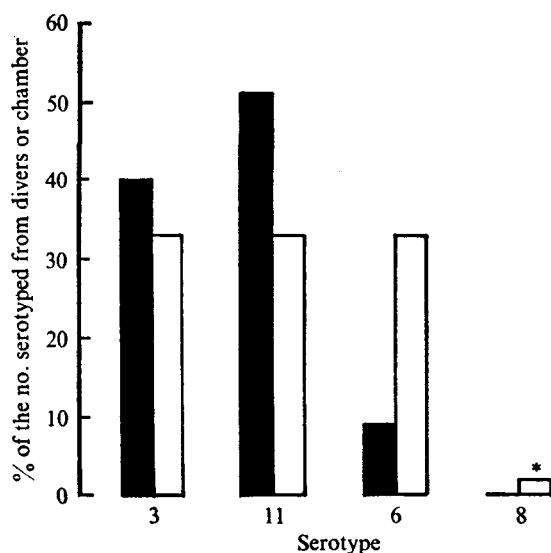


Fig. 6. Serotypes of *P. aeruginosa* isolated from divers ears and the chamber complex during dives R_1 – R_3 . ■, Isolations from the ears of divers (35 serotyped); □, Isolations from the chamber complex (46 serotyped), * A single isolation during R_1 .

in his ears, and he was not removed for 3 days. The 2b/5c strain later became predominant in his ears, but type 11 strains accounted for 16 of 18 isolations of *P. aeruginosa* from the ears of the other five divers, for 11 of 12 isolations from the chamber, for 4 of 4 isolations from the diving suits, and for all of the gentamicin-resistant strains. The remaining strains isolated were of type 2b/5c. The phage typing results indicated that all strains of each serotype were indistinguishable. No other strains of *P. aeruginosa* were isolated from any source during the dive. Although initial chamber contamination may not have been detected, the evidence suggests strongly that diver H introduced the infection.

The distribution of serotypes in R_1 – R_3 is shown in Fig. 6. The 46 isolations from the chamber were almost equally divided between 3 serotypes (nos. 3, 11 and 6), but 91% of the ear isolations were of two of these (nos. 3 and 11). *Pseudomonas aeruginosa* was isolated from the ears of 17 divers and only three (one of whom suffered pain) were colonized with type 6 strains. Throughout R_1 – R_3 the chambers were contaminated with *P. aeruginosa*, and this was not eliminated in the short periods between dives. Before the start of R_1 *P. aeruginosa* of serotype 11 was isolated from the 2500 chamber, and by day 15 of this dive serotypes 11, 3 and 6 were widely distributed in the chamber complex. Once established, this pattern of contamination remained consistent throughout the rest of R_1 , and throughout R_2 and R_3 . Serotypes 3 and 6 may not have been detected in the pre-dive screen for R_1 , or may have been subsequently introduced by divers or their equipment.

The data from the R complex point to the chambers as a possible reservoir of infection during and between the dives. The data from dive T_1 do not contradict this view and point to a single diver as the probable source of organisms which, in this dive, caused both ear infection and widespread chamber contamination. Both

sets of data suggest that in a saturation environment certain serotypes of *P. aeruginosa* are more likely than others to colonize the ear canal.

Comparison of results from the T and R complexes

There was no significant difference in the pattern of infection between the T and R systems, although in several respects T₁ constituted a special case. The greater size of the R complex appeared to offer no advantage, and the routine use of prophylactic ear drops did not prevent either changes in the ear flora or the occasional case of pain.

DISCUSSION

In 1974/5 the morbidity from otitis externa in divers using the T and R saturation complexes had reached critical proportions. The diving company required rapid control of the major operational problem, incapacitating ear pain, and data could be collected only as an adjunct to this. Nevertheless the results have a wider relevance than the assessment of control measures; no comparable microbiological survey appears to be available for a series of saturation dives under commercial conditions.

The results from the divers are compatible with the conclusions of previous studies, in particular those of Wright & Alexander (1974). Published data on chamber contamination are scanty, but Morris (1975) described the rapid contamination of submarines with bowel organisms and with *P. aeruginosa*.

In spite of the control measures described, colonization of the ear canal with gram-negative bacilli occurred in up to 70% of divers, usually within 7 days of entering saturation. *P. aeruginosa* was isolated at some stage from most of these divers, and from eight of the ten who suffered pain. Wright & Alexander's description (1974) of a decrease in the normal gram-positive flora of the ear canal concomitant with an increase in gram-negative flora was not apparent in this study, but our bacterial isolations were not quantified, antibiotic treatment was instituted early in infection, and bacteria could not be isolated from ear swabs thereafter. The significance of the observed changes of ear flora in the genesis of ear pain is difficult to assess, because of the effects of treatment and of the diver removal regimes. However, such changes are generally accepted as a major factor in the pathogenesis of acute otitis externa (Wright & Alexander, 1974), and our results support this, in that the ears of all the divers who suffered pain were colonized with gram-negative bacilli.

The very high incidence of severe ear pain, which precipitated this study, was greatly reduced by the control measures employed, and none of the divers in the survey suffered incapacitating pain. It is difficult to assess the relative importance in achieving this result of the different control measures used, but early detection and treatment of ear infection was probably the most important factor. Pre-dive screening of divers minimized the population at immediate risk of developing pain at the beginning of a dive, but 67% of these divers became infected thereafter. Decompression of infected divers was frequently delayed, and only one of this group suffered pain. Cleaning and disinfection of the chamber complexes did not

reduce bacterial contamination to an acceptable degree, but, together with the high general standard of hygiene enforced, may have contributed to the final result.

The efficacy of antibiotic treatment, with or without prompt decompression, in eliminating abnormal ear flora was not adequately established. Prolonged follow-up in the absence of diving was infrequent, and residual antibiotics probably contributed to the consistent failure to isolate bacteria from ear swabs obtained during and for several days after treatment. The rapid appearance of gentamicin resistance during the dive, T₁, may have resulted from inefficient distribution of the drug when used in a cream base. Antibiotic resistance was not a problem in dives where antibiotic drops were used, but, in the future, may arise during repeated cycles of infection and treatment, particularly if the treatment is merely suppressive. Adequate supervision of antibiotic therapy in a commercial, off-shore environment is difficult.

The scattered contamination of the chamber systems with mixed bacteria of human origin was not unexpected. The 'S.A.S.' areas were frequently wet, and bacterial replication was probably a principal factor in the gross contamination detected in them. They were probably a major source of infection. The humidity, high ambient temperature, and physical complexity of the interior of the chambers militated strongly against efficient disinfection. The problem was compounded by the very restricted range of disinfectants which can be used in the pressurized environment of a chamber complex, and the need for activity against *P. aeruginosa*. Bowel organisms (including *P. aeruginosa* in some cases) cannot be excluded from the chambers, and in the conditions of a saturation dive provide a potent source of environmental contamination.

The serotyping data are interesting, particularly as *P. aeruginosa* was a major cause of both ear infection and chamber contamination. They suggest that a single diver may be the source of organisms which rapidly spread both to his colleagues and throughout the chamber complex, and that the chambers may act as a reservoir of infection during and between dives. Bacteriological screening of divers before and during dives is thus probably of reduced value in limiting the spread of infection once the chamber complex is overtly contaminated, unless diver:diver contact, directly or via diving suits and equipment, is important in transmission. The small number of serotypes isolated may reflect a small number of sources with subsequent dissemination in and between the chamber systems (there had been some sharing of personnel between the T and R systems, and type 11 strains were isolated in both complexes). The possibility that, in a saturation environment, certain serotypes of *P. aeruginosa* are more pathogenic than others, is under further investigation.

The failure of prophylactic ear drops in the R₁-R₃ surveys parallels the experience of Wright & Alexander (1974), who used 0.25% acetic acid in 50% ethanol. Effective prophylactic preparations have been described (Beckman & Smith, 1972; Thalman, 1974; Hutchison & Wright, 1975), but these were not used in the conditions of a commercial saturation dive. We hope to conduct a more detailed assessment shortly.

These surveys are an example of the co-operation which is possible between a specialized University Department and a highly competitive industry, whose overriding requirement is the rapid solution or control of operational problems. The project was given the enthusiastic support of the staff of the newly formed Institute of Environmental and Offshore Medicine of this University, and Professor Nelson Norman of this organization first introduced me to the problem. I should like to thank Professor A. Macdonald for unstinting support throughout the project, Dr M. T. Parker for valuable advice, and Mrs M. Minton for able technical assistance. The strains of *P. aeruginosa* isolated were serotyped by Mr T. L. Pitt, Cross Infection Reference Laboratory, Public Health Laboratory Service, Colindale, London.

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