The effectiveness of a health-surveillance program for caisson saturation divers in a tunnel-boring machine: A microbiological survey

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ABSTRACT

The purpose of this field study is to report and evaluate the implementation of a health surveillance program we developed to monitor the microbiological load for saturation divers, including preventive and therapeutic interventions.

We extended the DMAC protocol for Saturation Diving Chamber Hygiene and added some components: ear inspections, swabs and environmental swabs every third day. The implementation was evaluated by analyzing the results of the activities.

In a pre-saturation dive check we examined a total of 17 divers. Here we present the data from all seven saturation phases, collected over a period of 1.5 years. In every saturation phase we have found pathogenic bacteria or fungi in divers and in the environment, but more in some periods than in others. We did not observe any serious infection that required a diver to abort his stay in the living chamber.

This health surveillance program has demonstrated the potential value of an early warning system to prevent problems. The bacterial load found in divers and in the environment was clearly visible. Prevention could be improved by more consistent implementation of the protocol. Fortunately, the infections had no serious consequences for the health of the workers or for the continuation of the work process. ❖

INTRODUCTION

During construction of the Western Scheldt tunnel in Holland (opened in 2003) the tunnel boring machine (TBM) went as deep as 69 meters. Maintenance work had to be carried out by divers in the cutter-head area in a pressurized work chamber. The effective working time, however, was severely curtailed when the boring machine reached a greater depth because a carefully controlled ascent, necessary to prevent decompression sickness, takes a great deal of time when there are significant pressure differences.

The introduction of saturation diving could substantially overcome this problem by establishing a relatively small pressure difference between specially constructed, pressurized living chambers at the surface and at the depth at which the work is performed. The pressure chambers provide all necessary life-support facilities for six divers. A diver may live for several weeks within the complex of linked pressure chambers, also called saturation habitats, before eventual decompression [1]. A detachable pressurized transport shuttle transports a team of divers to and from the work chamber in the tunnel boring machine, where the maintenance work is done. In this project, a diver could perform a maximum of seven dives in a week, with a maximum of six hours' working time each day, two hours' transport under pressure and 16 hours for physical and mental recovery per day.

For various reasons, infection is the most frequent medical problem encountered during saturation diving. Any infectious disease that develops is likely to threaten the health of other members of the team. There is a wide variety of pathogenic organisms present in the water and the seabed, including bacteria, fungi, parasites and viruses [2]. The closed environment of the living chambers, with its high temperature, humidity and hyperoxic environment, contribute to enhanced microbial growth. Gram-negative bacteria are predominant among the many microorganisms present in a saturation system environment; these are principally the *Pseudomonas* and the coliform groups, such as *Klebsiella* and *Escherichia coli*.

The *Pseudomonas* group is a natural inhabitant of fresh water and sea water and can readily enter the saturation habitat. The main source of coliforms is fecal excretion; therefore the organisms are a natural contaminant of the chambers, where the divers live for several weeks. The sources of microbiological contamination of the living chambers include the divers themselves and their excreta. Materials introduced into the chamber, such as headphones for audiovisual entertainment, mobile phones, daily newspapers, food, fresh water supply and dive equipment [3] are additional sources. In addition, divers can be contaminated as they work in the work chamber of the tunnel boring machine, *e.g.,* by using high-pressure water jet cleaning devices to clean the cutter heads.

In particular, infections of the external ear canal (otitis externa) are strongly associated with swimming and diving [4]. In divers these infections are most often caused by the *Pseudomonas* group, a major cause of morbidity during saturation dives. In this environment the symptoms associated with infection, such as severe pain, can be seriously incapacitating. They can even threat the continuation of work schedules [5].

Skin infections and other superficial infections from gram-negative bacteria are more common in the hyperbaric environment than in normobaric conditions [2,3]. Local trauma, the removal of lipids from the skin, the prolonged exposure to high humidity and the high temperature are all thought to predispose divers to skin infections. Divers with compromised skin constitute an ideal shelter for *Staphylococcus*, and these carriers present a special risk to those who have open skin lesions [6]. Unlike divers, caisson workers can be exposed to *Legionella pneumophila*, which causes Legionnaires' disease [8].

Standards for personal and workplace hygiene

The Diving Medical Advisory Committee (DMAC) is an independent committee that provides advice about medical issues and certain safety aspects pertaining to commercial diving. The committee comprises doctors involved in the practice of dive medicine in Northern Europe (currently France, the Netherlands, Norway, Sweden and the United Kingdom), representatives of relevant health authorities (the Health and Safety Executive in the UK, the Norwegian Directorate of Health), medical representatives from relevant navies (UK, the Netherlands and Sweden) and a diving safety officer nominated by the International Marine Contractors Association (IMCA). With its continuing advice to government bodies and to industry, DMAC enables the optimal coordination of medical support for dive activities worldwide.

In 1995 DMAC developed a protocol for Saturation Diving Chamber Hygiene (DMAC 26) [3]. For personal care, prophylactic ear drops were formulated, containing acetic acid and aluminum to minimize the chances of infection by maintaining an acidic environment in the external ear canal. The ear drops should be applied to the external ear canal two times a day.

The DMAC 26 protocol prescribes that the entire habitat be thoroughly cleaned and allowed to dry before a saturation intervention starts. The parts of the chamber that will be in contact with the skin should be disinfected using chamber cleaner, left for a minimum of 10 minutes, then rinsed and dried thoroughly. Showerheads should be removed, cleaned and dried. The chamber should be ventilated, and clean bedding and towels must be provided.

During saturation, the toilet, sink and shower areas, table surfaces and service locks and their immediate surroundings should be cleaned daily. Chamber walls, bulkheads and breathing masks should be cleaned twice each week. Bilges or floor areas beneath the deck plates should be drained and cleaned before the saturation phase starts, but they should not be actively cleaned or otherwise disturbed during the operation.

Shower areas should be drained after use, and the floor should be kept dry. Control of humidity, which should be at the dry end of the range of comfort, should safeguard against infection inside the living chambers. Procedures to ensure the purity of fresh water supplies should be carried out.

The DMAC 26 protocol does not advise routine swabs for microbe analysis from the ear canals of the divers. Only in cases where divers exhibit the clinical features of otitis externa does it recommend using ear swabs to evaluate the presence of pathogenic organisms. It is stated, but not prescribed, that routine swabs from chamber surfaces both pre-dive and during saturation are helpful in monitoring the efficacy of cleaning regimes [3,7].

Western Scheldt Health Surveillance Protocol

The construction of the Western Scheldt tunnel was an expensive operation, as are all tunnel construction projects. Work schedules were complicated, and serious delays were unacceptable. Maintenance operations were performed at great depths, under pressure in front of the tunnel boring machine, in water and in the seabed. It was estimated that the risk of an incapacitating otitis externa infection was a real threat to the project, based on negative experiences in the North Sea [5] and in other projects.

The Western Scheldt Health Surveillance Protocol added some components to the DMAC 26 protocol, including ear inspections and environmental swabs every third day, and the application of prophylactic ear drops containing acetic acid and aluminum acetate only once a day, in order to realize a comprehensive program for health and safety standards for saturation work according to best practice at that time.

The initial medical examination divers underwent was designed to prove whether the divers were fit for saturation work at the time. During the execution of their work, the divers and their environment must be closely observed to determine microbiological threats. If pathogenic organisms are detected, immediate action with topical antibiotics must be initiated. After the saturation work was finished, all divers would be medically examined to assess any adverse health affects from their time in saturation.

The purpose of this field study is to report and evaluate the implementation of the Western Scheldt Health Surveillance Protocol for saturation divers, including preventive and therapeutic interventions. The implementation is evaluated by analyzing the realization of the activities that were prescribed. To evaluate effectiveness we identified the microbiological load in the saturation habitat, the presence of microorganisms in divers in the saturation habitat and the incidence of infectious diseases.

METHODS

The Western Scheldt Health Surveillance Protocol monitored divers' health before, during and after exposure. This protocol attempted to control the risk of microbiological threat before signs and symptoms appeared. We decided to prescribe prophylactic ear drops containing acetic acid and aluminum acetate, to be applied once a day. Every diver had two bottles, one for each ear. In addition to this preventive measure, the occupational health service team decided to arrange for "early warning" microbiological ear swabs to evaluate the presence of pathogenic organisms. Every third saturation day a swab would be taken from the external ear canal and sent to the microbiological laboratory for analysis. In case we detected a positive sample, the diver's ear should be treated with topical antibiotics (otosporin drops, containing polymyxin B sulphate, neomycin sulphate and hydrocortisone).

We used topical antibiotic therapy instead of oral therapy for a variety of reasons, including the reduced risk of systemic side effects, the avoidance of resistance selection in the gut microflora, the higher achievable concentration of antibiotic at the site of action and the aim to use fewer drugs. Topical antibiotics are regarded as the drugs of choice for the elimination of microorganisms in cases of external ear infections [9].

To monitor transmission from the work environment to the divers' living chambers and to monitor the microbiological threat in general, it was decided that every third day the chamber surfaced, wash basins, shower heads, toilet rings and the bilge compartment would be investigated with microbiological swabs and analyzed. Special cleaning measures were prescribed after positive findings. In cases when there was a positive survey, the cleaning procedure would be scheduled for the next day. The protocol prescribed taking measures at the point of entry, during saturation and a final exit assessment, as well as scheduled environmental cleaning and inspection procedures.

PROTOCOL PRESCRIPTIONS

Entry assessments

To minimize the spread of communicable diseases, we examined all divers 24 hours prior to the start of the saturation compression. We examined the skin, the external ear channels and the nose. In addition to the standard physical examination for divers, all divers

FIGURE 1

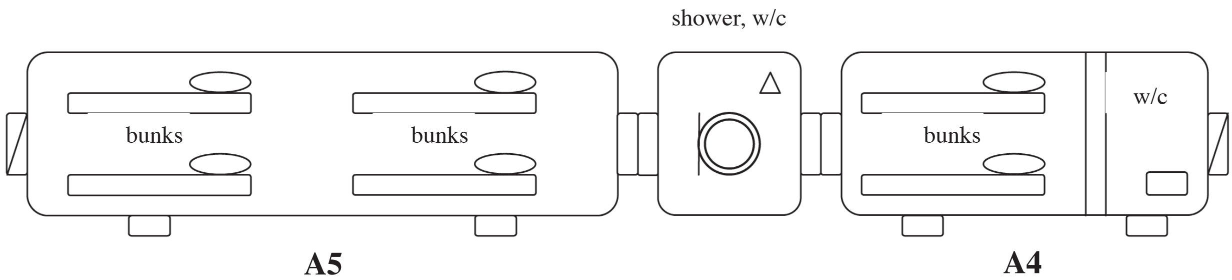

FIGURE 1 – Scheme of the saturation habitat used in the Western Scheldt Health Surveillance Project, showing the large unit A5 (6 beds) and the small unit A4 (4 beds) and the intermediate section, including the main entrance.

must meet the medical saturation standard [10,11] and should be free of visible current acne and of bacterial and fungal conditions. Any skin infection is thought to be more likely aggravated in the warm, humid, oxygen-rich environment of the saturation complex [7]. If an infectious process is suspected, it should be carefully evaluated. Blood should be taken from all divers to measure hemoglobin, hematocrit, erythrocytes and leukocytes.

Diver protocol during saturation

During saturation, the risk of communicable disease increases with the passing of time and because the men are closely packed. As personal hygiene and cleanliness are the single most important factors in the prevention of infections, we emphasized the importance of proper skin care to divers during their training [6]. All divers should shower after each excursion. Fresh linens and clothing were locked into the habitat every day. Our preventive regime included irrigating each ear once a day with 2 percent acetic acid in aluminium acetate solution, providing two bottles for each diver, one for each ear. Each morning the ears should be irrigated with a few drops, and the application should be timed by the clock and logged. In addition, ears should be swabbed every three days with plain swabs moistened with sterile distilled water. When pathogenic cultures are isolated, the diver should be treated with topical antibiotic eardrops (otosporin) every eight hours for seven days. The antibiotics in this medication are commonly prescribed for the treatment of bacterial infection and inflammation of the external ear channel, including *Pseudomonas* infections. When we found microorganisms in the divers' ears, they were treated immediately, before onset of the signs and symptoms of an infection.

Habitat cleanliness

The saturation habitat consisted of two quarters, A4 and A5. Each quarter had its own entrance lock and main chamber. The quarters were linked by a combined entrance air lock. The intersection entrance lock contained a hyperbaric toilet, a wash basin, a shower, a medical lock and air conditioning. The A4 and A5 main chambers had six and four places to sleep, respectively, a medical lock, air conditioning and ventilation. Both compartments housed three divers, for reasons of comfort and safety *(Figure 1, above)*.

Prior to a dive, all parts of the chamber should be cleaned with water and Tego 2000®, a biocide used to disinfect hyperbaric chambers. All bedding and mattresses had to be cleaned. No one was allowed to enter the saturation chamber in work boots, shoes or dirty greasy work clothing.

During saturation, the toilet, sink and shower areas, table surfaces, service locks and their immediate areas were to be cleaned daily with water and cleanser. Shower areas had to be drained after use and the floor kept dry; humidity levels were to be kept at the dry end of the range of comfort.

Our protocol dictated that the microbiological swabs be performed every third day in the habitat to assess whether the microbiological load was within acceptable limits. If we found microorganisms in critical areas in the habitat we recommended that the cleaning protocol be initiated at once.

Microbiological techniques

Ear swabs taken every three days were brought to a certified microbiological laboratory (Streeklaboratorium Zeeland) in a cooled container within four hours. The isolations were classified on the basis of colonial appearance and growth characteristics. The culture was isolated on agar gel for 48 hours of incubation in air at 37 degrees C. The results of the measurements are indicated as follows:

- s = sporadic
- + = a few
- ++ = moderate quantity
- +++ = many bacteria/microorganisms
- ++++ full of bacteria/microorganisms [2].

Microbiological swabs taken from critical sites such as the toilet, washbasin, shower and the floor under the bunks were plated out on an agar plate.

Exit assessment

After a final decompression over two and a half days the divers were once again able to be in the open air. The protocol directed that all divers be gathered and given a final medical examination. The content of this health check was identical to the entry assessment. All divers had to attend a four-hour bend watch. Divers were cleared to leave the habitat site if they were fit and had no complaints. In other cases, they were treated and stayed under the supervision of the diving doctor.

During the tunnel project, seven saturation phases were performed. The microbiological samples were collected over a time period of 1.5 years and analyzed in the same certified microbiological laboratory. The outcome of all the measurements was carefully documented in the medical database. We registered all the medical data gathered in the entry and exit assessments and monitored all preventive actions. All data (special complaints of the divers, the swabs taken from the divers' ears, swabs taken in the environment of the habitat, all acidic ear drops and antibiotics given to the divers) were recorded in sequence according to the time and place of events and gathered in a logbook. The microbiological laboratory recorded the specific type and quantity of the microorganisms. Due to operational circumstances we did not succeed in following the prescribed steps in the protocol each and every time. The Western Scheldt Health Surveillance Protocol was approved by the superintendent and introduced to the habitat crew before the saturation work was begun.

RESULTS

Evaluation of the Western Scheldt Health Surveillance Protocol implementation

Two diving companies participated in this saturation project. As there were not enough saturation divers within both companies, saturation divers from all over the world were contracted to join the project. At the start of every new saturation phase, the crew was different. The population characteristics of all 17 saturation divers involved are described in Table 1 *(below)*.

TABLE 1: ***Physical characteristics of 17 saturation divers exposed during the saturation project***

	mean	min	max
age (years)	33	23	44
height (cm)	181	172	186
weight (kg)	83	63	102
BMI (kg/m^2) *(body mass index)*	25.1	19.7	29.8

Most of the divers participated in two or more saturation phases during this project *(Figure 2, below)*.

We carried out the pre-dive medical examinations and all of the adapted medical examinations just before the saturation phase. No one was turned down. The living chambers were cleaned, and the

FIGURE 2

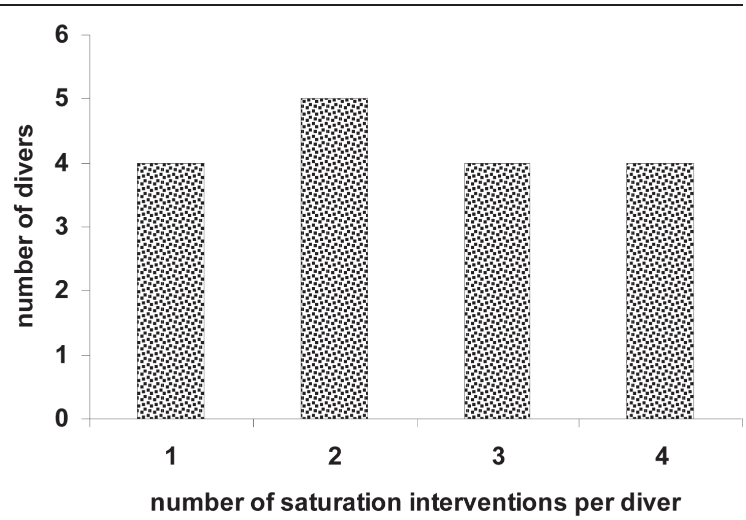

FIGURE 2 – Number of divers (*n*=17) who joined one or more saturation phases. The majority of the divers stayed for two or more saturation phases.

once-daily application of acidic eardrops was completed, in accordance with the protocol. Any health complaints were logged in the journal, along with the timing of treatments. Although ear swabs were to be performed every third day, on several occasions operational circumstances did not permit a swab to be performed at the prescribed time. Positive ear swabs were always treated with local antibiotics. We did not observe any serious infection that necessitated the diver to abort his stay in the living chamber.

The protocol prescribes microbiological swabs of the critical areas of the habitat every third day. Due to factors such as lack of time, fatigue and operational demands, it was not always possible to carry out. Working schedules were one problematic factor: The medical crew had regular daytime services on site in contrast to the diving crew, who had totally irregular working times that were based on the saturation working schedule.

Pre-dive medical exam

All saturation divers passed their annual medical check and were declared fit for diving. In addition, the divers were allowed to enter the saturation chamber only if they could meet the medical saturation standard [10,11]. One day before entering the saturation habitat we performed the pre-dive check, a medical examination of all divers. We examined a total of 17 divers and carried out 44 medical examinations. Special attention was given to eardrums, clearing of the ears, and the functioning of the nose and the skin.

Accident

During the third saturation phase there was an accident in the habitat. While a diver was unscrewing the medical lock, a can with hot water fell onto his upper right leg, resulting in a Grade II skin burn the size of a grapefruit. The affected skin was painful. An initial treatment with silver sulfadiazine cream, which is active against a broad spectrum of gram-positive and gram-negative microorganisms, was given. The wound was covered with a sterile Metalline® bandage, and the diver was given analgesic drugs for the night.

Shortly after the incident it was decided that the diver with the skin burn would be decompressed in the separate decompression lock, as the risk of wound contamination with *Pseudomonas* or enterobacteria was considered too great [7,8]. He was accompanied by another diver. Two new saturation divers were selected to enter the habitat.

Microbiological findings during saturation

Two examples of our microbiological findings will be presented as an illustration of our overall findings. The data presented in Table 2 *(facing page)* stem from the fourth saturation phase.

During the pre-dive examination all divers were found to be free of complaints, had normal eardrum aspects and could equalize their ears. On the fifth day in saturation, Diver H was found to have an ear flora containing *Pseudomonas aeruginosa* and *Klebsiella* bacteria, but had no discomfort. We treated the flora with antibiotics. Due to operational circumstances in this saturation phase it was not possible to perform additional ear swabs. At the end of this saturation phase, two divers had ear complaints despite all the measures that were taken. Treatment was continued after the diving phase.

In this saturation phase we found substantial bacterial contamination in the lavatory area of the chambers. The first swabs were taken on the eighth and the fifteenth days, when we detected enterobacteria, *Pseudomonas aeruginosa* and *Staphylococcus aureus (Table 2)*.

The samples at Day 8 showed that the shower valve in the A5 decompression chamber was contaminated with *Pseudomonas* and that seven days later the contamination had increased. We also found *Pseudomonas* on the A5 toilet ring, but by the next examination it had disappeared. After 15 days the A5 showerhead was contaminated with enterobacteria, as was the bilge water *(Table 2)*.

In the A4 decompression chamber eight days after the start of the phase, the shower valve and showerhead had no detectable bacterial load. We detected enterobacteria on the A4 toilet ring. By the 15th day this flora had disappeared, but despite the cleaning procedures, we found *Staphyloccus aureus*. After 15 days in saturation, both the shower valve and the showerhead, as well as the bilge water, were contaminated by enterobacteria *(Table 2)*.

Table 3 *(Page 440)* presents the results during the seventh saturation phase. Before the start of this phase all divers had normal eardrum exams and appropriate eardrum function.

On the fifth, the tenth, and the thirteenth days, we carried out the ear swabbings. On the tenth day we detected *Pseudomonas* in Diver H's left ear. He was treated with antibiotics, but with no clear effect.

TABLE 2 – Microorganisms found in microbiological cultures while monitoring six divers (H, F, L, A, O, P) and the work habitat during the fourth saturation phase, a period of 15 days. Pre-dive inspection was one day before diving; post-dive inspection was immediately after the diving period. Results of the determination of microorganisms are presented on the day of sampling. Before taking ear swabs, any ear-related health complaints were clarified. Treatment was continued as needed after diving.

Saturation/days			4	4	6		8	15	16	
Diver	**Ear**	**Pre-dive**	**Compl.**						**Post-dive**	
H	R	normal	no	***P++***	treat				normal	
	L	normal	no	***K++***	treat				normal	
F	R	normal	itch	N					normal	
	L	normal	itch	N					normal	
L	R	normal	no	N					normal	
	L	normal	no	N					infection	treat
A	R	normal	no	N					normal	
	L	normal	no	N					normal	
O	R	normal	no	N					normal	
	L	normal	no	N					normal	
P	R	normal	no	N					normal	
	L	normal	no	N					infection	treat
						SV. A5	***P+***	***P+++***		
						SH. A5	N	***Ent+++***		
						TS. A5	***P++***	N		
						bilge A5 water	N	***Ent+++***		
						SV. A4	N	***Ent+++***		
						SH. A4	N	***Ent+***		
						TS. A4	***Ent+++***	***S+***		
						bilge A4 water	N	***Ent+++***		

LEGEND TABLE 2

N: no pathogenic microorganisms
P: *Pseudomonas aeruginosa*
K: *Klebsiella*
Ent: enterobacteria
S: *Staphyloccus aureus*

compl. = complaints
itch: itching of the external ear channel
treat: beginning of 7 days of treatment with antibiotic drops

WB = washbasin
TH = toilet handle
TS = toilet seat
SV = shower valve
SH = showerhead
SF = surface floor
A5: large saturation tank
A4: small saturation tank

s=sporadic
+ = few microorganisms (<50 colonies)
++ = moderate microorganisms (50 < X < 100 colonies)
+++ = many microorganisms (>100 colonies).

diver	ear	pre-dive			compl.				compl.					compl.					post-dive
sat days			2				4				10				13				20
H	R	normal			no	N			no	**N**				no	**N**				normal
	L	normal			no	N			no	***P++***	treat			no	***P++***	treat			norml
R	R	normal			no	**N**			no	**N**				no	**N**				normal
	L	normal			no	**N**			no	**N**				no	**N**				normal
Q	R	normal			no	**N**			no	**N**				no	**N**				inf/treat
	L	normal			no	**N**			no	**N**				No	**N**				normal
J	R	normal			no	**N**			no	**N**				no	**N**				normal
	L	normal			no	**N**			no	**N**				no	**N**				normal
C	R	normal			no	**N**			no	**N**				no	**N**				normal
	L	normal			no	**N**			no	**N**				no	**N**				normal
B	R	normal			no	**N**			no	**N**				pain	***Ent++***	treat			inf/treat
	L	normal			no	**N**			no	**N**				pain	**N**				normal
			SV.A4	**N**			**SV.A5**	**N**				**WB.A5**	**N**				**SH.A4**	**N**	
			SH.A4	**N**			**SH.A5**	**N**				**SH.A5**	**N**				**TS.A4**	**N**	
			TS.A4	***P++***								**TS.A5**	**N**				**SH.A5**	***Ent++***	
			SV.A5	**N**								**SF.A5**	***Ent++***				**SV.A5**	***P++***	
			SH.A5	**N**								**WB.A4**	**N**						
			TS.A5	**N**								**SH.A4**	**N**						
												TS.A4	**N**						
												SF.A4	**N**						

On the thirteenth day we found the same bacteria and continued the antibiotic therapy. On the thirteenth day Diver B developed ear pain in both ears. We analyzed the bacteria in the external ear channel. It happened to be an enterobacteria species not commonly found in the external ear channels. After antibiotic therapy there were no signs of an inflammation. Unfortunately, post-dive we found a still-irritated red external ear channel. Examination of the chamber showed *Pseudomonas* contamination on the A4 toilet ring on the second saturation day. On the tenthth day we found many enterobacteria on the floor of A5. Surprisingly, three days later, on the thirteenth saturation day, we found enterobacteria on the A5 shower head and *Pseudomonas* on the A5 shower valve.

In Table 4 *(Page 442)* we present the data from all seven saturation phases. In every saturation phase we found pathogenic bacteria or fungi in men and in the environment, but in some periods more than in others *(Table 4)*. In Phase 1 on the fifth day we found *Pseudomonas* in the ear of a diver. On the eighth day we detected a fungus in two divers, determined to be *Candida albicans*. In Phase 2 we detected just one diver with *Candida* in his ear, without any complaints. In Phase 3 we diagnosed three samples that were positive for *Pseudomonas* on Day 5. The divers' ears were treated with antibiotics and the infections did not spread.

On the seventh day we found *Staphylococcus* in a diver's ear. Direct treatment had a good preventive effect. In Phase 4 we found *Pseudomonas* in one ear and *Klebsiella* in the other ear of the same diver. The standard treatment proved to be adequate. In Phase 5 on the third day in saturation we detected *Staphylococcus aureus* in one diver's ear. On the eighth day, four divers were affected, three with *Staphylococcus* and one with *Pseudomonas.* Later in Phase 5 we had only negative samples.

In Phase 6 on the fifth day we detected *Pseudomonas* in three divers who had no clinical signs. Standard treatment was prescribed, and subsequently no positive samples were found. In the final saturation phase, Phase 7, *Pseudomonas* was detected in one diver on the tenth saturation day. On the thrteenth day *Pseudomonas* and *Enterococcus* species were found in the ears of two other divers. Thereafter no positive samples were detected.

In the environmental survey we found no positive samples in the first two phases. In Phase 3 we found a moderate quantity of *Pseudomonas* contamination on the A4 toilet ring at the start of the phase. Five days later, on the same toilet seat, we found only a few *Pseudomonas* species. In the days following we did not find any continued contamination with *Pseudomonas.*

On the tenth day we found a few *Staphylococcus aureus* on the shower floor and on the toilet seat. In Phase 4 it is clear that the contamination of the saturation environment began on Day 8 of the saturation period. We found enterobacteria on the A4 toilet seat, *Pseudomonas* on the A4 shower valve and *Pseudomonas* on the toilet seat in the A5 chamber. On the fifteenth day in saturation we had positive samples of *Staphylococcus* on the A4 toilet seat, and enterobacteria on the A4 shower valve and showerhead. In chamber A5 we had positive samples of enterobacteria on the showerhead and *Pseudomonas* on the shower valve. Bilge water in both chambers was contaminated with enterobacteria.

TABLE 3 *(facing page)* – Microorganisms found in microbiological cultures while monitoring divers (H, R, Q, J, C, B) and the work habitat during the seventh saturation phase, duration 20 days. Pre-dive inspection one day before diving; post-dive inspection immediately after the diving period. Results of bacterial cultures are presented on day of sampling. Before taking ear swabs ear-related health complaints were investigated. Treatment is continued as needed after diving.

LEGEND TABLE 3

N: no pathogenic microorganisms
P: *Pseudomonas aeruginosa*
K: *Klebsiella*
Ent: enterobacteria
S: *Staphyloccus aureus*

compl.: complaints
itch: itching of the external ear channel
treat: beginning of 7 days of treatment with antibiotic drops

WB = washbasin
TH = toilet handle
TS = toilet seat
SV = shower valve
SH = showerhead
SF = surface floor
A5: large saturation tank
A4: small saturation tank

s = sporadic
+ = few microorganisms (<50 colonies)
++ = moderate microorganisms (50 < X < 100 colonies)
+++ = many microorganisms (>100 colonies).

	phase 1	phase 2	phase 3	phase 4	phase 5	phase 6	phase 7
days							
1		A4, A5 clear	TS.A4:P++, A5: clear		TS.A4:P+++, Ent +++		
2						A5: clear A4:clear	TS.A4:P++, A5: clear
3		E:Can++		E:P++, E:K++ (one diver)	E:S+		
4							E: all clear
5	E:P++		E:P+++, E:P+++, E:P++			E:P++, E:P+++, E:P+	
6							A5: clear, A4: clear
7		E:all clear					
8	E:Can++		TS.A4:P+, WB:A4:P+	SV.A5:P+, TS.A4:Et+++, TS.A5:P++	E:P+, E:S++, E:S++, E:S+		
	E:Can++		E: S++, A5: clear				
9							SF:A5:Ent+++, A4: clear
10			E: S++				E:P++
11	end decomp	end decomp	SF.A4: S+				
12			TS.A4: S+ A.5: clear				
13							A.4: clear, SV.A5: P++ SH.A5: Ent++
14					end decomp		E: Ent++, E: P++
15				TS:A4:S+, SV.A4:Ent+++			
				SV.A5:P+++, SH.A5: Ent+++, SH.A4:Ent+			
				Bilge water A4:Ent+++			
				Bilge water A5:Ent+++			
				end decomp			
16							
17			end decomp				
18						end decomp	
19							
20							
21							end decomp

In Phase 5 we found various bacteria on the toilet seat in the A4 chamber. In the succeeding days we did not detect any positive bacterial samples in the chamber environment. In Phase 6 we had no positive bacterial samples from the environment. In saturation Phase 7, we found a moderate quantity of *Pseudomonas* on the A4 toilet seat. On the fifth day, all sites in A4 and A5 were clear. On the tenth day, we found various enterobacteria on the shower floor of A5. On the thirteenth day, we found *Pseudomonas* on the A5 shower valve. Positive samples of enterobacteria were found on the A5 showerhead.

DISCUSSION

We consider the implementation of the protocol to be a partial success. All pre- and post-dive examinations were executed according to medical standards; acidic ear drops were given in accordance with the protocol; when positive swabs were taken, antibiotics were administered; and the protocol was followed in emergency cases.

Other aspects of the implementation were less successful. Ear swabs could not be taken every third day, and the environmental swabs were missed on about half of the occasions. The bacterial load found in divers and in the environment was clearly visible; sometimes serious infections were seen. Fortunately, the infections had no serious consequences for the health of the workers or for the continuation of the work process.

No rapid spread of infection from one diver to his colleagues and through the habitat was detected [5]. Even in the 21-day saturation phase, there was no increase in the incidence of ear infections, as one might have expected. However, in our surveillance program it became clear that pathogenic bacteria are present even when a protocol that is more comprehensive than the DMAC 26 protocol has been implemented. The microbiological load detected in the ear swabs of the divers and the environmental swabs in Phases 3, 4 and 7 are examples of a serious threat that existed despite all the preventive measures that were taken.

A strength of this case report is that we are able to show the outcomes of our health and safety protocol over an elapsed time of about one and one-half years.

Pre-dive screening of divers is assumed to decrease the risk of contamination. We checked the divers as well as the environment of the habitat and determined the places where there was a high microbiological load. This load varied from low to rather significant numbers of organisms in certain phases and in particular places. The toilet seat had nine positive hits out of 16 swabs, while the washbasin had two positive hits out of 16 swabs. In the lavatory area we detected enterobacteria, *Pseudomonas aeruginosa* and *Staphylococcus aureus*. *Staphylococcus* was detected in the divers' ears in Phases 3 and 5.

Another positive aspect of our study is that we had relatively large numbers of microbiological data. All microbiological swabs were analyzed in a certified microbiological laboratory. The outcome of the determination was the basis for further preventive actions.

Some aspects of the protocol could not be implemented. Not all of the planned investigations could be carried out, due to operational circumstances.

TABLE 4 *(facing page)* – Microorganisms found in the saturation divers' ears and in their work habitat. On the *x* axis, the different saturation phases are presented. Saturation days from 1 to 21 are presented on the *y* axis. Positive results from ear investigations are shown in unshaded blocks. Positive findings from the habitat are shaded grey. The results of microbiological cultures from the day of sampling are shown.

LEGEND TABLE 4

N: no pathogenic microorganisms
E: ear swab.
P: *Pseudomonas aeruginosa*
Ent: *Enterobacteria*
Can: *Candida*
K: *Klebsiella*
S: *Staphyloccus aureus*

compl.: complaints
itch: itching of the external ear channel
treat: beginning of 7 days of treatment with antibiotic drops

WB = washbasin
TH = toilet handle
TS = toilet seat
SV = shower valve
SH = showerhead
SF = surface floor
A5: large saturation tank
A4: small saturation tank

s = sporadic
+ = few microorganisms (<50 colonies)
++ = moderate microorganisms (50 < X < 100 colonies)
+++ = many microorganisms (>100 colonies).

Adequate supervision of the protocol in a commercial environment is difficult. Medical standards for preventive health care seem to conflict at times with the commercial interests of the contractor. It is therefore important to convince the contractors that these types of healthcare measures are carried out to help ensure the continuity of the project.

We were not permitted to set up a control group for this project. The stated reason was that any disruption to the health and safety of the divers could have consequences for the continuity of project's tight time frame, resulting in serious financial consequences for the contractor. We tried to determine infection routes by evaluating our data. As we were not able to genotype the isolations during the saturation phases, we could not demonstrate the spread of infection from one individual to another or from environmental sources to individuals.

The work of other investigators has shown that microorganisms can be a real threat to the health and safety of saturation workers. During 1974-1975 two out of seven saturation dives in the North Sea on the UK shelf were terminated because of outbreaks of incapacitating otitis externa, and others were disrupted. *Pseudomonas aeruginosa* was isolated from the ears of the divers with ear infections. In the terminated dives, two entire teams, each consisting of six divers, became infected a few days after entering saturation [5].

Ahlen *et al.* reported the occurrence of *Pseudomonas aeruginosa* in skin infections in operational saturation diving in the Norwegian part of the North Sea from 1987 to 1995 [12]. Skin infection, and more specifically, external otitis caused by *Pseudomonas aeruginosa*, is mentioned as the most frequent health problem associated with occupational saturation diving [4,5,8,13]. The current literature has shown that data obtained by genotyping *Pseudomonas* can support the search for the sources of infections [13]. There was an indication that a single infected diver could have been the source of organisms that rapidly spread to his colleagues and throughout the living chambers [13,14]. Other studies show that the living chambers may constitute a reservoir of infection during and between dives [5,15]. Ahlen *et al.* proved that skin infections in occupational saturation divers are commonly caused by environmental strains [15]. The skin infections in saturation diving are most obviously caused by microbes that flourish in the saturation environment. Therefore, the authors stressed the importance that improvements in the prevention of infections in saturation circumstances must be based on environmental control and elimination [12,15].

In our study in the third saturation phase, the bacterial load of *Pseudomonas aeruginosa* increased. Several measures were taken. Infected ears were treated with topical antibiotics. Sometimes ear complaints did not resolve despite all measures that were taken. Otosporin could be ineffective due to drug resistance. An effective alternative treatment is ofloxacin otic .3% solution. It has the added advantage of not inducing neomycin sensitivity, a condition that could mimic infection and could also have caused an apparent treatment failure.

Critical sites in the environment, such as toilets and showers, were cleaned by the saturation crew. Monitoring during the phase showed that the bacterial load lessened. This example is an indication that early warning by means of positive microbiological swabs can be of importance in maintaining health and safety.

Our experience with the Western Scheldt Health Surveillance Protocol can be summarized by the following recommendations.

It is our opinion that risk inventory and evaluation alone are likely inadequate for surveillance purposes. In this investigation we show that a regular check of the environment and the divers' ears with microbiological swabs, in combination with cleaning and adequate antibiotic therapy, can be beneficial for the protection of health and safety. Sampling of microbiological data is feasible, although implementation could be improved substantially. This health surveillance program demonstrates the potential value of an early warning system to prevent the potential outbreak of severe infections in ears or skin lesions caused by an increased bacterial load. In our opinion the Western Scheldt Health Surveillance Protocol contributes to the improved control of the health and safety of the crew in saturation circumstances and to the continuity of future saturation projects.

Prevention could be improved by better implementation of the protocol. We think it is necessary to instruct the supervisor and the saturation crew about the protocol and to convince them of the importance of the measures to be taken. In the training sessions for saturation divers it is very important to show them the threat that microorganisms in their daily work environment pose to their health and safety. It is important to better understand the measures taken in the protocol, rather than simply performing instructed tasks.

Dive doctors, in our opinion, have the responsibility of communicating the importance of education about microbiological threats in work under pressure to the government, contractors and HSE officials.

It is important that the measurements are taken on time and that the supervisor's orders are respected without further delay. A saturation schedule means a 24-hour, seven-day-a-week hands-on job. Each investigation should be carried out at the agreed time, regardless of the time of day, in accordance with the protocol. The swabs should be cooled on ice and transported to the microbiological laboratory as soon as possible [16]. The results should be sent to the dive doctors in charge. All results should be registered in an appropriate database for further analyses.

For safe and adequate saturation operations in the future, we recommend that more research on microbiological aspects be carried out.

1. We propose evaluation studies in future projects to identify sources and analyze the relations between the contamination of saturation divers related to specific microorganisms and the environmental isolates and potential sources using isolates of the microbes. The content of the protocol could be extended with the inclusion of specific infections in the environment and measurements to identify potential sources in divers.

2. In the future, we should evaluate the effectiveness of the Western Scheldt Health Surveillance Protocol on microorganisms in saturation in greater detail, as Ahlen *et al.* did in their work to identify infectious *Pseudomonas aeruginosa* strains in an occupational saturation diving environment [15].

3. We propose the registration of environmental factors in the habitat. Environmental factors such as humidity, temperature, and the levels of toxic gases like CO_2 in the atmosphere of the habitat are important factors for the resistance of a host to invasion by pathogens.

4. We believe it is necessary to record the results of the microbiological survey in saturation projects as a permanent part of the health surveillance program. This would contribute to increased knowledge and the improved safety and health of saturation divers, as well as to the continuation of saturation projects. ■

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