The Editor's Offering

Everyone who uses scuba, or any other method of supplying breathing gases underwater, should read Chris Acott's paper on equipment malfunction which opens the batting for the Original Papers. Using a strict definition of equipment failure, which excludes the effects of human failure to assemble the equipment properly, 10% of the diving incidents reported to the Diving Incidents Monitoring Study were equipment failure. Of these 105 divers, 27 came to harm. Contents gauge failure topped the list with 33 incidents, and nine of these caused morbidity. A diving incident is an error by a diver, or a failure of a diver's equipment to function properly, before, during or after a dive. Ninety percent of diving incidents are due to human error and the vast majority lead to no harm because the diver acts correctly and avoids harm. The safest response to equipment failure is to abort the dive in a controlled fashion. Buoyancy compensators failing to inflate when they should (14) and inflating when they should not (10) formed the second largest group of equipment failure problems. Spontaneous, unexpected inflation of a buoyancy compensator is an emergency which usually require disconnection of the power inflator hose to control it. Most compensators fill faster than they can be emptied and can rapidly become express lifts to the surface. Knowing how to "flare out", spread ones legs and fins and lean back, to slow the ascent will reduce the risk and knowing how to disconnect the inflator hose without looking will allow the diver to regain neutral buoyancy. Unfortunately not all inflator hoses are easy to disconnect (the Editor's needs both hands to pull apart). Response to the failure of compensator inflation requires emergency acquisition of buoyancy, or put more simply, dropping the weight belt.

Bob Wong revisits Taravana, that mysterious disease that afflicted Tuamotan breath-hold pearl divers in the 1950s. He has found it, disguised as decompression illness, in two spearfishermen whose breath-hold diving pattern was very similar to those pearl divers and whose underwater times approached those of submarine escape training tank (SETT) instructors who developed decompression sickness, as it was then known, following their breath-hold diving work. What all three groups had in common was diving to depths of 30 m, or so, frequently and repetitively. So the spearo who who is not quite himself after a weekend's fishing, may be much improved by a session of hyperbaric oxygen treatment (HBOT).

Dr Ian Millar's history of Victoria's hyperbaric facilities is concluded in this issue. We have been able to obtain photographs of what is quite definitely a 5 star facility with room to swing many cats. The photograph of three of the staff playing Twister in the main chamber has been suppressed. Hyperbaric staff are kept far too busy to indulge in such childish pursuits.

As no member has written to the Secretary objecting to the motions to alter the SPUMS constitution, passed at the Layang Layang Annual General Meeting, it is assumed that the membership has voted in favour of these changes and they now come into effect. As there have been a large number of changes since the last printing of the constitution, the Society will print and distribute the current constitution with the December Journal.

We print the final papers from the 1998 Annual Scientific Meeting. These include two papers by John Bevan on *Early diving accidents and fatalities* and *Sub-atmospheric diving systems*. His research has turned up some very interesting pictures. The Editor's favourite is that of Issa, an Arab diver, swimming past a Crusader castle wearing his snorkel fitted helmet, carefully avoiding a pair of huge Moray eels which have been tidying up the corpses dumped overboard by two Crusaders. In spite of his metal helmet Issa became the first known underwater war casualty when a Crusader archer shot him.

Chris Acott has contributed a paper on oxygen toxicity and the use of oxygen in diving as well as brief biographies of some of the great men of diving, JS Haldane, JBS Haldane, L Hill and A Siebe.

David Doolette and Phillip Prust discuss Cave diving in Australia on pages 158-161. Over the years the Cave Diving Association of Australia (CDAA) has introduced training schemes and a classification of caves, caverns and sinkholes which matches the dives difficulty with the minimum training needed by divers to explore them. Now cave divers must have two completely separate air supplies and all other equipment so that, as far as is possible, equipment failure or running out of air can be wholly avoided. A far cry from the early days (1960s) when buoyancy compensation was by holding an empty plastic bottle over the demand valve outlet to trap air.

A new name appears among the notices of courses in diving medicine. The Department of Diving and Hyperbaric Medicine at the Prince of Wales Hospital in Sydney will be holding a two week course for those who intend to work in the hospital field of Diving and Hyperbaric Medicine. Unlike most of the courses in diving medicine this course is not to insure that those who attend learn how to carry out competent diving medicals. This course is a multi-centre, co-operative operation to widen the options available to those interested in a career in diving and hyperbaric medicine. It is yet another indication that diving and hyperbaric medicine is busy building on the foundations of the last 25 years to fashion the fabric for a dynamic and far reaching medical speciality with its own well thought out and effective training programs for the future.

ORIGINAL PAPERS

EQUIPMENT MALFUNCTION IN 1,000 DIVING INCIDENTS

Chris Acott

Abstract

Among the first 1,000 incidents reported to the Diving Incident Monitoring Study, 105 (10%) were consistent with defined criteria for “pure” equipment failure. Of these incidents 57 (54%) involved a regulator or air supply, 24 (23%) involved a buoyancy jacket power inflator, 14 (13%) involved a depth or timing device and 11 (10%) involved some other diving equipment. Over a quarter of these incidents resulted in harm to the diver. A meticulous pre-dive check, the use of back-up equipment, additions and alterations to equipment design and adherence to strict standard diving safety practice will minimise the effects of all these equipment failures.

Key Words

Equipment, incidents, injury.

Incident reporting

Safety in diving is dependent upon an adequate understanding of the associated risks. Accident and fatality data are used as an index of safety and risk but are retrospective. Accidents are unpredictable,[1] therefore the development of strategies to prevent future accidents from retrospective analyses of accidents is imprecise and difficult.[2] Other limitations associated with accident/fatality data are: often events are reconstructed from a jigsaw of information that lacks substantiation of events by the victim; valuable information may be forgotten during the turmoil of the rescue and resuscitation so that the recorded events may be an oversimplication of what happened;[1] events are often changed to suit the perception of what happened and are seen in the light of “doing the right thing”,[1,3] and reports may be either subject to investigator bias and report “what must have happened” and not what did happen, or only legal issues may be addressed.[4]

It is easier to predict and prevent errors, rather than accidents, because errors are methodical, take on predictable forms and can be classified.[1,5] Because an accident is often the product of unlikely coincidences or errors occurring at an inopportune time when there is no “system flexibility”,[1] it is reasonable to assume that error prevention will also prevent accidents. It must be noted that most errors occur repeatedly, cause no harm and are recognised and corrected before they progress to an accident.[1]

Incident reporting is a method of identifying, classifying and analysing human error in the context of contributing and associated factors.[6-8] This method is now established in aviation,[9,10] the nuclear power industry and medicine, particularly in anaesthesia.[11,12] It is not a new concept, having been first used in the 1940s to improve military air safety, although the idea had its foundations much earlier, in 19th century Britain.[13] Practitioners of incident monitoring do not attempt to measure the absolute occurrence of any error, to solicit any specific type of error or to match one type of error to morbidity/mortality. Incident monitoring focuses on the process of error, regardless of outcome, and has no interest in culpability or criticism. Monitoring of incidents cannot identify the absolute incidence of error, but will show the relative incidence of errors or identify “clusters” of errors.[1-3,8,11,12] The safety implications of the application of incident monitoring to recreational diving are obviously the identification of the most common and dangerous errors and their contributing factors. This knowledge will help in the development of corrective strategies. Because of its unconstrained nature the application of such a technique will also result in a description of recreational diving practice and demography.

Diving is an equipment orientated sport and control of problems associated with the use of that equipment is an important part of diving safety. While it is inevitable that some equipment will malfunction, it is important to distinguish between true equipment failure or malfunction and problems related to design, misuse or inadequate maintenance so that flaws in equipment can be corrected. True equipment failure is difficult to define because almost every aspect of design, development, manufacture and maintenance involves human interaction. For the purposes of this study, a modified definition to that proposed by Webb[7] will be used:

“Equipment failure occurs when a piece of equipment fails to perform in the manner specified by the manufacturer, providing that it had been maintained and checked prior to use in accordance with the manufacturer’s recommendations”.

Previous reports of diving equipment malfunction or failure have shown these problems to be at best inconvenient and at worst harmful.[14-16] However, in these reports it is unclear whether there was a “true” equipment malfunction or if the problem arose as a result of equipment misuse or misassembly. Also, the way in which the equipment problem caused or contributed to any consequent accident was not identified. It was consequently decided to identify all the incidents involving “true” equipment failure (as defined by the above criteria) among the first 1,000 incidents reported to the Diving Incident Monitoring

Study (DIMS) and to propose strategies that could either prevent these faults from recurring or minimise their effects.

Method

Using the aviation[9] and anaesthesia[6] models, a diving incident report form was developed in 1988[8] and has since been modified. These forms have been distributed throughout the Australian and New Zealand diving community.

A diving incident is defined as any error or unplanned event that could have or did reduce the safety margin for a diver on a particular dive. An error can be related to anybody associated with the dive and can occur at any stage during the dive. An incident can also include equipment failure.

Divers are encouraged to fill out a DIMS form as soon as they have witnessed or have been involved in an incident. Anonymity is assured by the design of the questionnaire. This allows for accurate reporting without personal identification and legal exposure. Once reported, the data are collected and analysed and any identifying feature, if present, is removed.

The first 1,000 diving incidents reported to DIMS were examined for evidence of equipment malfunction or failure.

Results

There were 105 episodes of equipment failure amongst the first 1,000 incidents reported to DIMS and these are listed in frequency of occurrence in Table 1. Twenty seven of these were associated with morbidity and are listed in Table 2.

Fifty four percent of the reported incidents involved the diver's regulator and air supply, 23% the diver's buoyancy jacket, 13% dive computers and depth gauges and 10% miscellaneous diving equipment.

Discussion

This report of 10% of all diving incidents being due to true equipment failure is similar to previously published reports of accidents and incidents involving interaction between humans and machines in aviation, medicine and in industry. These studies show that between 8 and 10% of incidents arise from true equipment failure.[3,7,10] However, it must be noted that in the context of diving incidents, most equipment problems reported to DIMS were associated with equipment misuse, lack of understanding of how the equipment functioned, or to poor equipment design,

TABLE 1

105 EQUIPMENT FAILURES CLASSIFIED AND RANKED ACCORDING TO FREQUENCY

Type of Equipment	Incidents	Morbidity
Air supply	**58**	
Contents gauge	33	9
Regulator first stage	12	3
LP hose rupture	8	
Alternative air source	4	
Air cylinder	1	
Buoyancy jacket	**24**	
Inflator failure	14	2
Spontaneously inflated	10	5
Depth & timing devices	**14**	
Computer	11	6
Depth gauge	3	2
Miscellaneous	**9**	
Fins	5	
Surface signalling device	3	
Torch	1	
TOTAL	**105**	**27**

TABLE 2

MORBIDITY ASSOCIATED WITH EQUIPMENT FAILURE
(LISTED IN ORDER OF FREQUENCY)

Morbidity	Incidents	Cause
DCS	14	6 (C) 4 (CG) 2 (D) 2 (I)
Pulmonary Barotrauma	5	2 (F) 2 (CG) 1 (I)
CAGE	2	2 (CG)
Salt water aspiration	1	1 (CG)
PBT with CAGE	1	1 (I)
Near drowning	1	1 (F)
Ear barotrauma	1	1 (I)
Not specified	2	2 (I)
Total	**27**	**27**

Causes

(C) = Computer failure (6 cases).
(CG) = Contents gauge failure (9 cases).
(D) = Depth gauge failure (2 cases).
(I) = Inflator failure (spontaneous inflation 5 cases, failure 2 cases).
(F) = First stage failure (3 cases).

maintenance and servicing. These incidents will be the subject of a future report.

DIMS has identified failure of a contents gauge (that measures air cylinder pressure) as a major cause of morbidity in this study . It has been reported to be the major cause of “out of air” problems and morbidity in earlier studies.[17-19] Gauge inaccuracy was reported at every stage of a dive, although the majority were confined to the latter stages when cylinder air pressures were low. Currently, contents gauges are not required to be recalibrated or serviced following purchase.

Measures that could minimise the effect of these incidents include: a requirement for the recalibration of contents gauges with an annual regulator service; a thorough pre-dive contents gauge check, as described previously;[17] dive planning that includes depth, time and air consumption calculations; and an audible alarm (set at 50 bar) in the tank pillar valve and the contents gauge.

Regulator first stage failure and low pressure hose rupture did not necessarily occur when the air supply was at maximum pressure. In the reported incidents, 6 of the regulator first stage failures and 6 of the low pressure hose ruptures occurred at depth, including 2 new hoses which were not from an established manufacturer. Measures that should reduce the occurrence and minimise the effects of incidents include a visual hose inspection before every dive and the consequent replacement of all doubtful hoses.

The use of an alternative air source, a separate second stage, may enable a diver who has experienced a regulator failure to ascend safely, provided the diver’s buddy is close and aware of the diver’s predicament. Sharing a second stage is not recommended because published data show that such “buddy breathing” ascents are associated with an unacceptable level of risk.[19] However, in 2 of these incidents, the alternative air source (a power inflator and demand valve combination) developed a leak during the dive (a pre-dive check did not and would not have detected this fault), requiring disconnection to preserve the diver’s air supply. Other suggestions to minimise the effect of the sudden loss of an air supply include the addition of a small spare “pony” air cylinder. However, the other two alternative air source incidents involved the failure of the filling mechanism for such pony bottles and the divers concerned conducted the dive without an alternative air source. A diver’s response to any emergency is determined, in part, by training. Refresher training programs are available from most training agencies but are not as well patronised as they should be. These enable divers to relearn and practice emergency procedures, particularly, for an out of air problem.

In Australia the required annual inspection and testing of scuba cylinders is an important safety measure.[20] Although cylinder problems are rare, an undetected tank fracture could have explosive and fatal consequences.

The power inflator mechanism of a buoyancy jacket failed to operate in 14 incidents. A meticulous pre-dive check of the inflator would have detected this fault in almost all cases. During 10 separate dive incidents the inflator spontaneously inflated the buoyancy jacket. Consequent rapid changes in buoyancy are dangerous and it is not surprising that 7 of these incidents resulted in morbidity. To minimise the occurrence of these incidents, all jackets should be equipped with an accessible emergency dump valve that is designed to be able to exhaust air at a rate at least equal to that of maximum inflation. Unfortunately not all compensators provide this facility. In addition to this emergency dump valve a cut off mechanism should be added to the power inflator to prevent the rapid depletion of the diver’s air supply.

Six of the 11 incidents involving dive computers resulted in harm. To prevent sudden power failures, all computers should be equipped with either a low battery alarm or a mechanism by which the diver can test battery power. None of the divers who reported computer failures to DIMS had access to a set of dive tables. In this context, it is clear that computers should be used to assist dive planning and not as the sole method of dive management. In addition, all divers using computers should dive with an additional timing device and depth gauge.

All of the incidents involving inaccurate depth gauges caused harm. Even when a depth gauge is first purchased, the accuracy of the gauge is not known. Once purchased, there is recommendation for regular recalibration. A sensible safety measure is an annual recalibration. Divers also need to be taught to compare their contents gauge readings with those of their diving companion before, during and after a dive to assess the accuracy of both their calculations and contents gauge. Training programs need to emphasise depth, time and air consumption calculations.

The loss of a fin in an emergency situation may be fatal. In an analysis of diving fatalities, one study reported a 10% incidence of a missing fin or fins.[14] A pre-dive check must include the fin straps.

“Safety sausages”, an elongated sausage shaped coloured plastic tube which is extended by filling with air, are usually visible and easily maintained in an upright position in calm conditions, but from reports to DIMS they often fail to maintain their upright position in adverse conditions and are then invisible. These devices need to be made from sturdy material and tested in all conditions before being sold.

Limited visibility diving requires the use of a primary and secondary diving torch to provide continuous light. The water resistance of any diving torch needs to be tested before sale.

Conclusions

One hundred and five (10.5%) of the first 1,000 incidents reported to DIMS conform to a definition of pure equipment failure. Of these 105 incidents, 27 (26%) resulted in harm. Overall, these data are consistent with other papers in that "true" equipment failure accounts for between 8 and 10% of incidents and accidents in systems with interaction between equipment and humans.[3,7,10]

Sixty three (60%) of these reported incidents could be prevented by the combination of a thorough pre-dive check (as defined here) and an annual equipment recalibration.

Another 55 (52%) incidents could have been avoided if either equipment design was altered (the addition of a low battery alarm in dive computers, an audible low pressure alarm in contents gauges and tank pillar valves, a larger more accessible emergency dump valve in all buoyancy jackets and a cut off mechanism to the power inflator) or if there was a change of manufacturing material and testing procedure. It is reasonable to argue that all battery powered equipment should have either a low battery alarm or a monitor that indicates battery status.

Adherence to established diving safety procedures could have reduced the effect of 53 (51%) incidents.[21,22]

Problems associated with regulator first stages (including hoses) do not necessarily occur when the air supply is at maximum pressure. An annual scuba cylinder inspection and test as prescribed in AS3842.2 -1999 is essential.

The effect of another 48 (46%) incidents could have been minimised by the use of back-up equipment such as a second contents gauge, dive timer, depth gauge and torch. If a piece of equipment is considered essential, it is reasonable that at least one level of redundancy (e.g. duplicate equipment) is needed. This attitude is accepted by the Cave Diving Association of Australia.

The strategies proposed to reduce the occurrence and minimise the effects of these equipment failures in diving are summarised in Table 3.

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TABLE 3

EQUIPMENT FAILURES AND STRATEGIES TO MINIMISE OUTCOMES

Equipment	Strategy to be used	Corrective strategies
Contents gauge	1, 2, 3, 4, 9, 11	1 = Recalibration of equipment
Regulator first stage	2, 4, (9?)	2 = Addition to established pre-dive protocol
Buoyancy Jacket		3 = Low pressure alarm
Inflator failure	2, 10	4 = Good buddy diving
Spontaneous inflation	5, 10	5 = Equipment design additions
Fins	2	6 = Change of manufacturing materials
Torch	7, 9	7 = Added testing
Surface signalling device	6, 7	8 = Battery status alarm
Alternative air source	2, 4, 5, 7, 10	9 = Use of back up equipment
Depth gauge	1, 9	10 = Additional servicing
Dive computer	8, 9	11 = Good dive planning
Tank	12	12 = Annual servicing

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TARAVANA REVISITED
DECOMPRESSION ILLNESS AFTER BREATH-HOLD DIVING

Robert M Wong

Key Words

Breathhold diving, decompression illness.

Introduction

Decompression Illness (DCI) following breath-hold (BH) diving is extremely rare. In the past there were numerous BH divers around the world, such as Ama and katsugi divers of Japan, hae-nyo divers of Korea and sponge divers of Greece and Turkey, but now this mode of diving is much less common. These divers do not normally suffer from DCI.

Notwithstanding the rarity of DCI from BH diving, it does occur following extremes of BH diving. In 1958 E R Cross reported a condition known as "Taravana" among pearl divers of the Tuamotu Archipelago near Tahiti.[1] These divers did repetitive BH dives and they suffered from what appeared to be symptoms of DCI. Seven years later Paulev, a naval medical officer, described his personal experience of DCI from BH diving.[2]

Due to the rarity of this condition, it is likely that most medical practitioners are unaware of its existence. This paper reviews the condition and reports two Australian cases of DCI from BH diving.

Taravana

E R Cross described a diving syndrome, called Taravana, in Tuamotu Islander divers working in the Takatopo Lagoon.[1] Taravana is a Paumotan name meaning to fall crazily (tara = to fall; vana = crazily). The report listed 35 male divers. Twelve of them suffered from vertigo and one died. The ages ranged from 19 to 62, and the greatest depth dived was 25 "brasses". A brass is the distance one can reach with outstretched arms and therefore varies from diver to diver. A brass was the local equivalent of a fathom (6 ft). If this conversion is accurate, the greatest depth dived was some 45 m (150 ft). Cross also mentioned 8 female divers, only one of whom suffered from vertigo. Their ages ranged from 22 to 59 and the depths ranged from 5 to 24 brasses (9 to 43 m or 30 to 144 ft).

Typically the islanders dived from a canoe or an outrigger. They descended using a weight of about 4 to 6 kg (8 to 12 lb) attached to a line and wore goggles or a face mask. Divers at Hikueru Lagoon would hyperventilate for 3 to 10 minutes before diving. The technique was a deep inhalation, followed by deep expiration accompanied by a long drawn "whoooeee" sound. Before the dive, the diver lowered himself into the water and continued to hyperventilate at a faster rate. Just before he dived, he raised himself out of water to the waist, took a deep breath and descended feet first holding the weight. Time on the bottom ranged from 30 to 60 seconds. Ascent time was no more than 20 seconds from depths of 30 to 39 m (100 to 130 ft). As soon as he reached the surface, the diver hyperventilated again for 3 to 10 minutes and then dived. The maximum duration of a dive, from surface to surface, as observed by Cross in Hikueru was 2 minutes and 35 seconds. The average however, was 1 minute 30 seconds for a series of timed dives.

In Hikueru Lagoon, there were an estimated 235 divers. At the end of a 6 hour working day, 47 divers were affected by various symptoms of Taravana. 34 suffered vertigo, nausea and "mental anguish". Six were paralysed, partially or completely. Three suffered temporary unconsciousness and two were mentally affected. Two divers had died.

Cross related further that, in 1958, he spent a morning in the canoe of Turoa Hutihuti at Hikueru Atoll.[3] .."prior to his first dive of the day and during rest periods in and alongside the canoe, he hyperventilated for periods of three to ten minutes. During hyperventilation, the *tete*, or helper, prepared the weighted descending line and the rope and bag for the shell. Whilst continuing to hyperventilate, Turoa went over the side of the canoe and placed the weight between his feet. His rate of hyperventilation increased for about one minute just prior to descent. He then dropped rapidly to the bottom. The diver's time on the bottom and the duration of hyperventilation seemed to depend more on the abundance and quantity of shell in the harvest area than on physiological needs. Bottom time varied from 1 to 2 minutes. In the afternoon, he took me to all parts of the lagoon to observe other divers at work and to talk to divers who had been afflicted by various symptoms of Taravana. My diver told me that when the shell was abundant and of good quality, some divers hyperventilated only briefly but extended their bottom time to the break point of breath holding. Their time on the surface became very short as they dove to harvest the abundant shell they had found. It was then that the diver suffered the syndrome of Taravana".

The most common symptoms of Taravana were vertigo, nausea and, less commonly, mental anguish. Occasionally, vertigo was the only symptom

It has been stated that divers from Mangareva never experienced Taravana. The likely reason was that these divers had longer surface intervals, being 12 to 15 minutes instead of 4 to 10 minutes, and these divers used a less forceful but longer period of hyperventilation.

The reader is referred to the original article by ER Cross for further information.[1] Some of the symptoms of Taravana could be due to hypoxia, hypercarbia and drowning, but certainly other symptoms are highly suggestive of DCI, particularly the neurological symptoms.

It is of interest that the divers hyperventilated before diving. Hyperventilation lowers $PaCO_2$ but, although this prolongs breath-hold time, the diver risks loss of consciousness from hypoxia due to a low PaO_2 before $PaCO_2$ rises enough to provide the stimulus for another breath. Alveolar PCO_2 rises as a BH dive proceeds and normally hypercapnia provides the stimulus for surfacing. With hyperventilation, PCO_2 can be lowered so much that a dangerously low level of PO_2 (around 25–30 mm Hg), which can cause unconsciousness which may lead to drowning, can be reached before the PCO_2 reaches a level (50 mm Hg) that stimulates breathing.[4] Although oxygen concentration falls during descent this provides no hypoxic stimulation for breathing because the PO_2 remains relatively high at depth because of the increased pressure. Alveolar PO_2 increases with depth as the alveolar gas is compressed. During ascent, alveolar PO_2 decreases, partly due to oxygen consumption, but mainly due to decreasing pressure. There is a danger of hypoxia, just before reaching the surface, causing unconsciousness. This has been called "shallow water blackout" although it is more accurately hypoxia of ascent. When the alveolar PO_2 falls below the mixed venous PO_2, there is a transfer of oxygen from mixed venous blood to alveolar gas which raises the arterial PO_2. Although this is a transient effect, it may be an important factor in preventing loss of consciousness in the final stages of ascent. Yet this did not appear to occur often with the Tuamotu divers, perhaps because they descend without effort and do not swim up but are pulled up. Nevertheless 5 out of 235 divers went unconscious or died in the water, which is a 2% incidence, during a 6 hour working day.

DCI following BH diving in SETT

Breath-hold diving causing DCI was again reported by Paulev, a Medical Officer in the Royal Danish Navy.[2] The incident occurred in a Submarine Escape Training Tank (SETT) in the Norwegian Naval Base of Haakonsvaern at Bergen, when Paulev spent 8 minutes at 20 m as an attendant in a recompression chamber. After this he performed a number of BH dives in the tank to 20 m as an instructor supervising escapees. Each dive took 20-25 secs to reach the bottom, where he would sit or walk until he felt the need to breathe (about 2 minutes), then he ascended to the surface, which took 10 – 15 seconds. Surface intervals were between a few seconds and 2 minutes. He was in the water about 5 hours. During the last 2 hours, he experienced nausea, dizziness and eructation (belching). However, during the last 30 minutes, he developed pain in his left hip. The right knee started to hurt and eventually, the right leg felt tired and the right arm was weak. Two hours after leaving the water he had chest pain, abdominal pain, paraesthesia and anaesthesia in the ulnar side of the right hand and blurring of vision. He was compressed to 6 ATA (50 m)and treated with USN Table 3. Treatment was successful although a residual weakness of the right hand persisted.

Three other cases have also been treated in the Norwegian SETT. Each man had been compressed in the hyperbaric chamber before BH diving. All experienced neurological symptoms and were successfully treated, which supported the diagnosis of DCS from BH diving.

In his discussion, Paulev suggested that for breath-hold dives to 20 m the diver should not suffer from DCI if the surface interval was equal or greater than the time at depth. However, if the surface interval was only half the bottom time, the risks DCI was higher. For deeper BH dives, to 36.6 m (120 ft), a surface interval of 3 times the bottom time was needed to avoid DCS. A 10 minute surface interval may permit an indefinite series of dives to a depth of 42.7 m (140 ft). Perhaps this longer surface interval explains why the divers from Mangareva did not suffer from Taravana.

The symptoms these divers all shared were nausea and dizziness. The surface intervals had all been short, less than 10 minutes.

Australian cases

Case 1

ABC is a fit 40 year old Sales Representative (186 cm tall, weight 74 Kg, BMI 21.39) whose hobby is spear-fishing. He has been breath-hold diving since the age of 14 and dives regularly, at least once or twice a week. ABC considers that he has never experienced any problems while diving. However he commented that he had been close to suffering from “shallow water blackout” about 6 times. He is married with 3 children and is in good general health.

The symptoms which led to his presentation for treatment came on after he performed repetitive breath-hold diving for over 6 hours hunting crayfish and fish. In this time he did some 40 to 50 dives.

He and his friend started at 0800, dived to depths between 12 and 13.7 m (40 to 45 ft) for about two and a half hours. Each dive lasted two to two and a half minutes. The surface intervals were about 1 minute each.

At about 1030, they moved the boat to deeper water and started diving again at 1100. For three and a half hours, they dived to depths of 90 - 95 feet (27.4–29 msw). Each dive lasted between 2 to 3 minutes. The surface intervals were about 2 minutes after these deeper dives.

On one dive in the deeper depths, he caught a fish after some strenuous swimming. After this he felt exhausted and a little “giddy” and experienced a cramp in his left calf. He surfaced, feeling very tired so he merely floated on his back for a while to rest, then swam towards the boat. Despite feeling unwell, he continued diving.

He subsequently experienced headache (much like a sinus headache from which he suffers); difficulty in focusing with some visual blurring, “giddiness” (which was probably vertigo as there was some spinning), nausea and a feeling that he was going to pass out. He attributed this to his nausea, assuming that he had a viral infection. He also complained of being unable to balance. He could not concentrate and unable to think clearly as well as being lethargic. He denied any symptoms of pain in any joints or any altered sensation anywhere.

He went to work thinking the symptoms would disappear. He found that during the day he achieved nothing at work, even though he spent hours there. At night, he felt tired yet he was unable to sleep. When he got to sleep he woke frequently.

Eventually, 3 days after his dives, he decided to consult a doctor. The doctor thought that he had suffered from a hypoxic episode and would probably benefit from hyperbaric oxygen therapy. He presented the next afternoon for assessment at the Department of Diving and Hyperbaric Medicine.

On examination, he appeared tired. In fact, he fell asleep in the waiting room. He exhibited disturbance of cognitive function and demonstrable cerebellar signs with nystagmus, loss of fluency with limb movement with the finger-nose test and showed dysdiadochokinesis. He had mild ataxia, but there was no intention tremor or hypotonia. His muscle strength was normal with a score of 5/5, he was able to do a “duck walk” without any difficulty. Sensation was normal as were all the reflexes. He was unable to do a Sharpened Romberg Test, falling over in less than 2 to 3 seconds. Even with the Standard Romberg Test he only managed about 10 seconds. His other proprioceptive senses such as vibration and joint position sense were normal. The Mini-mental test score was 21/30, worst affected was his short term memory.

He was treated with a USN Table 6 using the Toronto modification, which has a slow rate of ascent, 60 minutes instead of 30 minutes, from 18 to 9 m (Figure 1). At 9 m oxygen is given for spells of 20 minutes with 5 minute air breaks. Ascent from 9 m takes 30 minutes. He was given 2 litres of IV fluids during treatment. He was dehydrated as he passed no urine in spite of the 2 litres of fluids. There was little improvement after the first oxygen period, although he thought his eyes had cleared, but he still felt quite dazed. After the second period, he felt mentally clearer and his headache and giddiness were gone. By the third period, he performed all the alternating rapid movements perfectly and there was no evidence of dysdiadochokinesis, but was still unable to perform the Sharpened Romberg. At 9 m he felt that he was mentally alert and was back to his "normal" self. However, he still could not manage the Sharpened Romberg, but fared a little better on the Standard Romberg.

On completion of USN 6, he felt he was back to normal. All tests were normal, he managed the Sharpened Romberg without any problems and his Mini-mental Test score was 30/30. The complicating factor was that he developed some retrosternal chest discomfort and a mild cough consistent with mild pulmonary oxygen toxicity. This is unusual, as he did not have any oxygen before treatment and the table was not extended. The unit pulmonary toxicity dose (UPTD) was not excessive.

ABC returned the next day for further treatment with a USN 5. There were no abnormalities before treatment and he remained well subsequently. After the treatment he was free from symptoms of oxygen toxicity. He was symptomless when reviewed 13 weeks later.

Case 2

DEF is a 56 year old ex-pearl diver, who was a champion skin diver in his youth in NSW. He still has a keen interest in breath-hold diving. He is a fit man and is still able to free dive to over 30 m (100 ft). He could hold his breath for about 3 minutes.

In 1994 he had used a dive computer to document an aggregate dive time of 50 minutes within a one hour period. His surface intervals are believed to have been very short, just sufficient to unload his catch and to take another big

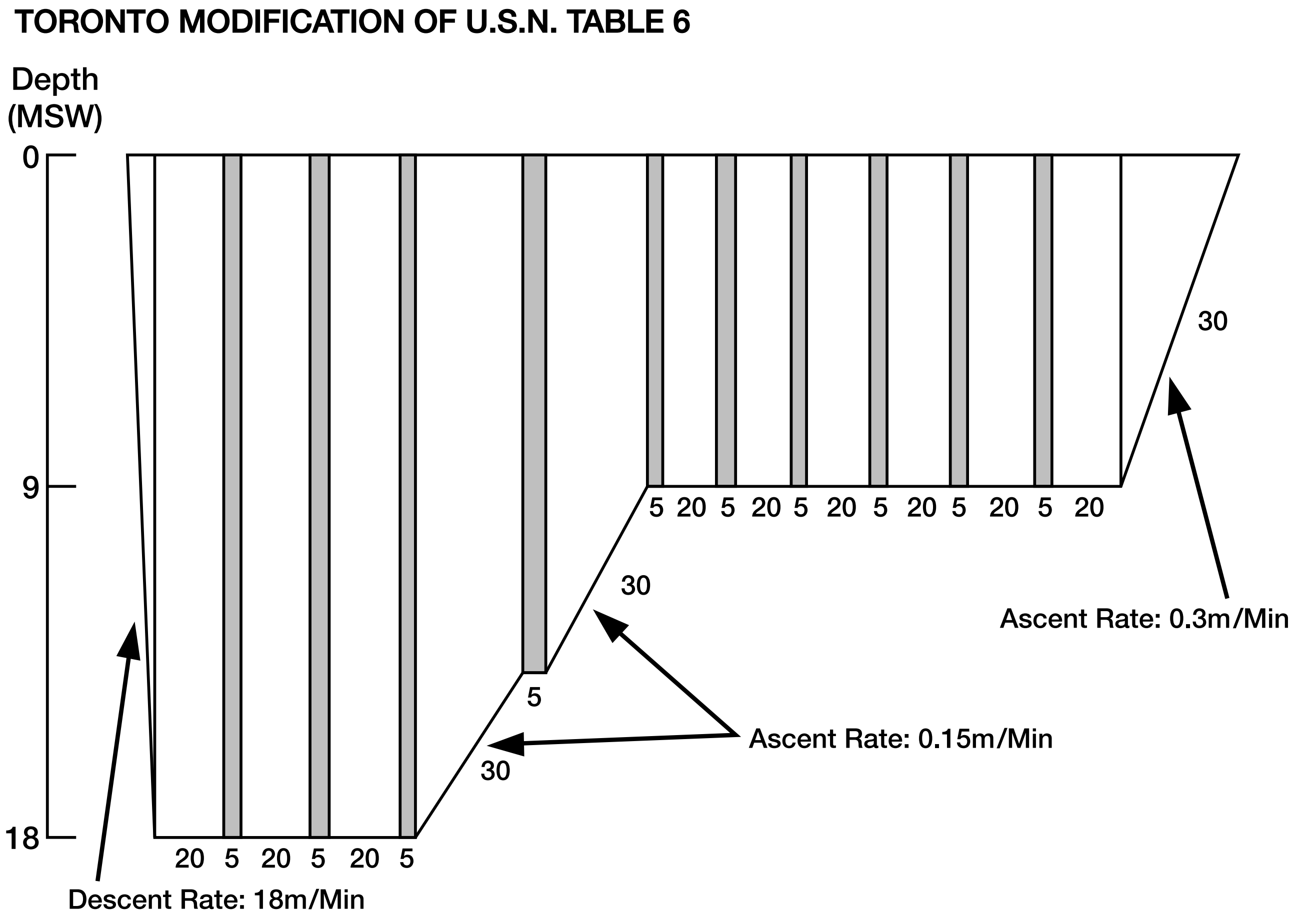

Figure 1. Toronto modification of USN Table 6. The modifications consist of a slower rate of ascent from 18 to 9 m, 0.15 m/minute instead of 0.3 m/minute, and at 9 m 20 minutes oxygen breathing periods separated by 5 minute air breaks. Ascent from 9 m to the surface is at the usual USN rate of 0.3 m/minute (1 ft/minute).

breath. At that time he used to dive for 5 – 6 hours each day.

In 1997 he presented to his local general practitioner with a history of attacks of dizziness, staggering and nausea after BH diving. He had experienced "staggers" previously when pearl diving in the 70s, and he stated that the sensation was similar. He reported that the attacks usually started after diving and were associated with difficulty in walking. On occasions he had been unable to drive home. Generally, these episodes resolved within 12 hours, but the most recent one persisted for 36 hours. Apparently, he had been suffering such symptoms for some 5 years.

He stated that he had consulted another medical practitioner in 1992. The diagnosis then was "a possible middle ear problem" but there was no follow up. It is not clear what the symptoms were that he presented but dizziness and nausea seem likely.

At his most recent consultation DEF had a poor Sharpened Romberg Test, but no other neurological abnormalities were detected. ENT referral was made, but apparently no pathology was found. Tests, including brainstem audiometry and CT scanning were all normal. No perilymph fistula was detected nor was any audio-vestibular pathology demonstrated. He did not seek or receive any treatment after that. From extensive discussion with the medical practitioner involved, the most likely diagnosis appears to be DCI. DEF said that when he used scuba equipment, he experienced no problems.

Discussion

Two earlier reports of DCI following BH diving have been reviewed and two Australian cases of decompression illness which resulted from BH diving have been presented. Since this paper was submitted, a further report of six cases of neurological problems in four breath-hold divers has been published.[5]

DCI from BH diving is extremely uncommon for a number of reasons. Among them are shorter dive times, lesser depths and longer surface intervals. All the cases reported above occurred in warm water and the divers were without thermal protection. Divers working off the coasts of Japan and Korea had to, before they acquired wet suits, come out of the water and huddle over a fire to warm up after a short period in the water. Cold divers have much reduced peripheral circulation and so less tissue exposed to the opportunity for gas uptake.

The Amas do not get symptoms of DCI because they limit the frequency of diving, the depth and the total dive time.[6] The depth might be as much as 25 m, but the total diving time was less than a minute. Nonetheless, Spencer and Okino, who used a precordial ultrasonic bubble detector, studied an ama diver who had done 30 dives to 15 msw in 51 minutes, averaging 53 sec each dive, and found that venous gas emboli were present for as long as one hour after the last dive.[7] It might be that, if such a diver continued to dive for a few more hours, DCI could ensue. In studies with Australian pearl divers, bubbles detected by doppler tended to peak at around 60 minutes, and with more severe profiles, the maximum grades were not reached until 120 minutes after the dive.[8]

Doppler ultrasound techniques have been used extensively to detect moving bubbles in decompression studies. Boussuges et al. used 2D echocardiography and continuous Doppler ultrasound recordings to study 10 breath hold divers who dived to a mean maximum depth of 32 msw (24 - 40 msw) for a mean duration of 3 hours 15 minutes (2- 6 hours). Three divers' dive profiles were recorded on computer. Echo studies were performed in 73% of the cases within half an hour of the last breath hold dive of the day (3-75 mins). They did not find any evidence of circulating air bubbles. Nonetheless, they concluded that the study was insufficient to eliminate the hypothesis of supersaturation in BH diving, and another study is being planned.[9]

Unlike humans, diving animals such as Weddell Seals and other Cetaceans (whales, dolphins etc) do not suffer from DCI or nitrogen narcosis. As they dive, nitrogen up-take is stopped by the collapse of gas-exchanging alveoli. During a dive the major fraction of the Weddell seal's lung gas is compressed into the non-gas exchanging parts of the respiratory tract. At the end of the dive, as pressure is reduced, this gas can expand to open the collapsed alveoli.[10]

Diving medicine texts in the 1970s still contained predictions of lung damage at depths deeper than 30 m.[11] The maximum depth of BH dive for humans was calculated to be about 40 m [Depth = P x (TLC/RV –1) x 10, where P is barometric pressure expressed in atmospheres and 10 represents the sea water equivalent depth in metres of 1 atmosphere].[12] But this calculation fell short of the actual depths reached. In 1951, Felco and Novbelli dived to 35 m. What had been overlooked was the effect of pressure on the rest of the body. The compression of legs and abdomen dislocates a litre or more of blood into the thorax which takes up space occupied by air at the surface. In early 1976, Mayol dived to 86 m. In November 1976, he reached a record depth of 100 m with a single breath in a dive of 3 min 39 secs. Mayol's depth has since been passed by other divers. Recently there has been a resurgence in deep breath-hold diving competitions.[13] The divers, usually wearing wetsuits, use weighted sledges to get down the rope and swim and pull themselves up to the surface. The women's depth record, in April 1999, was 113 m![14]

It is common for spearfishermen to dive regularly to 30 m. Those who are more accomplished can breath-hold dive for 2 to 3 minutes.

Certainly, it appears that repetitive BH dives can give rise to DCI in humans, especially in fit individuals who can breath-hold for prolonged periods and who also have large lung volumes. That DCI is a rarity is probably because most who practise this kind of diving either do not dive to great depths or do not do multiple repetitive dives, with short surface intervals, for 5 to 6 consecutive hours.

It is worth bearing in mind that anyone who has done repetitive BH dives for prolonged periods could suffer from DCI. The most common symptoms appear to be vertigo, nausea and lethargy. In the 2 cases mentioned above, pain was not a symptom. As with DCI from compressed air diving, recompression therapy is highly recommended.

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INTRODUCTORY COURSE IN DIVING AND HYPERBARIC MEDICINE

Department of Diving and Hyperbaric Medicine
Prince of Wales Hospital
Barker Street, Randwick NSW 2031

Monday 21st of February to Friday 3rd of March 2000

Objectives of the course
To provide a broad introduction to the theory and practice of diving and hyperbaric medicine (DHM)
To provide the formal teaching component required for the SPUMS Diploma of DHM
To promote integrated teaching of DHM
To promote the evidence-based practice of DHM

Course content includes
History and chamber types
Physics and physiology of compression
Decompression illness
Assessment of fitness to dive
Other accepted indications
for hyperbaric oxygen (HBO) therapy
Wound assessment including transcutaneous oximetry
Practical sessions including in chamber treatment

Cost $A 1,500.00

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THE WORLD AS IT IS

A HISTORY VICTORIA'S RECOMPRESSION FACILITIES, PART 2

Ian Millar

Key Words

History, hyperbaric facilities.

For the first part of this history the reader is referred to pages 71-72 of the June 1999 issue of the Journal. Here the story of the Hyperbaric Service as a wholly Alfred Hospital owned and operated facility is continued

In 1989 the two chambers, which had been temporarily linked in 1984, were relocated adjacent the new Trauma Centre and helipad with the intention that this relocation be temporary only, pending installation of a new, purpose built clinical treatment chamber system. The new, first floor Hyperbaric Service building was purpose constructed within constraints created by its location above the Emergency Department ambulance bay and by the necessity for it to also provide a corridor from the new Trauma Centre to the Diagnostic Radiology Department.

The chambers' air filtration system was upgraded to a standard sufficient for a new facility and one new compressor system had been purchased. The other main components of the system were essentially as installed in 1987 and minimally different from 1984.

The Hyperbaric Service also acquired a second hand monoplace hyperbaric chamber, donated by Royal North

Figure 2. Looking through the Vidor chamber with its 800 mm doors, only just wide enough for a stretcher to be passed through, into its second compartment and then on into the other compartments. On the left can be seen the oxygen supplies for the patients.

Figure 1. Looking down on the old Alfred chamber complex in 1996. The double glass doors open onto the helipad. In the top righthand corner is the ingenous crane arrangement needed to insert stretchers into the chamber. The stretcher was inserted into the two white half circles which hooked under the stretcher handles. Then the travelling beam was moved in through the entry door and the patient and stretcher were moved over one of the bunks shown in Figure 2 while the beam was lowered so that the stretcher could touch down. The narrow portion of the complex was a second, much smaller, compartment of the main treatment chamber.

Shore Hospital in Sydney who had completed the research program for which the chamber had been used. It was transported to Melbourne and installed with Lions Club funding, proving to be a useful additional resource.

The workload of the Hyperbaric Service grew throughout the 1990s, plateauing at around 2,500 treatments per annum from 1996–1998. This proved to be the effective maximum capacity of the chamber system, staffed for three routine treatment runs a day. For most purposes, the Service effectively operated with a single chamber. The Vidor chamber with its 800 mm diameter entrance provided

Figure 3. The new chamber being delivered in 1999.

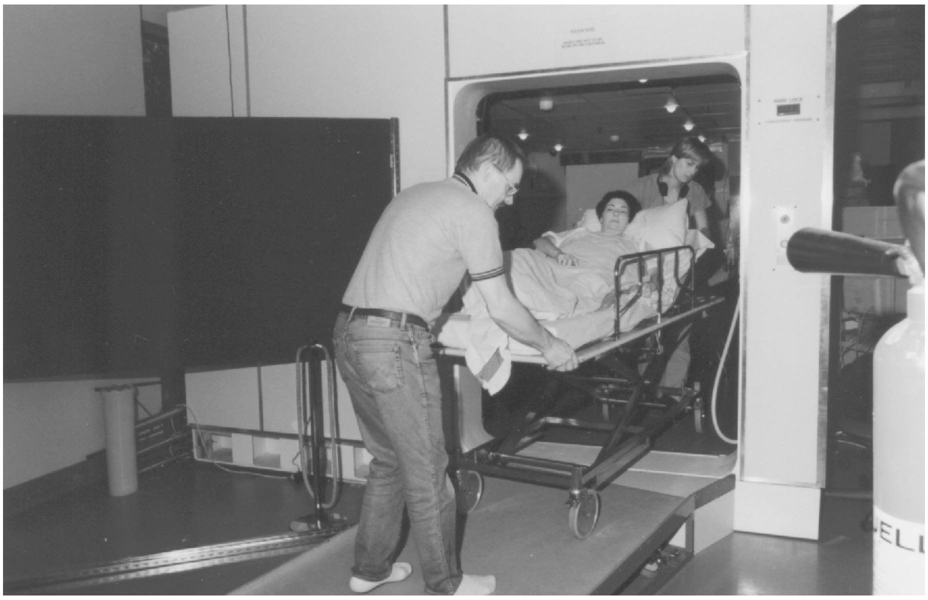

Figure 4. One of the entry doors to the new chamber complex.

the only acceptable access for supine patients and the many elective wound healing and chronic osteomyelitis patients who are mobility impaired. The Comex chamber was used principally for diver recompression to reduce the need for scheduled treatments to be cancelled.

The Alfred Hospital finally replaced the least suitable hospital based hyperbaric facility in Australia with a large rectangular walk in triple-lock facility in February 1999. The two chambers which were temporarily connected in 1984 had been finally separated 15 years later, their departure from service marked by a fine wake, at which many of those associated with the chambers over the years partied late into the night in a combination of celebration and reminiscence.

In May 1999, the Vidor chamber was stored in an outer Melbourne factory building, awaiting a new home. The 26 year old Comex chamber, however,was already on its way to a new stage of its career as a diver recompression facility. It was commissioned in Vanuatu during August 1999.

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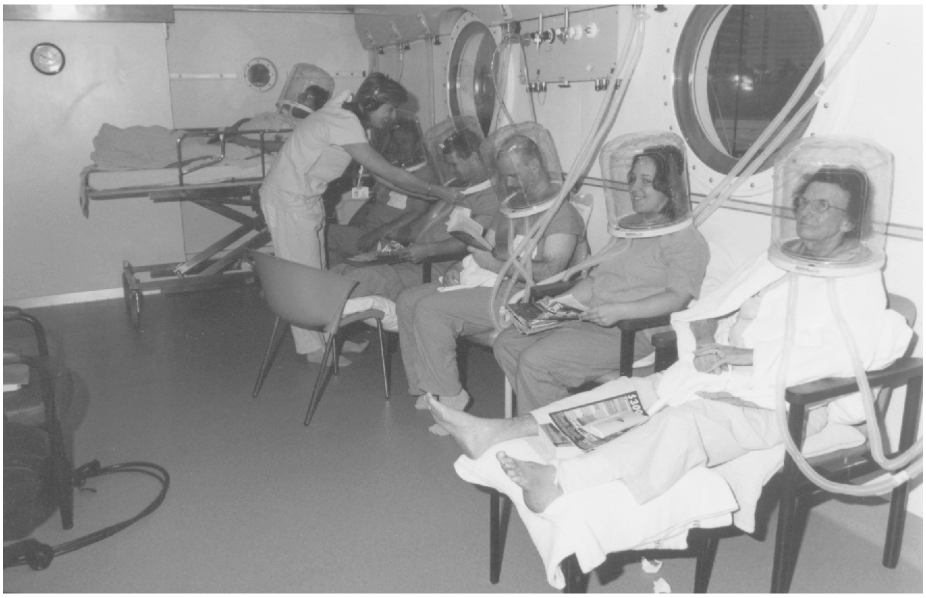

Figure 5. Patients in the new chamber's main lock, which is big enough to take an intensive care bed with plenty of room for staff and equipment. Patients wear transparent hoods when on oxygen. One tube delivers oxygen close to the patient's face and the other removes the flow to the overboard dump.

SPUMS NOTICES

SOUTH PACIFIC UNDERWATER MEDICINE SOCIETY DIPLOMA OF DIVING AND HYPERBARIC MEDICINE.

Requirements for candidates

In order for the Diploma of Diving and Hyperbaric Medicine to be awarded by the Society, the candidate must comply with the following conditions:

1 The candidate must be a financial member of the Society.

2 The candidate must supply documentary evidence of satisfactory completion of examined courses in both Basic and Advanced Hyperbaric and Diving Medicine at an institution approved by the Board of Censors of the Society.

3 The candidate must have completed at least six months full time, or equivalent part time, training in an approved Hyperbaric Medicine Unit.

4 All candidates will be required to advise the Board of Censors of their intended candidacy and to discuss the proposed subject matter of their thesis.

5 Having received prior approval of the subject matter by the Board of Censors, the candidate must submit a thesis, treatise or paper, in a form suitable for publication, for consideration by the Board of Censors.

Candidates are advised that preference will be given to papers reporting original basic or clinical research work. All clinical research material must be accompanied by documentary evidence of approval by an appropriate Ethics Committee.

Case reports may be acceptable provided they are thoroughly documented, the subject is extensively researched and is then discussed in depth. Reports of a single case will be deemed insufficient.

Review articles may be acceptable only if the review is of the world literature, it is thoroughly analysed and discussed and the subject matter has not received a similar review in recent times.

6 All successful thesis material becomes the property of the Society to be published as it deems fit.

7 The Board of Censors reserves the right to modify any of these requirements from time to time.

Key Words

Qualification.

CONSTITUTIONAL CHANGES

The Annual General Meeting in Layang Layang on May 7th 1999 passed the motions detailed below to amend the Statement of Purposes and Rules of the Society.

Under the heading **Definitions**

Alter rule 2.(a) by changing the words *30th June* to *31st December*.

Under the heading **Committee**

Insert new rules

21.(d) The Australian and New Zealand Hyperbaric Medicine Group is a Sub-Committee of SPUMS.

21.(d) (i) Its members must be members of the South Pacific Underwater Medicine Society Incorporated.

21.(d) (ii) Its Chairman shall have a place on the Committee.

Under the heading **Officers of the Committee**

Alter rule 22.(a) by adding the words, *the Chairman of the Australian and New Zealand Hyperbaric Medicine Group* after the words the New Zealand Chapter of the South Pacific Underwater Medicine Society Incorporated

22.(a) will then read

The Committee shall consist of a President, Immediate Past President, a Secretary, a Treasurer, Public Officer, the Editor of the Journal, an Education Officer, a representative appointed by the New Zealand Chapter of the South Pacific Underwater Medicine Society Incorporated, *the Chairman of the Australian and New Zealand Hyperbaric Medicine Group* and three other members of the Association entitled to vote.

22.(b) to be renumbered 22. (d) this reads

Each officer of the Association shall hold office until the annual general meeting three years after the date of that person's election but is eligible for re-election.

22.(c) to be renumbered 22. (e) this reads

In the event of a casual vacancy in any office referred to in sub-clause (a), the Committee may appoint one of the Association's members entitled to vote to the vacant office and the member so appointed may continue in office up to and including the conclusion of the annual general meeting next following the date of that person's appointment.

Insert new rule

22.(b) All officers of the Association, except those detailed in 22.(c), shall be elected by postal ballot if the number of candidates exceeds the number of vacancies.

Insert new rule

22.(c) The Editor, the Public Officer, the representative of the New Zealand Chapter of the South Pacific Underwater Medicine Society Incorporated and the Chairman of the Australian and New Zealand Hyperbaric Medicine Group shall be appointed to their positions. The first two by the Committee, the others by the New Zealand Chapter of the South Pacific Underwater Medicine Society Incorporated and the Australian and New Zealand Hyperbaric Medicine Group respectively.

Under the heading **Publications and Publicity**

Alter rule 41 by adding the words *The Chairman of the Australian and New Zealand Hyperbaric Medicine Group is the Association's official spokesman on Hyperbaric Medicine matters.* after the first sentence

Rule 41 will then read

Public statements in the name of or on behalf of the Association shall only be made by the President, Secretary or by another member of the Association specifically designated by the Committee to speak on any particular matter. The Chairman of the Australian and New Zealand Hyperbaric Medicine Group is the Association's official spokesman on Hyperbaric Medicine matters.

Insert new heading **Board of Censors**

Insert new rules

42. The Committee shall appoint a Board of Censors

42 (a) The Board of Censors shall be composed of the Education Officer, the President of the Society and a Director of a Hyperbaric Medicine Unit in Australia or New Zealand.

42 (b) The role of the Board of Censors is to advise the Committee on all matters of education in diving and hyperbaric medicine.

42 (c) A Diploma of Diving and Hyperbaric Medicine may be awarded by the Society, on the recommendation of the Board of Censors, to a member who fulfils the requirements set down by the Board and published in the SPUMS Journal from time to time.

As no member had written to the Secretary of SPUMS,C/o Australian and New Zealand College of Anaesthetists, 630 St Kilda Road, Melbourne, Victoria 3004, Australia, objecting to these amendments before September 1st 1998 it is assumed that the membership has voted in favour of the amendments.

Cathy Meehan
Secretary of SPUMS

Key Words

Meeting.

MINUTES OF THE SPUMS EXECUTIVE COMMITTEE TELECONFERENCE

held on 9/3/99

Opened 2000

Present

Drs G Williams (President), C Meehan (Secretary), T Wong (Treasurer), J Knight (Editor), D Davies (Education Officer), C Acott, V Haller, R Walker (Committee Members), M Bennett (ANZHMG Representative).

Apologies

Drs D Gorman (Immediate Past President), M Kluger (NZ Representative).

1 Minutes of the previous meeting

Minutes of the previous meeting on 14/11/99 accepted as a true record. Proposed Dr J Knight, seconded Dr R Walker.

2 Matters arising from the minutes

2.1 Indemnity Policy Update. Progress report given by Dr G Williams. Final figures will be presented at the next meeting.

2.2 Job description of the Convener. Dr Acott has committed himself to finalising this.

2.3 Upgrade of audiovisual equipment. Dr Acott will purchase a suitable computer controllable projector which will suit the Society's needs for the future. A waterproof Pelican case will be purchased to protect the projector. The Secretary will purchase a new Toshiba laptop computer which will be able to be used with the projector.

2.4 The SPUMS website still needs a lot of work. Dr C Meehan will focus on this as soon as possible. It was discussed whether the full Diving Doctors List (DDL) should be put on the website. Dr G Williams will seek an opinion from the AMA about the ethics of doing this.

2.5 New application forms have been formatted but not yet printed as 2000 subscription fees have not been fixed. At present it is proposed that fees remain the same.

2.6 Comment was made on the renewal notice format. The printing of current information on the back of the renewal notice has proved useful. This will be continued and refined. Renewals will be sent out November and reminders can then go out in January. In the past members have been kept on the mailing list until the March Journal has been posted and then removed before the June mailing if they have not renewed. This has always been a matter of courtesy.

There has been great resistance by members to supplying a copy of their course certificate with the renewal of their their position on the DDL. This is essential so that SPUMS may sight the documentation. The Society endeavours to get a full list of attendees from the various course directors but these are not always available. Reminder notices will be sent later in the year for those who have not updated the information necessary to remain on the DDL.

2.7 Revisions of Standards. Dr J Knight stated that AS/NZS 2299.1 1999 was now in the final draft. Dr C Meehan stated that AS 4005.1 faced one final meeting and that the SPUMS Diving Medical was progressing.

2.8 Committee positions and nominations. A ballot will have to be held for the three Committee Members positions. The papers will be sent out on 30/3/99 to all who are recorded as financial full members on that day.

29 There was considerable discussion relevant to SPUMS and Australian and New Zealand College of Anaesthetists (ANZCA) Special Interest Group (SIG). The future of the SPUMS Diploma and any certificate of higher training that may come from the SIG was discussed. These and other issues will be taken further at the SIG meeting in May.

2.10 Proposed SPUMS grant. The Education Officer will put a notice in the Journal about this.

2.11 SPUMS Diploma update presented by Dr D Davies. Dr G Williams raised the matter of a SPUMS Medal of Good Service, which will be discussed at a later date.

2.12 Motions for the AGM about constitutional changes will be printed in the Journal.

3 Annual Scientific Meetings

3.1 1999 ASM at Layang Layang update was given by Dr C Acott. All is in order. Unfortunately Mr Paul Lunn, who has been dive guide and co-ordinator for the last few meetings, will be unable to attend. Mr John Shepherd will take his place.

3.2 2000 ASM at Castaway Island update was given by Dr G Williams. The proposed dates are 6-13 May. The co-conveners will be Drs G Williams and V Haller. Various speakers and topics suitable for the millennium were discussed.

3.3 2001 ASM proposals were suggested and will be discussed at the next meeting.

4 Treasurer's Report

Dr Wong reported that funds were in good order.

5 Correspondence

5.1 Letter from Peter Barter OBE re future venue. Dr C Meehan to reply.

5.2 Letters from Drs Grahame Barry and David Noble. It was agreed that SPUMS full members, who had completly abandoned medical practice could surrender their vote and transfer to Associate Membership.

6 Other business

Due to the continuing problems that arise for SPUMS office bearers living in different parts of Australia and routine SPUMS enquiries and administration having to be forwarded to them from the ANZCA postal address it was again suggested that a single person be employed to act as administrator. This person to handle all routine enquires, direct specific enquiries to the appropriate office holder and carry out all routine task of processing subscriptions and maintaining the membership and DDL database. Mr Steve Goble has volunteered himself for the position and the Committee has accepted his offer. His employment will commence as soon as possible. SPUMS will supply him with a computer, modem, printer and internet address.

6.2 A receipt and information sheet has been designed to send to applicants as soon as their applications have been processed.

Closed at 2200.

Key Words

Meeting.

MINUTES OF THE SPUMS EXECUTIVE COMMITTEE MEETING

held at Layang Layang Resort
on May 5/5/99 and 7/5/99

Opened at 1345 5/5/99

Present

Drs G Williams (President), C Meehan (Secretary), J Knight (Editor), C Acott, V Haller, R Walker (Committee Members), M Bennett (ANZHMG Representative), M Davis (New Zealand member),H Stauntrup (European Representative).

Apologies

Drs D Davies (Education Officer), T Wong (Treasurer), D Gorman (Immediate Past President), M Kluger (NZ Representative).

1 Minutes of the previous meeting

Minutes of the Teleconference on 9/3/99 read and accepted as a true record. Proposed Dr C Acott, seconded Dr J Knight.

2 Matters arising from the minutes

2.1 Indemnity Policy. A final update was given by Dr Williams.

2.2 Job description of the Convener. Dr Acott has committed himself to finalising this.

2.3 Upgrade of the Audiovisual Equipment. The new computer data projector has been used very successfully at the meeting. This equipment will need to be carefully maintained, and surge protection used. The possibility of lending out the projector for use by other meetings was discussed. In this situation, a formal request in writing should be made to the Society, and due consideration would be given. An acknowledgment to the Society should be then made in the program. All the electronic equipment owned by the Society should be adequately insured. However, the borrowers of the equipment would be responsible for any damage occurring to the equipment while in their care.

2.4 Update on the SPUMS web site.

2.4.1 It was decided that the Australian and New Zealand Diving Doctors List (DDL) should be available on the web site. This would make access to the list easier and allow more frequent updating. The web site could also contain information of appropriately trained members who do diving medicals outside Australia and New Zealand.

2.4.2 As there are many requests for printed copies of the DDL, and not everyone has Internet access, there will be a need to print out DDL information and send it on request. It was decided that a printed DDL will no longer be distributed with the Journal. A notice will be placed in the Journal outlining the new routines.

2.4.3 What further information should be added to the web site was discussed. A brief synopsis of the Layang Layang ASM was suggested to be produced by Dr Knight . Photographs of the key speakers should also be included. It may be of interest to have selected abstracts available as well, as a regular feature.

2.5 Revision of the SPUMS medical will be finalised at the next committee meeting to be held at the Hyperbaric Technicians and Nurses Association (HTNA) conference in Adelaide in late August 1999.

2.6 All committee positions, except for the three Committee members, were unopposed. The ballot to select the Committee Members will be conducted and declared at the AGM. The new education officer, Dr D Griffiths, will select the third member of the SPUMS Board of Censors.

2.7 Updates on the Australian and New Zealand College of Anaesthetists (ANZCA) Special Interest Group (SIG) on Diving and Hyperbaric Medicine and the Australian and New Zealand Hyperbaric Medicine Group (ANZHMG) were given by Dr M Bennett. Discussion included education, training and Medicare issues in HBO.

2.8 Update on the SPUMS Membership Database. Final corrections to the database are underway.

2.9 Mr Steve Goble has been employed as administrator. A letter will be written outlining the conditions of employment. There will be a trial period of six months after which there will be a review.

3 Annual Scientific Meetings

3.1 1999 ASM Layang Layang progressing satisfactorily.

3.2 2000 ASM Castaway Island. The dates for the ASM are 6-13 May 2000. SPUMS will have the sole use of the resort. The theme will be *Diving Medicine in the New Millennium*. There will be only one guest speaker, Dr David Elliott. There will also be panel discussions using the skills of the attending registrants. A formal call for abstracts will go out in the June Journal. The conveners will appoint a suitable dive guide.

3.3 2001 ASM proposals. Correspondence from Mr Peter Barter to the Secretary, dated 13/12/98, offering the Madang Resort Hotel, Madang, PNG, as a venue for the 2001 SPUMS ASM, was discussed. It was decided that a site inspection should be carried out as soon as possible, by Mr Geoff Skinner from Allways Dive Expeditions, to assess the suitability of the venue. Dr Meehan to respond to the correspondence, stating that the venue was being considered, and that a site inspection would take place as soon as possible. Having one convener with help from the SPUMS administrator, Mr Steve Goble, attending the meeting, was discussed. This would facilitate the administrative aspects of the meeting and the administrator could be responsible for the audiovisual equipment at the meeting. The disadvantage of having only one convener was that the experience gained by co-convening a meeting, would be lost to those who had not been in this position before. Dr Williams volunteered to convene the meeting. Whether there will be a co-convener in 2001, or whether the SPUMS administrator will attend the meeting instead, will be discussed at a future meeting.

4. Treasurer's Report

The Treasurer's report was presented by Dr R Walker as Dr Wong was unable to attend the ASM due to injury. It was proposed that the subscription fee remain the same.

4. **Correspondence**

4.1 Letter from Queensland Health re review of hyperbaric chamber therapy legislation. Dr M Bennett, as ANZHMG chairperson, and Dr J Knight, as SPUMS representative on and Chairman of Standards Australia Committee SF/46 have replied to this Letter. A copies of this correspondence should be on file with the Secretary.

4.2 Letter from Dr Luna re overseas addresses on the Diving Doctors List. Dr Meehan to respond to this. As in future the DDL will be available on the web site (see 2.4.1) overseas addresses can be included (see 2.4.2).

4.3 Letter from Adventure Education Sub Aqua Dive Centre to Dr M Davis and his reply.

4.4 Letter from Dr P Chapman-Smith. Dr Meehan to respond to this.

5. **Other Business**

5.1 Dr M Davis gave an update of the status of the New Zealand Chapter, which is not very active.

5.3 Update. Dr Henrik Straunstrup (European Representative) gave a review of European matters.

Closed1445 7/5/99

Key Words

Minutes.

SPUMS

ANNUAL SCIENTIFIC MEETING 2000

will be held at

Castaway Island, Fiji
from May 6th to 13th 2000

The Guest speaker is Professor David Elliott.

The Conveners are Drs Vanessa Haller and Guy Williams.

Members wishing to present papers should contact
Dr Haller at
55 Two Bays Crescent,
Mount Martha, Victoria 3934, Australia

The booking agent is

Allways Dive Expeditions
168 High Street
Ashburton, Victoria 3147, Australia.
Phone + 61-(0)3-9885-8863
Fax + 61-(0)3-9885-1164

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LETTERS TO THE EDITOR

DAN PROVIDES FUNDS FOR VANUATU CHAMBER

DAN S.E.Asia Pacific
PO Box 38a
Ashburton 3147
31/7/99

Dear Editor

I would like to bring to the notice of SPUMS members that DAN SEAP has now recommenced its evacuation cover for Vanuatu. A recompression chamber, which has recently been installed in Santo, is expected to be operational some time in August.

DAN SEAP has provided training and financial support to assist the establishment of a recompression chamber, the lack of which forced DAN SEAP to cancel its evacuation cover to this popular destination last year, in Vanuatu. In late April, DAN SEAP provided substantial funds to send Bob Ramsay, a Director of DAN SEAP, from the Royal Adelaide Hospital and Dr Tony Holley from Townsville General Hospital to Vanuatu. Tony and Bob spent 7 days in Santo training dive operators and their staff in chamber management, maintenance and use. Dr Holley also made presentations on the management of diving accidents to dive staff, hospital staff and local doctors in Port Vila and Santo. DAN SEAP would like to thank Dr Holley very sincerely for his efforts. We also wish to pay special tribute to Bob Ramsay for his tremendous efforts over the past 18 months or so in advancing this chamber project to its current stage.

The funds came from the DAN America Chamber Support Program and we are very grateful to DAN America for diverting these funds to the DAN SEAP Region. This has a direct benefit to both our members and to the diving community in general. It is a good example how any support for DAN is used to improve dive safety. This is the major difference between DAN and other diving organisations. Travel insurers and other companies that sell dive insurance are “for profit” entities. As such, revenue is diverted to the directors and/or shareholders. As a non-profit association, DAN has no shareholders, most of its directors act on a completely voluntary basis and any surplus funds are directed towards improving diving safety.

A visit to the DAN SEAP Web Site at www.danseap.com.au will introduce readers to around 70 pages of information about DAN and its activities.

John Lippmann
Executive Director DAN SEAP

Key Words
Accidents, diving safety, hyperbaric facilities.

BOOK REVIEWS

A HISTORY OF CRITICAL CARE AND HYPERBARIC OXYGEN THERAPY

TW Feeley. Editor.
International Anesthesiology Clinics Vol 37 No. 1 Winter 1999
Lippincott Williams and Wilkins, Philadelphia, Pennsylvania.
Annual Subscription $US 166-202 depending on the country.

This volume is devoted to previously published articles which appeared in International Aesthesiology Clinics when Intensive Care or Critical Care units were being set up across the world in the 1960s and hyperbaric oxygen (HBO) was finding uses outside the diving world. The seven papers, Development of Intensive Therapy: Background and Development (1966), The Assisted Respiration Unit (1964), pH and Acid-Base Balance Measurements (1989), The Development of Cardiac Resuscitation (1963), Cardiac Deterioration in Shock (1964), Septic Shock (1964) and Hyperbaric Oxygenation, are well worth reading.

The papers all have a historical intoduction to the then state of the art. All the topics have had a vast influence on the way that medicine is practised today.

Diving doctors and divers, should turn to page 137where they will find 30 fascinating pages covering the history of the use of oxygen at increased pressure followed by a summary of the Current Status (1965). By then HBO treatments had been used, to increase oxygenation, for gas gangrene, peripheral vascular insufficiency, impending blindness, cerebral oedema, right to left cardiac shunts, ischaemic pain, carbon monoxide poisoning, staphylococcal and other infections, myocardial infections, strokes, asphyxia neonatorum, hyaline membrane disease, cancer radiotherapy, shock, massive pulmonary embolism, bowel obstruction, emphysema and sickle cell anaemia. Not all the results were good and with the newborn, intubation and ventilation have provided better results.

The possible future uses of hyperbaric oxygenation in 1965 included plastic surgery (not yet), extensive burns (yes) and respiratory conditions associated with impaired gas transfer and hypoxia (too many problems). Anaesthesia and anaesthetic equipment get four pages ending with a comprehensive list of how to avoid the problems from changing chamber pressure. The final section covers the dangers of hyperbaric chambers, fire, barotrauma , decompression sickness, air embolism, aseptic (dysbaric) bone necrosis, nitrogen narcosis and oxygen toxicity.

The last three sentences of the paper sum it up. "We stand like the Wright brothers at Kitty Hawk. Our machine is ready and the conditions are suitable; the future of the method rests with us. Accurate, carefully controlled experiments can bring success; unbridled enthusiasm brings only disrepute."

John Knight

Key Words

Anaesthesia, book review, history, hyperbaric oxygen, resuscitation.

SCIENTIFIC DIVING TECHNIQUES

A Practical Guide for the Research Diver.

John A Heine

Best Publishing Company, P.O.Box 30100, Flagstaff, Arizona 86003-0100, U.S.A. 1999

Price from the publishers $US 39.50. Postage and packing extra. Credit card orders may be placed by phone on +1-520-527-1055 or faxed to +1-520-526-0370. E-mail divebooks@bestpub.com .

I looked forward to reading this book with considerable enthusiasm. The last half century has seen an enormous expansion of scientific diving with a concomitant proliferation and increasing sophistication of techniques. An up-to-date synthesis and analysis of these techniques into a single compendium is long overdue and would make an important reference and training manual.

Unfortunately this book does not live up to its catchy subtitle as *A practical Guide for the Research Diver*. This is disappointing given the extensive experience and expertise of the author. In large part the book identifies techniques used in scientific diving but does not discuss how to apply these methods or the merits and limitations of particular techniques. While the book covers reasonably thoroughly much of the technology used by, and available to, scientific divers, it falls short on critical analysis of pros and cons, and how to use and apply the technology.

The book starts well with a brief history of scientific diving and later, in Chapter 1, emphasises the important point that scientific diving is a field in its own right and distinct from recreational, commercial, military and other forms of occupational diving. Thereafter it fades.

Chapter 3 is ostensibly about "specialised equipment and procedures", but there is little on procedures at all, although detailed advice is what most scientific divers would find particularly useful. Rather than simply stating that blue water and ice diving require "specialised procedures" it would have been more useful to describe these procedures. Lift bags, which are a relatively simple and commonly used tool in scientific diving, get a mention but there is no discussion of the key techniques and procedures in their safe operation.

In the chapters on locating and mapping sites and measuring physical factors, the technologies used are presented but there is little about the particulars of using the equipment for scientific purposes. There is nothing about *how* to conduct mapping at different spatial scales, nothing on the trade offs in the design of sediment corers and sediment traps, nor about problems of the presence of divers contaminating water samples intended for nutrient analyses. There is nothing in the book about search techniques. Such information is critical to effective field operations and obtaining robust data.

Chapter 6 on measuring biotic factors and processes is notably more detailed and useful, and the several helpful "how to" suggestions may reflect the author's particular experience. But even here fundamental issues are ignored. Unfortunately the common practice, on land, of locating quadrats at randomly generated *x, y* co-ordinates is simply not practicable underwater. The author does not offer robust alternatives for the scientific diver.

The section on photography introduces much of the still, movie and video equipment available for and commonly used in scientific diving, but again there is little on how to use this gear to obtain reliable scientific data.

Strong positives of the book are extensive citation of reference literature (much of which addresses many of the deficiencies and omissions I have pointed out) and lists of equipment manufacturers and suppliers, although both have a strong bias to US-based work and technology. A notable omission is an index.

In summary, while there is useful information in the book, overall it is rather superficial as a practical "how to" guide to scientific diving techniques. There is too much listing of gadgets and techniques, and too little critical appraisal of how to safely execute techniques underwater for obtaining robust data.

Craig Johnson

Key Words

Book review, occupational diving.

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PROCEEDINGS OF THE XXIII ANNUAL SCIENTIFIC MEETING OF THE EUROPEAN UNDERWATER AND BAROMEDICAL SOCIETY, BLED, SLOVENIA 1997.

Igor B Mekjavic, Michael J Tipton and Ola Eiken. Editors.
Biomed D.O.O., Ljubljana, Slovenia, 1997.

Review copy provided by Best Publishing Company, P.O.Box 30100, Flagstaff, Arizona 86003-0100, U.S.A.
Price from Best Publishing Company $US 44.50. Postage and packing extra. Credit card orders may be placed by phone on +1-520-527-1055 or faxed to +1-520-526-0370. E-mail divebooks@bestpub.com .

It is always difficult to review a Proceedings from the eclectic world of Diving and Hyperbaric Medicine, containing (as they often do) a great diversity of material in subject, origin and quality. This is particularly so of these regular proceedings of the EUBS meetings. Some of the work presented here will be entirely familiar to readers of this journal, telling as they do of the commonality of disease across the globe. A case series illustrates that gas gangrene is the same terrible disease in Finland as Australia (Korhonen and Niinikoski, pp 161-165), delay to treatment of severe carbon monoxide poisoning is as much a problem in the UK as closer to home (Hamilton-Farrell, pp 185-189) and the principles of autopsy after a diving accident are no different in Italy than Glebe (Longobardi et al., pp 112-113). There is something comfortingly familiar about some of these papers, as if we should be reassured by the knowledge that we all make the same mistakes and draw the same false conclusions in the global village.

And yet these papers are only a small part of this collection of research lifetimes. While there may be some repetition across language and culture, one of the great strengths of this meeting and these proceedings is that very cultural diversity. Papers from Slovenia, Turkey, Spain and Germany all jostle for attention within these covers and many are insightful and innovative. Much of the work presented here is not elsewhere available in English and deserves the expanded audience. Olszanski et al. (pp 91-95) and their Polish work on the evaluation of decompression stress by haemostatic and complement assays following saturation air and nitrox exposures is one example, and Ruzicka et al. (pp 216-219), dealing with dynamic predictive modelling of transcutaneous oximetry from the Czech Republic, another.

In a break from previous proceedings of these meetings, the editors have included only presentations for which they had complete manuscripts. The exclusion of abstracts has probably improved the overall quality of the material, at least in the opinion of some of those who attended the presentations themselves. The editors are to be commended for discharging well what must have been the difficult task of maintaining clarity through several translations.

There is a preponderance of Diving (32/48, 67%) compared with Hyperbaric papers here. There is also balance enough of basic research and clinical medicine to offer something for most readers. Less positively, 13 of the 18 clinical papers are case reports or case series. While this leaves 5 reports of clinical comparative studies, none is controlled and randomised, nor even prospective. We must all address this lack of controlled evidence if we wish to be left in charge of the henhouse.

These proceedings are a welcome addition to our library and I would recommend them to any comprehensive therapeutic compression facility. They will prove a useful source of references for future researchers, make an edifying and amusing browse during those late-evening treatments and are not always easily available in general medical libraries.

Mike Bennett

Key Words
Book Review, hyperbaric research, underwater medicine.

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DEEP, DEEPER, DEEPEST

R F Marx
ISBN 0-94-1332-66-7
Paperback, 326 pages.
Best Publishing Company, P.O.Box 30100, Flagstaff, Arizona 86003-0100, U.S.A.
Price from the publishers $US 14.95. Postage and packing extra. Credit card orders may be placed by phone on +1-520-527-1055 or faxed to +1-520-526-0370. E-mail divebooks@bestpub.com .

“The ladder seemed a very long one to me, although there were not more than eight or ten feet between the edge of the vessel and the level of the sea; but the terrible moment is that when one touches the surface of the waves: although the sea was that day as calm as a pond, I felt myself beat about and buoyed up by the natural movement of the waves rolling one over the other, in spite of the leaden weights attached to me. But it was much worse when my head went under the surface, and I saw the water dancing about round my helmet. Had I too great a supply of air in the apparatus, or had I too little? Really it would be difficult for me to say; the fact is, that I felt almost suffocated. At the same time, it seemed that a tempest was roaring in my ears, and as if my temples were screwed up tight in a vice. In good truth I had the strongest desire to go up again immediately, but shame was more powerful than fear, so I slowly descended – too slowly for my liking – for this ladder down into the deep appeared as if it would never end, and yet the water at this spot was not more than thirty or thirty-two feet deep".

So goes the account, reprinted in Marx's excellent book, of a novice diver's first descent into the River Thames in 1859, providing perhaps the first graphic descriptions of two of the known occupational hazards of diving, middle ear squeeze and noise exposure.

The book starts with a history of free diving, beginning (as far as is known) in the 5th millennium BC. The natural dangers of breath-hold diving for sponges and pearls in depths exceeding 30 m were often compounded by the brutal treatment of the divers by their employers. The little known role of free divers in maintaining the Spanish treasure fleets and recovering the cargoes of their frequently sunken ships is described in detail.

Diving remained a risky endeavour, of limited usefulness, until the development of the diving bell. The first use of this device has been attributed to Alexander the Great during the siege of Tyre in 332 BC. Further diving bell implementation was undocumented until 1531 when one was used to locate two of Emperor Caligula's pleasure galleys in Lake Nemi near Rome. Its advantages became widely known after a demonstration by two Greek engineers in Toledo, Spain, before Charles V and 10,000 spectators. One of its limitations, a fixed quantity of air, which became polluted with carbon dioxide as its oxygen was consumed, was overcome by Denis Papin, a French physicist, who provided a fresh gas supply to the divers using a bellows on the surface, but maximum depth was limited by the available pumps to around 70 feet. William Halley subsequently devised a method by which fresh air could be lowered in barrels.

Later chapters describe one atmosphere diving suits ("diving machines"), first developed in 1715 by the Englishman John Lethbridge, as a barrel shaped device with openings through which the arms could reach outside, and culminating in the Swiss-built bathyscaphe *Trieste*, which descended to the deepest known depth in the oceans, 10,900 meters in the Marianas Trench. There are detailed descriptions of the development of the helmeted diving suit and its use in the attempted salvage of the *Royal George* in the 1830s and the *Laurentic* during and after World War I. The advent of diving bells and compressed air diving was accompanied by the additional dangers of nitrogen narcosis and decompression illness. The former limited the operational depth for air diving to around 60 m. Deeper depths were rendered achievable using the non-narcotic gas helium. Acceptable methods for prevention of the decompression illness ranged from the systematic development of decompression tables (and more recently computers), to the elaborate gas switching procedures (heliox to nitrox with progressively increasing O_2 fractions) proposed by Hannes Keller, a Swiss mathematician, which were validated by spectacular demonstrations in which divers reached 300 m and required only 270 minutes of decompression time. The technique was not initially adopted perhaps because the final open sea dive in this series was tragically marred by death due to technical error.

The rich history of the development of scuba, military diving, underwater habitats, submarines and submersibles is followed by concluding chapters on underwater archaeology, treasure hunting, oceanography and the use of ROVs, perhaps best known for exploring and photographing the interior of the wreck of the *Titanic* at a depth of over 4,000 meters. The book is capped by a list of over 50 suggested readings.

In every book there are features that one might have hoped for. In this instance, it is a pity that such an exhaustive book does not have an index. Although various chapters describe the impact of physiological constraints such as bubble formation, the history of decompression table development, treatment methods, and other challenges such as the prevention of hypothermia and the high pressure nervous syndrome (HPNS) are lightly covered.

Marx has researched his topic well, and there are few errors or oversights. A limiting factor for helium-oxygen breathing mixtures is stated to be narcosis, rather than HPNS. The 1974 Comex *Physalie* chamber dive to 606 m (2,001 ft) has been superseded many times, the world record, again achieved by Comex, now standing at 701 m.

One of the strengths of this book is the degree to which Marx has brought the history to life. He has amply spiced the text with numerous anecdotes and direct quotations, similar to the one above. It is a remarkably complete history in a small package. Most of the accomplishments of the well-known pioneers from ancient to modern times are included, along with countless others. The text, which is a joy to read, is supplemented by sharply reproduced black and white photographs and line drawings. For the casually interested, this book is both entertaining and enjoyable. For diving history buffs looking for a compact, readable description of man's forays into the underwater world, here it is.

Richard Moon

Key Words

Book review, diving operations, history.

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SPUMS ANNUAL SCIENTIFIC MEETING 1998

EARLY DIVING PROBLEMS AND FATALITIES

John Bevan

Key Words

Accidents, equipment, history.

Abstract

Diving accidents and incidents contribute to a steep learning curve. Over the centuries, divers of all descriptions have provided us with a wealth of useful data to help us learn and understand the physics and physiology of diving through their self-sacrifice, though perhaps not necessarily intentionally. This paper traces a variety of such events which befell divers in bells, semi-atmospheric systems and helmets as they adventurously pioneered their downward quest.

Early accidents

The early history of diving medicine has already been well-documented and it is not my intention to duplicate this effort. My aim is to relate some of the lesser-known examples of early diving incidents and accidents which have provided the subject material for aspiring diving medics.

Since the earliest form of diving would have been breath-hold diving, there is little of interest that can be said about related accidents. However, the the first recorded underwater war casualty was the Arab diver, Issa, who in 1190 served with the fleet of Saladin during the Third Crusade. He carried money and letters between the fleet and the shore. Eventually he was shot and killed by a Crusader archer. Figure 1 is a rather fanciful illustration showing him swimming in helmet, with a built in snorkel, and wearing weights round his waist. Above him Crusaders are dumping the dead and below him two large Morays are tidying up the mess.

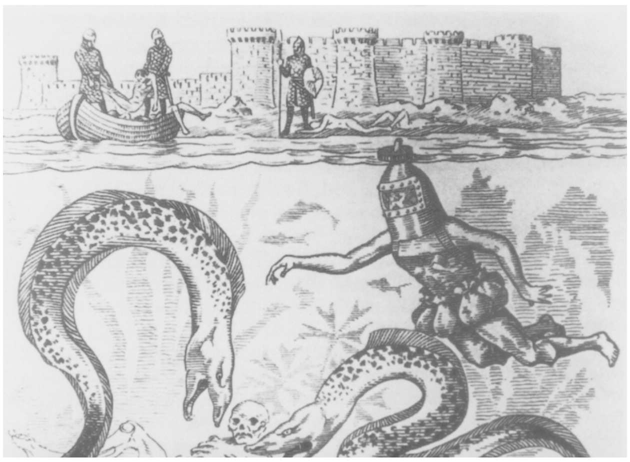

Figure 1. The Arab diver, Issa, who in 1190 served with the fleet of Saladin during the Third Crusade, carried money and letters between the fleet and the shore. He was the first recorded underwater war casualty.

The first genuine diving accidents would have arisen with the use of diving bells where there is every opportunity to generate a plethora of diving illnesses.

It is not surprising, therefore, to find that as early as 1535 in the very first reliable account of any bell diving operation, the first reference to the problem of ear-clearing is also recorded.[1] On 15 July 1535 the Italian bell diver Francesco da Marchi dived in the bell designed by Gulielmo di Lorena when he was able to survey the Roman galleys sunk in Lake Nemi, near Rome, and explained: *If you can swim you can undo the buckle of the harness, leave the vessel, and rise to the surface as I did the second time I entered the apparatus and went to the bottom. Be warned, that for 20 days afterwards, with every step I took, my ears tingled.*

After carrying out the first recorded free ascent from a diving bell, Marchi is lucky that it was only his ears that suffered from barotrauma! Marchi had more to say about pressure equalisation problems; *... when I was going under water I felt such a pain in my ears that it seemed that a steel dagger had been put into me, which transfixed me from ear to ear, and I felt very great pain. I tell you that it was so great that a vein in my head broke, so that the blood came out of my mouth and nose ...*

We probably have here the first recorded example of a sinus squeeze and underwater nose bleed as well as the ear clearing problem. Marchi also recorded for the first time the dangers of being eaten alive whilst diving: *I tell you that the fish called* laterini, *which are in this lake and which are not bigger than your little finger, appear below as thick as a man's arm and three palms long. If I had not been told about these fish, I would have been frightened by the great multitude that swam in my direction, especially as I was carrying four ounces of bread and one of cheese with me to eat, and because the bread was hard and black it fell to pieces and a huge number of fish came round and surrounded me, and as I had no breeches on, they came to bite me in that part which a man can think of ... I was not wearing breeches, because in Tuscany at the time of Duke Alessandro de Medici, who was my patron, when some fishermen once went to fish along the Arno, there was one of them who dived under the water to catch some fish by hand (and there are a lot of people in that province who *catch fish under water), and he got caught by his breeches on the root of a tree, and they could not dislodge him, and he stayed there dead ... which was the reason why I did not put any on, and so the fish freely bit me in that part more than in any other.*

There has to be a whole string of firsts in this account. The first record of an underwater meal break, the first animal attack on a bell diver, the first case of injury to a diver in "that place which a man can think of" and perhaps the first bell diving practical joke if Lorena had had his tongue in his cheek when he suggested to Marchi to take his trousers off and take a piece of dry bread down with him!

The 17th century

Perhaps it was excessive use of a diving bell or pulmonary barotrauma from a bell dive that caused the earliest diving accidents. As early as the 17th century, perhaps the first diving medic made his appearance and proposed a special treatment for divers with "falling sickness".[2] This was Nicholas Culpepper (1616-1654) and apart from allegedly curing decompression illness the treatment had a beneficial side effect of curing the diver's scabby head at the same time: *FOX GLOVE - (Digitalis purpura) ... the herb bruised and applied, or an ointment made with the juice thereof ... and a decoction of two handfulls thereof with four ounces of polypody in ale, has been found by late experience to cure divers of falling sickness, that have been troubled with it about twenty years. I am confident that an ointment thereof is one of the best remedies for a scabby head.*

But before anyone re-introduces this alternative medical treatment in place of therapeutic recompression it should be pointed out that the word "divers" in those days was commonly used to denote "various people", and that "falling sickness" normally referred to epileptic fits. On the other hand, the administration of the medicine with a pint of beer would certainly fit a diving context.

Asphyxia would have been a perfectly reasonable problem to encounter in bell diving. Indeed, as early as 1663, a Scotsman named James Maule recorded that at depths below 16 fathoms (96 ft, 29 m) bell divers were liable to faint.[3] Maule's diving bell was made of lead. It was two and half feet (0.75 m) deep and as wide at the base. This was a very small bell and it is hardly surprising that, with claims that they could dive to 24 fathoms (144 ft, 43.6 m) for half an hour, the poor diver would faint. In fact he would probably have been dead for the last 20 minutes of the dive!

The dangers of breath-holding during an ascent either in or from a diving bell would have been an early experience for the underwater adventurers. The first allusion to this problem has been traced, by fellow historian Nigel Phillips, to a letter from Thomas Bartholin the Younger of Copenhagen, Denmark, to his colleague Dr Johann Ludwig Hannemann, a professor at Kiel, in Germany written on 20 September 1676.[4] Bartholin refers to Wynmann who had stated: *... that divers use a suitable glass vessel, very large and capacious, into which they give off the breath of their nostrils or mouth.*

Bartholin also referred to a previous letter received from Hannemann saying: *But those who braved the seas held their breath with a greater danger. I shall not add a word about respiration, as you will have demonstrated it lucidly in your letter, from the medical point of view.*

Is Bartholin talking about breath-holding here? The letter he refers to from Hannemann has been traced, but, being in Latin, a translation is awaited and unfortunately is not yet available.

Not long after, Sir Edmond Halley (1656-1742), while pursuing his day job as a salvage diver, was exploring the frontiers of diving physiology. In July of 1691 he tested his new diving bell at Pagham harbour on the south coast of England and in October that year took out a patent for his revolutionary life support technique entitled an "Engine for Conveying Air into a Diving Vessel".[5,6] His intention was to demonstrate how he could remain in the submerged bell for as long as he wished thanks to his invention. The experiment was an outstanding success and he remained one and a quarter hours at a depth of 60 ft (18 m). Unbeknown to Halley, he had been the first person to exceed the no-stop dive duration recommended by the Royal Navy nearly 300 years later. Halley also claimed that there was no limit to the depth he could reach with his bell. It is clear that his new technology would have introduced him, and those who followed his example, to hyperbaric exposures easily capable of producing decompression sickness.

One of Halley's less well known records of a bell diving problem was that of the cut finger incident. Though perhaps not life-threatening or likely to have made the front page of the Phil Trans Roy Soc, Halley's observation that blood was green when viewed underwater was perhaps the first time this curious fact had been brought to the attention of the public.

The 18th century

Halley clearly carried out quite a few dives with his bell because he took a special interest in the problems of ear-clearing. So much so that, on 22 February 1722, he read a paper to the Royal Society on the subject entitled "Of protecting the drum of the ear under water" which had to wait over 200 years before it was published.[7] In it he described, perhaps for the first time, the mechanics of ear clearing: *... I related a constant effect of the pressure of the condensed Air upon the outward passage of the Ear, which was felt by all persons that went down in the diving engine, not without pain; till such time as a valve (as I conceive) that is placed near the Drumm of the Ear being forced by the great pressure of the external medium, gave way and slippd up; whereby the Air in the Cavity within the bony caverns of ye Ear immediately became of the same density & elasticity with the external, whence present Ease ensued ... The constancy of this effect made me conclude that there was a valve obstructing the entrance of any thing into a cavity of ye Ear from without ... which if I mistake not they call the Eustachian Tube ...*

The well-known Swedish "urinator", Martin Treiwald, who had developed an improvement to the life support system in his campana urinatoria, provided a useful insight into some of the life-threatening problems associated with his profession in 1736.[8] He described how divers in semi-atmospheric diving suits were risking instantaneous drowning if the atmospheric compartment of their diving dress lost its watertight integrity and how a bell diver once saved his own life by stopping a leak in his bell by simply placing his hand over the leak: *I will not for brevity sake, mention the many impediments that attend other inventions, only that of a water armour, in which the man is drowned in an instant, when such a machine receives the least leak. Whereas experience has shewn, that when such an accident has happened to the diving bell, as to my knowledge it did once, when the diver was 12 fathom* (72 ft, 22 m) *underwater, and a pretty large hole happened to be struck in the bell, by a boult of the wreck he went upon, at which time the air rushed out of the same with such violence as astonished the beholders by the excessive boiling on the surface of the water, fearing, not without reason, that the man in the bell was drowned; but he clapped his hand to the hole or leak, and gave a sign to be hauled up, which was done with all the ease and safety as if no accident had happened to him, the water having only risen about half a foot into the bell by this leak.*

The very same diver that was then in the bell is 63 years of age, and has used the business of diving ever since he was 20, in a common diving bell, till of late, and is as yet a pretty strong and healthy man.

The increasing use of semi-atmospheric diving systems led to an inevitable increase in accidents. In 1763 J T Desaguliers produced a comprehensive list of important observations in his Course of Experimental Philosophy,[9] including one concerning a semi-atmospheric suit: *... though this diving engine be better than a great many, yet it has the same inconveniency of not being fit for great depth of 11 fathom* (66 ft, 18 m) *he felt a strong stricture about his arms by the pressure of the water; and that venturing two fathoms* (12 ft, 3.6 m)*lower to take up a lump of earth with pieces of eight sticking together; the circulation of his blood was so far stopped, and he suffered so much, that he was forced to keep his bed six weeks. And I have heard of another that died in three days, for having ventured to go down 14 fathom* (84 ft, 25.5 m).

Desaguliers then gave the first clear description of the potential dangers of pulmonary barotrauma in bell divers.[10] *Care must be taken not to take up the bell too fast, because the condensed air in the bodies of the divers must expand itself by degrees, and be breathed out; otherwise, if they were too suddenly delivered of the outward additional pressure, the air within them would burst them outwards.*

Desaguliers could not exclude the well-documented ear-clearing problem from his review but added a bonus in his record of the danger of the use of ear plugs when diving and perhaps the first intervention of a diving surgeon.[11] *At first they felt a small pain in their ears, as if the end of a tobacco pipe was thrust in their ears; but after a little time, there was a small puff of air with a little noise, and they were easy. ... One of the men, to prevent this pressure, stopped his ear with a pellet of chewed paper; but that pellet was pushed in so far, that the surgeon had much ado to get it out.*

Diving bells were the safest way to dive during this period and much attention was given to improving their design further. Charles Spalding of Edinburgh, Scotland, made several such improvements but continued to use Halley's life support system. One account of Spalding's successful bell diving operations stated *Mr Spalding, impelled by curiosity and intrepidity of spirit, and a genius for mechanics, made several attempts to remain for a considerable time in deep water under the bell which was always crowned with success. He at length became such a proficient in the aquatic art, that he could remain if necessary for a whole day in water of 12 or 14 fathoms deep* (72 to 84 ft, 22 to 25.5 m!).

Not only are we looking here at the first saturation dives but the ringing in the minds of diving medics with an interest in decompression procedures must by now be reaching a deafening level.

Sadly, on 2 June 1783, Charles Spalding became a fatal diving accident statistic whilst diving with his bell on the recently sunk wreck of an East Indiaman outside Dublin harbour, Ireland. A newspaper account[12] gave the following description of the accident: *They had been down three times the preceding day, and in the last fatal attempt, had remained an hour and a quarter; during the first hour, the signals had been properly attended to, and three supplies of fresh air conveyed down, but unhappily, as is supposed, the last barrel had not reached them, which must immediately have brought on a speedy suffocation, so as to have prevented them from adopting the mode of preservation invented by Mr Spalding, of cutting the weight that hung from the center of the bell, by which means it must have immediately reached the surface of the water ...*

Upon drawing up the bell, Mr Spalding was found reclining on his breast, and Mr Watson sitting erect.

It does seem very strange that Spalding did not initiate an emergency ascent as his bell was specially designed to do. Perhaps there was a different reason for the accident. The same newspaper proposed an alternative and very interesting explanation for the fatal accident in the following day's edition: *From the authority of several skilful investigators into the ill-fated cause of Mr Spalding's death, it appears evident, that it was undoubtedly owing to a highly noxious effluvia, either arising from the putrid bodies in the Indiaman, or the great quantity of medical plant called Ginseng, part of the cargo; his death must have been instantaneous, from the highly active and exalted state of the putrid air ...*

This appears to be a very likely cause of the deaths of the two bell divers. As such, the sad event provides the first recorded death of a diver due to breathing a contaminated air supply.

The same year, 1783, William Tracey (b 1735), a ship broker at Portsmouth, attempted a dive on the wreck of the ROYAL GEORGE at Spithead, Portsmouth.[13] He used a semi-atmospheric diving suit which included a copper section which covered his head and chest. He appears to have tried to go too deep and suffered a very serious neurological problem as a result. In his own words:[14] *I returned to London in Nov 1782, where I lived ... at heavy expense, much increased by procuring diving machines, pipes, and other necessary apparatus, in order the more effectually to discover the state of the ROYAL GEORGE lay in etc, in which undertaking of going down under water, the first time, the pressure of the water occasioned my great injury, as it was from that pressure I am now a cripple.*

A friend added further information: *... when inspecting the ROYAL GEORGE in his first imperfect machine, received a material hurt, by pressure of water, which brought on lameness for many years, with two bad ruptures, and has been for the last two years an entire cripple on crutches.*

The chronicle of the use of semi-atmospheric suits must be riddled with such disaster stories.

On the other hand, the good news is that in 1799 a medic named Dr Thornton, Physician to the General Dispensary, Guy's Hospital, London, began promoting oxygen treatment as a cure for a variety of ailments. He published a series of papers including "A Remarkable Case of Scrophula cured by Vital Air, A Remarkable Case of Internal Pain in the Heel, and an Incipient Mortification, cured by Inhalation of Vital Air, A Case of Melancholia, A Case of St Antony's Fire cured by Vital Air".[15]

The 19th century

Another good word is put in for oxygen by a Mr J Elliott in a letter to the Mechanics Magazine in 1832.[16] Elliott related his observation concerning a bell dive in the river Thames over the site of the digging of the Thames Tunnel by Sir Mark Brunel and the young Isambard Kingdom Brunel, where the river bed had collapsed into the tunnel and caused it to flood, in 1827. The great scientist Michael Faraday carried out a bell dive and first discovered the beneficial effect of hyperbaric oxygen on breath-hold times: *At the time of the first irruption of water into the Tunnel, Mr Faraday descended in the bell with Mr Brunel, Jun; and in a lecture at the Royal Institution, Mr F stated a remarkable fact, that Mr Brunel, when he dived under water from the bell into the Tunnel, was able to remain full two minutes under water without experiencing any great inconvenience. He accounted for the fact in this way: when the bell was lowered to the greatest depth (about 30 feet* [9 m]*) the air inside was necessarily much compressed; the persons in it, therefore, though they inhaled the same bulk of air which they would under other circumstances, yet as two atmospheres were compressed into one, inhaled twice the quantity, and of course a much larger supply of oxygen was furnished to the lungs.*

Staying with this subject, a Dr Foley made some enlightening remarks about the positive effects of hyperbaric oxygen treatment in 1864,[17] when he quoted from a sitting of the Societe Medicale d'Emulation: *... if a patient be in want of more oxygen than he can get under the ordinary pressure, let him be exposed to an atmosphere rendered artificially denser. This can be done by constructing a small chamber, communicating with a forcing-pump, and provided with an air-gauge and a safety valve. A patient confined in such a chamber may be subjected without inconvenience to the pressure of about two atmospheres and a half. By this treatment catarrh, asthma, and other complaints of the respiratory organs may be removed. In croup the compressed air will flatten down the adventitious membranes; and in disorders arising from weakness compressed air will arterialise the blood and increase the vital power of the patient.*

Finally, on the subject of hyperbaric oxygen, Alphonse Esquiros mentioned in passing in his book on English Seamen and Divers dated 1868.[18] "The workmen also quote an instance of a consumptive person who was entirely cured by using the diving bell."

Returning again to the 1830s we pick up our next diving-related incident which is one of asphyxia. The danger which threatens when inexperienced people experiment with equipment they do not understand was well demonstrated in 1836 when a second-hand shop dealer decided to try on one of Charles Deane's old diving helmets with its attached jacket:[19] *A tradesman in Blackman Street named Caston, carrying on the occupation of a 'general* *dealer' had a narrow escape from suffocation a few days ago, under singular circumstances. Amongst some articles he had purchased at a sale was a diving apparatus. Never having before seen a machine of similar construction, Mr Caston determined to try it in the first instance on terra firma, and for this purpose drew the helmet or cap over his head, and then adjusted that part of it which fitted the lower extremities. He however omitted the most essential part of the apparatus - namely, the valve which admitted the air onto that portion which fitted over his head and face. The neglect nearly cost him his life; for when one of his servants entered the warehouse, Mr Caston was discovered rolling in great agony. The servant entered just in time to extricate his master.*

Not very far away, a little down river on the Thames, a brig had sunk in the middle of the fairway and was a major obstruction to the shipping traffic. The Lord Mayor of London commissioned Colonel Pasley of the Royal Engineers to clear the wreck using gunpowder. Pasley originally considered using a diving bell but eventually decided to try to employ his own Sappers and Miners who could use the new diving helmet and dress. Corporal Henry Mitchell, one of his best men was sent down in a Fraser design of diving dress. Figure 2 shows how the work was carried out. Unfortunately, because he was untrained and completely inexperienced in diving, he became foul of the wreck and died. Mitchell was the first military fatal diving accident. Pasley was so grieved about the accident that he personally commissioned and paid for Mitchell's grave stone.[20]

Between the years 1839 and 1843, the biggest diving operation to date was carried out at Spithead, Portsmouth, when Colonel Charles Pasley in charge of a team of Royal Engineers, Royal Sappers and Miners and Sappers from the East India Company, completely cleared the wreck of the 108-gun ROYAL GEORGE from the prime naval anchorage. It was an enormous feat of engineering and helmet diving. To Pasley's credit, not one fatality occurred to a diver under water during the entire operation, though there were some interesting incidents.

One of the most insidious of these was the emergence of serious cases of "rheumatism". Pasley became quite concerned about it because it was affecting the efficiency of his operations. On 25 May 1841 he noted in his personal journal,[21] that Corporal Harris "has rheumatism" and Corporal Jones is "excellent. He remains 1 1/2 hours under water" in 13 fathoms (78 ft, 23.6 m) and in August Williams stayed down 2 hours" and again on 29 June and 14 July Corporal Harris "is ill". George Hall, the noted civilian diver who introduced helmet diving to the Royal Engineers did not escape this strange "illness" either. The local newspaper reported on 31 August 1841[22] that: *Mr George Hall, who has distinguished himself so much under Colonel Pasley at Spithead, having been obliged to give up his employment on the 8th instant, and having soon after quitted Portsmouth on account of an illness, which though not serious, rendered him unfit for the laborious duty for some time ...*

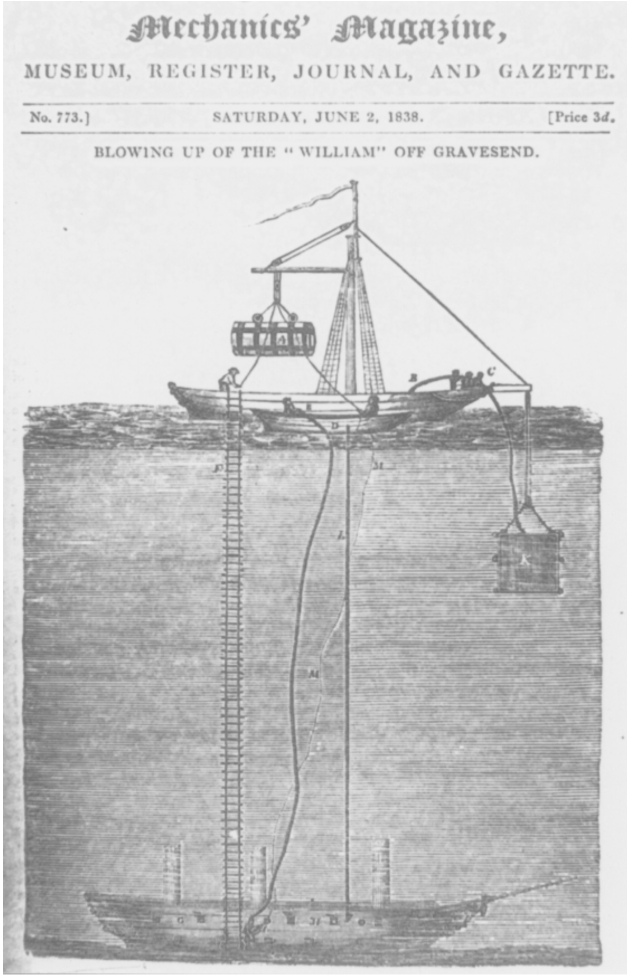

Figure 2. On 21 May 1838 Cpl Henry Mitchell became fouled on the wreck of the *William*. He died from either hypothermia or drowning. This was the first British military diving fatality.

The "rheumatism", and even "violent attacks of rheumatism" became such a major problem that in 1846, the Royal Engineers published an Aide-Memoire[23] to establish the best way to avoid the condition developing: *To guard against the effects of damp and cold striking through the dress, the diver must be well clothed in flannel or woollen dresses: he generally puts on two suits, each consisting of a pair of drawers, stockings, and a Guernsey frok; these must be well dried, and aired on being taken off: constant change is necessary so that every diver should have about six suits in wear. At Spithead the regulations as to drying were strictly enforced; a cabin was set apart in the vessel on board of which the men were quartered, as a drying room, with a stove in the centre and rails all round for hanging the dresses on; the divers' attendants received them as they were taken off, took them to the drying room, and supplied fresh ones before the ensuing tide: in this way* *the divers were always provided with warm comfortable garments, but notwithstanding these precautions many were subject to violent attacks of rheumatism.*

In the years ahead, "rheumatism" reared its ugly head many more times. One Whitstable diver who had been diving since the early 1830s, named William Wood, attracted the following comment from the author of an article about him in 1875:[24] *I am sorry to say that since the above was written, poor Mr Wood has died. He suffered terribly for many years with rheumatism, the result of spending so much of his time under water.*

Returning to Pasley and the ROYAL GEORGE, even more insidious were his references to divers who became "over-fatigued". On 22 June 1842 he wrote a letter to the Admiralty[25] to let them know his policy on recruiting new divers when his own divers became unfit to continue their work: *... as the number of volunteers far exceeds the number actually required I have given orders that only the best of the whole shall be employed, and in case of their being attacked by rheumatism or over-fatigued, which occasionally happens, that they should be replaced by the next best.*

Pasley was a little more explicit in his letter to the Admiralty on 7 December 1843 when he used the actual word "paralysis": *I now write to request through you, that their Lordships will be pleased to extend this exemption to the case of Philip Trevail of the Royal Sappers and Miners, who was sent as a patient to Haslar Hospital on 20th of October and remained there 36 days, in consequence of his having been severely injured whilst diving, not by any accident, but from his extraordinary zeal, which induced him to over-exert himself and remain too long under water, which caused him a sort of paralysis of one side, as the Surgeons informed me, when I visited him in hospital. Before this period he was one of the strongest and most active men in his corps ...*

These notes penned by Pasley in 1842 and 1843 represent the first reliable references to "type II" decompression sickness cases.

The Canadian diver J B Green has provided one of the earliest and most descriptive accounts of a serious case of decompression sickness following a series of deep dives he carried out in 1854: *I removed the face of the armour, and sat down to await for the implements. I had sat but a moment, when a sharp pain shot like lightning through my lower extremities, and the next instant it went through my whole system, so prostrating me that I could not move a limb, or even a muscle ... The best physicians pronounced me incurable ... it was five tedious months before I could step; and in the spring I was only so far recovered as to walk a very little with crutches.*

As soon as Green felt well enough to dive again, he repeated the exercise and was immediately struck down once more, in which state he remained for the rest of his life.[26]

Paul Bert (1833-1886), the great French physiologist pointed out very serious problems suffered by sponge divers using the English diving apparatus whilst those using the diving equipment produced by Rouquayrol and Denayrouze had no problems whatsoever. He quoted the unpublished memoire of M Aublé, the agent for the Society for Sponge Fishing. A certain amount of national bias may be detected in the account: *During the 1867 cruise, no serious accidents occurred among the men who were equipped with this apparatus for fishing. But in the same season, out of 24 men who used 12 suits of English manufacture, 10 died ... three of them died suddenly as they were leaving their submarine work and ... others had languished from one to three months, paralysed in the lower limbs and bladders.*

This is the earliest record of death in divers by decompression sickness so far found.

The temptation to go too deep and stay too long was greatest where gold bullion lay waiting to be recovered. This was certainly the case when the SS *Alphonso* sank in 160 feet (48.5 m) of water. Two of the best divers from Siebe Gorman, Alexander Lambert and David Tester, recovered £20,000 in 1885 but "their urinary organs were affected for the rest of their lives".[27]

The phenomenon of a suit squeeze became possible once the "tight" diving dress had been introduced (as early as 1835) by John Bethell. If the diver's air pipe burst at or near the water surface, the pressure would immediately fall to atmospheric pressure within the air pipe. Since the pipes were made to be incompressible by the inclusion of a spiral wire in the wall of the pipe, it did not collapse and the pressure in the diver's helmet would fall quickly to atmospheric pressure. In effect, the diver would become a semi-atmospheric diver with only his head protected from the ambient pressure! The result was inevitably catastrophic for the diver. The first time this happened was to the unfortunate Private Roderick Cameron on 4 October 1841. Dr John Richardson of Haslar Hospital described the effect in a paper to the British Association in 1842: *On the 4th October 1841, Roderick Cameron, a private in the Royal Engineers a well-made, tall, active and intelligent man, who had been trained for some time as a diver, descended to the bottom in 13 fathoms (78 ft* [23.6 m]*) and in a few minutes afterwards the air-pipe burst close to the pump. The air escaping with a loud rushing noise ... instantly made the accident known, and the workmen commenced immediately to haul the man to the surface by the safety line, the air pump being kept in action all the time. Cameron himself imagines that he became aware of the accident sooner than those up on the deck, and he had time to make the signal of danger before he felt that they were pulling him up. His first sensation was that of suffocation, from want of air, and* *he felt that the collar of the helmet, the leads on the back and breast and the dress on the body generally pressing upon him, as if he was about to be crushed, after which he lost all perception. It is supposed that he was brought up to the surface in less than one minute, and air was immediately admitted into the helmet by unscrewing the eye-piece. No water had entered the caoutchouc dress. In less than quarter of an hour he recovered his consciousness and was soon afterwards able to speak. He was immediately removed to Haslar Hospital, three miles distant from the scene of the accident. When first examined at Spithead, the face, head and neck and breast were discoloured, and the tint became darker before he reached the hospital. When he arrived there, his face was considerably swollen, his neck more so; both had a dark purple hue, and large patches of extravasated blood separated the conjunctiva from the sclerotica of both eyes ... Leeches were applied to the throat, and he was placed in a warm hip-bath ... he was anxious to return to his duty as a diver, but was not permitted to do so again that season ...*

The same thing happened to Private John Williams on 11 July the following year. This time Dr John Liddell of Haslar Hospital gave the gory details:[28] *.. he was conveyed to the hospital, where he arrived one hour after the accident. His face was then one mass of lividity; his neck was excessively swollen, bloated, and suffused with livid coloured blood. Dark patches of ecchymosis that did not coalesce existed over his clavicle and shoulders ... He vomited some blood before he reached the hospital, and afterwards he made occasional efforts to vomit ... The haemorrhage had ceased from the nose and ears, which were still covered with clotted blood ... On admission, warmth was applied to his extremities; some warm tea was given him, which he swallowed with the greatest difficulty; he had a turpentine enema; and in the course of the day, twenty ounces of blood were taken from the arm ...*

The divers are employed four hours at a time, during the slack of low water, and in that space they usually descend four times. On their ascent after an hour's submersion, they appeared to me, while they were leaning against the hulk's side to be pale, languid and exhausted, though they did not admit that they were fatigued.

The severity of the decompression insult the divers were experiencing is also clearly stated here and it is comforting to note that diving medicine has moved on from leeches and turpentine enemas. Private Williams was back diving within 25 days and Pasley also decided to put non-return valves in the diver's helmet where the air supply hose was connected.

A more serious case of suit squeeze was enacted in the USA in 1854 when an English diver named Tope using a tight diving dress was lowered down a mere 40 ft (15 m). The account speaks for itself. *The signal line was at once worked to ascertain if anything was wrong; but receiving no answer, they at once drew him to the surface, and on opening the armour, to their horror, found him quite dead; although he had been down but one minute. The corpse presented such a dreadful spectacle; blood was oozing from the eyes nose and mouth ... we found the head very badly swollen, the face and neck so filled with blood as to resemble liver, while the remainder of the body was as white as unclouded marble.*

Within just ten years or so of the Royal Engineers adopting diving as a *bona fide* military activity, they had the opportunity to apply it in a military conflict when Britain, in an unusual alliance with France and Turkey, declared war on Russia in 1854. The principal theatre of the conflict was the Crimea. This is where the first fatalities of helmet divers occurred during an armed conflict. Sadly, as they might have preferred, the divers did not die "with their boots on" but were the casualties in a devastating storm which dashed their ship, the PRINCE, to pieces on the rocks at Balaclava with the loss of over 140 souls on board.[29] The diving casualties were Sgt William Carns and four privates of the Royal Sappers and Miners under the leadership of two civilian divers from Guernsey, Mr John Gordon and Mr Orchard.[30]

A further civilian diving casualty of the Crimean War was that of John Deane's partner, William Edwards of Whitstable, Kent, who died of dysentery and "fatigue" during diving operations at Kertch.[31]

The diving career of Frank Davis (1844-1885) was one of the most successful and well respected until one day in November 1879. His account explains what happened next: *Got a few days work to examine the bottom of a well at Short Heath for Birmingham water works company in one hundred and twenty feet* (36 m) *of water. Did this satisfactory although owing to the great depth and severe cold it was very distressing. I must mention that I caught a severe cold which partly paralysed me and brought on severe rheumatism through sleeping in a damp bed while at this job and I had to return to London where for months I was laid up not able to work and under medical treatment.*

Three years later, he records: *Unemployed until early in January during the whole of which time I was under medical treatment for rheumatism ... Still under medical treatment and this is now November.*

Frank Davis died two year later while working in India. His sad experience must have been repeated many times by his colleagues who, tragically, were working in complete ignorance of the cause of their "rheumatism" and paralysis.

It has become clear that the international diving profession was plagued with a very high incidence of all forms of decompression illnesses well into the early 1900s. The work of the Admiralty Committee on Deep Water Diving (1905-6), and Professor J S Haldane's decompression tables (1908) that were generated as a result, provided the desperately needed turning point in this disaster-ridden profession.

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OXYGEN TOXICITY
A BRIEF HISTORY OF OXYGEN IN DIVING

Chris Acott

Key Words

History, hyperbaric research, incidents, injuries, oxygen, medical conditions and problems, unconscious.

Introduction

The Earth was probably formed about 4,600 million years ago by the gravitational coalescence of cold material. Initially there was a tenuous atmosphere of hydrogen and helium which was lost because of a weak gravitational field. The secondary atmosphere was created by the thermal and radioactive decay of various Earth's constituents. Ammonia dissociated into nitrogen and hydrogen and water vapour into hydrogen and oxygen. However, by far the greatest source of oxygen was, and still is, from photosynthesis. There is some evidence to suggest that the atmospheric concentration of oxygen cannot have changed for the past 345 million years.[1]

Discovery of oxygen

Oxygen was not discovered until the 18th century, although its presence in air, as a gas which supported combustion, was postulated by Boyle and Hooke (1666), Lower (1669), Mayow (1673) and demonstrated by Joseph Black (1728-1799) in 1754. He showed that when a substance burned it gained weight.[2] Boyle and Hooke demonstrated that respiration kept animals alive. Before this scientists believed Aristotle's theory that respiration cooled the blood.

In 1772 Carl Wilhelm Scheele (a Swedish chemist, 1742-1786) showed that air was a mixture of two gases, one which he called "fire air" because it supported combustion and the other "foul air" because it did not.[2]

Independently, in 1774, Joseph Priestley (1733-1804) also discovered oxygen by heating red mercuric oxide. He noted that a candle burned "with a remarkably vigorous flame". Priestley was unsure of what he had discovered but because he believed in the "phlogiston theory" he called it "dephlogisticated air".

The phlogiston theory had been devised by Johann Becher in 1669. It stated that during combustion or respiration a substance was liberated. This substance was called phlogiston (from Greek, meaning "burned") by Georg Ernest Stahl about 1700.[3]

In 1774 Priestley discussed his discovery with Antoine Lavoisier (1743-1794) who immediately appreciated its significance. In 1781 Lavoisier named dephlogisticated air "oxygen" (or acid producer) and in 1786 he refuted the phlogiston theory, despite opposition from Priestley and others.

Thomas Beddoe's publication *Considerations on the Medical use and on the production of Factitious Air* followed Lavoisier's work and was the first publication to postulate oxygen's therapeutic role.[4]

Central Nervous System oxygen toxicity

Soon after the discovery of oxygen, and the introduction of the combustion theory of respiration, it was suggested that oxygen might be toxic as an increased oxygen concentration would induce an increased respiratory exchange thus accelerating pulmonary circulation and congesting the lungs. In 1789 Lavoisier and Seguin challenged this view by stating there would not be an increase in the body's oxidative processes.[5] However, it was not until 1849 that the animal data of Regnault and Reiset showed that there was no evidence of an increase in oxidative processes due to an increased concentration of oxygen.[6]

In 1878 Paul Bert first described the central nervous system toxic effects of hyperbaric oxygen in his classic work *La Pression Barometrique*. This book was translated into English in 1943 and reprinted in 1973 by the Undersea Medical Society.[7] CNS oxygen toxicity is sometimes referred to as the "Paul Bert effect". He showed that oxygen was toxic to all living matter, insects, arachnids, myriapods, molluscs, earthworms, fungi, germinating seeds, birds and other animals. Among other experiments he transfused normal animals with blood from those that had convulsed while breathing oxygen. These animals did not convulse and so he concluded that the toxic properties of oxygen were direct effects. He described this toxicity as "A profound modification in the metabolism of tissues".[7]

He attempted to determine the most favourable oxygen partial pressure but concluded that *an increase in oxygen tension above its normal value in ordinary air seemed to bring no advantage,......When any difference is noticeable it is in the favour of normal air*.[7] In many of his experiments, particularly on larger animals, the tension of carbon dioxide was not controlled.

Since his experiments, many other investigators, Lorrain Smith (1899),[8] Hill and MacLeod (1903),[9] Barach (1926),[10] Behnke (1934)[11] and Bean and Rottschafer (1939)[12] have shown the toxic properties of an increased partial pressure of oxygen in various species. Bean and Rottschafer exposed animals to hyperbaric oxygen until they convulsed and then continued the exposure. The animals repeatedly convulsed until they died.[12] This is referred to as the "Bean Effect".

The first human exposure to hyperbaric oxygen was recorded in 1910 by Bornstein. Two men breathed 2.8 bar oxygen for 30 minutes while Bornstein breathed it for 48 minutes, none showed any ill effects.[13] However, in 1912, Bornstein breathed 2.8 bar oxygen for 51 minutes when he developed cramps in both hands and legs, signs of oxygen toxicity.[14]

Pulmonary or whole body oxygen toxicity

Pulmonary oxygen toxicity was first described by Lorrain Smith in 1899 and is often called the "Lorrain Smith effect" or chronic oxygen toxicity.[8] He had noted the CNS effects of hyperbaric oxygen and postulated that other tissues, especially the lungs, would be affected by oxygen. His experiments on mice and birds showed that 0.42 bar had no effect but 0.74 bar of oxygen was a pulmonary irritant after a 4 day exposure. The liver, spleen and kidneys were also affected by prolonged oxygen exposures. There were intra- and inter-species variations in susceptibility to pulmonary oxygen toxicity. He showed that intermittent exposure allowed recovery, so delaying the development of toxicity.[8]

In 1926 Barach, using rabbits, investigated the use of normobaric oxygen for the treatment of pulmonary tuberculosis. He concluded that "the highest concentration of oxygen compatible with safety should be regarded as 60 per cent."[10]

CNS oxygen toxicity and diving

Oxygen's use in diving is limited by its toxicity. Fear of its acute toxic effects delayed its use in decompression and recompression treatment.[15]

With the development of the Davis Decompression Chamber in 1929 and the formation of the Admiralty Committee on Deep Diving Unit in 1930, the Royal Navy (RN) began experimenting with oxygen decompression from 60 fsw (18 m) for air dives to 300 fsw (90 m).[4] Both animal and human trials were conducted between 1930 and 1933.[16,17] Data from these human oxygen breathing trials are shown in Table 1.[18]

This research stimulated Behnke to begin his research into the human tolerance to oxygen in 1934.[19] Behnke believed that the toxic effects of oxygen had delayed its use in the treatment of decompression illness, although earlier workers, Zuntz[20] and Hill[9,21] had advocated its use.

Table 2 lists Behnke's oxygen exposure limits established by his experiments on oxygen toxicity between 1934-1936.[18] These time limits were used both by Behnke and Shaw[15] and by Yarborough and Behnke[22] in the development of air/oxygen treatment tables for decompression sickness and also by Van Der Aue, ten years later, in USN Treatment Tables 1-4.[23]

In 1941 Case and Haldane reported 8 exposures to very high pressures of oxygen. Two were to 7 bar for 4 minutes. Both resulted in oxygen toxicity, relieved by breathing air. The second exposure resulted in a convulsion, five minutes after coming off oxygen, during decompression. The other six exposures were to 6.15 bar. One subject exposed for 4 minutes had no symptoms. The other subjects were exposed for 5 minutes. One had no symptoms while the other five developed symptoms. None of these subjects convulsed.[21,24]

In 1942 JBS Haldane, Derrick and Donald undertook an exposure to 10 bar oxygen for 25-30 seconds with no signs of toxicity .[21]

In 1942 Donald was appointed as the Medical Officer to what became the Admiralty Experimental Diving Unit, based at the Siebe Gorman factory near London. He was to develop oxygen tolerance limits for Royal Navy (RN) divers to enable them to use oxygen rebreathing sets in combat. This research was a result of the successful attack by Italian divers, riding on torpedoes and using oxygen rebreathing sets, on the two battleships, HMS QUEEN ELIZABETH and HMS VALIANT, inside Alexandria Harbour, Egypt, in 1941.[25]

Between 1942 and 1945 Donald conducted 2,000 experimental dives using RN volunteers. Each experimental diver was monitored closely by 2 attendants. Working and non-working dives were conducted in both "dry" and "wet" environments and at various depths (25-100 fsw). These experiments produced the most extensive records of human acute (CNS) toxicity but war time conditions prevented their publication in full until 1992.[26]

Presenting symptoms in non-working dives (underwater) described by Donald are listed in Table 3.[27] When convulsions occurred they lasted for, on average, 2 minutes and were similar to Grand Mal seizures. Often there was no warning. The post-ictal stage lasted 15 minutes. There were no permanent residua. Lip twitching often progressed to a convulsion. Once this relationship was established the experiments were stopped when a diver developed lip twitching. One diver was accidentally kept on oxygen during and after his convulsion, when he restarted breathing he commenced fitting again within 30 seconds.[28]

The safe depth limit for oxygen-diving (no convulsions) was found to be 25 fsw (7.6 m), the shallowest depth tested, whether the diver was resting or active.[29] There was no time limit placed on this exposure although the longest exposures had only been for 2 hours. The exposure limit of the absorbers used by the RN at that

TABLE 1

RN DEEP DIVING UNIT DRY CHAMBER OXYGEN TOLERANCE TRIALS 1930-33

Pressure	Subjects	Exposure	Symptoms
2 bar	12	60 minutes	None
3 bar	4	30 minutes	None
4 bar	1	13 minutes	Twitching face. Stopped with air breathing
4 bar	1	16 minutes	Twitching lips. Taken off O_2 then convulsed while breathing air

Table constructed from[18]

TABLE 2

DRY CHAMBER OXYGEN EXPOSURE LIMITS (BEHNKE et al.)

Pressure	Subjects	Time Limit
1 bar	10	4 hours
2 bar	3	3 hours
3 bar	4	3 hours
4 bar	2	<45 minutes

Table constructed from[18]

TABLE 3

SYMPTOMS AND SIGNS OF OXYGEN TOXICITY UNDERWATER IN 388 NON-WORKING DIVERS

Symptoms	Number	%
Lip Twitching	303	61.0%
Convulsions	46	9.3%
Vertigo	44	8.9%
Nausea	43	8.6%
Respiratory change	19	3.8%
Other twitching	16	3.2%
Drowsiness etc	16	3.2%
Visual disturbance	5	1.0%
Hallucinations	3	0.6%
Paraesthesia	2	0.4%
Total	**497**	**100.0%**

Table constructed from [27]

time was 90 minutes.[30] The results of Donald's experiments are listed in Table 4.

Donald's conclusions are best expressed in his own words:[28]

The most important finding in this large series of exposures was that the symptoms of oxygen poisoning vary enormously in different people and in the same person during different exposures. No list of warning signs or symptoms can be given that would ensure a safe and timely cessation to the exposure.

..variability of the group is independent of the depth."

..it is emphasised that no signs or symptoms can be given that would ensure a timely cessation of oxygen breathing in all cases. The variation of symptoms even in the same individual, and at times their complete absence before convulsions, constitute a grave menace to the independent oxygen-diver. The only possible conclusion is that such tensions of oxygen should be scrupulously avoided.

The variation of tolerance between individuals, the variation of tolerance of each individual, the impairment of tolerance with work and underwater, all make diving on pure oxygen below 25 ft of sea water a hazardous gamble.

In 1947 Dr Edgar End began using 3 bar oxygen in the treatment of decompression sickness in Illinois compressed air workers. The treatment tables were short, being 90-120 minutes long, and were apparently very successful. His results have not been published.[31]

TABLE 4

SUMMARY OF THE RESULTS FROM DONALD'S EXPERIMENTS

1 Individual variation of tolerance.

2 Susceptibility increased with depth, in a "wet" environment (this difference decreased with depth) and with exercise.

3 Susceptibility varied with water temperature. There was an increased susceptibility in water less than 9°C and above 31°C.

4 Convulsions can occur at anytime, frequently without warning.

5 The 5 epileptics tested did not show any increase in susceptibility.

6 The depth limit for oxygen diving should be 25 fsw (7.6 m) as no convulsions occurred at this depth. No time limit was suggested but the longest exposure was 2 hours.

In 1954 Lanphier developed the USN oxygen limits.[32] These were for exposures of between 25 (7.6 m) and 40 fsw (12 m). He ignored Donald's data and the limits were based on some experimental data, "educated guessing", "previous experience" and an arbitrary addition of 25% which became the "working limit".[33] These limits were subsequently revised in 1959 for the use with nitrox mixtures. Lanphier believed that toxicity was seen after a briefer exposure to a nitrox mixture than with an equivalent pressure of pure oxygen due to a change in gas density.[34,35] This was not Donald's opinion.[36] In the 1970s the USN Experimental Diving Unit had a time limit of 4 hours at 20 fsw (7.6 m).

In 1977 Hendricks et al. showed pulmonary tolerance of an exposure to 2 bar oxygen could be extended if air breaks were given.[37]

In 1993 Harabin and Survanshi analysed all the available data and showed that for all symptoms of CNS toxicity 1.3 bar oxygen was the threshold, with the threshold for convulsions at 1.7 bar.[38]

Summary

A brief summary of the important dates in the use of oxygen in diving and the studies on oxygen toxicity.

1669 The Phlogiston Theory developed by JJ Becher.

1733 Joseph Priestley born in Leeds, UK.

1742 Carl Wilhelm Scheele born in Sweden.

1743 A Lavoisier born in Paris.

1772 Scheele discovered oxygen.

1774 Priestley discovered oxygen which he named "dephlogisticated air". Lavoisier met Priestley in Paris and subsequently repeated Priestley's experiments.

1777 Scheele published his research.

1781 Lavoisier named "dephlogisticated air" oxygen.

1786 Scheele died.

1789 Lavoisier and Sequin demonstrated the pulmonary effects of prolonged use of normobaric oxygen.

1794 Lavoisier guillotined.

1796 Beddes and Watt published a paper on the medical uses of oxygen.

1804 Priestley died in the USA.

1878 P Bert published "La Pression Barometrique: Recherches de Physiologie Experimentale".

1880 Fleuss developed his oxygen rebreather for the use by miners.

1886 P Bert died.

1897 Zuntz used hyperbaric oxygen in the treatment of decompression sickness.

1899 J Lorrain Smith published his data on pulmonary oxygen toxicity.

1906 von Schrotter et al. suggested the use of hyperbaric oxygen in the treatment of decompression sickness.

1912 Bornstein and Stroink first recorded human exposure to hyperbaric oxygen.

1917 Karsnew published the animal pathological histology associated with pulmonary toxicity. He also showed post mortem data on toxicity in other organs.

1926 A Barach investigated the use of normobaric oxygen in the treatment of tuberculosis. He concluded "...the highest concentration of oxygen compatible with safety should be regarded as 60 %."

1929 Soper calculated that using oxygen during decompression may halve the time required for decompression. Davis developed a submersible decompression chamber.

1930 The 2nd RN Deep Diving Unit formed and started to use oxygen in decompression from 60 fsw (18 m) in air dives to 300 fsw (90 m) in the Davis Submersible Decompression Chamber.

1934-6
Oxygen tolerance experiments by Behnke et al.

1935 Behnke and Shaw investigated the use of hyperbaric oxygen in the treatment of decompression sickness.

1939 Behnke and Yarborough developed their air/oxygen treatment tables but these are rejected by the USN. The "John Bean" effect published.

1941 Italian oxygen divers attack HMS QUEEN ELIZABETH and HMS VALIANT, in Alexandria Harbour, Egypt.

1942-45
K Donald's experiments on underwater oxygen tolerance.

1947 Edgar End commenced using 3 bar of oxygen in the treatment of caisson workers with decompression sickness.

1954 Lanphier developed the USN oxygen tolerance limits. He revised these limits in 1959 when nitrox mixtures were used in diving.

1977 Hendricks et al. published their data that showed that pulmonary tolerance could be extended by using air breaks.

1992 A Behnke died.

1993 Harabin's analysis of the data published showed that the threshold for any symptom was 1.3 bar and for convulsions was 1.7 bar.

1994 K Donald died.

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IS MAGNETOENCEPHALOGRAPHY APPLICABLE IN CLINICAL NEUROPHYSIOLOGY OF DIVING?

Nico Schellart and Dik Reits

Key Words

Investigations, research.

Introduction

At present neurology uses many brain imaging techniques for diagnosis. In addition to Positron Emission Tomography (PET), Single Photon Emission Computed Tomography (SPECT) and (functional) Magnetic Resonance Imaging (MRI), mostly used to image brain metabolism and cerebral blood flow, multi-channel EEG and MEG (magnetoencephalography) brain mapping are used to quantify, with millisecond time resolution, information processing and spontaneous activity in the human brain.

Since an MEG machine can only be used at normal pressures, physiological research for diving is limited to the application of normobaric gas mixtures, with compositions presumed to mimic, to some extent, the effects of hyperbaric pressure. Possible future applications of MEG in diving medicine are for mapping local brain dysfunction due to severe neurological decompression illness (DCI) and chronic brain disorders due to diving. Nowadays, MRI is used to establish brain damage due to diving,[1] but a negative MRI cannot rule out arterial gas embolism (AGE) or decompression sickness (DCS).[2] As well as showing anatomical damage, dysfunction can objectively be established with MEG and EEG (especially when combined). These techniques can be used for assessing the effects of HBO treatment of patients with brain disorders.

To assess the applicability of MEG we did a pilot study to answer the question whether systemic hypercapnia influences

1 the spontaneous MEG
2 visual MEG responses and
3 sensory cognitive processing.

To provoke systemic hypercapnia we used voluntary breath holding, for convenience called apnoeas in this paper. Apnoeas are required during breathhold diving for e.g. collecting pearl and other sea organisms, underwater photography and underwater games. Systemic hypercapnia was also induced by hypercarbia exposure by breathing CO_2 enriched air (mimicking conditions during long, deep dives, and with failing rebreathers). As far as we know (quantitative) MEG and EEG data during breathholds and systemic hypercapnia has never been published in the recent literature.

Theory and methods

MEG mapping is based on the recording outside the brain of the change of the magnetic field (range 10^{-14} to 10^{-12} Tesla), due to neuronal activity occurring in restricted parts of the brain. This change is measured by the evoked current change in a small sensor, a superconducting coil. Advanced MEG machines have tens of such sensors or channels mounted in a helmet filled with liquid helium.

When a neurone processes synaptic information the highest current density occurs in the main dendritic shaft (if any) and in the axon, for instance, of a pyramidal cell in the cortex. When, in a brain structure, many thousands of such cells have the same orientation, then the activity of this structure can by measured by MEG and EEG. However, MEG is especially suitable when these cellular currents, together represented as an electric dipole, run parallel to the scalp surface. In contrast, EEG is most suitable to record a dipole which is oriented perpendicular on the scalp surface. This means that, when a sensory stimulus is applied, its neurophysiological response can basically be detected by MEG and EEG, but sometimes the response (or a part of the response) is undetectable with the one method whereas it is well detected by the other technique. Table 1 (on page 152) gives the most obvious features of both methods.

On the basis of the features of both techniques it can be concluded that EEG and MEG applied simultaneously will give very complete, detailed, non-invasive, objective information about neurological functioning of the human brain.

The apnoea experiments were done with three male volunteers (45-52 years old, in total 10 sessions) and the hypercarbia experiments with four males (20-22 and 52 years old, each one session). The Declaration of Helsinki tenets were followed. Consent was obtained from the subjects after informing them about the aim of the study, the procedures of the various experiments, the symptoms of hypercapnia and the prevention of hyperventilation.

We used a whole-helmet CTF MEG machine with 62, and later with 151 channels. In addition, in some sessions, EEG (6 or 22 electrodes) was recorded simultaneously. Apnoeas (two or three per session) lasted 120 to 225 seconds and were preceded by normal ventilation (normal apnoeas) or by three deep inspirations (pre-breath apnoeas). There was at least 6 minutes of rest between apnoeas.

Results

Within 150 seconds of normal apnoea, SaO_2 decreased about 4% (finger tip oximetry) and heart rate increased about 4%. However there was large variability in both results across the experiments. Subjects reported

TABLE 1

COMPARISON OF FEATURES OF EEG AND MEG

Feature	Electro-encephalography (EEG)	Magneto-encephalography (MEG)
Signal measured	Potentials at scalp	Magnetic field around head
Temporal resolution	0.1 ms	0.1 ms
Bandwidth	0.1 Hz - 5 kHz	0.1 Hz - 5 kHz
Spatial resolution	1 - 2 cm	0.2 - 0.5 cm
Noise level	0.1 µV	3 x 10^{-15} Tesla
Topographic maps	-	More detailed
Localization source	-	More precise
Radial source	Yes	No
Volume conductance	Yes	No
Influence skull	Yes	No
Preparation time	-	Much shorter
Head movements	Less sensitive	Not allowed
Magnetic protheses (in and at body)	Allowed	Recording impossible
Amalgam fillings and MRI scan made	Allowed	Recording impossible

normal alertness and normal vision during the apnoeas. With closed eyes, apnoeas yield an increase of 0.35 ± 0.06 (mÅSD, 7 sessions) Hz of the peak frequency in the (occipital) alpha rhythm in the spontaneous MEG (and EEG). The peak-amplitude did not change consistently, but the alpha peak became narrower (Q_{3dB} increased 34 ± 14%). Also the (centro-temporal) mu rhythm, occurring in one subject, showed a frequency increase. The effect of normal apnoeas and pre-breath apnoeas seem to be basically similar.

With eyes open the changes of the alpha rhythm and 8-12 Hz alpha band (no alpha peak distinguishable) are inconsistent. The amplitude of the delta rhythm increased under both conditions. The beta (12-40 Hz) and theta (4-8 Hz) bands did not show consistent changes across subjects. The brain maps (2 D representations by iso-fT contours calculated for various time instants of the responses of all sensors) of any band displayed no, or only subtle, changes. The EEG showed basically the same effects.

Hypercarbic exposure (3-4% CO_2 for 35 min or 5% for 5 min) resulted in a transient increase of the frequency and amplitude of the alpha peak (2 subjects) or no changes (2 subjects, 35 min).

Amplitudes of visual evoked responses, to appearing/disappearing checkerboard patterns, applied during apnoeas did not decrease consistently. Also response latencies did not increase consistently. The component in the response related to cognitive functioning, the P300 (investigated with a 'visual odd ball' paradigm), did not change either (2 subjects, in total 3 sessions).

Discussion and conclusion

The brain tissue PO_2 and PCO_2 during apnoeas is not known. The small systemic decrease of SaO_2 does not mean that the PO_2 in the gray matter of the brain diminishes as strongly as in the periphery, where vasoconstriction occurs. In contrast, in the brain, hypoxia as well as hypercapnia produces a vasodilatation, which will increase cerebral blood flow. This will counteract the diminishing of brain tissue PO_2 due to the decrease of arterial PO_2. A further decrease of diminishing tissue PO_2 is caused by the higher heart rate which, however, is supposed to be absent under water (diving reflex). Taking these effects together, it is probable that tissue PO_2 does not change much. The increase of tissue PCO_2, which also induces a small pH decrease, is probably of more importance. Since unpublished data shows that hypoxia alone decreases the alpha frequency, the increase of the alpha frequency (occipital) and the power increase of the delta band (0.5 - 2 Hz, mainly frontal) during apnoeas should be due to hypercapnia.

These preliminary findings about spontaneous activity indicate that the sources of the alpha rhythm (which is located mainly occipitally), the mu rhythm (which is located centro-temporally) and the delta activity (predominantly frontal) are influenced by a long apnoea. At the same time, the invariance of the evoked responses suggest that during apnoeas the occipital cortex and the visual cognitive centres are probably not influenced substantially during subjective normal vision. Possibly, cerebral tissue PO_2 and PCO_2 change insufficiently to establish an obvious effect on vision and cognition.

Therefore, the changes of the alpha, mu and delta rhythms may be caused indirectly.

From this preliminary study we conclude that MEG is applicable in certain aspects of diving research which can be studied at normal pressures. Similarly, as with normobaric EEG examination, it can be used diagnostically in diving medicine. It may also be helpful to elucidate the controversial issue of whether sport diving implicitly has a risk of brain lesions,[3] a notion claimed by several MRI studies.[4,5] However, most promising seems to be its application before and after treatment of neurological DCI with hyperbaric oxygen in a recompression chamber, since MEG (combined with EEG) is a powerful, objective assessment of brain function.

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CAVE DIVING IN AUSTRALIA

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Key Words

Cave diving, deaths, history, safety, training.

Introduction

The first cave dives in Australia were probably dives in the early 1950s in Tasmania and New South Wales. Diving continues in these areas usually as an adjunct to ‘dry’ cave exploration. The majority of cave dives in Australia take place in the vicinity of Mount Gambier in South Australia and on the Nullarbor Plain. This select history of the cave diving in these latter areas tracks the development of rules, equipment and diving techniques specific to cave diving.

Beneath Mount Gambier is an aquifer in a limestone layer up to 150 m thick. This aquifer is rain fed and flows slowly from the north west to the south east where water exits at springs on the coast, primarily Ewens Ponds. Many sinkholes (cenotes) have formed by dissolution of the limestone at cracks and joints and eventual collapse of the roof of the resulting water filled cavern. Parts of these sinkholes can be dived with either direct access to the surface or with daylight visible.

In the very early 1960s divers in Mount Gambier began to dive the well-known local sinkholes; The Shaft, 10-80, The Black Hole, Kilsby’s and Piccaninnie Ponds. By the middle of this decade the word had spread about these enormous caverns filled with crystal clear water and there were many divers from Mount Gambier, Melbourne and Adelaide visiting these sinkholes, it not being unusual to find 6 car loads of divers at any sinkhole on a weekend. For the most part, these dives were conducted within sight of daylight using standard open water diving equipment and techniques. Air supply was typically a single tank with J valve without octopus or pressure gauge. Using wetsuits and usually no buoyancy vests in these deep sinkholes required that weight belts be detached and hooked onto a convenient submerged tree branch. Single, low output lights were used and there were no cave diving reels.

A very few people were exploring the dark zones of sinkholes or entering true caves and experimenting with the forerunners of modern cave diving equipment. There was some experimentation with base fed lines which worked well in the larger sinkholes and much less well in true caves. As a result of this limitation of base fed line the first cave reels were built about 1968. The need to monitor air supply was apparent to the few divers using cylinder pressure gauges. At this time perhaps only one diver was using twin cylinders in some caves. Octopus regulators or truly redundant air supplies (twin cylinders) only began to be introduced around the mid 1970s but were resisted by most divers because of the cost. Octopus regulators became accepted equipment for cave diving by 1976 and for sinkhole diving a couple of years later.

Despite the advances made by a few divers, most sinkhole diving was being conducted under the illusion that daylight was always visible and special techniques were not necessary. With inadequate gear, some divers pushed into deep water or into the dark zone, in some cases with tragic consequences. Between April 1969 and December 1974 in five separate incidents 11 divers drowned needlessly in sinkholes in the Mount Gambier area. In three of these incidents divers became lost in the caves without a guideline and in one incident a diver was entangled in fishing line used as a guideline. Three incidents involved air diving to at least 60 metres and presumably nitrogen narcosis was a factor. In all cases the divers had little or no training in cave diving techniques which likely would have saved them.

Cave Divers Association of Australia

In 1973 a group of sinkhole divers met in Mount Gambier to discuss the consequences of the sinkhole diving deaths. The private owners of The Shaft had already closed access to that site and divers feared that other sites may close or that more divers might perish. The result of this meeting was a decision to form an association to regulate cave diving in Mount Gambier. A committee was elected and charged with the task of forming the Cave Divers Association of Australia. A constitution was written and a three category testing system for sinkhole and cave diving skills was devised. The land-owners were advised of this new self-regulation system whereby only divers holding the appropriate level of qualification should be allowed access to dive sites.

Skills were tested at separate levels representing three categories of dive sites: straight sided sinkholes, sinkholes with overhangs or small tunnel sections and true caves. The practical and theory tests included buoyancy control, air management, guideline use in normal and silt-out conditions, anti-silting technique, decompression, nitrogen narcosis, and stress testing. During the first ten years of the association this system persisted and improved with better information being made available for divers to prepare themselves for examination. Since the mid 1980s the testing system has given way to a training system where intensive instruction at each of four cave diving levels is provided by the Cave Divers Association of Australia.

During the 1970s cave diving techniques in Australia developed as more diving was done in true cave sites and a fourth category covering confined or long distance cave penetration was introduced. Most Australian cave diving techniques were developed out of necessity and in isolation from the cave diving communities that were developing overseas. However, increasing frequency of visits here by overseas cave divers and overseas travel by Australian cave divers has allowed exchange of ideas. Nevertheless, much of the technical development was driven by necessity in the Australian explorations, particularly of the long caves on the Nullarbor plain which will be discussed in connection with Cocklebiddy cave.

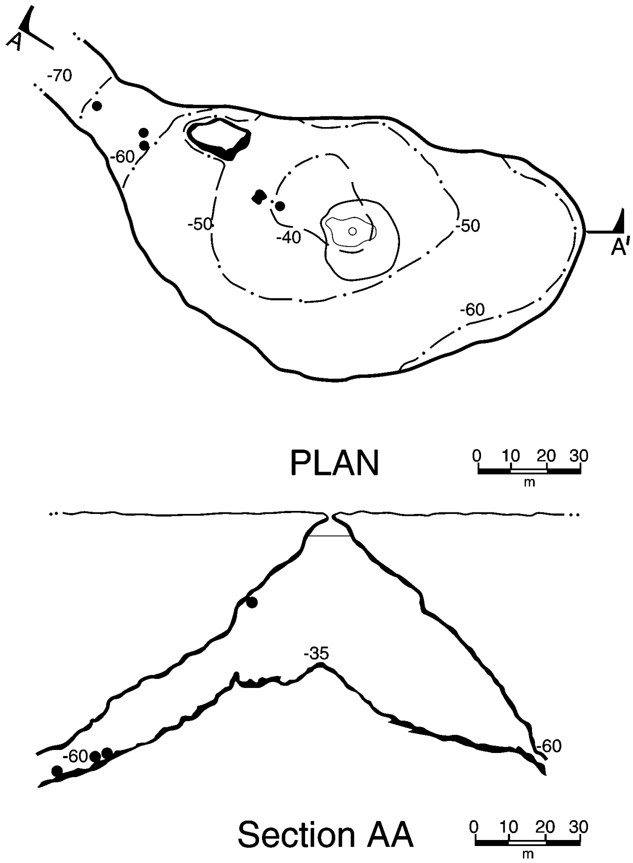

Figure 1. Cross section map of sinkhole L158 (The Shaft) near Allendale East, South Australia, redrawn from the map produced by the CDAA Research Group in 1984. The black dots are where the four bodies were found.

Three significant cave sites

THE SHAFT

On a dairy property in Allendale East is The Shaft, one of Australia's most famous and infamous sinkholes. The small entrance was exposed during ploughing in 1938. During the summer months, around noon, sunlight enters the cave through the small entrance providing a brilliant shaft of light that tracks across the debris cone. The Shaft became a popular dive site in the 1960s with much of the main cavern, in sight of the shaft, explored to considerable depth. Using a base fed line, a very few divers had explored to depths of 60 m, out of sight of the entrance light, but it was otherwise not widely known that the cave extended beyond sight of the entrance light. The low output lights of the day could not reveal the extent of the cave from this point.

In May 1973 eight divers each equipped with a single 72 cu ft tank and low output light entered The Shaft planning to reach 250 feet (75 m) depth. No guideline was used as they believed that the entrance light would be visible. Two divers ascended relatively early from 55 m and 60 m respectively while the other divers continued deeper towards the tunnel area where the entrance light is not visible and their low output lights would be of little use in orienting themselves. From depths ranging up to at least 68 metres two divers managed to find the surface after being temporarily lost but the other four divers drowned.

Immediately following the multiple fatality the landowners closed the site to all recreational diving for several years. Later, a very small group of divers regained limited access to this site. In the early 1980s this group negotiated expanded access to the cave for a mapping project which produced maps of the cave in 1984. Care was taken not to repeat the fatalities of the past and diving was limited to a depth of 50 m. Subsequent to the mapping project negotiations with the landowners resulted in the re-opening of the site to suitably qualified divers under the guide system and the 40 m depth limit that exists today.

In the early 1990s permission was gained from the landowners to explore the deeper sections of the cave. Using trimix breathing gas and high output (400 watt) lights, a series of dives were conducted into the "tunnel" region to a depth of approximately 85 m and approximately 200 m horizontally from the entrance, giving a clearer picture of this part of the cave.

COCKLEBIDDY

Dry caving expeditions to the Nullarbor plain in the late 1960s established the existence of large underground lakes in the caves of the Nullarbor plain that may prove suitable for diving. A number of these have since proved to be spectacular dive sites including Cocklebiddy cave. In a limestone layer 90 m below the surface of the desert is the lake entrance to Cocklebiddy cave. In 1972 three divers dived 300 m into the enormous, shallow, north trending tunnel from this lake using low output lights and twin independent 72 cu ft cylinders filled only to 100 bar, the maximum the portable compressor they had could manage. What they could not know was that the cave would continue over five kilometres from this point.

In 1974 divers pushed 500 metres into this tunnel and in 1976 a team found and crossed the Rockpile, a large dry chamber formed by rock fall at 1,000 m, and dived 150 m into the second section of the water filled tunnel. In the late 1970s divers reached 500 then 1,000, then 2,000 m into the second sump. Carrying sufficient air supply for these longer dives became possible with the availability of 88 cu ft aluminium cylinders used in single and triple back mounted configurations and staging of additional cylinders. The necessary lighting was provided by the construction of home-made high output, long duration canister lights. The use of high pressure copper tubing from surface compressors allowed air cylinder to be refilled at the entrance lake rather than transported out of the cave.

In 1983, pushing a makeshift sled, consisting of cylinders and buoyancy compensators strapped to a broom handle, divers reach Toad Hall, another rock fall 2,500 m beyond the Rockpile. Crossing the 300 m, unstable rock fall at Toad Hall they found the water-filled tunnel continued.. In 1984, just weeks before a planned Australian expedition, a five member French team scooped the third sump. Using Aquazep diver propulsion units two divers reached Toad Hall and dived some 1,500 m beyond, to the terminal feeders they claimed prevented further progress. Weeks later the Australian team returned to Cocklebiddy, determined to push further than the French. Pushing three improved cylinder transport sleds, six divers transported 60 cylinders to Toad Hall. A single sled and three divers continued to the terminal feeders. One diver used a single cylinder to explore the terminal feeders and then, rather foolhardily, pushed the single tank in front of him into the narrow extension of the main feeder branch for another 250 m without finding the end. He returned with this single air supply almost exhausted.

In 1995, after a long period during which exploration was focused on the neighbouring Pannikin Plains cave, there were a number of successful, and unsuccessful, swims to Toad Hall, a large expedition returned to the third sump. Using sleds towed behind diver propulsion vehicles, a single diver was put into the third sump, for a scooter assisted dive to the end of the French line and then a streamlined swim, with twin cylinders detached from the diver, to continue the exploration of the main feeder. This expedition was successful, but only 20 m beyond the previous extent of the line the cave narrowed sufficiently to exclude even this streamlined diver.

TANK CAVE

Underneath an old water tank in a paddock near Mount Gambier is a small underground lake at the end of a low, mud filled chamber. In the mid to late 1960s a couple of divers independently dived this site with out much success. They did not push on with exploration as other similar sites had never yielded much cave. Nevertheless, they spread the word about the cave and, in the mid 1980s, it was dived again. After passing the very tight, silty entrance two divers swam approximately 100 m into the cave before trepidation at negotiating the entrance squeeze urged them to return. They later produced a beautiful map of their finds.

Three other divers, including one who had been there in the 60s, returned and, after a false start, made a 240 m dive up what is now know as the B tunnel using twin 50 cu ft cylinders. After some time, with a change of owners, the cave was closed. Subsequently, in the early 1990s the property was sold again and the present owners initially allowed access restricted to a few divers, but now all suitably qualified CDAA divers can access the site through a rigorously managed guide system. Since the early days the entrance chamber has been cleared, the squeeze widened by removal of some rock so that the cave could be entered using twin 90s or larger cylinders. The entrance is gated for security. The known extent of the cave now exceeds 8 km of passage.

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JS HALDANE, JBS HALDANE, L HILL AND A SIEBE: A BRIEF RESUME OF THEIR LIVES

Chris Acott

Key Words

Decompression illness, equipment, history, general interest, physiology.

Introduction

In the 19th century there were numerous attempts to explain the symptoms of decompression sickness which ignored Boyle's and Bert's bubble theories. These explanations included: spinal cord damage caused by cold or exhaustion; frictional tissue electricity caused by compression-or decompression-induced organ and vascular congestion. Allbutt's "System of Medicine", published in 1900, reported that decompression sickness "was attributed to the mechanical effect of pressure on the circulation". However, despite these controversial views, all the salient clinical features of decompression sickness were described between 1870-1910.[1-3]

Haldane, Hill and Siebe are names synonymous with the development of diving and diving medicine. This paper is a brief outline of the lives of the J S Haldane, J B S Haldane, Leonard Hill and Augustus Siebe.

John Scott Haldane (1860-1936)

J S Haldane was born in Edinburgh on the 3rd May 1860 and died in Oxford during the night of March 14/15th 1936. His family (whose motto was "Suffer") was affluent and influential. He studied at the University of Jena after graduating from the University of Edinburgh Medical School.[4-7]

He taught physiology at the Universities of Dundee and Oxford and was noted mainly for his work on respiratory physiology. His research demonstrated great intellectual curiosity and often involved self experimentation. He was assisted by his son (JBS Haldane) in much of his work. He developed several procedures and apparatus for the physiological study of breathing and gas exchange; these included the haemoglobinometer and the Haldane-Henderson Gas Analysis apparatus.[7]

In 1893, following self experimentation, he concluded that respiration was regulated by carbon dioxide. With a colleague he remained in an air tight box (named "the coffin") for up to 8 hours rebreathing the atmosphere and noting their reactions. "At 7 percent (oxygen concentration in air) there is usually distinct panting, accompanied by palpitations, and the face becomes a leaden blue colour. At the same time the mind becomes confused." This data were not published until 1905.[9] In 1914 the "Haldane Effect" was published. His book *Respiration* was first published in 1927.[8]

In 1895 he investigated a serious accident in which 5 London sewer workers died. He discovered "sewer gas" (hydrogen sulphide) by descending into the shaft to take samples of the air and sewerage. He recommended aerating the sewers and attaching safety ropes to all sewerage workers.[7]

In 1911 he led an expedition to Pikes Peak, Colorado, USA, to study the physiological effects of low barometric pressure.[5,6]

In 1913 he became a director of a mining research laboratory. He found that "fire damp" (a mixture of CO, CO_2 and N_2) was far more lethal than the effects of an underground explosion. As a result of his firedamp experiments he recommended: "In view of the difficulty of recognising by ordinary means the presence of poisonous amounts of this gas (carbon monoxide), I propose the plan of making use of a small warm-blooded animal [a mouse or very small bird] as an indicator of carbon monoxide”.[7]

He was also a philosopher.[7] He tried to clarify the philosophical basis for biology and its relationship to physics and chemistry. His publications included *Materialism* (1932) and *The Philosophy of a Biologist* (1935).

Haldane also conducted extensive research into the physiological effects of hyperthermia. He became known as “the father of the salt tablet” because he recommended salt replacement during excessive sweating.[5]

In diving he is best known for his “staged” decompression method. In 1908 with co-workers Boycott and Damant Haldane published his decompression tables. “In the ordinary diving table, therefore, the stay on the bottom is so limited that the diver can be decompressed safely in half an hour”.[9] These tables decreased the incidence of decompression sickness and are still used today, in a modified form, either as a decompression table or in a diving computer. Haldane had so much faith in these tables that he stated “compressed-air illness has now practically disappeared except in isolated cases where from one cause or another the regulations have not been carried out”.[9] He also suggested that oxygen should be used to shorten decompression provided the pressure was kept less than 2 bar (atmospheres absolute) because of the fear of oxygen toxicity.[1]

However, Haldane made little contribution to the therapy of the decompression sickness although he recognised that recompression was the treatment of choice but stated “the trouble, however, about the use of recompression chambers is that it is often very difficult to get the patient out without the symptoms recurring”.[8-10]

DECOMPRESSION EXPERIMENTS

Heller, Mager and von Schrotter believed that a uniform decompression at a rate of one atmosphere per 20 minutes was safe.[1,10] Uniform decompression was also advocated by L Hill and M Greenwood (they had decompressed themselves without any serious symptoms from 5-6 atmospheres after short exposures).[3] However, Haldane had doubts about the safety and efficacy of uniform decompression practice.[9] At that time the Royal Naval decompression rate of 5 fsw/minute (1 atmosphere/ 6.5 minutes) had an unacceptable high rate of decompression sickness.[9] Haldane was commissioned by the Admiralty to develop safe decompression procedures. (Haldane’s brother, Richard Burdon Haldane, was the Secretary of State for War at this time and helped Haldane obtain this contract; L Hill had also applied for the same contract but was rejected.)[11]

Haldane’s experiments were conducted at the Lister Institute in a recompression chamber donated by Dr Ludwig Mond FRCS. Financial support was from both the Admiralty and private contributions.[9] The diving company, Siebe Gorman, did not contribute financially to Haldane’s experiments but did support the experimental work of L Hill and M Greenwood.[12,13]

Haldane made the following assumptions:[9]

1 for bubbles to form, the pressure of gas in the tissues must exceed the external pressure;
2 that body tissues will hold gas in a supersaturated state unless a certain limit is reached;
3 that any decompression is free from risk only if the degree of supersaturation “can be borne with safety”;
4 that tissue perfusion was the limiting factor in inert gas uptake.

His decompression experiments examined three different variables:[9]

1 the depth and pressure exposure;
2 the exposure duration;
3 the mode and decompression rate.

Initially, a few experiments were conducted on rabbits, guinea pigs, rats and mice but it was difficult to detect symptoms in these smaller animals and so the goat was chosen as the experimental model “because they were the largest animals which could be conveniently dealt with” and “those who are familiar with them can detect slight abnormalities with a fair degree of certainty”. The dog was rejected because they had noted that Heller et al. had previously used them to produce “safe” decompression profiles that had failed in humans.[9]

Goats were excluded from the experiments if they were ill. Only 5-8 goats were used per experiment. The chamber was not ventilated because they thought that CO_2 had a minimal effect on the susceptibility to decompression sickness. The chamber temperature was not controlled and no allowance was made for any variation in atmospheric pressure. Large pressure variations were used to produce minor to severe symptoms. The compression time of 6 minutes was neglected in short exposures but included in longer, deeper exposures.[9]

THE 2:1 STAGING RATIO

At the time of the experiments, Haldane knew from Naval diving data that decompression from 2 bar produced no symptoms irrespective of the time of exposure, however, decompression from 2.25 bar produced the “occasional slight case”. Examination of caisson workers’ case histories showed that there were no deaths recorded in decompressions from 2.6 bar and previous experiments showed that a rapid decompression from 2.36 bar only produced “slight symptoms” in 1 of 22 goats while decompression from 2.7 bar produced symptoms in 2 of 23 goats. An assumption was therefore made that decompression from 2.25 bar would be without risk. Goats could also be decompressed from 6 bar to 2.6 bar without producing any symptoms. However, if the goats were decompressed from 4.4 bar to 1 bar, only 20% escaped symptoms (in both of these decompressions the pressure difference is 3.4 bar). Hence the assumption that halving the pressure would not produce any symptoms.[9]

TISSUE PERFUSION HALF LIVES

Haldane used a "perfusion" mathematical model of gas uptake. These "perfusion half lives" were calculated from data available at that time[9] and were not arbitrarily derived as has been reported. These data were from: Moir's case histories of decompression sickness in caisson workers;[1] their own animal experiments;[9] self experimentation by Hill and Greenwood[3] and a mathematical model considering the body being as a uniform tissue.[9]

SYMPTOMS

The symptoms in goats were "protean in character".

1 "Bends" : the bends, or limb pain, was the commonest symptom. The affected limb (commonly the foreleg) was raised.
2 "Pain": pain was detected by "urgent bleating and continual restlessness" with the goat often gnawing at the affected area "such as the testicles".
3 "Temporary paralysis": The paralysis "may be of two kinds". Both were noted about 15 minutes after decompression and had improved within 30 minutes, the animal being "quite well" the next day. Some goats showed general weakness, dyspnoea, foot drop and dragged their hind legs, while others were noted to be well but had foot drop or "palsy in one or more hind or fore limbs".
4 "Permanent paralysis": The hind legs were noted to be paralysed immediately post decompression. Any spontaneous improvement was followed by a permanent relapse. Urinary retention and an acute gut distension were also noted.
5 "Obviously ill": The goats were noted to be apathetic and ill. They refused "to move or to be tempted with corn (of which goats are inordinately fond)". Some were noted to be "castrated, of male habit", presumably they were impotent.
6 "Dyspnoea": Dyspnoea was a sinister symptom usually occurring just before the animal died.
7 "Death".

This data showed that goats had an individual variability and susceptibility to decompression sickness.[9]

John Burdon Sanderson Haldane (1892-1964)

JBS Haldane, born at Oxford on 5 November, 1892, was considered a genius. He was educated at Oxford Preparatory School, Eton and New College, Oxford.[11] He went to Oxford to study mathematics and biology, but graduated in classics and philosophy.

From the age of 3 he assisted his father during his research by providing blood samples and recording the experimental data. In 1901 he co-authored, with his father, a paper on how haemoglobin combines with oxygen. In this paper he contributed the complex mathematical analyses.[11]

While he was at Eton he worked closely with his father in the First Royal Navy Deep Diving Committee on the prevention of decompression sickness.[11,13]

He assisted, and was used by, his father in his research into mine "fire damp". He described one episode in a north Staffordshire mine: ".my father told me to stand up and recite Mark Antony's speech from Shakespeare's Julius Caesar.......and somewhere about "the noble Brutus" my legs gave way and I collapsed on the floor, where, of course, the air was alright. In this way, I learnt that firedamp is lighter than air".[11]

During World War 1 he served with the Black Watch in France and Iraq and was wounded twice.[11]

He became the Reader in Biochemistry at Cambridge University (1922-32) and the Professor of Genetics at London University (1933-37). In 1930 he became the Fullerian Professor of Physiology at the Royal Institution.

His interest in genetics was stimulated by a lecture he attended on Mendel's genetic principles in 1901. In 1912 he published his first paper on genetic linkage. He later published on the genetics of haemophilia and colour blindness. His book The *Causes of Evolution* was a landmark in population genetics. Among many scientific firsts he investigated the biochemistry of gene action, the genetic control of enzyme reactions, calculated mutation rates for genes, created linkage maps for human chromosomes and analysed human pedigrees to understand different modes of inheritance. While at Cambridge (1922-33) he formulated a mathematical model of natural selection.[5,6]

He was a member of the Admiralty's Second Deep Diving Committee in the 1930s. During World War 2 he assisted Kenneth Donald with some of his experimental work on oxygen toxicity in divers.[14]

A committed Marxist, he was chairman of the editorial board of the communist *Daily Worker* between 1940 and 1949. In 1956 he rejected the Marxist ideology because of the Lysenko controversy and "Soviet interference in science".[4]

In protest at Britain's involvement in the Suez crisis he emigrated to India in 1957. He adopted Indian nationality and became Professor of the Indian Statistical Institute in Calcutta. However he resigned in 1961 because of personal differences with his colleagues. He became the Head of the Orissa State Genetics and Biochemistry Laboratory in 1962. He died in Bhubaneswar, India on December 1st, 1964.[7]

Leonard Hill (1866-1952)

Little has been written about Leonard Hill and his contribution to our understanding of decompression sickness and diving medicine. He advocated a linear or uniform decompression profile (this style of decompression is used in the saturation diving) as opposed to Haldane's "staged" method. He was closely associated with the Siebe Gorman Diving Company which financed the majority of his experimental work.[13]

His book, *Caisson Sickness and the Physiology of Work in Compressed Air* was published in 1912 and is considered by some to be a classical work.[10]

His research included decompression sickness, oxygen toxicity and the effects of carbon dioxide in diving. He also experimented with nitrox and heliox mixtures.[3,10,12,13] Much of his early experimental work involved self experimentation. For example, while trying to define the saturation rate of fast tissues with nitrogen, Hill and a colleague, W Greenwood, were pressurised to provide various samples of urine which were measured for nitrogen content.[3] These data were used by JS Haldane to determine one of the tissue half lives for his staged decompression method.[9] He also designed a unique experiment in 1900 that not only showed that bubbles caused decompression sickness but that recompression was the treatment of choice. Although recompression treatment had been advocated earlier by some clinicians but it was not universally accepted until 1924.[15] Hill used a frog. "Thus, after keeping a frog in highly compressed air for some time and then rapidly decompressing the animal, bubbles of gas were seen to appear in the capillaries and stop the circulation. On recompression, the bubbles were observed to shrink until the circulation became re-established. The cause and cure of compressed-air sickness could thus be projected as a demonstration on the screen".[11]

In the 1930s he was a chairman of the Royal Navy's 2nd Deep Diving Committee.[12,13]

Leonard Hill was responsible for the original medical standards for deep diving. He stated that the original format for a diving medical "was similar to that employed by the Air Ministry," and "that the diver should be possessed of a very stable mentality," and "that it is necessary for the deep-sea diver to be more fit than a diver engaged in shallow water." His medical standards were refined over the following years.[15]

He was also a medical physiologist who noted the increased difference in systolic blood pressure between the legs and arms in aortic coarctation which is called "Hill's sign".[12]

Christian Augustus Siebe (1788-1872)

Siebe was born in Saxony, Southern Prussia. At a young age his family moved to Berlin where he was educated. He was a brilliant engineer and machinist who showed great skill in modelling, chasing and watch making. In 1802 and 1803 he was awarded medals for his workmanship.

He joined the Prussian army in 1812 and served as an Artillery officer during the Napoleonic Wars. In 1813 he was wounded during the Battle of Leipzig (also called the Battle of Nations). Following his medical discharge from the army he moved to Kiel, then in Denmark, where he obtained employment as a watchmaker.[5]

In 1816 he emigrated to Great Britain and obtained work as a watchmaker with Garrards of London (who were at that time Jewellers to the Crown). Although he lived in London for majority of his life he only applied for British citizenship in 1862. This was granted on the 12 December, 1862.

In 1819 he became the manager of an engineering firm based at 145 High Holborn, London. In that year he was also married. He had 3 sons and a daughter.

In 1828 he produced a successful rotary water pump that gained him public notice. He also designed a breech loading rifle and a weighing machine. In 1851 he manufactured a Galvanic battery.

In 1830 the Deane brothers brought their design for an improved diving apparatus to his shop in Denmark Street and asked him manufacture it. George Edwards, another engineer, also modified the Deane diving equipment and brought his ideas to Siebe. In May 1837 Siebe tried to establish himself as an independent supplier of diving equipment and approached the British Admiralty. In 1840 Siebe adopted Edward's modified version and released the diving suit as his own.

During the salvage from, and destruction of, the ROYAL GEORGE wreck in Spithead, Siebe's closed diving rig became the preferred suit because the helmet could not flood when the diver leaned forward. The operation also required the highest standard of air pump and Siebe's pump was superior, hence his diving rig became the preferred one for the Royal Navy. From here the saga of the origins of the closed diving dress started. Siebe's son, William Henry Siebe, and son-in-law, William Augustus Gorman, and later Sir Robert Davis, a chairman of Siebe Gorman Company, were probably responsible for the propagation of the story that A Siebe was the first to design the "standard" diving dress. For greater detail on the origin of the "standard" diving dress the reader is referred to Bevan's excellent historical book *The Infernal Diver*,[16] from which these details have been taken.

Augustus Siebe died on the 15 April, 1872 from "chronic bronchitis". His son, Henry, and son-in-law, William A Gorman, had taken managerial control of Siebe's business in 1868 which became known, in 1870, as the Siebe Gorman Company.[12,16]

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BILATERAL DEAFNESS ASSOCIATED WITH DIVING

Alfred Buchner and Matthias Heppe

Key Words

Case report, ENT.

Case report

A 61 year old male German diver went to Egypt and the Red Sea for a live-aboard diving holiday. He had 30 years experience and more than 500 dives in the former German Democratic Republic. Before he went he had medical examinations for fitness to dive and was considered "fit to dive without any restrictions".

During the first day on board he performed two relaxing dives without any strenuous events. The profiles were 10 to 15 m (30 to 45 ft) for about 30 minutes. He did not use a diving computer and there were no records available.

On day 2 he performed three dives. The first dive was 30 minutes at 14 m (42 ft). After a surface interval of three hours the second dive was 30 minutes at 20 m (60 ft). The surface interval was 3 hours 30 minutes before the third dive, which was to 35 m (105 ft) for 20 minutes. Dives 1 and 2 were in a group of divers with a divemaster while dive 3 was a camera dive with a buddy. He did regular safety stops on all dives. The last dive was "not very much controlled" according to the diver's report. He had no equalisation problems at all and did not do any Valsalva manoeuvres during the dives.

After the third dive he complained of "stomach problems", nausea, dizziness, sweating and pallor. He vomited once but there was no vertigo. He felt tired and went to bed early. The divemaster reported that this dive party consumed a lot of alcohol. The patient stated that he drank much "as normal". Waking up the next morning he realised that he was completely deaf in both ears. There were no symptoms or signs of decompression illness.

A doctor from a mobile service was called on board. He stated that there were no haemorrhagic portions of the tympanic membranes nor any perforation. Nevertheless he diagnosed bilateral barotrauma to the middle ears. One and a half litres of saline, and steroids, were given intravenously. Oxygen was administered by mask through a Wenoll system.[1] There was no change in the deafness after this treatment.

The patient was then referred to a hyperbaric oxygen chamber in Hurghada (Egypt). According to the medical report he was still on oxygen 48 hours after the last dive. There were no other complaints apart from the hearing loss. He was treated with a US Navy (USN) Table 6. He was still deaf after 4 hours and 45 minutes of treatment. The next day a USN Table 5 was performed (2 hours and 15 minutes). Again there was no change of the existing deafness.

Six days after the last dive he eventually arrived at the EURO-MED-CLINIC Hyperbaric Oxygen (HBO) Centre, in Fürth, Germany.

He had severe hypertension (210/140 mmHg), diabetes mellitus and obesity (107 kg, 182 cm). With oral hypoglycaemic agents and anti-hypertensive medication he returned to normal values. He was still deaf in both ears with no sign of barotrauma, no rupture of the foramen rotundum (round window) as diagnosed by the ENT Department. No vestibular lesion was found. Magnetic resonance imaging and CAT scanning displayed no tumours, no haemorrhage nor any trauma. The only finding was a slightly affected maxillary sinus on his left side. Neurological examination was found normal apart from the deafness and a late SEP (somatic evoked potential) of the posterior tibial nerve bilaterally.

We commenced treatment with intravenous hydroxy-ethyl-starch, 1,000 ml daily, and Pentoxifylline with a loading dose of 100 mg on day 1 and dose increments of 100 mg on day 2 and day 3. A daily dose of 300 mg was continued until day 9. No steroids were given because of the patient's coexisting diabetes mellitus. He had HBO treatment for 8 days in a multiplace chamber (HAUX Starmed). Each treatment consisted of three 30 minute periods on oxygen, separated by 10 minutes air breaks, at 2.4 bar absolute pressure. There was no change in his deafness.

After this we transferred him to a Center for cochlear implants for further treatment.

We searched Medline from 1992 to 3/1998, using the key words: "diving + deafness". We did not find a case of bilateral deafness reported as due to diving.

We believe that the dive profiles, with each dive deeper than the dive before, with the pre-existing, but formerly ignored, medical history of severe hypertension, mild diabetes and obesity led to a higher susceptibility to decompression illness. We think that this was bilateral decompression illness affecting the inner ears, probably with a rupture of endauricular membranes.

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SEMI-ATMOSPHERIC DIVING SYSTEMS

John Bevan

Key Words

Equipment, history, occupational diving.

Abstract

Semi-atmospheric diving systems are those where a part of the diver's external body is maintained at atmospheric pressure and he breathes air at atmospheric pressure, while the remainder of his body is exposed to ambient water pressure. Two principal methods were used to achieve these ends. A self-contained system, where the diver took his air supply to the sea bed with him and a surface supplied system. Since the earliest reliable report of this type of diving system being used in 1660 by a Frenchman, Chevalier de Beauve, many aspiring divers have attempted to exploit the technique with varying degrees of success, ranging from acquisition of great wealth to sudden death. This paper describes the application of this poorly understood and appreciated diving technique which spanned nearly three centuries.

Semi-atmospheric diving equipment

I coined this term in an attempt to define more clearly a significant branch of diving technique which is generally poorly understood, misunderstood and misrepresented. I define semi-atmospheric diving systems as those where a part of the diver's body is maintained at atmospheric pressure and he breathes air at atmospheric pressure, while the remainder of his body is exposed to ambient water pressure. Thus a snorkel is not considered to be included in this definition. But if, for example, the diver's head, or head and chest, or head, chest and legs, are encapsulated in a rigid container which maintains atmospheric pressure within, then it is included.

Two principal methods were used to achieve these ends. First, a self-contained system where the diver took his air supply with him to the sea bed. These are mainly the so-called "barrel divers" whose legs were enclosed within the atmospheric compartment and therefore they had limited lateral movement capability. And second, a surface-supplied system, where the diver received his air supply from the surface. These divers had the use of their legs to varying degrees depending on the design of the suit, and were therefore able to walk about on the sea bed in a manner equivalent to the standard helmet diver.

When described in this basic manner, the inherent problems associated with the technique's exploitation quickly become apparent to anyone with a knowledge of the effects of pressure imbalances. Two main points to bear in mind are the fact that the arterial blood pressure in a fit young man is about120 mmHg and the hydrostatic head of pressure below a depth in sea water of 1.6 metres is more than 120 mmHg. Therefore it follows that when adjacent parts of a human body are exposed simultaneously to atmospheric pressure on one side and water pressure in excess of 1.6 metres depth on the other side, the tendency will exist to collapse the veins, to prevent arterial blood circulation and to force blood back up the arteries. Needless to say, at the same time there would be an increasing pressure differential between the inside and outside of the atmospheric compartment of the diving dress, which would be attended by an increasing tendency for water to leak into the diving dress. Any major structural failure of the seals would be followed by an instantaneous and complete flooding. To ensure a strong seal at such points, such as around an arm or a leg, very tight bindings were used which were, in effect, tourniquets.

Despite all these impositions, for several centuries, the inevitable pain, physical trauma and risk of a horrible death were justified by the significant opportunities (either real or imagined) to accumulate great wealth. What is surprising is that it worked at all! This is reminiscent of Johnson's controversial pronouncement on women preachers being "like a dog's walking on his hinder legs. It is not done well; but you are surprised to find it done at all".[1]

Though not the first report of a semi-atmospheric system, the following account, dated 1763, by J T Desaguliers in England is given here because it gives a useful introduction to the mode of operation of a surface-supplied arrangement.[2] *... other inventions have been contrived for diving. One is a sort of a case of armour of copper represented at Figure* 3 [Figure 1], *to preserve the diver's body against the pressure of the water. This case consists of two pieces to be joined together on the body. AGBE is the piece for the head, and upper part of the body. The head has two copper pipes PP, to which are to be screwed several lengths of leathern pipes to reach up to the top, and communicate with the air at top of the water. These pipes are kept open by small hoops of brass or copper within the leather. There is a convex glass G before the face to look through to see objects under water. The piece E slides out, and then the diver having put in his left arm, and thro' the hole opposite to B gets in his body, and raises up his right arm from E to B, and puts it thro' the hole B, then the piece E is slid up and made water-tight, and held in place by a strong ring at E. The breeches or lower piece F being put on, besides the rings at E, is made fast to the upper piece by two bars with screws Cc, Dd. The arms and hands, as well as the thighs, and legs and feet being covered with leathern hose, these leathers are fastened to the rings at B, and on the other side, as also to the breeches at F. The air pipes being fastened at PP, the diver is let down into the water, where he works at the bottom, and has a small line to*

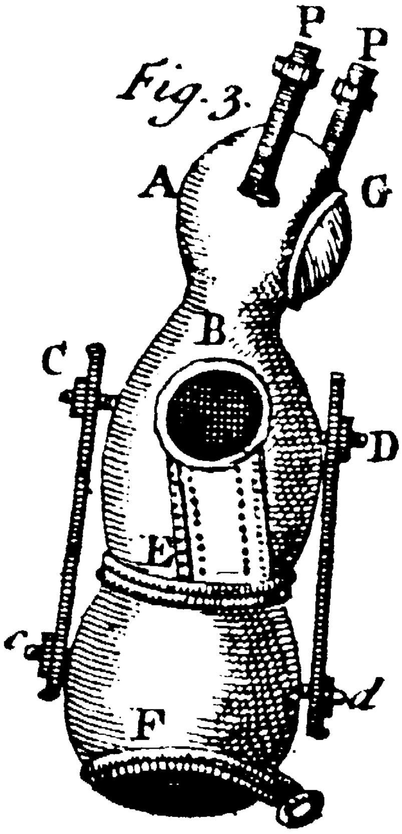

Figure 1. Figure 3 from Desaguliers.[2]

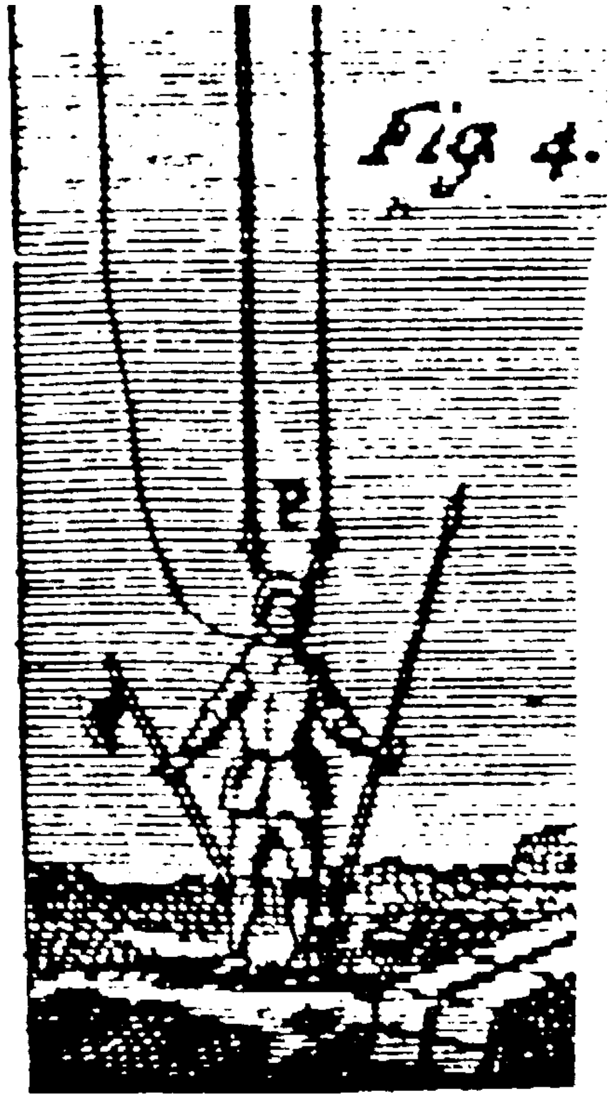

Figure 2. Figure 4 from Desaguliers.[2]

pull and make signals when he would be drawn up again; or when he would have the boat above him move in any direction. See the diver with his tools Fig 4 [Figure 2] *and the air pipes going up at P, together with his line for signals.*

This kind of diving machine has its inconveniences. 1. When the diver goes down to only a moderate depth, the lateral pressure of the water squeezes the air-pipes so strongly, that the assistants above are obliged to blow down air to the diver with bellows. But the greatest inconveniency is,

2. That when the depth is considerable, the diver, though his breast and the rest of his body be guarded against the pressure of the water, feels all the additional weight upon his arms and thighs, especially where his leathern hose are fastened to the armour, so as sometimes to stop the circulation of the blood, as some have experienced it to their cost. For the external air comes down to them from above being taken into the diver's lungs, has only the spring sufficient to bear the pressure of the common atmosphere, and above 1/8 more upon occasion as it is expanded about 1/8 by the heat of the human body: where-as the arms and thighs defended only by oiled leather, must bear all the pressure of the water according to its depth, besides what they used to bear above the ground. The uniformity of the pressure does indeed help a little, and these machines are much used, because the places where ships are usually cast away are but shallow. About 16 years ago I was informed that there had been granted about 14 patents for making these kind of instruments, several different persons having obtained those privileges, because in their improvements, which they called new inventions, they varied a little from those that had gone before them. For great depths, in which sometimes ships have been cast away, or to which they have sometimes slipped by length of time, where the shore has been steep, or in pearl and coral-fishing, these armour machines are quite useless .

But the use of semi-atmospheric systems can be traced back much further. Chevalier de Beauve referred to the use of such a surface-supplied diving dress in 1660, in a letter to Chevalier de Borda. He also described how he himself dived in a similar suit to a depth of 8 metres at Dugay-Trorien at Rio de Janerio in 1711 and included detailed illustrations of the equipment which showed the rigid shell for the head and torso as well as the two pipes to the surface, one for supply and one for exhaust of the atmospheric air.[3] This design was to be copied many times again in the succeeding years.

Barrel diving

The most successful proponent of semi-atmospheric diving systems was undoubtedly John Lethbridge of Newton Abbott, Devon, England. He became the most famous of the “barrel divers”, so-called because their diving suit was essentially a barrel (or some form of substitute) fitted with arrangements to allow the diver’s arms to penetrate to the outside, where they were of course exposed to ambient pressure. The barrel itself was large enough to hold sufficient air for a dive lasting up to 30 minutes or more before being hauled back to the surface for flushing out or recharging with fresh air. The equipment therefore undeniably qualified as a self-contained semi-atmospheric diving system. Lethbridge had his diving engine built by a cooper in Stanhope Street, London. He described it as follows: *It* is *made of wainscot, perfectly round, about six feet in length* (1.8 m)*, and about two and a half* (0.75 m) *diameter at the head, and about 18 inches* (0.45 m) *diameter at the foot, and contains about thirty gallons* (135 litres)*; it is hooped with iron hoops within and without to guard against pressure. There are two holes for the arms, and a glass about four inches diameter, and an inch and a quarter thick to look thro’, which is fix’d in the bottom part, so as to be in a direct line with the eye, two air holes upon the upper part, into one of which air is conveyed by a pair of bellows, both of which are stopt with plugs immediately before going down to the bottom. At the foot part there’s a hole to let out the water ... It requires 500 pounds weight* (170 kg) *to sink it, and take but 15 pound weight* (7 kg) *from it and it will buoy upon the surface of the water. I lie straight upon my breast all the time I am in the engine, which hath many times been more than six hours, being frequently refreshed upon the surface by a pair of bellows. I can move it about 12 foot* (3.6 m) *square at the bottom, where I have stayed many times 34 minutes. I have been ten fathoms deep* (60 ft, 18 m) *many a hundred times and have been 12 fathoms* (72 ft, 22 m)*, but with great difficulty.*

At the deeper end of his range, Lethbridge found that he needed to wear a sort of a saddle on his back to wedge himself against the top of the barrel. This he found necessary because the differential pressure squeezing his arms and acting where they penetrated the barrel’s hull, was so great that he was pushed bodily away from the bottom of the barrel. His claim for a long endurance inside the barrel is interesting because it must have meant the arrangements for sealing the leather sleeves on his arms were such that he could have recovered his blood circulation each time the barrel was brought to the surface. I have theorised that in view of the ribbon-like ends to the sleeves shown in Lethbridge’s illustrations (Figure 3), he used a “Chinese finger” interlacing arrangement of these ribbons down the length of his arm. I presume the effect was, as the sleeve tended to be thrust back into the barrel by increasing ambient water pressure, the interlaced part automatically tightened over his arm. The result would have been a strong and secure attachment to the arm as well as spreading the area of differential pressure over a wider area, hopefully causing less pain than if it was restricted to a small area. That there was considerable pain involved, there can be no doubt. Perhaps this was when the term “No pain, no gain” was first coined.

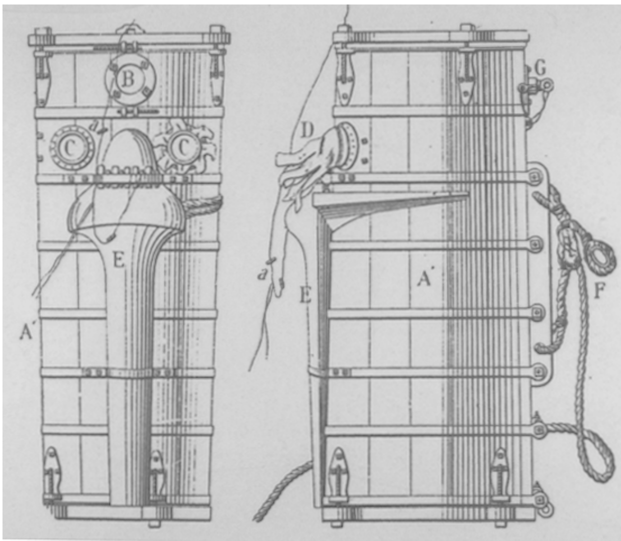

Figure 3. 1715 Lethbridge’s diving barrel. John Lethbridge (1678-1759), of Newton Abbot, Devon, invented this self-contained diving suit in 1715. After a successful demonstration in Marseille, France, he demonstrated his “engine” to the Honourable the East India Company (HEIC) in the Thames during April 1720. He and Jacob Rowe became partners and worked all over the world including Cape Town, South Africa. He amassed great wealth.

The hole at the foot to let water out indicates that the sealing arrangements were by no means perfect. Furthermore, after six hours inside the barrel there was more than just water accumulating at the foot. Any accidental tipping forward of the barrel would have been a particularly unpleasant event bearing in mind that the diver’s body was effectively clamped to the bottom of the barrel with no facility for raising it inside. Indeed, there was a good chance of drowning in a relatively small volume of water if the head end went lower than the foot end.

Lethbridge demonstrated his “engine” in Marseilles, France in 1715 and again to the East India Company in the River Thames in 1720. Other exploits included salvage of 27 chests of silver and 64 cannon from the *Vansittart*, sunk in the Firth of Forth and in 1724 work on the Dutch ship *Slot ter Hooge* sunk off Madeira. In 1726 he worked again in Madeira and recovered 349 silver bars, 9,067 guilders worth of coin and two cannon. In 1727 he worked at Cape Town, for the Dutch East India Company on the wrecks of *Zoetigheyd* and *Rotterdam*, in 1728 he worked on the *Meresteyn*, and in 1734 he recovered a valuable cargo of Spanish piastres from a wreck in Marseilles harbour.[4,5]

A Captain Jacob Rowe, also from Devon, appears to have become involved with Lethbridge at an early stage and in 1720 published "A demonstration of the Diving Engine - Its Invention and Various Uses". He described a barrel-like semi-atmospheric diving system, but this time constructed from sheet copper and designed to quite a high standard. He had various diving adventures between 1721 and 1731 but he does not appear to have achieved the level of success attributed to Lethbridge.[6,7]

Diving suits

The earliest example of a semi-atmospheric diving suit still surviving today is exhibited in a museum at Brahested in Finland. It is constructed from pigskin and the seams are extremely well sewn in "shoemaker fashion". The two air pipes are made of hollow wood sections, one attached at the top of the dress and one at the back of the head. Unfortunately, there does not seem to be any sign of an internal, rigid structure which must have once existed. The suit was illustrated in a letter from the Swedish Admiralty to the King of Sweden in 1727 so it is likely to be of Swedish design.[8]

Another surface-supplied system appeared a few years later around 1754. This was described by Dr Richard Pococke on a visit to the Isle of Wight, England.[9] In his own words: *I went there in order to go to the Needles to see the curious manner of diving which they lately began ... They are let down in a machine made of leather, strengthened at the knees and shoulders, and if I mistake not, at the head with brass. There are two leather tubes to it - one for the air to go down and to speak by, and the other to pump out the air. They stay down five minutes ... Sometimes as it is imagined, when they have gone too far down, they have bled at the nose and eyes.*

It would seem that this diving activity was the same as that referred to later by William Holloway, Deputy Searcher for the Customs at the Port of Cowes on the Isle of Wight when he wrote.[10] *I am to acquaint your Honor that I have in my possession the diving engine that some years since worked on the wreck of the ASSURANCE, Man of War lost at the Needles ... Our engine is not of the bell kind, but is a copper case made as fit to the body of the diver as may be, with leather boots and sleeves so that he has the use of his hands, feet and knees. A thick glass is placed opposite the eyes through which he perfectly sees and is supplied with fresh air by bellows through one pipe equal to the depth of water, the foul air passing off by another.*

This diving dress appears to be similar to the earlier dress used by Chevalier de Beauve. An interesting point to note from these descriptions is that it was relatively easy to have voice communications with the diver in a surface-supplied semi-atmospheric diving system because the air exhaust pipe would have been open at its distal, surface end and could therefore have been used as a simple voice-pipe, for two-way communications.

Denmark was the site of the next appearance of a surface-supplied semi-atmospheric diving dress. Heinrich Schultz demonstrated his diving suit in Copenhagen in 1760 and managed to reach a depth of 6 Fathoms (36 ft, 11 m) and remained underwater from 0930 to 1200 in the presence of the whole Board of Admiralty. His hands were covered with leather gloves well lacquered with bees wax and hogs lard, fastened to a copper armour at the wrists. The suit had a copper helmet and harness with iron pieces on the legs with joints. This design shows important improvements because rigid covers were now provided to other parts of the body in addition to the head and chest and the only parts exposed to ambient pressure would have been at the flexible joints of the limbs.[11] It would seem fair to say that this was one of the more successful designs for this type of suit. Thirty six feet (11 m)water depth was quite an achievement.

Meanwhile, back in England, the Royal Navy had suffered an embarrassing incident when, in 1782, HMS ROYAL GEORGE suddenly sank whilst at anchor at Spithead, near Portsmouth, taking over a thousand people down to a watery grave. Immediately a William Tracey, a wealthy ship broker at Portsmouth with 11 children, was awarded the salvage contract against stiff competition from 117 other hopeful contenders. He worked at it for the next two years. The project broke him both physically and financially and he ended up as a debtor in Fleet Prison,

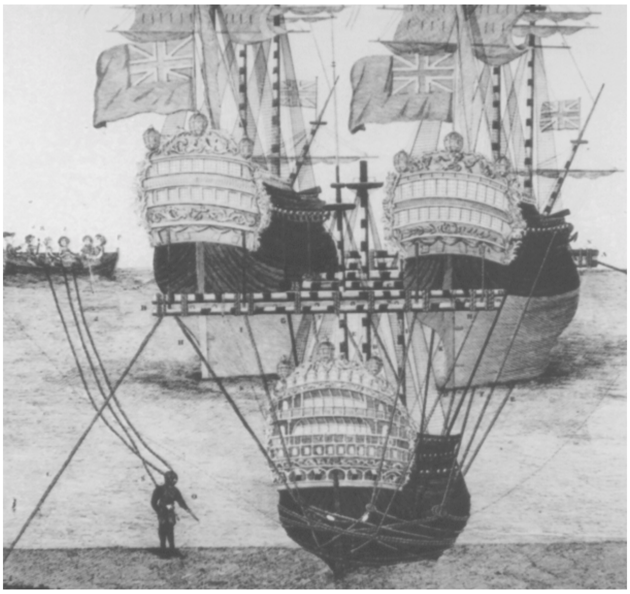

Figure 4. William Tracey (b 1735) was a diver and broker at Portsea, Hampshire, who attempted salvage of HMS ROYAL GEORGE in 1782-3. Unfortunately he was crippled by diving on HMS ROYAL GEORGE. By 1817 he was a "decayed ship owner" in the Fleet Prison when he was given a Trinity House pension.

London. But the interesting part for us was his use of a surface-supplied semi-atmospheric diving suit, very similar to the one described by Desaguliers back in 1763. Tracey had bought the diving equipment in London but it seems that the equipment failed on its first dive.[12] A contemporary illustration shows Tracey on the sea bed alongside the wreck of the ROYAL GEORGE (Figure 4). However it is unlikely that he made it to this depth which would have been of the order of 90 ft (27 m).

The year after Tracey's disastrous attempt to raise the ROYAL GEORGE, John Braithwaite arrived in Portsmouth to recover cannon etc. from the wreck, by arrangement with the Admiralty. Though Braithwaite was very secretive about his diving technique and equipment, sufficient information leaked out to establish that he was using a similar technique to Tracey. On 9 July 1784 the following report appeared.[13] *An artist lately arrived in London in his own sloop ... has four assistants and by means of leather tubes often spends 5 hours on board the unfortunate ship ... by this means he is supplied with fresh air and communicates with his people.*

And two years later, a Dutch Consul in Lisbon sent an intelligence note to his government in the Hague, Holland dated 21 February 1786 describing what he had spied going on in Gibraltar. *Meanwhile a Savoyard in the pay of the Spanish Ambassador reports that he was present in Gibraltar (at the time of salvaging the guns) and he saw the clothes and pipes that the English used with so much success and with which they can stay under water for almost 2 hours.*

The French Consul in Cadiz, about the same time, sent his intelligence to HQ in Paris on 14 March 1786. He made a detailed examination of their machine. *One of his* (Braithwaite's) *servants and a boy had dived down to more than 15 feet* (4.5 m) *of water from on board the ship "Bellandre". He had conversed with them through two leather conduits or pipes that could be paid off as the machine went down. ... The machine was hoisted by a swing boom, using two warps and two blocks with tackles.*

The references to diving clothes, two pipes, the ability to talk down the pipe, all point to a surface-supplied semi-atmospheric diving dress. Braithwaite became very successful with the diving "machine" and ranks close to Lethbridge in the financial success league.

The next contender appeared in the small town of Breslau, Germany. Here M Klingert developed another similar diving dress in 1798. This was when he demonstrated the system by sending Frederick Joachim, a huntsman, down to the bottom of the River Oder where he allegedly sawed through a tree trunk. The excellent and detailed illustrations of the diving dress (Figure 5) have been published very widely but nothing further is known of its success or otherwise. The sealing arrangements for the suit

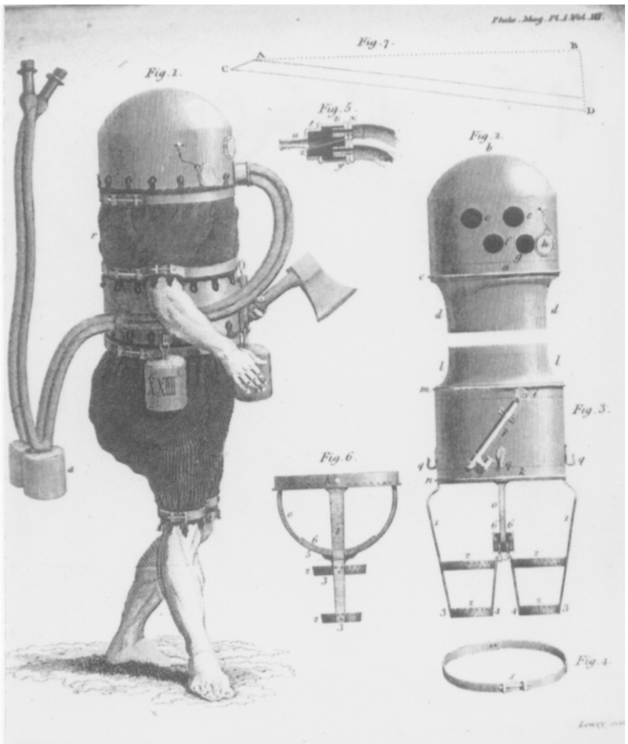

Figure 5. In 1798 M Klingert, of Breslau, Germany, used a semi-atmospheric diving machine to dive in the Oder River.

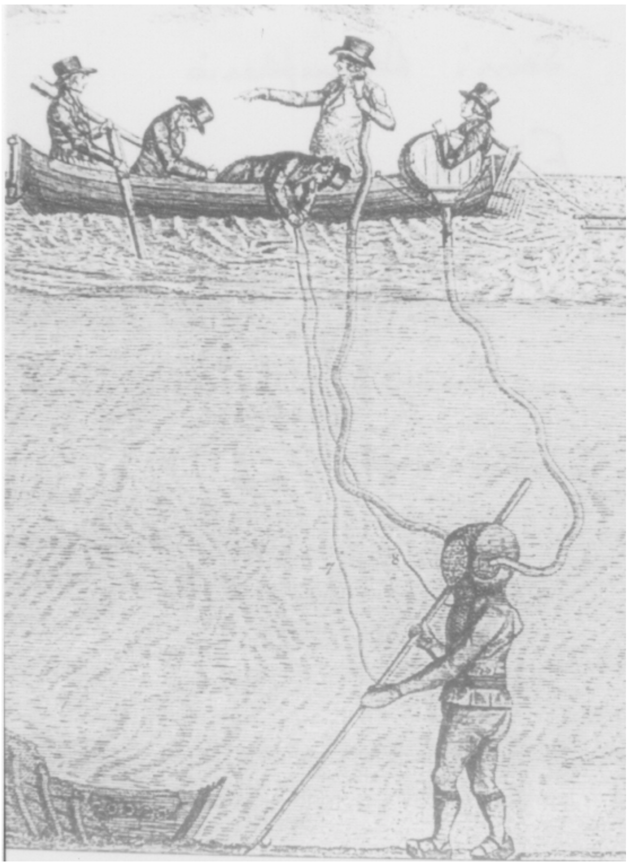

Figure 6. Peter Kreeft on the sea bed. Between 1800 and 1805 Kreeft, a German, produced the "Busseruhn" diving dress at Barth in Pommerania.

at the arms and legs show that a metal clamp was bolted tightly to achieve the seal. The pain must have been excruciating. The legs were clamped into a frame just above the knees, so designed to protect the crotch from the inevitable suit squeeze.[14] Walking with immobilised knees would have been an interesting spectacle to behold.

Not far away at Barth, Pommerania, another German diver by the name of Peter Kreeft produced a successful surface-supplied semi-atmospheric diving suit around the year 1800 and worked it for about five years. He called his suit the “Busseruhn” and the rigidity was provided by a frame inside a flexible, waterproof suit. An excellent illustration of the suit being dived (Figure 6) shows clearly how atmospheric air was flushed down one pipe to the diver and a second pipe returned the exhaust air to the surface. The latter pipe can be seen being used as a voice pipe by an attendant on the surface.[15]

The wreck of the ROYAL GEORGE at Portsmouth continued to attract ambitious divers throughout this period. In 1801 Enoch Tonkin began hounding the Admiralty for permission to work on the wreck. Later with Ralph Tonkin and the Braithwaites, he eventually succeeded in salvaging the valuable cargo, consisting of some 27 treasure chests and miscellaneous material worth a total of £30,000, from the wrecked East Indiaman *Earl of Abergavenny*, sunk in 60 ft (18 m) of water near Weymouth in Dorset, England. A drawing of the suit, which included a description of its construction, has survived (Figure 7). It had a body of copper and iron boots with *Joints as of mail covered with strong leather and canvas over it to prevent the leather being cut.* The suit had strong leather for the arms and a *glass eye, size of a dessert plate, an inch thick* and the whole suit was painted white.[16]

This represents the last known successful application of this type of diving system. The familiar diving helmet and dress was introduced in 1829 and the problems associated with differential pressures on a diver’s body was solved once and for all.

But surprisingly there were a few later designs. In France for example, Jules le Batteux re-invented the barrel diver in 1853 which had been so successfully exploited by John Lethbridge. His barrel was fitted with fully enclosing sleeves and gloves for the diver.[16]

The last example came as recently as 1894 when an Australian engineer named Alexander Gordon, together with his colleague J Buchanan, designed, patented and built a very strange dress which provided for the divers hands only to be exposed to ambient pressure.[17,18] This elaborate and extremely heavy diving suit does not appear to have got much further than its first sea trial.

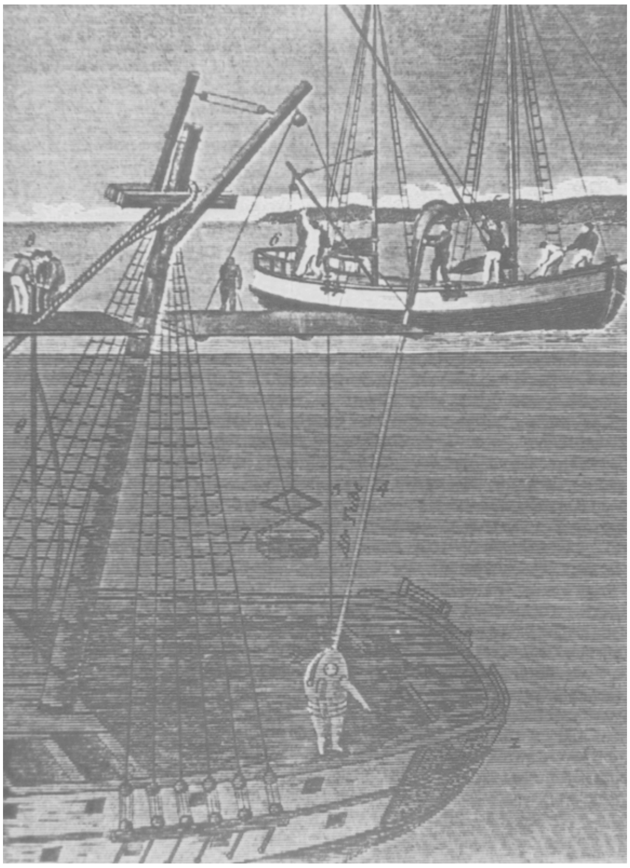

Figure 7. John Braithwaite (1760-1818) working on the *Earl of Abergavenny* on September 29 1805, wearing Tonkin’s diving machine which he had hired. He later teamed up with Ralph and Enoch Tonkin for further salvage on this ship. The original illustration is captioned ”CURIOUS DIVING-BELL”.

Improvements to the design

For completeness, it should be mentioned that a variation on the system did emerge, which tended to increase slightly its limited depth capability. This was to add a spring-loaded exhaust valve to the outlet of the exhaust pipe. This meant that the air supply had to be provided at a pressure higher than atmospheric, depending on the strength of the spring loading on the exit valve. The higher air pressure was, however, not equivalent to the depth of the diver so the exhaust air had to be released at or near the sea surface, again necessitating the two pipe air supply system. The technique did have the effect of reducing the pressure differential between the inside and outside of the rigid part of the dress and allowed the dress to be used slightly deeper than without the modification.

Conclusion

This paper has dealt with a unique form of diving system which deserves to be better known and understood.

Whilst a semi-atmospheric diving system is plagued with major inherent disadvantages, it cannot be denied that it was successfully applied in several significant salvage operations spread over three centuries.

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A BRIEF HISTORY OF SCUBA DIVING IN THE UNITED STATES

Drew Richardson

Key Words

History, recreational diving.

Summary

This presentation provides a brief overview, with dates, of how recreational scuba diving developed and is developing in the United States of America.

Introduction

Recreational compressed air diving, except for occasional experimenters using home made surface supplied equipment, came into being with the invention of the Aqualung by Cousteau and Gagnan. Self contained underwater breathing apparatus (scuba) had been envisaged, and even used long before the 1940s, but it was the simplicity of Cousteau's Aqualung (twin hose scuba equipment) and the manufacturing and technical support available which enabled recreational diving to move from "macho" breath holding to spear fish to scuba diving and photography.

This paper shows how much the development of recreational diving in the USA has been influenced by publicity, both books and films.

Early ideas

We start in antiquity, for in 1680 Borelli, an Italian, wrote of a closed circuit rebreather and swim fins. If the equipment had been made and used it would have been the first "frogman" outfit.

Nineteenth century

In 1831 an American machinist, Charles Condert, designed a self-contained diving dress. This was the only US predecessor to Cousteau's concept of scuba.

Recreational diving supports the recreational diver training industry, which supplies its trainees with travel, equipment and instruction. The first "how-to" diving manual appeared in 1836 when John Deane published, in London, his *Method of using Deane's Patent Diving Apparatus*.

In 1864 two Frenchmen, Rouquayrol and Denayrouze, developed the first tank based, demand valve type of scuba which was actually used successfully. Five years later Jules Verne popularised the concept of scuba by featuring the use of Rouquayrol units in his book *20,000 Leagues Under the Sea*, published in 1869.

Twentieth century

In 1916 John Williamson, an American, was the first to use underwater cinematography commercially while filming a version of *20,000 Leagues Under the Sea*. This film was the first American use of special effects and was one and a half years in production. The underwater scenes were shot in the Bahamas with other shots at Universal's studios in New Jersey and Los Angeles. Captain Nemo's submarine was a genuine working craft

The Bottom Scratchers, a famous "macho" club of underwater game hunters, was formed by San Diego skin (free or breath-hold) divers in 1933. The era of "goggling" and game taking began in America. Game taking defined the sport until the 1960s.

The first US-developed mixed gas rebreather was manufactured in 1937 by American Diving Equipment and Salvage Company (later to be known as DESCO). This was used by Max Nohl during his world record dive to 126 m (420 feet).

In 1938 Guy Gilpatric wrote *The Compleat Goggler*. This was the first book for skin divers. Free diving popularity began in earnest throughout the US, especially in California. Many goggling clubs were formed.

Owen Churchill helped popularise skin diving in the USA in 1940 by mass producing "Churchill" fins under licence from the patentee, Frenchman Louis Corliew. They were sold to recreational swimmers and to the US military.

The scuba era

The commercial production of the Aqualung in France allowed Europeans to scuba dive. but the equipment was not available in the US until 1948. That year *Rene's Sporting Goods* opened in Westwood, Los Angeles near UCLA. An immigrant from France, Rene Bussoz was the husband of a cousin of Simone Cousteau. Rene displayed three Aqualungs from Cousteau at the 1948 National Sporting Goods Association (NSGA) show in New York. The Show generated moderate interest in scuba. Soon after, the first US article on Cousteau appeared in *Science Illustrated*.

The US Navy (USN) evaluated the Aqualung in 1949. Douglas Fane, commander of an underwater demolition team (UDT) visited France and was the first American to try an Aqualung, at Cannes. Lieutenant N Blocknick submitted a report on the apparatus. Later that year Cousteau brought 6 Aqualungs to Los Angeles and conducted training. Cousteau, Rene Bussoz, Johnny Weismuller and two others made the first Aqualung dives in the US off Point Dume, California.

In 1950 the magazine *Life* ran a seven page pictorial essay on Cousteau and his work. Through the article, Cousteau's films came to the attention of Universal Pictures. Universal acquired the rights to the first four Cousteau films for $11,000. Each short film appeared in theatres across the US. These films significantly increased the public's awareness of the Aqualung.

1951

American actors Richard Widmark and Dana Andrews starred in *The Frogmen*, a film about the exploits of the USN's UDT divers. Aqualungs were shown prominently in a movie for the first time. Most recreational diving historians credit this film with helping accelerate growth of the sport. The film earned an Academy Award Nomination. Rene Bussoz is believed to have formed US Divers to handle the film's contract and supplied the Aqualungs, but the company was not active for several more years.

Skin Diver magazine, originally called *The Skin Diver*, was started by Chuck Blakeslee and Jim Auxier in their garage in LA. The new magazine instantly became the leading journal of spear fishing/hunting. It played an important role in maturing underwater photography and dive travel.

Rachel Carson's book, *The Sea Around Us*, drew attention to the marine environment. It was the first American book on environmental protection of the seas.

1952

US Divers began marketing in the US. The company took a full page advertisement in Skin Diver Magazine and published a small 24-page manual, *Self Contained Diving*. Their first equipment catalogue appeared in 1953.

National Geographic published Cousteau's article *Fish Men Explore a New World Undersea* and Cousteau's *Silent World* was published in the US.

1953

Popular Science Magazine outlined the procedure to "make your own Aqualung". The article described the necessary modifications to aircraft oxygen regulators for use underwater. The author suggested using low pressure CO_2 cylinders. He also provided instructions for its use. The same issue also showed how to build an underwater housing for a camera.

E R Cross published Underwater Safety, the first modern diving manual in the USA, it had 86 pages and was distributed by Healthways. Rene Bussoz sold his holdings in US Divers to Air Liquide France.

1954

Hunters of the Deep, one of the first diving science documentaries made in the US, was produced by the Scripps Institute of Oceanography, the USN and the Hancock Institute. It showed marine "scientists" working with Aqualungs. Conrad Limbaugh, the Scripps Institute's first diving officer, was a primary photographer.

Two other films, Creature of the Black Lagoon (considered a benchmark film in its day for special effects) and Disney's 20,000 Leagues Under the Sea featured lots of diving. They were also considered to accelerate growth of sport diving.

LA Dept. of Parks and Recreation ran the first organised Scuba Training program in the US. Bev Morgan and Al Tillman, both diving pioneers ran the program.

1955

Dacor Begins Manufacturing

Sam Davison formed Dacor which made a new adjustable double hose regulator. Dacor went on to become a major equipment manufacturer.

1956

Wetsuits entered the market when Dr. Hugh Bradner, at University of California, researching the protective properties of "Arctic" long johns found the much better insulating properties of neoprene foam, which was being manufactured by Rubatex as automobile insulation. Up to this point most divers wore thick woollen garments as "insulation". Early wet suits were marketed by the Beaver company of La Jolla, California.

Ted Nixon introduced the American Diver Down Flag (red with a diagonal white stripe)to warn boaters away from divers. The flag has become national symbol of diving.

1958

Sportsways "Waterlung" regulator became the first single hose regulator popular enough to replace double hose regulators.

Diving manufacturers showed their wares at the NSGA show each year. In this year Voit, US Divers, Healthways, Dacor and Swimaster began talks about forming their own trade association. This stayed a "social club" of chief executives until 1963 when the Diving Equipment Manufacturers Association (DEMA) was formed.

America's first diving hero, Mike Nelson, dashed into US living rooms in Sea Hunt, which became America's most popular television show in the late 50s. It had a four season run. Lloyd Bridges became a role model for many young, diving enthusiasts. The series brought a whole generation into diving.

1959

The Young Men's Christian Association (YMCA) began the first national scuba training program and offered the first nationwide diver certification.

The first amphibious camera, the Calypso, became available from US Divers. It marked the beginning of a new era in diving.

1960

Neal Hess and Al Tillman formed the National Association of Underwater Instructors (NAUI) and conducted the first instructor certification course in Houston.

1963

Gustav Dalla Valle and Dick Bonin started Scubapro Company which went on to introduce many equipment firsts.

DEMA was formed to promote the recreational diving industry.

1964

The USN carried out Sealab I, 11 days in saturation with scuba diving excursions, at an average depth of 58 m (193 ft).

1965

In *Thunderball* James Bond went underwater to save the world. This was the most underwater footage yet taken. The film won an Academy Award for visual effects. Seen in most cinema theatres in the US, the film glamorised and updated the image of scuba. Diving retailers outfitted many people to look "just like Bond".

1966

John Cronin and Ralph Erickson formed the Professional Association of Diving Instructors (PADI) in Chicago. PADI later moved to California. PADI launched the "Positive Identification Card" or PIC. PADI was the first training organisation to recognise the need to work closely with dive retailers and travel providers.

1967

The Undersea Medical Society, now the Undersea and Hyperbaric Medical Society (UHMS), was formed with offices in Bethesda, Maryland. UHMS and its members have significantly advanced knowledge of the medical aspects of diving.

1969

See & Sea Travel opened its doors. It was the first major dive travel wholesaler in the US to cater exclusively for diver travel. As such it ushered in the era of dive travel in the US. Later the firm focused on live-aboard dive boats.

1971

Scubapro introduced the jacket style buoyancy compensating device (BCD). The "Stab Jacket" began to eliminate the existing "horse collar" BCDs. Jacket style BCDs have become the industry standard.

1973

US Divers discontinued the sale of spearguns. This radical action, for the time, ushered in the era of eco awareness for the recreational diving industry.

1974

With the film *Jaws*, Hollywood-induced "shark-o-phobia" chased people out of the water. Recreational diving retailing and certification dipped dramatically after the film's release, ending 15 years of consecutive industry growth and beginning a long depression.

1977

The movie *The Deep* also showed the horror of the underwater world. The repercussions on recreational diving were a bit lighter than with Jaws.

DEMA produced its first Trade Show in Miami. The show established itself as "neutral ground" where the entire industry could meet. DEMA has made itself a potent force for professionalism and unity within recreational diving industry.

1980

Duke University's F G Hall Hyperbaric Center in North Carolina started to provide a "Dive Accident Network" to support divers in need of medical care. The name was later changed to Divers Alert Network (DAN) which now provides medical support to divers support and diving medical research.

1981

DEMA initiated the "Graduated Entrance Method" (GEM) program of diver training with the backing of PADI and NAUI. The program suggested a kinder and gentler philosophy of dive instruction. This approach brought more families and busy professionals to scuba training.

1983

DEMA produced a string of promotional films that were shown as trailers in movie theatres. These were *I'd Rather be Diving*, *Treasure Diving*, *The Seven Wonders of the Diving World* and *Scuba Diving in America*.

Orca released the "Edge" dive computer. This was the first commercially successful dive computer. Recreational divers could now experience multi-level diving guided by a computer. Unfortunately some early computers allowed repetitive dives that bent their users.

1985

New Dive Tables, designed and researched exclusively for recreational divers, were published by the Diving Science and Technology Corporation (DSAT). This algorithm has been used in a number of American dive computers.

1990s

Through this decade environmental awareness has continued to rise. Dive travel has exploded to the ends of almost every airline route and live-aboard dive boats go even further afield. Technical diving has entered the recreational domain. Enriched air nitrox is available in many dive shops. Rebreathers have become available to the recreational diver. Diver training has continued to emphasise safety through streamlined education.

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DIVING MEDICAL CENTRE

SCUBA DIVING MEDICAL EXAMINER'S COURSES

A courses for doctors on diving medicine, sufficient to meet the Queensland Government requirements for recreational scuba diver assessment (AS4005.1), will be held by the Diving Medical Centre at:

Royal North Shore Hospital
Sydney
2nd to 4th October 1999
and
Bond University
Gold Coast, Queensland.
Easter weekend 2000.

Previous courses have been endorsed by the RACGP (QA&CE) for 3 Cat A CME Points per hour (total 69)

Phone Brisbane (07)-3376-1056 for further details

Information and application forms for courses can be obtained from
Dr Bob Thomas
Diving Medical Centre
132 Yallambee Road
Jindalee, Queensland 4047
Telephone (07) 3376 1056. Fax (07) 3376 4171.

GLEANINGS FROM MEDICAL JOURNALS

CARBON MONOXIDE POISONING

Hyperbaric or normobaric oxygen for acute carbon monoxide poisoning: a randomised controlled clinical trial

Carlos D Scheinkestel, Michael Bailey, Paul S Myles, Kerry Jones, D James Cooper, Ian L Millar and David V Tuxen

Key Words

Carbon monoxide, hyperbaric oxygen, oxygen, reprinted, treatment.

Abstract

Objective: To assess neurological sequelae in patients with all grades of carbon monoxide (CO) poisoning after treatment with hyperbaric oxygen (HBO) and normobaric oxygen (NBO).

Design: Randomised controlled double-blind trial, including an extended series of neuropsychological tests and sham treatments in a multiplace hyperbaric chamber for patients treated with NBO.

Setting: The multiplace hyperbaric chamber at the Alfred Hospital, a universityattached quarternary referral centre in Melbourne providing the only hyperbaric service in the State of Victoria.

Patients: All patients referred with CO poisoning between 1 September 1993 and 30 December 1995, irrespective of severity of poisoning. Pregnant women, children, burns victims and those refusing consent were excluded.

Intervention: Daily 100-minute treatments with 100% oxygen in a hyperbaric chamber - 60 minutes at 2.8 atmospheres absolute for the HBO group and at 1.0 atmosphere absolute for the NBO group - for three days (or for six days for patients who were clinically abnormal or had poor neuropsychological outcome after three treatments). Both groups received continuous high flow oxygen between treatments.

Main outcome measures: Neuropsychological performance at completion of treatment, and at one month where possible.

Results: More patients in the HBO group required additional treatments (28% v. 15%, P=0.01 for all patients; 35% v. 13%, P=0.001 for severely poisoned patients). HBO patients had a worse outcome in the learning test at completion of treatment (P= 0.01 for all patients; P= 0.005 for severely poisoned patients) and a greater number of abnormal test results at completion of treatment (P=0.02 for all patients; P=0,008 for severely poisoned patients). A greater percentage of severely poisoned patients in the HBO group had a poor outcome at completion of treatment (P= 0.03). Delayed neurological sequelae were restricted to HBO patients (P=0.03). No outcome measure was worse in the NBO group.

Conclusion: In this trial, in which both groups received high doses of oxygen, HBO therapy did not benefit, and may have worsened, the outcome. We cannot recommend its use in CO poisoning.

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PFO AND DCI

Risk of decompression sickness with patent foramen ovale.

Bove AA. *Undersea Hyperbaric Med* 1998; 25 (3): 175-178

Key Words

Cardiovascular, decompression sickness, reprinted.

Abstract

Several reports have described populations of divers with decompression sickness (DCS) who have a patent foramen ovale (PFO). The presence of a PFO is known to occur in about 30% of the normal population, hence 30% of divers are likely to have a PFO. Although observations have been made on the presence of a PFO in divers with and without DCS, the risk of developing DCS when a diver has a PFO has not been determined. In this study, Logistic Regression and Bayes' theorem were used to calculate the risk of DCS from data of three studies that reported on echocardiographic analysis of PFO in a diving population, some of whom developed DCS. Overall incidence of DCS was obtained from the sport diving population, from the US Navy diving population and from a commercial population. The analysis indicates that the presence of a PFO produces a 2.5 times increase in the odds ratio for developing serious (type II) DCS in all three types of divers. Since the incidence of type II DCS in these three populations averages 2.28/10,000 dives, the risk of developing DCS in the presence of a PFO remains small, and does not warrant routine screening by echocardiography of sport, military, or commercial divers.

From

Cardiology Section, Temple University Medical School, Philadelphia, Pennsylvania, USA.

SCOMBROID POISONING

Scombroid fish poisoning: successful treatment with cimetidine.

Guss DA. *Undersea Hyperbaric Med* 1998; 25(2):123125

Key Words

Biology, case report, marine animals, reprinted, toxin.

Abstract

Reported is a patient with a clinical syndrome characteristic of scombroid fish poisoning after ingesting yellowfin tuna that may have been allowed to sit at room temperature for some time before preparation. The patient was treated with an intravenous infusion of cimetidine with prompt resolution of a diffuse, well demarcated, erythematous, pruritic rash. The treatment was without sequelae and permitted early discharge from the emergency department. A brief review of scombroid fish poisoning and its treatment is provided.

From

Department of Emergency Medicine, UCSD Medical Center, 200 West Arbor Drive, San Diego, California, USA.

TOURISM

Managing patient records and documenting service delivery: the results of a "best practice" remote area nursing program.

Wilks J, Barnes J, Paul K, Wood M and Jones D. *Aust J. Rural Health* 1997; 5: 153-157

Key Words

Medical conditions and problems, reprint, tourism.

Abstract

This paper describes a "best practice" demonstration program for monitoring nursing services in remote locations. A four-phase project involving paper- and computer-based patient information systems was implemented at nursing clinics off the coast of Queensland. Patient demographics, diagnoses and details of health service provision were recorded. Results showed a marked improvement in the detail of patient records over the program period. Monitoring of services also provided useful planning and policy information for company management, while a systematic approach to maintaining patient records addressed several medico-legal issues.

Travel and Health Research in Australia.

Wilks J and Grenfell R. *J Travel Med* 1997; 4: 83-89

Key Words

Medical conditions and problems, reprint, tourism.

Abstract

Travel and tourism is a major industry in Australia, employing 6.9% of the nation's workforce (535,600 persons) and generating $Aust 46.9 billion in 1993-94. While economic and marketing analyses have traditionally dominated the field of tourism research in Australia, health and safety issues that impact on the business of tourism are now emerging. Travel medicine is still a small specialty area, though it has established a legitimate role within the tourism industry by providing services in prevention and treatment. To date, little attention has been given to empirical research, even though field studies are a critical component in the provision of accurate medical advice for patients. This paper reviews the Australian research that is available and identifies areas where further work should be conducted.

ROYAL NEW ZEALAND NAVY DIVING MEDICINE COURSE

10th to 13th October 1999

Naval Health Services will hold a course in Diving and Hyperbaric Medicine from Sunday 10/10/99 to Wednesday 13/10/99 at the Naval Base, Devonport.

The course introduces candidates to the principles of diving and hyperbaric medicine, and focuses on the assessment of an individual's fitness for diving and hyperbaric exposures and the first aid for common diving illnesses.

The course is recognised by the New Zealand Department of Labour, the United Kingdom Health and Safety Executive and the Board of Censors of the South Pacific Underwater Medicine Society which gives recognition under AS/NZS 2299.1 1999.

The maximum number for the course is 25. The course fee is $NZ 750.00 (including GST). This covers course notes and morning and afternoon tea. Enrolment requires a deposit of $NZ 150.00. Cheques should be made payable to **NZ Defence Force-Navy.**

For further information, including information about accommodation, contact

Angie Smith
PA to the Director of Naval Medicine
Naval Base
Private Bag 32901
Auckland
Phone +64-(0)9-445-5972
Fax +64-(0)9-445-5973
E-mail marcom@navy.mil.nz

ROYAL ADELAIDE HOSPITAL HYPERBARIC MEDICINE UNIT

Basic Course in Diving Medicine

Content Concentrates on the assessment of fitness of candidates for diving. HSE-approved course.

Dates
Monday 1/11/99 to Friday 5/11/99

Cost
$Aust 750.00

Advanced Course in Diving and Hyperbaric Medicine

Content Discusses the diving-related, and other emergency indications for hyperbaric therapy.

Dates
Monday 8/11/99 to Friday 12/11/99

Cost
$Aust 750.00
$Aust 1,300.00 for both courses taken back to back

Diving Medical Technicians Course

Unit 1 St John Ambulance Occupational First Aid Course (an essential prequesite) and medical lectures at RAH. (Cost of First Aid course in Adelaide $Aust 520.00 payable to St John Ambulance.)
Unit 2 Diving Medicine Lectures and
Unit 3 Casualty Paramedical Training.
Cost of three unit course $Aust 1, 250.00

Dates

October/November 1999

Unit 1	18/10/99	to	22/10/99
Unit 2	25/10/99	to	29/10/99
Unit 3	1/11/99	to	5/11/99

Diver Medical Technician Refresher Courses
(includes lectures and practical)

Dates

October 1999
25/10/99 to 29/10/99

Cost $Aust 500.00

For further information or to enrol contact
The Director, HMU,
Royal Adelaide Hospital, North Terrace
South Australia, 5000.

Telephone	Australia	(08) 8222 5116
	Overseas	+61 8 8224 5116
Fax	Australia	(08) 8232 4207
	Overseas	+61 8 8232 4207

ROYAL AUSTRALIAN NAVY MEDICAL OFFICERS' COURSE IN UNDERWATER MEDICINE

November 22nd to December 3rd 1999

The course concentrates on diving physiology, fitness to dive, and emergency management of diving injuries.

Practical involvement includes opportunity to dive with different types of equipment and a recompression chamber dive.

The course fee for 1998 was $1,330.00. The 1999 fee is expected to be about the same but is yet to be determined.

For information or to enrol contact

Officer in Charge
Submarine and Underwater Medicine Unit
HMAS PENGUIN
Middle Head Road
Mosman, New South Wales 2088

Tel: (61) 2 99600333
Fax: (61) 2 99604435
E-mail : Robyn.Walker.150150@navy.gov.au

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THE SEA PEOPLE'S GUIDE TO DIVERS
By **RICO**

Humans say that to see themselves as others see them is a great blessing. Imagine then what a blessing it would be to see themselves as other species see them. If only we could find a way of giving them a Sea People's view of themselves. Well, actually, we can...

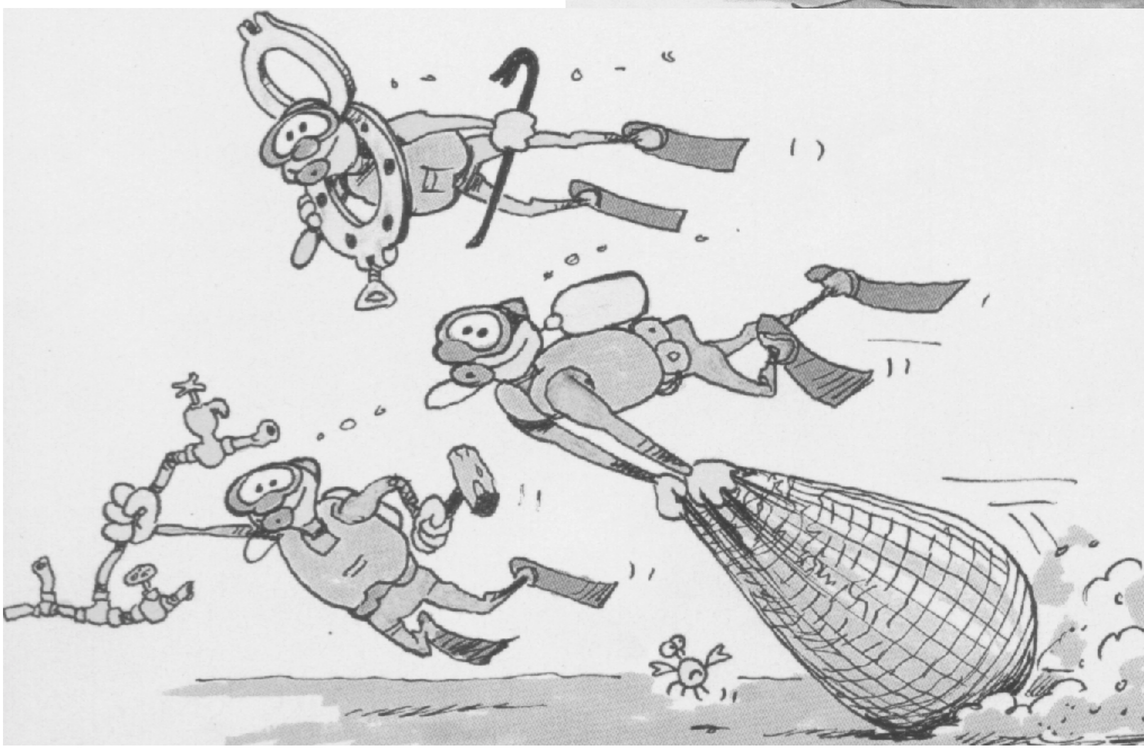
This is the last of the series and shows divers who cannot be found at SPUMS conferences.

Shoaling Lager Sharks

Shoaling Lager Sharks are qualified in the art of evading the ordeal of kitting-up. They are party animals who arrive at a dive site in a carnival convoy of jet-skis and booze. They were going to dive, but since the sea is so flat it would be a waste of a rare water skiing day to go wetside. So they assist the loading of dive boats, wave goodbye to their courageous companions and gambol on the surface of the sea. They are just as helpful when their knackered buddies flounder back onto the beach. They are so envious they didn't dive . So eager are they to catwalk their suntans at the end of the day, they're usually first in the pub, and thereby sentenced to getting the first round in.

Brass Wrasses and Dragnet Diver

For one group of divers, non-ferrous metal holds a holy significance; just staring at it can transport them far down the briny corridors of maritime history. Brass Wrasses arrive on site with a six-pack of metal polish, and hope to find something, anything, to shine up. The Dragnet Diver is less selective, and anything remotely artefactual is fair game for his Tardis of a goody-bag. At the end of his dive, woe betide any luckless invertebrate in the path of his trawl net.



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