The Editor's Offering

The Journal congratulates LCDR Robyn Walker RAN as our first female President. The new Committee, elected at the 1999 AGM, is listed on the opposite page. Its members will hold office for the next three years.

The attention of members is drawn to pages 76-77 where the constitutional changes passed at the 1999 Annual General Meeting are printed. The changes do not come into effect until voted on by the membership. If any member objects, in writing, to the Secretary of SPUMS before September 1st 1999 a postal ballot will be held. Otherwise it will be assumed that the membership has voted in favour of the changes.

Shi-Lu Chia and Edwin Low have reported the treatment and results of 169 patients treated for decompression illness (DCI) at the Naval Medicine and Hyperbaric Centre in Singapore. They treated 2 fewer patients in 1997 and 1998 than all those that they had treated between 1991 and 1996. Recreational diving has definitely arrived at their chamber.

Georg Petroianu and Ursula Helfich present evidence that intravenous lignocaine really has an anti-inflammatory effect. A postulated anti-inflammatory effect was the basis of the use of lignocaine in treatment of DCI

This issue is unfortunately without any letters to the Editor. Letters on any topics to do with diving and hyperbaric medicine and diving safety are always welcome. Without letters from the membership the Journal is less interesting than it should be.

The list of contents may appear short but it covers a wide range of topics in some depth. Depth is especially important in David Elliott's paper on submarine escape where he describes the process and equipment which led to successful escapes, that is reaching the surface without developing DCI, from depths of 182 m (600 ft). The compression time was 20 to 30 seconds. Three seconds after reaching pressure the escape hatch opened and the subject was on his way and ascended at 2.6 m (8.5 ft) a second. That is 156 m/minute or nearly 16 times as fast as most recreational diving computers now allow! The total time from start of compression to reaching the surface was between 93 seconds and 103 seconds depending on compression time. What can be described as the ultimate quick, deep dip.

Submarine rescue rather than escape is Robyn Walker's contribution. Australia's new Collins class submarines are structurally different from the earlier Oberon class purchased from the UK, so changes had to be made to escape and rescue arrangements. Australia now has a rescue vehicle which can mate with a chamber complex, big enough to take the whole crew of a submarine, on its mother ship and with a stranded submarine. This is a capability the Royal Australian Navy has not had before.

After reading these two papers readers should turn to page 119 where a computer assisted method for optimising survival in a disabled submarine is described. With human error playing such a large part in less than effective action during emergencies this program, with it red, yellow and green coding of behaviour available to the crew, is a great step forward. One of the authors, James Francis, was a Guest Speaker at the 1997 ASM in Waitangi.

Many divers have heard of Professor A A Bühlmann of Zurich. His decompression algorithm is found in many dive computers. Jürg Wendling and his colleagues have provided a brief history of the deep diving research carried out at the University of Zurich. Hannes Keller' contributions, with gas switching during decompression and personal testing of his ideas during deep dives, led to Bühlmann's algorithm for decompression.

Chris Acott's paper on the history of diving and decompression illness takes the reader from around 4,500 BC to the present day. It is the only short but comprehensive resume of the subject that the Editor and the proof-readers have ever met. It should be of great help to those wanting to find out about past events.

John Bevan has provided a clear account of the development of the diving helmet. The Deane brothers' smoke helmet developed into a safe open helmet supplied with compressed air from a surface based pump. Others moved from the open helmet, which was still being used in the Torres Strait pearl fisheries in the late 1960s, to the closed helmet attached to the waterproof diving suit. This got away from the risk of flooding the helmet when leaning forward and replaced it with the risk of overfilling the suit and "blowing up" if the exhaust valve was wrongly adjusted or stuck. John Deane in his 26 years of commercial diving always used an open helmet. For those interested in the early history of helmet diving and of the Deane brothers the book review of *The Infernal Diver* on pages 78-79 should encourage them to write to Submex to obtain the book.

Tuna "farming", which is really a fattening process, has a short, but distressing, history. Many divers, who only had recreational diver training, working in and around the nets developed decompression illness (DCI). This is not surprising given the pattern of diving. However intervention by Health and Safety authorities has been able to reduce the incidence of DCI by better training (to commercial standards), the use of surface supplied breathing equipment and voice communications. It is to be hoped that safety is not sacrificed for profit in the future.

ORIGINAL PAPERS

DECOMPRESSION ILLNESS AFTER AIR DIVES TREATED IN SINGAPORE 1991-1998

Shi-Lu Chia and Edwin Low

Key Words

Air embolism, decompression illness, hyperbaric oxygen, treatment, treatment sequelae.

Abstract

The Naval Medicine & Hyperbaric Centre (NMHC) is the only recompression chamber facility in Singapore. We receive all local cases of decompression illness (DCI) as well as a substantial number from the surrounding South-East Asian countries.

From 1991 to 1998, 169 patients were referred to NMHC for suspected DCI, either decompression illness (DCS) or cerebral arterial gas embolism (CAGE). Of these, 108 cases of DCS and 5 cases of CAGE were subsequently included in this study. The patients were treated according to our facility's clinical protocols using recompression schedules based on Royal Navy Treatment Tables. Selected demographic, historical, clinical and prognostic data of the eventual study cohort were captured in a computer database and analysed retrospectively.

The majority comprised male divers (86.1%) and most were recreational divers (75.9%). Almost one-fifth of the patients (18.5%) admitted to a previous history of DCI. Alarmingly, two-thirds received no attempts at standard diving first aid at the dive location following onset of symptoms, and only 44.4% began recompression therapy within 24 hours of their dive injury. One quarter of all patients continued to dive despite the onset of symptoms. 71.3% of all patients presented with neurological complaints, which most commonly involved numbness and/or paraesthesia of the extremities. Joint pain was frequently localised to the shoulders, and the incidence of upper limb arthralgia was more than twice that of lower limb pain in this series. No patient deteriorated or failed to respond to recompression and 81.5% achieved complete symptom resolution following completion of the prescribed treatment sessions. Patients who were classified as Type I DCS tended to receive fewer treatments than patients with Type II DCS, although there was no difference in short-term outcome between the two groups. For the patients with CAGE, treatment outcome was good when recompression was initiated early.

Recompression therapy using short oxygen tables leads to an acceptable outcome in the majority of patients with DCS, even when treatment is delayed. Our data support reports elsewhere that joint pain in DCS associated with bounce diving is more likely to be localised in the upper compared to the lower limbs. In our series, patients with pain-only complaints tended to require fewer treatments than those with Type II DCS, although we found no differences in the short-term outcome between the two groups.

Introduction

Decompression illness (DCI) is the archetypal diver's disease, encompassing a spectrum of clinical signs and symptoms which arise when changes in the ambient pressure result in the unnatural introduction of gases into body tissues. Estimates of DCI incidence have ranged from as high as 1 per 6,000 dives for the general diving population, to as low as 1 in over 50,000 for "undeserved" cases among divers who have no apparent increased risk for DCI.[1-4] Fatalities are even more uncommon, and it may generally be said that diving is a relatively low-risk activity for the medically fit individual who observes safe diving practices.

Recreational diving has been growing steadily in popularity in South-East Asia in recent years. The rate of growth of the sport diving industry in the region has been estimated at between 17-20% annually over the past 5 years and this trend may well be expected to continue over the next few years. The Naval Medicine and Hyperbaric Centre (NMHC) is the only diving medical and hyperbaric facility in Singapore, and is recognised by the Divers Alert Network as a centre for the treatment of diving emergencies such as DCI. Although its raison d'être is centred around the support of military diving operations, it also manages a growing number of civilian referrals for diving-related injuries, as there are, at present, relatively few accredited recompression facilities in South East Asia.

This brief report summarises the findings of a recent review of 108 cases of decompression sickness (DCS) and 5 cases of cerebral arterial gas embolism (CAGE) that were treated at our facility between 1991 and 1998.

Methods

DATA COLLECTION AND ANALYSIS

Detailed clinical and treatment histories of all cases of decompression illness that are referred to our facility are documented in standardised records. A chart review of 169 patients that had been evaluated by our centre for suspected DCI (either DCS or CAGE) from 1991-1998 was performed by the authors and the relevant information was extracted into a computer database. Only divers who had been using compressed air as the breathing gas were considered. 56 subjects were excluded for one or more of the following reasons: inadequate clinical evidence for diagnosis of DCI or an alternative diagnosis made, refusal or default of recompression therapy, or secondary referral after treatment had been partially completed in another hyperbaric facility. 113 patients were eventually included in the final analysis. Cases of DCS have been analysed separately from the patients with CAGE.

The grading of treatment outcome was based on both objective and subjective parameters, and classified into the following categories.

Complete recovery.

Total resolution of symptoms and signs

Partial recovery with minor residual symptoms

Incomplete recovery with the persistence of symptoms and/ or signs that were not distressing nor incapacitating. Patients in this category typically had vague and intermittent niggling complaints which did not affect their activities nor cause them significant discomfort.

Partial recovery with major residual symptoms.

Incomplete recovery with the persistence of deficits that were significantly distressing or incapacitating to the patient.

No recovery.

Initial outcome was defined as the patient's clinical condition as assessed within 24 hours after the first recompression session, whereas short-term final outcome refers to the patient's clinical condition as assessed 24-48 hours after completion of all prescribed treatments. In this review, we have used the traditional Type I and II DCS nomenclature as we have found it to be useful and expedient in our clinical practice, although we recognise its short-comings compared with an evolving classification that is based on descriptive symptomatology.[5,6] The definition of Type I DCS was restricted to musculo-skeletal pain and dermatological complaints only, whereas Type II DCS was a far broader category comprising those patients with neurological and cardio-respiratory symptoms and signs.

Statistical analysis was performed, using the SPSS computer package for the Windows environment. The main instruments used were the Pearson Chi-square test (2 tailed) for comparing proportions and the Student's T-test (2 tailed) for means. Comparisons were considered to be statistically significant for $p < 0.05$.

CLINICAL MANAGEMENT

All cases were treated in one of two multiplace chambers that are equipped with built-in breathing systems (BIBS) for oxygen delivery. Standard Royal Navy (RN) oxygen tables were used, mainly Tables 61 and 62. Patients were typically started on Table 62 and oxygen extensions added according to the observed clinical response after the first oxygen period. For very mild cases of musculoskeletal or dermatological DCS (Type I DCS), Table 61 was at times used as the initial table, although the treatment would be extended to follow the Table 62 protocol should there be unsatisfactory resolution of symptoms at the initial treatment depth. No ancillary or adjuvant therapy specific to DCI was used, other than intravenous hydration in those patients who were clinically dehydrated. All CAGE patients were on intravenous fluids during recompression.

All patients were reviewed daily, and subsequent management was guided by the patient's condition. Patients who continued to complain of significant symptoms following the initial recompression treatment (major residual symptoms/signs) usually underwent a repeat session of the first table, whereas those who demonstrated marked improvement were retreated on RN Table 61. These treatment sessions were repeated daily until no further improvement was observed on 2 consecutive treatments, or until complete resolution of the presenting complaints was achieved.

Results DCS patients

DEMOGRAPHICS

The number of patients that were treated annually by our facility for DCS was fairly constant between 1991-1995 at about 8 a year. That number has increased steadily over the past 3 years and is now about 26 cases a year (Table 1). Eighty two (75.9%) were recreational divers. There were 14 (13.0%) commercial and 12 (11.1%) military divers. There were 93 males (86.1%) whose ages ranged from 20-58 years (mean 31.2 years). The 15 females (13.9%) had a mean age of 30.2 years with a range of 21-48 years (Table 2).

TABLE 1

DCS PATIENTS TREATED

Year	DCS Patients treated
1991	9
1992	6
1993	8
1994	7
1995	10
1996	15
1997	26
1998	27
Total	**108**

TABLE 2

AGE-GENDER DISTRIBUTION

Age	Male	Female	Total
20-24	23	1	24
25-29	18	7	25
30-34	21	4	25
35-39	19	1	20
40-44	7	2	9
45-49	3	0	3
>49	2	0	2
Total	**93**	**15**	**108**

PREVIOUS HISTORY OF DCS

Twenty of our patients, almost a fifth (18.5%), had previously suffered at least one episode of DCS for which they had sought medical attention, although none admitted to any residual symptoms from this past encounter. Five (4.6%) divers had a history of bronchial asthma, and one (0.9%) with chronic hypertension was on long-term medication. None of our patients volunteered a history of cardiac valvular or septal defects, and physical examination did not reveal any cardiac abnormality in any of the divers.

DIVE PROFILE

The average depth of the dive immediately preceding the onset of symptoms was 27.2 m, while the mean maximum depth reached for all patients was 31.2 m. Other researchers have noted that a sizeable proportion of recreational divers develop DCI after just one day of diving[3,4] and we found that 22.2% of our patients were afflicted following just one dive. The information provided by many patients regarding their dive profiles was often incomplete or imprecise, but it appeared that many, if not most, recreational divers were performing repetitive and/or multilevel diving.

Among our patients, only five (4.6%) divers claimed to have descended no deeper than 10 m on all dives, although about 1 in 10 (12/108) divers reported sustaining their "hit" immediately after a dive of 10 m or less. However, of the latter group, most had completed at least one other dive on the same day. Unfortunately incomplete data concerning the other dive profiles and surface intervals often prevented us from making meaningful comments on whether repetitive limits had been exceeded.

ON-SITE MANAGEMENT AND EVACUATION

Alarmingly, 27 (25.0%) of our patients continued to dive following the onset of symptoms. The mean number of additional dives undertaken by these patients was 5. When recreational divers alone were considered, 21 (25.6%) persisted in diving despite their symptoms.

Barely a third, 36 divers (33.3%), reported receiving any diving first aid (100% oxygen or rehydration) at the dive site. Only 48 (44.4%) of the afflicted divers began recompression therapy within 24 hours of symptom onset, but this may be due to the fact that our facility is far from many of the popular dive sites in the region.

SYMPTOMS

Reliable information regarding time from surfacing to onset of symptoms was obtained from only 48 patients (44.4%). In this group the mean time was 3 hours and 39 minutes. Thirty nine divers (81.3%) had symptoms presenting within 3 hours, 42 (87.5%) within 6 hours and 44 (91.7%) within 12 hours of surfacing.

The presenting symptomology is shown in Table 3. Neurological symptoms and/or signs (Type II DCS) were the most frequent complaint with 77 divers (71.3%) reporting them. The majority (72 patients) presented with numbness and/or paraesthesia. 10 patients had upper limb weakness, while lower limb weakness was also present in 10 divers. Visual disturbances (3 patients) and bowel and bladder dysfunction (7 patients) were relatively uncommon.

Musculoskeletal pain and aches were also prevalent (64.8 %), although only 31 divers (28.7%) complained of pain or aches as the only symptom (Type I

TABLE 3

SYMPTOMS OF DCI IN 108 PATIENTS

Symptom	Number	(% of total)
Joint Pain/Ache	70	(64.8)
Shoulder	33	(30.6)
Elbow/arm	39	(36.1)
Hip	10	(9.3)
Knee/leg	21	(19.4)
Back	8	(7.4)
Neurological	77	(71.3)
Numbness/paraesthesia	72	(66.7)
Upper limb weakness	10	(9.3)
Lower limb weakness	10	(9.3)
Bowel/bladder difficulties	7	(6.5)
Visual complaints	3	(2.8)
Fatigue/lethargy	36	(33.3)
Headache	10	(9.3)
"Chokes" (Respiratory)	5	(4.6)

DCS). Pain was most commonly localised to the upper limbs and particularly the shoulders (30.6%), a pattern that has been reported by other investigators. The frequency of upper limb joint pain was approximately twice that of joint pain in the lower limbs (55 vs 27).

OUTCOME

Following the initial recompression, only 36 patients achieved complete symptom resolution and 15 responded poorly with either no relief or minimal relief (Table 4). However, after completion of all prescribed sessions, almost all patients demonstrated substantial recovery, with 88 patients (81.5%) achieving complete recovery and only one patient having major residual deficits (Table 5). No patient deteriorated during or following treatment. There was no major complication suffered by any patient that directly resulted from recompression therapy for DCS. There was no recorded oxygen-induced convulsions or pulmonary barotrauma.

We found no statistical relationship between outcomes and time from injury to treatment, or between Type I and II DCS. Patients with neurological complaints did not appear to fare any worse than patients with musculo-skeletal or constitutional symptoms only. We found, however, that patients who had been classified as Type I DCS at presentation tended to require fewer treatments that those who were diagnosed as Type II (1.90 vs 2.68, $p<0.05$).

CAGE Patients

Five cases of CAGE were treated at our facility during this period. All were male, ages ranging from 23 to 40. Three were recreational divers. All presented with a history of rapid, uncontrolled ascent accompanied by an acute onset of significant neurological deficit, such as loss of consciousness or hemiplegia, during ascent or upon surfacing. No patient had any clinical or X-ray indication of pulmonary barotrauma such as pneumothorax, pneumomediastinum or subcutaneous emphysema, nor did any have clinical evidence of a cardiac septal defect.

Two patients were comatose upon arrival and mechanically ventilated. One of these was transferred to us, after a delay of about 24 hours, from a foreign hospital. His condition continued to deteriorate following

TABLE 4

RESPONSE TO INITIAL RECOMPRESSION TREATMENT

Recovery	**n**	**Treatment Delay**		**DCS Type**		**Previous DCS History**	
		< 24 hrs	**> 24 hrs**	**I**	**II**	**Positive**	**Negative**
Complete	36	16 (33.3)	20 (33.3)	9 (29.0)	27 (35.1)	6 (30.0)	30 (34.1)
Partial/ Minor	57	25 (52.1)	32 (53.3)	20 (64.5)	37 (48.1)	13 (65.0)	44 (50.0)
Partial/ Major	10	4 (8.3)	6 (10.0)	1 (3.2)	9 (11.7)	0	10 (11.4)
None	5	3 (6.3)	2 (3.3)	1 (3.2)	4 (5.2)	1 (5.0)	4 (4.5)
Totals	108	48	60	31	77	20	88
		n/s		n/s		n/s	

Note. Figures in parentheses refer to percentages within each sub-category; n/s = not significant)

TABLE 5

SHORT-TERM FINAL RECOVERY FOLLOWING COMPLETION OF ALL PRESCRIBED TREATMENTS

Recovery	**n**	**Treatment Delay**		**DCS Type**		**Previous DCS History**	
		< 24 hrs	> 24 hrs	I	II	Positive	Negative
Complete	88	41 (85.4)	47 (78.3)	26 (83.9)	62 (80.5)	17 (85.0)	71 (80.7)
Partial/ Minor	19	6 (12.5)	13 (21.7)	5 (16.1)	14 (18.2)	2 (10.0)	17 (19.3)
Partial/ Major	1	1 (2.1)	0	0	1 (1.3)	1 (5.0)	0
Totals	108	37	54	31	77	20	88
		n/s		n/s		n/s	

Note. Figures in parentheses refer to percentages within each sub-category; n/s= not significant the first treatment (RN Table 63) and he eventually died. Fortunately for the second patient, we were able to commence recompression on Table 62 within 8 hours. He regained consciousness and a measure of lucidity midway through the second treatment. A total of four sessions of Table 62 was eventually administered, and he responded remarkably well with virtually no residual functional deficits after the final treatment. He has since returned to work and has had no further complaints over almost a year of follow-up.

Two other patients presented initially with transient loss of consciousness subsequent to a rapid ascent, which was followed by neurological symptoms. Both were treated within 6 hours, and each achieved complete recovery following two recompression sessions.

Our last patient complained of transient loss of consciousness accompanied by numbness and weakness of his lower limbs following a precipitate ascent. He was initially evaluated at another non-hyperbaric medical facility and was only referred to us after almost 48 hours. By this time his complaints had mainly resolved except for the numbness. Two treatments were administered, but only marginal improvement was noted.

No specific pharmacological adjunct was used for any of these patients.

Discussion

The rising number of patients with decompression illness that have been referred to our facility over the past few years is most easily, and also most likely, explained by the surging popularity of recreational diving both in the region and globally. No doubt, the increasing popularity of diving destinations in South East Asia has also added to these numbers.

In so far as the epidemiology of DCI and other diving injuries are concerned, recreational divers represent the population which is most at risk. It is not difficult to see why. The general level of training is uneven, regulation of dive operators is problematic, and frequently recreational divers themselves seem willing to “take the odd chance” to maximise personal enjoyment rather than individual safety.

The proportion of patients in our study who admitted to a previous history of DCS is rather high. DAN noted a figure of only 6.6 % (confirmed cases) in a recent report.[4] It has been suggested by some that divers who have had a past history of DCS are at an increased risk of future DCS, but it is unclear whether this is due to an intrinsic genetic or physiological factor, or whether it is the unsafe diving technique practised by the diver in question that places him at increased risk.

The high figure reported in this study may perhaps be explained by a process of self-selection and an element of recall bias. It may reasonably be expected that divers who have previously suffered from DCS would be more familiar with the signs and symptoms of the disease and more aware of its consequences. Hopefully they would be more likely to seek treatment. We were unable to discern any relationship between a history of previous DCS and treatment outcome, following basic stratification for other parameters.

As alluded to above, some of our patients had been performing fairly shallow and “safe” dives but had nonetheless been afflicted with DCS. Closer questioning and clinical evaluation of these patients often revealed no other definite risk factors. There has been some interest in the phenomenon of “shallow water bends”, particularly among the lay diving community. This refers to the onset of DCI following apparently innocuous dive profiles at shallow depths and of short duration. It is unclear if this phenomenon actually exists, although it has been proposed that some reported cases may have been due to arterial gas embolism (AGE), e.g. in the presence of a previously unsuspected congenital cardiac septal defect.[7] Other reports may have omitted information about preceding dives that would have contributed significantly to the inert gas load.

Our finding that a quarter of the patients persisted in diving despite their symptoms is a rather disturbing one. It is uncertain whether these patients did so because they were unable to appreciate that they could have developed DCS, or whether they simply chose to ignore their symptoms. Nevertheless, it is worrying that the dive supervisors and operators were not more vigilant to the possibility of DCS and failed to advise their charges accordingly.

The presenting symptomology is consistent with reports published elsewhere.[3,4,8,9] It has been suggested that DCS resulting from bounce diving is more commonly associated with upper limb pain, in contrast to the greater proportion of lower limb complaints that are encountered in compressed air workers and saturation divers. This claim is compatible with our results. A recent retrospective study has also supported this observation, and concluded that counter-current exchange of inert gas may be implicated in the distribution of limb pain in DCS.[10]

The treatment results in our series of 108 patients with DCS compare favourably with those reported elsewhere (Table 6), although studies in which the majority of patients received early recompression (12 hours or less following symptom onset) tend to report better outcomes. Recent data from DAN’s diving accident database have strongly suggested that for up to 12 hours following onset of DCI, earlier times to treatment correlate with improved prognosis.[4] However, we found no statistically significant impact that delay to treatment (within 24 hours or more than

24 hours) makes on either the initial or final response to recompression. Most of our patients typically require more than 12 hours to arrive at our facility, and it is likely that the critical threshold or “golden hour” for optimal results with recompression is within 12 hours of the injury.

Nevertheless, the generally satisfactory outcomes support the argument that recompression should be attempted even when it is delayed and there are numerous reports in the literature documenting favourable outcomes in such situations.[11-13] We recently managed a young woman with neurological DCI who only sought treatment at our facility almost 5 days following the onset of her symptoms. Her complaints, which included patchy numbness and paraesthesia over her arms and feet, as well as weakness of hand grip, were completely resolved following a single recompression session using RN Table 62. A case-control or even a controlled trial would be useful in shedding further light on the optimal temporal envelope for treatment.

The number of CAGE patients treated is too small to be subjected to any meaningful statistical analysis, but our experience seems to suggest that the outcome is generally good to excellent provided that treatment is initiated early. This small series also supports previous observations that the association of CAGE with pneumothorax and significant pulmonary barotrauma is uncommon.[14,15]

TABLE

SELECTED REPORTS OF TREATMENT OUTCOMES FOR DECOMPRESSION SICKNESS

Author	Year	Cases	Results	Remarks
Erde and Edmonds[11]	1975	100	5 patients treated with air tables. 20/95 treated with oxygen tables left with incomplete recovery.	Recreational divers
How et al.[8]	1976	115	63% complete recovery. 6% no significant clinical improvement.	Both air and oxygen tables used. Mean delay to treatment 50.9 hours
Bayne[17]	1978	50	Complete recovery in all cases. 49 with full recovery after a single treatment.	Equal numbers of Type I and II DCS
Kizer[18]	1980	157	17% with significant residual symptoms	10% were AGE cases. Average delay to treatment > 7 hr.
Gray[19]	1984	812	751 cases treated with oxygen tables. 83 % full recovery after 1 treatment. 7 deaths.	244/248 Type I DCS and 54/57 Type II DCS full recovery after 1 treatment.
Gorman et al.[20]	1987	88	15 cases with residual symptoms/ signs detected on follow-up	USN oxygen tables. Follow up with neurological clinical evaluation, EEG and CT scan.
Brew et al.[21]	1990	125	68 patients with residual symptoms/ signs following completion of prescribed treatment.	AGE cases included. Mean delay to treatment was 57 hours for DCS and 12.7 hours for AGE.
Gardner et al.[9]	1996	100	30 patients with partial recovery.	USN and RNZN (oxygen-helium) tables. Mean delay to treatment 8 hours.
Arness MK[3]	1997	94	Complete recovery in 91% of cases.	USAF-modified USN oxygen tables. 82 % of cases treated within 24 hours of onset of symptoms

Conclusion

Recompression therapy using short oxygen tables leads to an acceptable outcome in the majority of patients with DCI, even when treatment is delayed. However, since improved outcome has been associated with shorter times to recompression (within 12 hours), and this seems particularly true of CAGE, one avenue of enhancing secondary prevention is to focus on properly educating the diving community to better recognise DCI in its myriad presentations and so encourage earlier evacuation. It is also vitally important that dive operators and supervisors be suitably equipped and trained to provide the appropriate first responder care to diving casualties and, in particular, in the administration of 100% oxygen. With recent advances in transportable chamber technology and as experience with them in the field increases, one option would be to explore the feasibility of making such chambers more readily available.[16]

Despite the wealth of clinical experience with recompression protocols, many unanswered questions remain regarding patient selection and the relative merits of different tables and protocols. Our understanding of prognostic factors and adjuvant pharmacotherapy is also inadequate. These and other issues have to be addressed through a concerted effort by the diving medical community in order to further improve the delivery of care to our patients.

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PLA_2 INHIBITION BY LIGNOCAINE: IS IT CLINICALLY RELEVANT ?

Georg Petroianu and Ursula Helfrich

Key words

Decompression illness, drugs, treatment.

Abstract

The place of lignocaine administration for DCI treatment seems to be well established. The rationale for its use is a putative anti-inflammatory effect of the drug, most probably due to its ability to inhibit phospholipase A_2 (PLA_2). The purpose of the study was to quantify "in vitro" lignocaine's ability to inhibit this key enzyme and to elucidate the type of inhibition. Lignocaine inhibits PLA_2 through interaction with the enzyme-substrate complex. This occurs at plasma concentrations which are easily achievable clinically. Therefore the use of lignocaine as an anti-inflammatory drug seems warranted.

Introduction

The SPUMS Journal has published two papers on the use of lignocaine as adjuvant therapy in the treatment of decompression illness (DCI).[1,2] While both authors agree that lignocaine has a well established place in DCI therapy and that the anti-inflammatory effect of lignocaine might be the strongest rationale for using it for this purpose, there appears to be little data available on the magnitude of these anti-inflammatory effects.

Lignocaine is a known phospholipase A_2 inhibitor.[3,4] This study was to quantify "in vitro" lignocaine's ability to inhibit this key enzyme and to elucidate the type of inhibition.

Material and Methods

Blood samples were taken from nine healthy human volunteers. PLA_2 derived from the platelet membranes was incubated for 30 minutes with either TRIS buffer (native samples or controls) or lignocaine. Lignocaine concentrations of 1, 10 or 100 µg/ml (4.3; 43.0; 430 µM) were used. PLA_2 activity was measured by a modification of the method described by Flesch[5] and Sundaram,[6] while protein concentrations were determined by a modified Lowry method.[7,8] PLA_2 activities were expressed in pmol/mg protein/min. Mean values were used for statistical analysis with the Mann-Whitney rank order test. Baseline values (native activity) were considered to be 100%. All other values were expressed as a percentage of the baseline value.

For K_M and V_{MAX} determinations commercially available purified porcine PLA_2 (Sigma; Steinheim, Germany) was incubated with different substrate concentrations (0-300 µM) in the presence or absence of lignocaine (100 µg/ml = 430 µM) for 30 minutes. The PLA_2 activity was determined in a commercially available radioactive PLA_2 assay (Scintillation Proximity Assay: SPA; Amersham, Braunschweig, Germany). Data were plotted as Michaelis-Menten and Lineweaver-Burk diagrams.

Results

Lignocaine inhibits human platelet membrane PLA_2 activity in a statistically significant manner. However in the concentration range used (1-100 µg/ml) no dose dependency could be observed: the lowest concentration used led to a maximal inhibition of the enzyme (Figure 1).

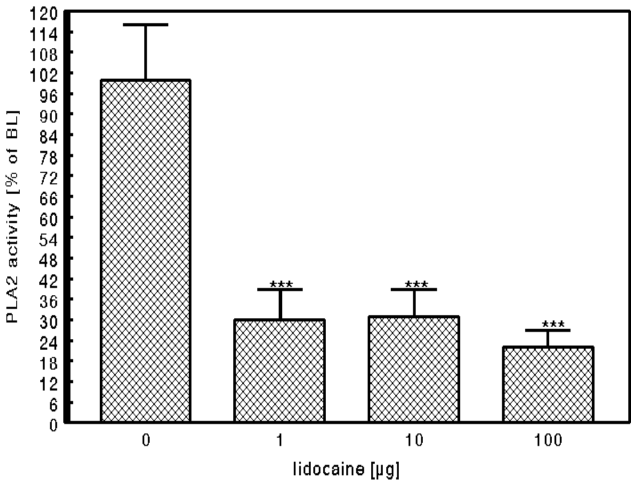

Figure 1. Lignocaine inhibits human platelet membrane PLA_2 activity in a statistically significant manner ($p \geq 0.010$). However in the concentration range used (1 - 100 µg/ml) no dose dependency could be observed.

Lineweaver-Burk representation of the data (using porcine PLA_2) suggests an interaction of lignocaine with the PLA_2 molecule and the enzyme-substrate-complex (non-competitive or mixed inhibition). The coordinates of the intersection point are x = -0.16 and y = -0.06. The inhibitor constants K_I (for the enzyme-inhibitor; EI) and K_I' (for the enzyme-substrate-inhibitor; ESI) were calculated. K_I (4,800 µM) is one order of magnitude higher than K_I' (409 µM) suggesting that the main mode of action of lignocaine is interference with the enzyme-substrate complex formation. The correlation coefficient for data determined in the absence of the inhibitor is $r_{native} = 0.96$ and for data determined in the presence of the inhibitor is $r_{Lignocaine} = 0.98$ (See Figure 2 on page 10).

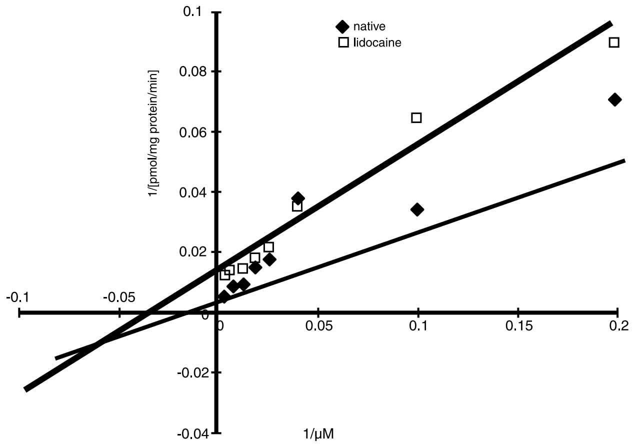

Figure 2. Lineweaver-Burk representation of the data (porcine PLA_2) suggests an interaction of lignocaine with the PLA_2 molecule and the enzyme-substrate-complex [non-competitive (mixed) inhibition].

Discussion

The effective plasma concentration range of lignocaine in humans is 1-20 µg/ml (4-80 µM). The lowest lignocaine concentration used (1 µg/ml) produced maximal inhibition of the human platelet derived PLA_2. Therefore the anti-inflammatory effect of lignocaine is easily achievable using common clinical dosages. The data derived from experiments using porcine enzyme show that the anti-inflammatory effect of lignocaine is mainly due to interaction with the enzyme-substrate-complex. The inhibitory constant K_I for porcine PLA_2 is in the 400 µM range. The most probable explanation for this value (five times higher than the upper limit of the effective plasma concentration range) is the higher sensitivity of the human enzyme to lignocaine inhibition compared with the porcine variant. Different activities/sensitivities for PLA_2 of different origins are well recognised.[9]

Conclusion

We conclude that lignocaine´s ability to inhibit PLA_2 through interaction with the enzyme-substrate-complex occurs at plasma concentrations which are easily achievable clinically. As such the use of lignocaine as an anti-inflammatory drug seems warranted.

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Ursula Helfrich is a medical student at the same university.

THE WORLD AS IT IS

A HISTORY OF RECOMPRESSION FACILITIES IN VICTORIA , PART 1

Ian Millar

Key Words

History, hyperbaric facilities.

Hyperbaric medicine in Australia has largely arisen out of the need for decompression chambers to be available for the treatment of decompression sickness in divers. Two notable exceptions were the chambers established in Sydney at the Prince Henry Hospital and in Melbourne at the Peter MacCallum Clinic. The former was a large chamber designed for cardiac surgery under pressure. When this use was superseded by the introduction of cardiac bypass machines, the chamber continued in service as Australia's early home of hyperbaric medicine. The system has recently been refurbished and relocated to the Prince of Wales Hospital in Randwick. The Peter MacCallum chamber was a monoplace chamber designed to allow the administration of radiotherapy to patients who were pressurised and breathing 100% oxygen. Early work had suggested that HBO might act as a radiosensitiser, increasing the effectiveness of the radiotherapy in killing cancer cells. Unfortunately this promise failed to be fulfilled and use of the Peter MacCallum chamber was abandoned.

In the later 1970s and early 1980s a Vickers acrylic hull, monoplace chamber was located at Prince Henry's Hospital, Melbourne. This provided treatment for a small number of gas gangrene patients, divers and others for a number of years until the Alfred facility was established in 1987. A further Vickers monoplace chamber was to be installed at the Royal Melbourne Hospital but it was never removed from its packing case! It spent some time in the Fremantle Hospital before finding its way, recently, to the Prince of Wales hyperbaric facility in Sydney.

On various occasions treatments were also provided in Melbourne using chambers operated by the Board of Works in support of pressurised tunnelling operations and using commercial diving chambers at the wharves.

Meanwhile, in eastern Victoria, diving medicine expertise was being developed to support the Bass Strait off-shore oil industry and the abalone divers of eastern Victoria and southern New South Wales. Dr Geoff Macfarlane, a general practitioner and GP anaesthetist based in Bairnsdale, undertook training in Scotland and established the Bass Strait Medical Centre with a number of his colleagues. In addition to diving medical examinations and health surveillance, this group provided the medical direction for treatment of decompression illness using recompression chambers located on oil rigs, pipelaying barges and at the Abalone Divers Co-operative at Mallacoota. Inevitably this expertise was called upon for the treatment of a growing number of recreational scuba divers. At the same time the number of commercial divers who developed problems declined as safety standards improved.

In the early 1980s, a long established and well respected safety promotion organisation, the National Safety Council of Australia, Victorian Division (NSCA) became involved in the provision of rescue, firefighting and industrial emergency services in support of power station construction in the Latrobe Valley. The NSCA Emergency Services group grew rapidly and became a provider of emergency services resources to the official emergency services, the military and industry. In addition to rescue, ambulance and firefighting helicopters and an industrial emergency services group, a small diving group was established. This expanded with the acquisition of the Underwater Training Centre from Cronulla in southern Sydney. This acquisition brought with it a twin lock recompression chamber that had been manufactured by the Vidor company in Newcastle, NSW. This was soon joined by another twin lock chamber that had been used by the French commercial diving company Comex in Bass Strait, a further second hand chamber from South Wharf in Melbourne and a Dräger Duocom, a small two person, transportable rescue chamber.

After the saturation treatment of one critically ill civilian diver, on a pipelaying barge, had cost Esso over $2,000,000, it became clear that, with land based chambers and experienced chamber operating staff, the NSCA was well placed to accept responsibility for recompression of diving casualties. Medical management continued to be provided by Dr Geoff Macfarlane and his Bairnsdale colleagues until the NSCA employed its own medical staff in 1984 and sponsored their initial training in diving medicine. The NSCA's first doctor, Dr Ian Millar, gained valuable experience from Dr Macfarlane and his colleagues and subsequently went on to join the staff of the Alfred and become Head of the Hyperbaric Service.

The NSCA had mounted the old South Wharf commercial diving chamber on a semi-trailer to create a relocatable emergency treatment facility. This chamber was used for the treatment of a number of Victorian decompression illness cases, culminating in a three day saturation treatment for a casualty of extreme depth scuba diving in early 1984. The quadraparetic, shocked patient had displayed deterioration during depressurisation following an initially promising response to pressurisation to 50 m. Dr Macfarlane and ex-Navy diver Tom Keogh were confined inside the 1.8 m (6 ft) diameter twin lock chamber for the three days. Truckloads of mixed gas were brought in to create and maintain the reduced oxygen environment necessary to avoid oxygen toxicity for the attendants. The necessary logistic support was pieced together in the Latrobe Valley airport hanger in which this saga unfolded. A Navy team was flown in to assist and direct the treatment, led by Dr Des Gorman and John Pennefather. Carbon dioxide absorption was achieved in various ways including spreading soda lime around the chamber, pumping air through a canister, using a Zodiac inflatable boat pump, and breathing from the mouthpiece and by using hose and canister assemblies taken from Navy oxygen rebreather diving sets. During the second day and night of this emergency, the Comex and Vidor chambers were linked together by the NSCA in order to provide a more appropriate saturation treatment facility. This was an extraordinary demonstration of the ability of the NSCA Chief Executive (John Friedrich) to make thing happen, with engineers, welders, cranes and the local pressure vessel inspector involved in the cutting of a flange from the side of the Comex chamber to use in the manufacture of a connecting spool piece to link the chambers.

The joined Comex and Vidor chamber complex at the Underwater Training Centre in Morwell became the main recompression facility for Victoria from 1984 – 1987. The trailer mounted chamber was relocated to the Royal Adelaide Hospital where it was operated by NSCA staff until a new Dräger twin lock chamber was purchased. The mobile chamber was subsequently relocated onto a diving support vessel but after the liquidation of the NSCA it returned to commercial diving service . Later it was used in support of the construction of the Sydney Harbour tunnel.

The number of diving emergencies presenting for treatment grew each year and with knowledge of developments in hyperbaric medicine overseas, it became apparent that Victoria's principal hyperbaric chambers should be in a public hospital, preferably a large teaching hospital. In 1987, the NSCA moved its main base of operations from the Latrobe Valley to the West Sale Aerodrome. This increased pressure for a move of the now isolated Morwell decompression chamber complex. In addition to lobbying the Health Department, a number of Melbourne hospitals were contacted directly. Only at the Alfred and Prince Henry's were individuals found with an interest in acquiring this unusual service for their Hospital.

Prince Henry's had been the Melbourne home of hyperbaric medicine for some years with its monoplace chamber and access to diving industry multiplace chambers on various occasions. However, plans for the closure of Prince Henry's were afoot and when Dr David Tuxen, Director of Intensive Care at the Alfred, showed interest, the choice of became obvious. In addition to its clinical services, the Alfred offered the best helicopter access with Fawkner Park adjacent.

The proposal to relocate the chambers was not accepted immediately, however, as the Health Department showed reluctance, presumably because it had been not at all unhappy that the NSCA had been carrying the costs of treating most divers. As a result, the closure of the NSCA Morwell facility saw divers flown to Royal Adelaide Hospital for some months, often in transportable, two person Dräger Duocom chambers. This period saw Dr Ian Millar and his NSCA colleagues gain some of the most extensive experience in the world in the operation of transportable, transfer under pressure systems.

Other key players in the process of lobbying the Health Department over this period were South Pacific Underwater Medicine Society members Drs Chris Lourey, John Knight, David Brownbill and Des Gorman.

When the Comex and Vidor chambers were finally relocated to the old South block at the Alfred Hospital in November, 1987, Ian Millar and his NSCA deputy medical officer Malcolm Osborne were appointed as Visiting Medical Officers. They provided specialist input into the establishment of the Hyperbaric Service along with NSCA hyperbaric technician Tom Nalpon. With Department Director, Dr David Tuxen and Charge Nurse Mandy Wilson, The Alfred Hyperbaric Service was born.

The use of the chambers grew rapidly, creating particular challenges for all involved in treating critically ill, ventilated patients in the traditional diving industry, cylindrical, circular manway decompression chambers. The numbers of elective hyperbaric medicine patients and divers continued to expand also, taxing the capabilities of the system. One more saturation recompression treatment was undertaken in the facility, this time an air saturation at 18 m. The support available in the hospital make this a significantly easier logistic exercise than the previous one, although the nursing and medical care for the severely embolised, unconscious, ventilated patient taxed all concerned.

In March 1989, the NSCA collapsed financially and was subsequently went into liquidation when it was discovered that the resourcefulness of John Friedrich had extended to innovative and unsustainable financing and not just highly competent emergency services operations. The chambers that had previously been on "permanent loan" from the NSCA were sold to the Alfred by their new owners, the liquidators of the NSCA. The Hyperbaric Service became a wholly Alfred Hospital owned and operated facility by employing the,by then unemployed, NSCA technical staff.

Part 2 of this paper will appear in the September issue of the SPUMS Journal.

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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.

MINUTES OF THE SPUMS EXECUTIVE COMMITTEE MEETING

held at the Hyperbaric Medicine Unit
Prince of Wales Hospital, Sydney on 14/11/98

Opened at 1044

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 (ANZ HMG Representative).

Apologies

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

1 Minutes of the previous meeting

Minutes of the previous meeting on 11/5/98 and 15/5/98 accepted as a true record after minor adjustments. Proposed Dr D Davies, seconded Dr C Acott.

2 Matters arising from the minutes:

2.1. Indemnity Policy Update. Dr Williams gave an update on this.

2.2. Job description of the Convener. This is still pending.

2.3 Upgrade of audiovisual equipment. Dr Acott is researching this.

2.4 SPUMS on the Internet. Dr Meehan presented a report.

2.4.1 Domain name is http://www.SPUMS.org.au. Contact details need to be updated. The SPUMS workshops should be published on the site. The site should routinely be updated quarterly, when the journal comes out, or at any other time the need arises.

2.4.2 Insertion of links from and to various other organisations has been discussed.

2.4.3 We need to decide which search engines to use.

2.4.4 New information on the site should be co-ordinated through the Secretary. There could then be deadlines set for insertion of new material onto the site, as is set for the Journal. Out of date material should be removed at this time. Information can be added at anytime, but I think in general it should be updated quarterly.

2.4.5 Index of SPUMS journal articles, and the Quarterly title page of the journal.

2.4.6 Requests for articles should go through the

Editor. Articles can be charged at $10 per article. This can be coordinated by the Editor. Back journals can be purchased for $10. We can suggest that if there is an interest in an article, then by joining SPUMS, that journal will be sent as part of SPUMS membership.

2.4.7 It is still under discussion as to whether the Diving Doctors List (DDL) should be published on the website.

2.4.8 The SPUMS diving medical could also be published when it is fully updated.

2.5 New application forms have been designed for membership and the DDL. A copy of a certificate of satisfactory completion of a SPUMS approved course must be included with the initial application to be included in the DDL. The Treasurer must view this and confirm that the applicant is a financial member before authorising Steve Goble to add the applicants details to the list.

2.6 Format of the renewals for membership and for DDL. This year details held by SPUMS have been printed on the back of the renewal forms and only corrections will need to be made when renewing membership. This has saved a lot of time and effort by members and has allowed more accuracy in correcting the database.

2.7 ANZHMG representative as a SPUMS committee position and as the SPUMS spokesperson for Hyperbaric Medicine (HBOT). A motion will be proposed at the 1999 Annual General Meeting (AGM) to achieve this.

2.8 Membership drive. We should always be on the lookout for new members. The benefit of writing articles about SPUMS in some other journals as well as of designing a SPUMS sticker promoting the DES telephone number was discussed.

2.9 Revision of the SPUMS DIVING MEDICAL, AS 4005.1, and AS 2299. These are all very much underway. Both the committees for AS 2299, and AS4005 have met recently following the closure to final public comment on the draft documents. At the next meeting Dr Knight will update on AS2299 and Dr Meehan on AS4005. The SPUMS DIVING MEDICAL is in its final draft and will be fine tuned at the next committee meeting.

2.10 Three-year terms for committee positions. There have been no comments from members with regard to this. Changes to the constitution to reflect this will be proposed at the 1999 AGM. It will be beneficial to the committee if changes to the Executive Committee can be staggered.

3 Annual Scientific Meetings

3.1 1998 Palau ASM. Financial update. A profit of $4,000 was made. There was discussion of the deletion of the workshop on The Aging Diver. Notice should be given in advance if there is a change in the program.

3.2 1999 Layang Layang ASM update. Call for papers.

3.3 2000 ASM venue is Castaway Island, Fiji. The proposed conveners are Drs G Williams and V Haller. It is suggested that this be a family orientated conference. The topic will be something in line with the millennium.

3.4 2001 ASM Kavieng, PNG was proposed. Dr C Meehan is willing to act as convener. It was decided to postpone discussion on Kavieng as a suitable venue until extensions to the Malagan Beach Resort were completed.

4 Treasurer's Report

The Auditor's Report was viewed. There was discussion about the need for alterations to the format of the report to make it more comprehensive.

5 Correspondence

5.1 ANZCA Special Interest Group (SIG) on Diving and Hyperbaric Medicine. Letters from Drs Bob Wong and M Bennett were considered. Dr J Knight is the SPUMS representative on the SIG Committee. The SPUMS Committee proposes to the SIG that a group be formed from the two committees to discuss education. The SPUMS Board of Censors would be part of this group.

5.2 HOTAA letter Stuart Bain, and ANZHMG reply, Dr Mike Bennett.

5.3 Workplace Health and Safety (WHS) ascent training workshop. Letter from Richard Evans of PADI. A change in the wording of the WHS document has satisfied all parties involved.

5.4 Letter from Dr D Walker re WHS Snorkellers questionaire. Already replied to by Dr C Meehan

5.5 Letter from Dr Amoury Vane. This has been replied to by Dr C Meehan.

6 Other Business

6.1 HSE number. How to get HSE approval. Raised by Dr C Meehan.

6.2 Proposed alteration of the timing and postage of the DDL. Dr J Knight proposed a change to the enclosures with the Journal. In future the March Journal will have the March DDL, the June Journal have the Conference Booklet, the September Journal include the September DDL and the December Journal present the Index for the year.

6.3 SPUMS diploma. An update on current applicants was given by Dr D Davies. It was proposed that there be a grant created that could be used to help towards the costs of an applicant presenting their thesis at a SPUMS ASM, if the thesis covered material relevant to the ASM. The grant could be in the vicinity of $2,000. Application would have to be made to the Board of Censors and from there to the SPUMS committee. Proposed Dr G Williams, seconded Dr J Knight.

6.4 Requirement to publish the Diploma thesis in the SPUMS Journal. This is to be discussed further at the next meeting.

6.5 Discussion of the steps required to get the Journal on Medline. Drs J Knight and M Bennett are to follow this up.

6.6 ANZHMG Business. An update was given by Dr T Wong.

6.7 Improved relationship between the HTNA and SPUMS. Possibility of approaching HTNA regarding support of their ASM. Publication of selected papers in the SPUMS Journal would be welcomed.

6.8 Suggestion that the 1999 SPUMS face-to-face committee meeting be held at the end of August 1999 in Adelaide, in conjunction with the HTNA meeting. Provision has been made for the Sunday to be free for this purpose. This was approved by all.

6.9 Potential SPUMS executive members for next year were discussed.

6.10 Further corrections and revisions to the constitution to be put forward at the 1999 AGM were discussed.

6.11 Congratulations to Dr J Williamson on his appointment to Membership of the Order of Australia to appear in the next issue of the Journal.

6.12 It was decided that the Diving Doctor List should clearly state that Diving Medicals to AS2299 should be performed only by doctors who have completed an approved course in diving medicine of 10 or more days duration and that doctors having attended these courses are marked in the list with an asterisk.

Closed at 1730

Key Words

Meetings

MINUTES OF THE NEW ZEALAND CHAPTER OF SPUMS AGM 1998

Held on 13th June 1998 at Pacific Rendezvous, Tutukaka.

The meeting opened at 1700.

Present

Andy Veale, Simon Mitchell, Mike Davis, David Sage, Heather Sage, Rex Gilbert, Tina Gilbert, Olwyn Evans, Courtney Kenny, John Aiken, Richard Willoughby.

Apologies

Lyndsae Wheen, Alastair Leggat, Lee Nixon, Mark Fraundorfer, Rees Jones, Julian Roberts, Tony Slark, Simon Cotton, Harold Coop, Brian Lineham, Martin Rees, Chris Heron, Roger Deacon.

1 Minutes of previous meeting

Accepted as a true record.

2 Business arising from the minutes

The meeting felt that deposits should not be returned if it was clearly stated in the pre-meeting information package. This money should be retained.

Founders fund noted not to have been touched.

3 Correspondence

Three doctors responded to item in the SPUMS Journal re diving medicine in the Cook Islands. Michal Kluger was following this up. At present letters have been written to the Ministry of Health in the Cooks, but to date there has been no reply. Lyndsae Wheen has contacted the interested doctors and has their details on file.

4 Chairman's report 1997-98

This has been a quiet year following the success of the SPUMS meeting in Paihia convened by Mike Davis. Time has been taken to correspond with the Cook Islands following a diving death some 15 or more months ago. Letters were written to the various ministers of Health, but no replies have been received to date. A meeting with the dead diver's uncle from the Cooks was organised, and it was clear that there are significant problems relating to diving in the Cooks. This will be followed up in 1998.

A new hyperbaric chamber operating out of Auckland's North Shore was brought to my attention. The facility will be open by August 1998 and is actively seeking a Medical director. It is to be operated to the standards of the ANZHMG.

Michal Kluger

5 Secretary/Treasurer's report

The organisation of the signatories for the SPUMS account took considerable time due to the inertia of our banking system, while organising the SPUMS meeting took the remainder. The considerable help obtained by Simon Mitchell is appreciated. There have been a few enquiries re joining SPUMS and application forms have been sent.

The question of non-attendees and deposits requires clarification. Two people who failed to attend at short notice paid $100 deposit. A question was raised regarding the management of people who paid deposits and did or did not attend. The $1600 deposit paid to Aqua Action needs to be refunded.

Unfortunately due to career change and the attendant pressure that this will entail, I will be tendering my resignation.

Lyndsae Wheen

6 Financial report

Expenses

Aqua Action deposit	$1,600
Post/phone	$100

Income

1998 ASM deposit	$1,000

Account Balances

ASB	003-2625-00	$1417.91
ASB	005-2348-00	$564.28
BNZ	019-4214-97	$3362.43

LyndsaeWheen

7 Election of officers

Nominated for Secretary/Treasurer, Alastair Leggat; Proposed Lyndsae Wheen, seconded Michal Kluger. Carried.

8 Other business

None.

9 Venue of 1999 meeting.

Mike Davis and others suggested returning to Tutukaka next year, due to excellent diving and venue at the Pacific Rendezvous. Andy Veale suggested looking at having an overseas speaker (e.g. Richard Moon) who could be sponsored jointly by SPUMS and one of the major hospitals. The committee will look into this for next year.

The meeting closed at 1730.

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.

The amendments will not come into effect until approved by the general body of members. Any member who objects to the amendment should notify the Secretary of SPUMS, Dr Cathy Meehan, C/o Australian and New Zealand College of Anaesthetists, 630 St Kilda Road, Melbourne, Victoria 3004, Australia, in writing, before September 1st 1999. If any member objects a postal ballot will be held. If no objection is received it will be assumed that the membership has voted in favour of the amendments.

Cathy Meehan
Secretary of SPUMS

SPUMS DIVING DOCTORS LIST

The SPUMS Diving Doctors list will no longer be sent out with the Journal. Instead it will be available on the SPUMS Home Page at http://www.SPUMS.org.au .

Cathy Meehan
Secretary of SPUMS

SPUMS

ANNUAL SCIENTIFIC MEETING 2000
will be held at
Castaway Island, Fiji from May 6th to 13th 2000
Guest speaker Professor David Elliott

Convenors 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.

The travel agent is Allways Dive Expeditions.

BOOK REVIEWS

THE INFERNAL DIVER

John Bevan
ISBN 0 9508242 1 6 (1996)
Submex Ltd, 21 Roland Way, London SW7 3RF, UK.
Price from the Publishers £75.00 plus postage.
Review copy book 482 of an edition of 1,000 copies.

This book is worth its high price. Start saving up for it now. It is the biographies of Charles and John Deane, the inventors of the diving helmet, the men who invented the waterproof canvas diving dress which kept divers warm until the invention of the wet suit, the men who introduced ambient pressure diving. The book is large (31 by 21.5 cm and 314 pages) and profusely illustrated (185 in all), many pages have two or more illustrations. It takes its title from the younger brother, John Deane, who was nicknamed "The Infernal Diver" during the Crimean War by William Russell, the Special Correspondent for The Times, whose articles on the appalling conditions for the sick and wounded in the Crimea and the hospitals in Turkey led to Florence Nightingale's involvement at Scutari.

The author, besides being a guest speaker at the 1998 SPUMS Annual Scientific Meeting, is the Chairman of the Historical Diving Society in the UK and Editor of *Underwater Contractor*. He was also involved in the rediscovery of the *Mary Rose* in the mud of the Solent, which led to her recovery and preservation on display in Portsmouth Dockyard. John Deane had recovered one of her guns in 1836. With his many contacts, John Bevan has found and gathered very many threads surrounding the lives of his two subjects, and their contacts and inventions and modifications of equipment, and woven them into a pattern which persuades the reader to keep turning the pages, even when meals are announced. It is quite clear that a tremendous amount of time and research has gone into this book. It is a great credit to its author.

Both Deane brothers were educated at the Greenwich Royal Hospital School, now the National Maritime Museum. Their father had been a sailor and the boys were accepted as "paupers and objects of charity". They were clever enough to go on to the Senior School after they had learned to read and write. They both went to sea at the start of their careers. After Charles had left the sea, he had the idea of a helmet, supplied with air from outside the building by a pump, to retrieve people from a smoke-filled building. He patented the idea in 1824. By 1828 the brothers had modified the smoke helmet so that it could be successfully used underwater. At this stage they had a waterproof suit, with integral feet, which could be tied around the wrists and neck. Over this they put the helmet with a canvas jacket attached, which allowed the surplus air to bubble out from under the jacket. This kept the neck of the suit above the water in the jacket. Unfortunately when the diver leant forward the water might go above the neck of the suit, which was uncomfortable, or even the nose and mouth, which could be fatal.

Other people, as well as the Deanes, modified diving helmets and suits. A number of people introduced a closed suit, one with the helmet fixed to the suit, and this did away with the risk of drowning when one leant over too far, but it introduced another risk, "blow up" or the diver as a Michelin man, but without his ability to move. Surprisingly John Deane in his 30 years of diving never used a closed suit.

August Siebe made diving helmets for the Deanes and later on, when the firm he founded became Siebe Gorman, the invention of the diving helmet was wrongly attributed to him. This book makes it quite clear that Siebe was an excellent mechanic who had great skill with attention to detail and many good ideas. After various accidents, non-return valves were fitted to helmets at the air inlet to prevent the sudden loss of pressure when the supply hose ruptured. By trial and error the equipment became safer. But learning to dive was by doing the job underwater, no diving school nor any instruction manual existed until John Deane wrote the first in 1836. It was 18 pages long and its title was *Method of using Deane's Patent Diving Apparatus*.

The various inventors and improvers of diving gear had their disagreements and even legal actions against each other. Through this turmoil John Deane managed to keep his head above water, even when he had to lean forward. In the end he and his colleagues from Whitstable became the most effective wreck salvors in Britain.

The reader is led through the intricacies of salvage from the time when the Deanes were called in when the diving bell could not do it, to the days when the standard dress diver was the first choice. The economics of salvage meant that survival in business required prompt payment at the end of a job in order to be able to carry out the next one. Contested claims made life very difficult. The Deanes had their share of troubles when Colonel Pasley of the Royal Engineers persuaded the Admiralty to renege on their agreement to allow the Deanes to salvage guns from and break up the ROYAL GEORGE, which had sunk in Spithead many years before and was still a menace to shipping. The salvaging of the guns and the blowing up of the ship took some years and is a fascinating tale.

Charles Deane died in 1848 aged 52. In 1854 with the Crimean War in progress, the Admiralty arranged for John Deane and two of his divers to travel to the Crimea for underwater explosive work. The spectacular explosions that had been planned to blow up blockships could not be carried out because of the Russian batteries. Nevertheless, John Deane had an interesting war, salvaging many objects, and ended by superintending the major part of the destruction of the port facilities of Sebastopol. Among the trophies taken back to Britain were the British-built gates of one of the dry docks. Then John Deane, who was then 56, retired from diving. He lived on until 1884.

This is a brief and very incomplete, review of this fascinating book about the early years of helmet diving. Everyone with an interest in the history of diving should read John Bevan's The Infernal Diver.

John Knight

Key Words

Book review, history, equipment, diving operations.

THE LADY AND THE PRESIDENT

Peter Stone

Ocean Enterprises, 303-305 Commercial Road, Yarram, Victoria 3971, Australia.

1998. Hardcover, 300 pages, many illustrations, some in colour.

Cost from the publisher $46.00 plus $6.50 postage and packing.

This new book, with a title that could be direct from today's newspaper headlines is, in fact, a historical book, rather than a contemporary account.

The extension of the title, *The Life and Loss of the SS President Coolidge*, still does not adequately describe the content. This book is much more than the story of a ship and her loss. It spans the period from 1902 up to the present and includes the early history of two steamship companies, the Dollar Line and the President Line.

The author tells, in factual detail, of the fateful entry into the war of the *President Coolidge* and the bureaucratic situation that existed between the military who directed her movements, the owners and the crew who sailed her. The *President Coolidge* entered the war as a troop carrier, and it was on one of these trips that she came to grief. Even after her sinking, the story stays alive with the recounting of the inquiry into the sinking which, seemingly, could not lay blame on the military in this time of war.

When the *President Coolidge* hit two mines while approaching the anchorage at Luganville, she had 5,000 US troops on board. In the subsequent sinking of the vessel, only two lives were lost. A great photographic record exists of her stranding prior to sinking, due to the proximity of the large base. These photographs are well used in the book.

Espiritu Santo, a military base (also known as "Button"), was one of the most advanced bases short of the Solomon Islands and was the point from which many attacks on Guadalcanal were launched. The American base was occupied from June 1942 until about 1945, but the main military activity was transferred to the Solomons after they were recaptured. The US Military had about 40,000 men stationed on Santo and about 500,000 passed through on the way to the Pacific battles. In its hey day Luganville and districts had 4 major hospitals and 43 cinemas, a far cry from the Luganville of today. This tale gives a detailed account of the setting up of the air bases and the part they played in the Guadalcanal campaign during the war. The, post-war, search for and identification of the missing aircraft, and their crews, are also recounted.

Salvage of such a large ship was considered, but no real efforts were made to re-float her. Later salvage of the propellers and, for environmental reasons, the bunker oil occurred. The exploits of the salvage divers, the personalities involved and the salvage methods are well explained (1969-77).

The heritage of this, is the largest easily accessible shipwreck in the world, with the bow at about 21 m (70 ft) and the stern sits at almost 75 m (250 ft), and all of this is an easy shore dive.

All who have dived the *President Coolidge* know of her formidable size, sitting just beyond the shore line. Although many thousands have dived her, no one can know the ship like Allan Powers. Allan, a keen underwater photographer and pioneer skin and scuba diver from NSW, stayed on to develop the dive tourist industry based around Santo, but specially centred on the *President Coolidge*. Allan knows her like no one else can. To sit and talk over a beer in an evening and listen to Allan talk is living history at its best.

The reference to The Lady is to a decoration that graces the Smoking Room. The Lady, standing in front of a Unicorn is a 90 cm (3 ft) square, three dimensional ceramic wall fresco. The Lady was boarded over to protect it during the time the ship saw service as a trooper. It was only discovered in 1981, when the temporary boards fell away with decay. A penetration dive to visit "The Lady", who is at 45 m (150 ft) is very much a part of the diving trip, for suitably experienced divers.

The book is indeed a historical document. It is written with style and wit, Peter Stone talks to the old players and it becomes their story. Facts are quoted and the many photos are well annotated to ensure that this fine story lives on.

You get the feeling that Peter started to write a divers guide for the *President Coolidge* but found the whole story so engrossing that it became much more than just a divers guide. Well done Peter, it was a joy to read, and at least this part of the regional diving history has been well recorded. Thanks should also go to Santo residents Allan Powers and Reece Discombe for taking the time to “tell all” to Peter when he embarked on this book. There is an extensive index and references to pertinent events; also the findings of the sinking investigation are reproduced in an appendix.

I commend this book not only to all who have dived or intend to dive in Espiritu Santo, but also all who have an interest in the military activity at “Button” during the build up and the attacks on the Solomon Islands. The book is also the complete story of the *President Coolidge* from the events that allowed the laying down of her keel, her working life and her current place in history. I cannot use words like death, or demise, when referring to the *President Coolidge*, as she lives on in many ways. Today She may be different, but She is still magnificent.

Note:

The Republic of Vanuatu was formed in 1980. Prior to that time it was known as the New Hebrides. Espiritu Santo is the largest island in the group, on which the town of Luganville is located.

Bob Ramsay

Key Words

Book review, general interest, history.

Bob Ramsay is Senior Technical Officer in the Hyperbaric Medicine Unit at the Royal Adelaide Hospital.

PROCEEDINGS OF THE TWELFTH INTERNATIONAL CONGRESS ON HYPERBARIC MEDICINE

Editors A Marroni and F Wattel

838 pages, hardcover.

Best Publishing Company, P.O.Box 30100, Flagstaff, Arizona 86003-0100, U.S.A. 1998.

Price from the publishers $US 64.00. 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 International Congress on Hyperbaric Medicine is held every three years. In 1996, the Congress was held in Milan, Italy, under the presidency of Professor Alessandro Marroni. On this occasion, the Congress was held in conjunction with the annual meeting of the European Underwater and Baromedical Society, the 3rd Consensus Conference of the European Committee for Hyperbaric Medicine and an International Divers Alert Network meeting. Covering the extent and scope of these meetings has resulted in this volume being considerably thicker than the previous four Congress proceedings which have been published by Best in matching hardcover format.

One would not normally expect many diving doctors to purchase a book of Proceedings such as this and with 838 pages and 120 separate articles, this is not a casual read. It does deserve a place on many more bookshelves than just those of Congress attendees, however. Whilst several of the more significant studies reported have since been published in peer reviewed journals, all practising hyperbaric physicians and diving doctors who are called upon to give expert opinion should review this book for the wealth of information it contains, much of which may not be published elsewhere, at least for some time. By its nature, the International Congress draws together workers with different interests and perspectives from those encountered if one only attends US and Antipodean meetings.

While many disparate ares of hyperbaric medicine are covered, there is a significant focus on the use of hyperbaric oxygen in musculo-skeletal injury which provides a good degree of useful information. In the diving medicine sections I found it most interesting that extreme breathhold divers do not seem to generate detectable intravascular bubbles despite 40 or more 2-3 minute dives to 24–40 m over a period of three hours or so. On the subject of detectable bubbles, two groups independently report of the use of tear film bubble detection as a potentially more sensitive means of assessing decompression stress. It is rather unfair to single out individual areas however. Basic science and clinical researchers, specialist and generalist clinicians with interests in recreational or professional diving medicine or hyperbaric medicine will all find material of relevance here.

Make sure you at least have access to this book and review the Table of Contents.

Ian Millar

Key Words

Book review, meeting, hyperbaric oxygen, hyperbaric research, medical conditions and problems, underwater medicine.

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SPUMS ANNUAL SCIENTIFIC MEETING 1998

A SHORT HISTORY OF SUBMARINE ESCAPE: THE DEVELOPMENT OF AN EXTREME AIR DIVE

David Elliott

Key Words

Accident, bell diving, decompression illness, emergency ascent, history, hyperbaric facilities, rescue, surface decompression, transport, treatment.

Introduction

"One of our submarines is missing..." This announcement is rarely heard but, when it is, even those who have no links with the sea may feel some inner foreboding. For many the depths of the sea remain unseen and full of mystery and so the prospect of men who may be entombed for days, while fate slowly determines the conclusion, becomes high drama.

Fortunately it is not the public's perception with which we are concerned here though, as in many other safety issues, it does need to be acknowledged that the political response to adverse media publicity can be a useful spur to the funding of relevant research and development. In relation to submarine rescue and escape, much research has had practical application, some has been important academically and quite a bit is relevant to diving.

The problem

Submarines have been a significant factor in naval warfare for more than two hundred years but, for our purposes, the 150-year or so history of the submarine can be simplified:

- depths have extended from several inches to those of the worldwide oceans.
- power sources have developed from muscles to nuclear fuel.
- submerged duration has progressed from minutes to months.

Those with a realistic chance of emerging alive from a submarine trapped at depth are likely to be still at atmospheric pressure (or maybe just a little more), and there are only two ways out. One is by direct transfer at the same environmental pressure into a rescue bell or another submarine. The other route is to emerge from the submarine into the sea outside, to be exposed to the full pressure of that depth and then to float up to the surface. The first is "Submarine Rescue", and the second "Submarine Escape".

Submarine Rescue avoids exposure to the extremes of raised environmental pressure and the consequent physiological problems. Rescue may be associated with some decompression risk if the internal pressure has built up within the stricken boat but, because the survivors make their transfer at close to atmospheric pressure, there are few physiological lessons relevant to diving.

Submarine Escape, in contrast, means that the survivors have to get out of the boat by emerging into the sea where they are exposed to the full environmental pressure of that depth. The extreme physiological consequences of this provide analogies with diving which are worthy of review.

With each procedure there is the common problem that there is only a limited time that the survivors can remain safely waiting in a submerged submarine compartment. The oxygen is being consumed, carbon dioxide is accumulating and, with leaks and flooding, the internal pressure may be rising. In some boats the period of waiting could be days but in other operational circumstances escape may be urgent.

There is also another factor which determines how long survivors need to wait for rescue and that is the enforced delay waiting for arrival of a rescue vessel. So, while Submarine Rescue may be the preferred method, it is not always practical. This is why Submarine Escape will remain an important option: it does not depend on the arrival of a rescue vessel and escape can begin immediately.

The first submarine escape

Of course there may have been some successful escapes from sunken boats previously but the escape of the crew of Wilhelm Bauer's submarine on 1st February 1851 was the first to be witnessed and well reported. The story illustrates very well the basic challenges that all submarine survivors must overcome if they wish, like Bauer, to escape from a watery tomb.

Wilhelm Bauer, who had been a corporal in the Bavarian Artillery, designed an all-iron submarine *Brandtaucher* which was used against the Danish blockade of Kiel Harbour.[1] Propulsion was by a propeller powered by his two crewmen who also had to control the angle of the boat underwater by means of hauling a heavy ballast weight back and forth along the bilges. The hull had four square windows for observation and to provide illumination. It was a prototype pressed into premature service by its investors and the following translation is adapted from Bauer's own written account.[2]

Operated by Bauer and his two assistants, Witt and Thomsen, the submarine lost its horizontal stability at 9 a.m., after some 14 minutes running out to sea and shortly after flooding the flotation compartments. The tilt of the stern's more rapid descent caused the horizontally-adjustable ballast to shift further towards the back, and the increasing pressure crushed the starboard side of the hull fracturing a propulsion drive wheel. The boat, now leaking water through several seams, came to rest stern lowermost at around 16 metres.

The three men were trapped in a disabled and leaking submarine and seemed doomed to certain death. Bauer's frightened companions tried to plug the leaks and pump out the water but Bauer realised that the rising water level could be their salvation. He realised that when the trapped air became compressed to ambient pressure, it would be possible to open the hatch, escape outside and float to the surface. He then had to convince his two crewmen to stop plugging the leaks because this would only delay their escape and cause them to use up valuable oxygen. Instead he urged them to rest and conserve their energy.

Some four or more hours later, when the three men were in the cold and near-dark of the compressed air remaining trapped in the uppermost bow, they heard chains and grappling hooks against the hull and Bauer became concerned that a salvage attempt might obstruct their escape. The water level was rising more slowly now and so they unscrewed an iron bar from the pump and used it to try and pry open the hatch. A frightening stream of cold water was their reward. The most powerful man of the three used his back against the hatch, it suddenly flew open and the escaping air swept him out into the sea. Instantly Bauer grabbed his other companion who was desperately trying to hold on, pulled him by the hair, and they were both swept out of the hatch by the remaining air stream.

They were rescued by the astonished crews of the salvage boats and, though cold and exhausted, there were no reports of any symptoms that might imply decompression illness.

Four years later Bauer built a successful 12-man submarine in St Petersburg and it completed more than 300 dives. Bauer built an escape lock into this boat as a result of his previous experience[3] and it has been suggested that it was also a lock out for hard-hat divers.

Escape breathing apparatus

There are many claims for the first true submarine, most were later than Bauer, but these rivalries concern us less than the origins of breathing apparatus for the escaper. The reasons for such apparatus are not always defined but appear to have been a concern that the escaper would be affected by build-up of carbon dioxide during ascent, would be unable to control inspiration and might drown.

The first oxygen-regenerating device used in the UK was the Davis submarine escape apparatus (DSEA) designed by Robert Davis in 1903. It was based on the Fleuss apparatus of 1878,[4] but the oxygen cylinders of those days were too large for the hatches. To avoid this problem the Hall-Rees apparatus (Figure 1) was designed to use sodium peroxide for both oxygen generation and carbon dioxide elimination, but because the process was slow to get going, the escaper had first to be enclosed in the air retained by a type of open diving dress with a helmet.[4,5] A potential problem was that, if it became wet, the sodium peroxide would burst into flames, but it was the first individual escape apparatus to be brought into service and lasted through to the end of the First World War. As one submarine commander is said to have remarked *"it might offer a sporting chance"*. A more compact oxygen apparatus was designed by Dräger in 1911 and, with modifications, was used by the German Navy for some 35 years. The DSEA was later adapted for use by the Royal Navy (RN) (Submarine Escape Breathing Apparatus) with, at Haldane's suggestion,[6] an apron to be extended by the escaper in order to slow down the rate of ascent (Figure 2).

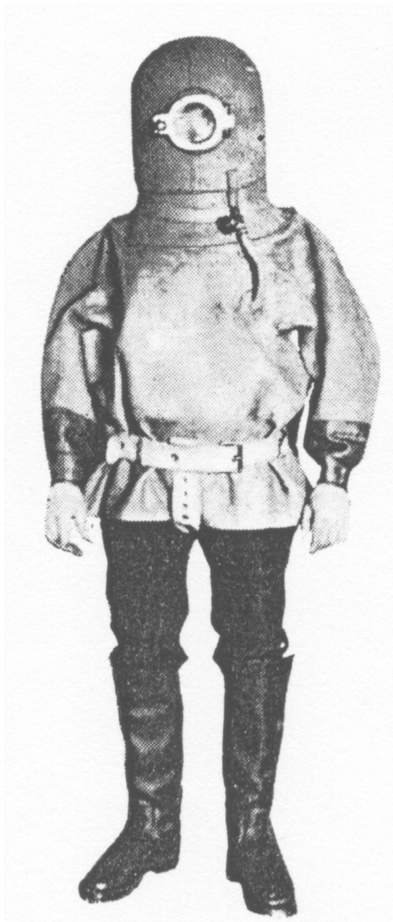

Figure 1. The Hall-Rees submarine escape breathing apparatus with built-in sodium peroxide oxygen generation [Fig 507 from Ref 4].

Figure 2. Davis submarine escape apparatus (DSEA) with vane extended to slow the rate of ascent. [Fig 252 from Ref4].

Perhaps unimpressed by these early developments, Lt Kenneth Whiting made a "free escape" in 1909 from the torpedo tube of a US Navy submarine at 26 feet (8 m),[7] a brave demonstration of a method that, somehow, has never caught on.

A very readable account of this whole period, with many stories of survival from sunken submarines up to those of *HMS Truculent* in 1950, has been written by Shelford.[5]

In 1917 HM Submarine *K-13* sank in Gareloch but was located immediately enabling the bow to be hauled to the surface and 46 men saved directly into air at atmospheric pressure; a fortunate outcome and maybe the first true Submarine Rescue (Figure 3). In 1918 there was a successful escape with Dräger oxygen "lungs" by the crew of the German *U-57* which had been mined off Dover.

These relative successes were overshadowed in 1927 when the US submarine *S-4* was rammed off Provincetown and sank in 100 feet (30 m). The rescue vessel could not get there for 16 hours. Although some survivors were still alive, gales and other problems meant that a hose to blow fresh air into the survivors' compartment was delayed another 20 hours, too late to save life.

The beginnings of planned Submarine Rescue

In response to this tragedy, an old seaplane hanger was removed from the US submarine *S-1* in 1928 and Momsen halved it to make prototype rescue bells which later, redesigned, became the McCann bell.[5]

In 1930 this rescue bell was tested to 1,000 feet (304 m) by the USN but it was recognised by the RN that, to be of practical use, accurate and early location of the disabled submarine is essential and, from a UK point of view, to maintain a world-wide network of rescue bells would be impossible.

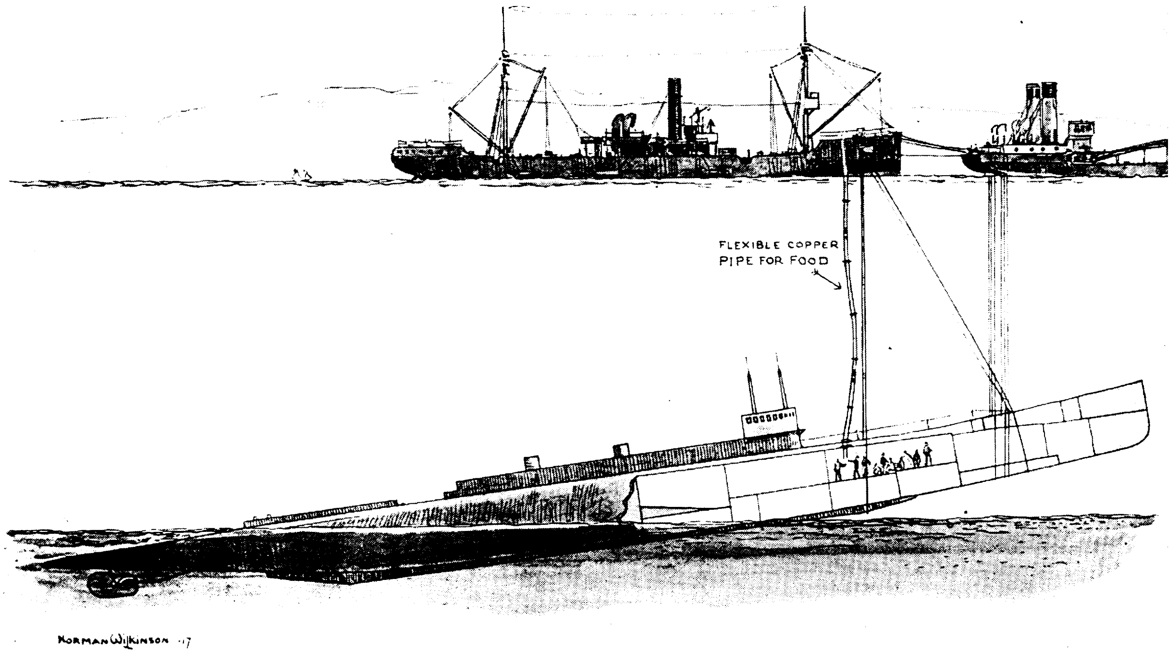

Figure 3. K 13, the first submarine rescue operation. [Fig 393 from Ref4].

Development of individual escapes

In 1930 individual escape without outside aid through either a submarine hatch or torpedo tube was reviewed.[8] Based on demonstrated ascent times from 40 feet (12 m) of 11 seconds without swimming and 8 seconds with swimming, a limit of 50 feet (15 m) had been decided for individual escape. For deeper escapes an individual escape apparatus with twin hoses and a carbon dioxide scrubber, “the lung”, was introduced by Momsen and others.[5] An oxygen supply is illustrated in the paper and was used to charge the lung before use. Simulated escapes were made through the water from 60 feet (18 m) and in the wet pot of the Experimental Diving Unit (EDU) from 250 feet (76 m) but with decompression stops. After some open sea tests from a bell, escapes down to 206 feet (63 m) were made from the salvaged submarine *S-4* submerged at sea. Compartment escapes were made from 100 feet (30 m) and from a special escape lock at greater depths. Ascent was made up a buoy line and the escaper timed any necessary stops by counting 16 breaths as one minute. Subsequently a simulated ascent was made in the EDU chamber from 357 feet (108 m) but the details are not given. These trials were conducted at the time when the US Navy Submarine Escape Training Tank, 18 ft (5.5 m) diameter and 100 feet (30 m) depth, was being built.

Only a year later there was a fatality after a 15 foot (4.5 m) training ascent using the Momsen Lung when the subject, in a manner later to be found typical of such incidents, fell back in the water on reaching the ladder.[9] The first experimental studies of pulmonary barotrauma followed.[10]

In 1931 the submarine HMS POSEIDON sank off Hong Kong in 125 feet (39 m) and, for the first time, the oxygen-regeneration breathing equipment was used.[6] An account of the escape by one of the survivors, Holt, tells that two of the eight in the forward torpedo compartment died during the flooding-up phase which lasted some 3 hours, one with no breathing apparatus and one whose apparatus became depleted. Six survivors escaped from the compartment but one was killed by a head injury sustained on emerging through the hatch. They developed decompression sickness from what had been their one and only exposure to raised environmental pressure. Perhaps the most relevant observation for divers is that 3 were examined again 12 years later and all three had juxta-articular necrosis of a shoulder and/or hip after this one exposure.[12]

The use of the “Momsen lung” for compartment escapes with ascent at 50 feet (15 m) per minute was reviewed in 1936 because of concerns about the risk of decompression sickness if the survivor was exposed to a prolonged period of preparation at pressure before escape.[13] During trials in the wet pot at EDU, subjects breathed compressed air at a depth of 100, 150, 167, 185 or 200 feet (30, 45, 51, 56 or 61 m) for predetermined exposure times. Exposure time was defined as half compression time plus time at maximum depth, but the rate of compression is not stated. The subject then submerged and breathed from the lung for two minutes and then was decompressed still submerged. In some the “lung” was charged with oxygen and in others with air. *Four series were conducted at 100 feet with a total of 1,231 exposures. The first case of caisson disease occurred following an exposure of 37 minutes breathing oxygen, but .. breathing air ... not until 43 minutes.* Similar results from other depths led to a conclusion that, breathing air for the ascent, safe exposure times were

100 ft (30 m) for 37 min
150 ft (45 m) for 18 min
200 ft (61 m) for 13 min.

The year 1939 was a tragic year for submarine accidents with nearly 300 fatalities. In February *SM I-63* of the Imperial Japanese Navy sank after a collision and 83 died. Then, in May, the US submarine *Squalus* dived with an air-induction valve open (though marked “secured”) and sank in 243 feet (74 m) off Portsmouth, New Hampshire. Twenty-six of the crew died but, after a wait of nearly 24 hours for the rescue vessel, 33 were saved in the next 15 hours in 4 trips of a McCann bell. The account of the first open-sea use of heliox diving for the salvage of the *Squalus* is a separate story.

Nine days later, *HMS THETIS* sank on her initial trials off Liverpool in 150 feet (46 m) of water with her stern showing but only 4 survived, 99 died. In his review,[6] Donald concluded that the lethal effects of compressed foul air were not appreciated at the time. Then, only two weeks later, the French Navy who had just ordered but not yet received a McCann rescue bell, lost their submarine *Phenix* in 300 feet (91 m) and 71 men died.

War experience suggested that the majority of successful escapees had not used breathing apparatus and this was confirmed in 1946 by the reviews of an Admiralty Committee. In the meanwhile the US Navy abandoned the “oxygen lung” and adopted free escape for submariners with training in the 30 m tank at New London.

The dangers of deliberate flooding prior to compartment escape were recognised. Any decision to delay the flooding process, perhaps misguidedly because it symbolises abandoning one’s ship, leads to an accumulation of carbon dioxide and toxic fumes. Compression of only a low percentage of carbon dioxide can lead to the toxic and potentially lethal effects of its increased partial pressure. Relief by breathing from DSEA, an oxygen “lung”, can lead to an oxygen convulsion exacerbated by the vasodilatation from prior carbon dioxide. Also, if there are leaks in the escape compartment which are high up, maybe into another compartment, the precious air lock could be lost before equalisation occurs.

Nitrogen narcosis during deeper escapes and decompression sickness afterwards were other hazards.

Animal work using goats became intense and demonstrated a safe path to be followed by human volunteers.[6] They showed that, after 3 to 5 minutes at depth, escapes would be possible from 250 feet (76 m) and suggested that faster and deeper cycles would be possible. Compression and ascent were at 2 feet (0.6 m) per second. The use of 60/40 nitrox led to bends which showed that, contrary to expectations, the oxygen content could not be ignored in decompression calculations but, in any case, the carriage of nitrox solely for escape would not be feasible in operational submarines. Human subjects were used during rapid compression to 300 feet (91 m) to study the effects of narcosis, but found no significant disturbances and concluded only that escape tasks should be kept as simple as possible.[15]

Evidence from human escapes about the desire to breath during a long ascent was ambiguous: some had no problem, some had an urgent desire to inhale and others became unconscious during the ascent without it seems inhaling a significant amount of water. Paton had shown in 1947 that the desire to breathe in is more easily resisted during ascent because of the diminishing partial pressure of carbon dioxide during ascent.[16] At the Royal Naval Physiological Laboratory (RNPL), Wright calculated that there would be no significant accumulation of carbon dioxide in lungs or body during an ascent with exhalation at 4 ft (1.2 m) per second from 300 ft (91 m).[17] There was still some concern that escapees might drown during an ascent of more than one minute and, immersed in water in a chamber, some volunteers felt a great need to breathe during ascents from 150, 200 and 300 feet (45, 61 and 91 m). Characteristically, Wright then tested deeper (330 feet, 100 m) and slower (2 feet, 0.6 m per second) ascents on himself. Time at the bottom was 60 sec at 300 feet (91 m) and 30 sec at 330 ft (100 m) and no decompression injuries occurred. Around 1950 a positive buoyancy stole attached to an immersion suit was introduced in the Royal Navy. With a positive buoyancy of 10 lbs (4.51 kg) the ascent rate for every escaper was increased to around 4 feet (1.2 m) per second.

In 1950 the sinking of the submarine *HMS TRUCULENT* highlighted the dangers of compartment escape from shallow depths and, in particular, with the subsequent loss of some 40 persons on the surface after their escape, the dangers of immersion hypothermia.

Buoyant ascent training by the Royal Navy began in 1953 in the new escape tank (SETT) at the submarine base, *HMS DOLPHIN*. The US Navy performed simulated escapes at New London with rapid compression from as deep as 450 feet (136 m) and in 1960 two open sea escapes from 300 feet (91 m).[18] Compression time was 25 seconds, 7 seconds were spent at maximum depth and ascent was at 5 feet (1.7 m) per second.

In 1962 escape trials (Upshot 1)[19] from 240 ft (73 m) were made from *HMS TIPTOE*. Compression in 30 seconds was not linear, with time at depth of 27-49 seconds, and ascent was at 6 feet (1.8 m) per second using the buoyancy stole and streamlined by the hood of the immersion suit. In spite of a bottom time, in diving terms, of a minute or more, most of the inert gas uptake would be during ascent. A greater compression rate was considered necessary and the Hood Inflation System (HIS.) was devised.[20] After more goat trials[21] to 500 feet (152 m), human trials were conducted with a linear compression in 20 seconds to the maximum depth and ascent after 20 seconds at maximum depth. One case of neurological decompression illness occurred after a 30 second exposure so this was abandoned. To compress a chamber on air at those rates to exactly 500 feet and then to maintain a precise decompression required great skill. On one occasion, with enormous banks of high pressure compressed air available, the senior escaper was once accidentally compressed to 300 feet (91 m) in around 2 or 3 seconds. He was decompressed immediately and, quite unfazed, lit a cigarette to help pass the obligatory “bend watch”. Smoke came out of both ears. His only complaint, after this barotrauma, was that on getting home some three hours later, the drums had sealed and he could not show this new trick to his children. A small story but one that characterises the many willing submariners who volunteered to be subjects for this work.

In 1965 the escape trials (Upshot IV)[22, 23] were conducted from *HMS ORPHEUS* at a keel depth of 500 feet (152 m) off Malta. The single escaper entered the escape tower wearing an immersion suit with an integral stole providing 150 lb (68 kg) positive buoyancy. By holding a hose into a compressed air supply in the tower, which was regulated to provide compressed air at 1 psi (6.8 kPa) over ambient, the escaper’s buoyancy stole was inflated and, with an overflow from that into his hood set at 0.5 psi (3.4 kPa), he always had a respirable space around his head during the subsequent phases of flooding and then rapid compression.

With a vent open into the boat, incoming sea water was allowed to flood the tower to a height related to the depth of the submarine, the escaper remaining at the submarine’s atmospheric pressure during this time. When the sea water reached its predetermined height, the water would begin to cascade down the vent which was the signal for those within the boat to close it (Figure 4). The last man out would simply cap the vent from within the tower. Then, with only a small air space in the tower around the head of the escaper the sea water, continuing to flood in, would compress it rapidly. In fact the compression to depth took around 15 seconds and a triple spring nose clip helped to clear the ears. There was one ruptured drum from the 87 escapes. The partial pressure of oxygen in the compressed air reached 3.4 bar.

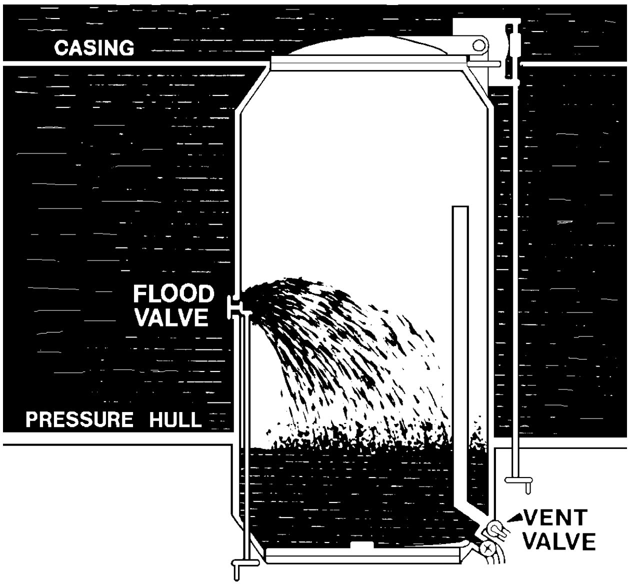

Figure 4. Single-man escape tower, for use by escaper with Hood Inflation System, shown when flooding up and venting into the submarine, with no change in pressure in the escape tower, before the phase of rapid pressurisation of the remaining air lock. [from Ref 23]

On equalisation, the spring-loaded hatch flew open so that, with a bottom time at 500 feet (152 m) of some 4 seconds and no time to wave to those watching through the periscope, the escaper was accelerating towards the surface achieving a terminal velocity through the water of around 8 feet (2.4 m) per second which is an ascent rate of nearly 500 feet (150 m) per minute. A compressed air dive to 500 feet, a bottom time of some 20 seconds and a decompression of around one minute. Exhilarating was the commonest comment. The water was clear and those who made more than one escape learned to control their direction through the water and to modify their speed of ascent. Within the latent period before the onset of oxygen toxicity and nitrogen narcosis, the whole dive was just too quick. As the medical officer at the receiving end I had some anxieties about the potential consequences and treatment of a decompression barotrauma with deep onset, but there were no decompression symptoms.[24]

After more goat trials to 950 feet (288 m) and some human trials to 620 feet (189 m) in the laboratory, on compressed air and with no narcosis, approval was given for more trials (Upshot V) at sea. In 1970 from *HMS OSIRIS* at 182 m (600 ft) manned escapes were made with 20 to 30 seconds compression time, 3 seconds at maximum depth and ascent at 8.5 feet (2.6 m) per second. One subject, after a 500 ft (152 m) escape, had an episode of impairment of vision and balance both of which responded to recompression. Research has continued since then, trying to push the envelope a bit further but, with one or two other episodes of possible decompression illness during validation exercises down to 180 m (590 ft) in 1987,[25] it seemed wiser to stop. The volunteers and the ethical committee could relax, wise in the knowledge that all should be able to escape from a disabled submarine at the depths tested and that, should a deeper escape be needed, the probability is that significant proportion will arrive at the surface safely.

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Dr David H Elliott was one of the guest speakers at the SPUMS 1998 Annual Scientific Meeting. He is Co-Editor of The Physiology and Medicine of Diving, which was first published in 1969, with the most recent edition in 1993 and is also the civilian consultant in diving medicine to the Royal Navy. His address is 40 Petworth Road, Haslemere, Surrey GU27 2HX, United Kingdom. Fax + 44-1428-658-678. E-mail 106101.1722@compuserve.com
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THE HISTORY OF AUSTRALIAN SUBMARINE ESCAPE AND RESCUE OPERATIONS

Robyn Walker

Key Words
Accident, bell diving, decompression illness, emergency ascent, history, hyperbaric facilities, rescue, surface decompression, transport, treatment.

Abstract

The Royal Australian Navy has developed and implemented a sophisticated submarine escape and rescue organisation. It includes not only the material hardware but a framework for review, accountability and progress. This paper outlines the development of the system looking historically at the events which initiated its formation.

Background

Australian submarine operations date back to WW1. The AE1 was commissioned in 1913 and was lost with all hands on approximately 14 Sep 1914 off New Britain. The submarine failed to return from patrol and the cause of its loss remains unknown. No trace of the AE1 has been found.

The AE2 was commissioned in June 1913 and was lost as a result of enemy action in the Sea of Marmora on 30 April 1915. The AE2 was the first allied warship to penetrate the Dardanelles and saw 5 days of action in these waters before being sunk by enemy fire. The entire crew survived. Rumours that the AE2 has been found off Turkey are yet to be confirmed.

During the period 1915-1922 Australia had a series of J boats, originally built for the Royal Navy (RN), but these do not appear to have seen much action. From 1918-1939 the Oxley and Otway were commissioned by the Royal Australian Navy (RAN), but again little action was seen by these boats.

It was not until the 1960s that the RAN purchased the Oberon Class of submarines from the RN and we became an active submarine nation. With this purchase came the corporate knowledge of the RN with respect to submarine escape matters: the single escape tower (SET), the built in breathing systems (BIBS) and submarine escape immersion equipment (SEIE). The RAN relied entirely on the RN for expertise in submarine escape, rescue and air purification systems.

During the 1980s there appears to have been a decrease in the flow of information coming from RN and policy changes were often "found" by accident with no information available as to how these decisions were made.

The 1990s saw the introduction of the Collins Class Submarines and, along with the requirement to build a unique submarine, came the requirement to develop and maintain in-house expertise in submarine escape, rescue and air purification matters. This resulted in the establishment of a department with a full time focus on submarine escape, rescue and air purification as they pertain to Australian submarines.

Why Maintain a SUBSUNK Organisation?

There are a number of reasons why the Australian government has directed the RAN to maintain a submarine escape and rescue organisation:

a it is morally difficult to place colleagues and subordinates in dangerous situations,

b one should attempt to reduce the danger to a level which is perceived to be acceptable,

c to maintain morale: few people are willing to place themselves in a totally unsurvivable situation, and

d to comply with OH&S frameworks: the RAN has an obligation to make every practicable effort to provide the safest work environment for its personnel.

It is acknowledged, however, that, in time of war, the deployment of resources to recover survivors other than in home waters is unlikely and possibly not even then.

Premise

There have been over 170 recorded peacetime submarine sinkings in the world since 1900 and no less than 10 in the last 10 years. It is said the most likely scenario for a submarine accident will be at times of transit through ports, channels and fishing grounds with collision and grounding the most likely mechanism.

The basic underlying premise that applies is that, once a submarine becomes disabled, at least one compartment remains intact or can be secured for long enough for survivors to decide upon and carry out a course of action. Therefore the sole aim is to save life.

Before the Collins Class

Until the early 1990s Australia's focus was on escape, via the single escape tower. This is where the survivor, dressed in submarine escape immersion suit (SEIS), leaves the submarine via the SET and makes a buoyant ascent to the surface. This is effective down to a depth of 180 m. We adopted the philosophy of the RN and accepted their system would work.

Compartment escape was provided to cater for the situation of rapid and uncontrollable flooding of a compartment when there would not be time to operate the SET. This is effective only down to a depth of 60 m, after which the risk of life threatening decompression illness (DCI) becomes too high.

While the RAN recognised rescue was the preferred method of leaving a submarine, logistic constraints virtually negated the possibility. The non-existence of rescue resources, the sheer size of the Australian submarine operating area and the logistic nightmare of deploying a foreign rescue capability conspired to prevent rescue being a serious option for SUBSUNK scenarios.

The dawning of a new era

With the advent of the Collins Class submarine further stumbling blocks became evident. Whilst the Collins Class SET is designed to the same parameters as the RN model, it is not the same in all respects and therefore required vigorous testing to provide both designer and user confidence that the system's capability was a known quantity and not simply implied.

Compartment escape in the Collins is an unknown commodity. Each Collins escape compartment is large compared to the Oberon and therefore time to flood the escape compartment is considerable, time under pressure increases and the risk of significant DCI increases. Secondly the battery compartments in the Collins are not pressure tight and are part of the escape compartment. Therefore a battery flood may result in:

a the production of oxygen and hydrogen gas by dissociation,

b the possibility of fire or explosion arising from sparking/high temperature in the vicinity of the gases produced,

c generation of chlorine gas, and

d the generation of a toxic atmosphere under pressure as a result of all the above.

Therefore, for a number of reasons, compartment escape in Collins is riskier than for an Oberon submarine.

A number of rescue vehicles were available, mainly in the northern hemisphere. The United States Navy Deep Submergence Rescue Vehicle (DSRV) is capable of pressurised rescue (up to 2 ATA or 2 bar) using the forward compartment of a submarine as a mass recompression chamber (RCC). If a country uses the DSRV the foreign government is financially responsible for all operating costs and total or partial loss replacement in the event of damage. The current cost of one DSRV is estimated to be in the vicinity of US$500 million dollars, which is a fairly daunting figure. The British LR5 is a commercial submersible and capable of road transfer only. It is not likely to deploy to Australian waters and has no surface transfer under pressure capability.

The air purification system within the Oberons was well researched and understood, operated in small compartments and within well trialled parameters. The Collins air purification system is different in design and has never been trialled as it does not exist in any other class of submarines.

The SEIS has undergone development and the MK 8 suit has been superseded by the MK 10 (Figure 1). This incorporates a number of changes including a change to a single skin with a life raft built into the pocket. Neither the MK8 nor the Mk10 had been trialled in a Collins submarine.

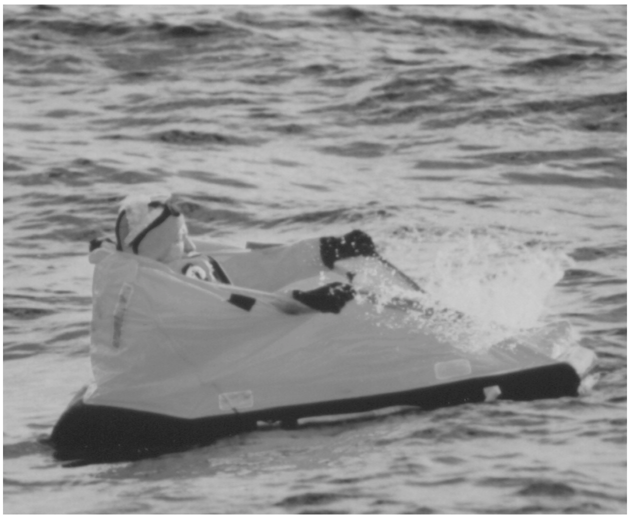

Figure 1. A "survivor" on the surface on the surface in the Mk 10 escape suit with the life raft inflated.

Warships in general can provide accommodation, secure communications, direction finding, underwater telephone, manpower and facilities for lifting patients off the ship by helicopter, however there is usually insufficient deck space and stability to mount and operate a rescue capability. There is insufficient deck space to mount and operate a sufficiently large RCC facility for either escape or rescue and warships usually have no dynamic positioning capability. It is therefore difficult to maintain accurate station over the disabled submarine and deploy a rescue vehicle or remote operated vehicle (ROV).

In summary there were a significant number of deficiencies in our submarine accident response plan ie:

a lack of facilities for escape (platform, medical team, RCCs),

b we could no longer rely on compartment escape as a viable alternative,

c lack of rescue capability,

d the installation of a untested air purification system: can the survivors survive until the rescue forces arrive?,

e the new escape suits had not been tested with a Collins and

f the lack of a platform for rescue.

SUBSUNK exercise 1993

For the first time in 1993 medical involvement in a SUBSUNK exercise occurred. Only 4 "survivors" were recovered but this was enough to highlight deficiencies in the medical management plan. It took over 11 minutes to retrieve the survivor from the water and transport to the triage area. Triage was difficult due to the small space allocated and due to the lack of oxygen stores in this area. Difficulties were encountered in transporting the patients around the ship and in securing the patients to the stretchers. The medical kit containing drugs and equipment was disorganised and difficult to use.

The way ahead

The Chief of Navy issued a directive in August 1994 instructing the submarine hierarchy to review all safety arrangements at all levels before the RAN had any active involvement in sea trials of Collins. Instructions were given that the RAN must be able to provide appropriate and timely medical treatment for those who escape, the numbers to be provided for were non-negotiable (55, maximum crew numbers for a Collins) and the contingency plan was not to be restricted to current national resources. There was also to be sufficient on board survival resources for maximum crew numbers to sustain life for 7 days while awaiting the arrival of the rescue forces.

In October 1994 the Submarine Escape & Rescue Project was established with the directive to produce the remedy prior to the start of Collins dived sea trials in February 1995.

The Australian Submarine Corporation was contracted to provide a submarine escape and rescue service (SERS) comprising:

a recompression facilities for 55 people,

b an extension of life support (ELSS) capability,

c a rescue submersible capable of operating in waters down to the crush depth of the submarine, and

d a transfer under pressure facility (up to 5 ATA).

Exercise Black Carillon I

Black Carillon 1 demonstrated the adequacy of the SERS for dealing with a mass escape. Fifty five survivors were rescued from the water, triaged and allocated to one of 4 broad medical treatment areas: immediate recompression, immediate resuscitation, medium priority and delayed priority. Twenty two survivors underwent simulated recompression therapy over the 8 hours of the "escape".

Exercise Black Carillon II

Black Carillon II demonstrated the successful mating of the rescue submersible Remora with an Oberon class submarine, Otama. The Remora was launched from the mother ship, successfully navigated its way to the submarine's position on the bottom of Jervis Bay and crew were transferred from the submarine to the surface.

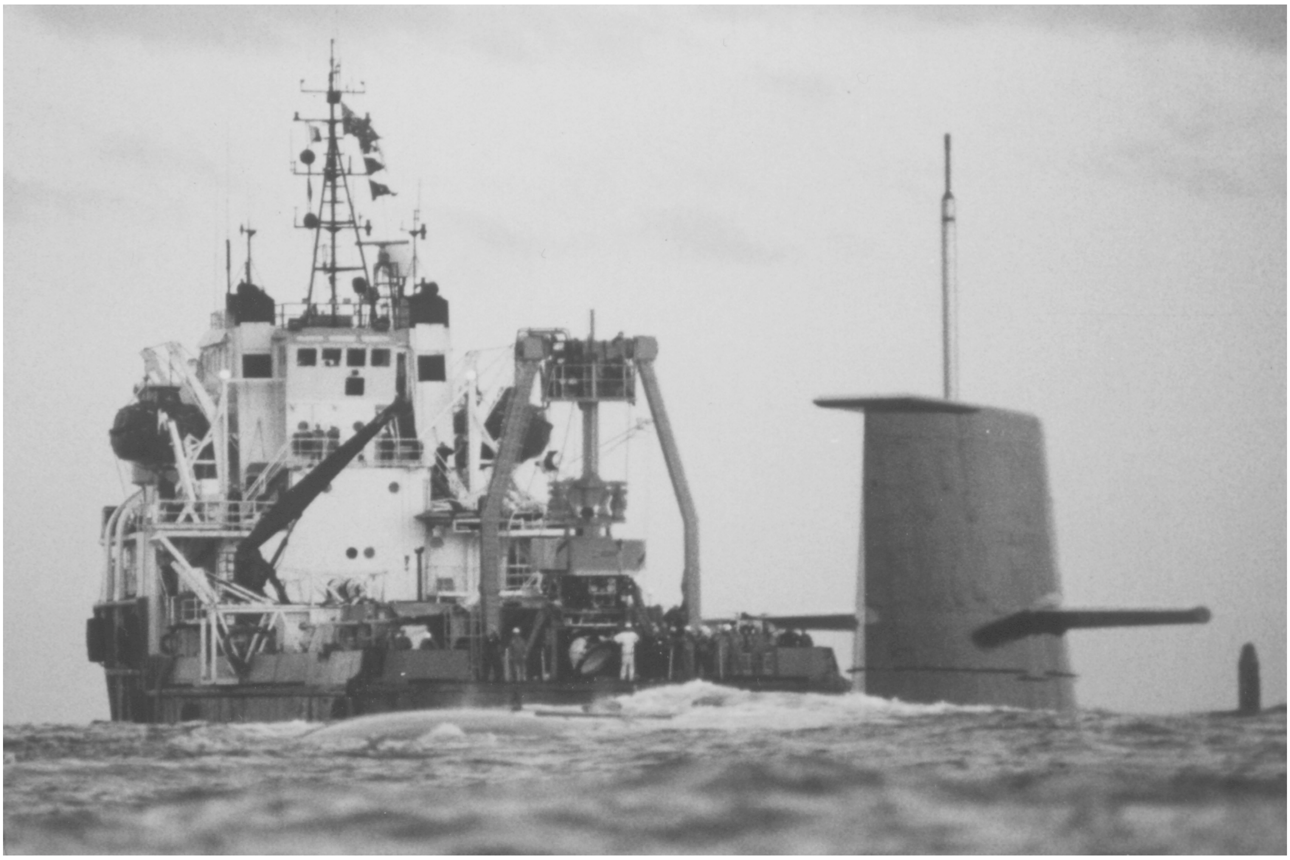

Figure 2. SEAHORSE SPIRIT (mothership carrying SERS), with HMAS COLLINS in the foreground, during Black Carillion 98.

Exercise Black Carillon 98

The logical progression of demonstrating the submarine escape and rescue capability continued. Black Carillon 98 had three broad aims:

1 ESCAPEX: to demonstrate, with minimal risk, the function of the single escape tower fitted to the Collins Class submarines for actual escape. This involved 9 instructors from the Submarine Escape Training Facility making a successful escape from the submarine which was bottomed in approximately 45 m. This is the ultimate proof that the SET will function as designed. Steps taken in the lead up to this exercise included tower functioning trials, to demonstrate the tower pressurisation rates were within acceptable limits and that the tower system operated as designed. Trials have also confirmed the SET performance with both the MK8 and MK10 suits at maximum operating depths. Trials have also verified the hood inflation system configuration for the MK10 suit.

2 RESCUEX: the second broad aim was to demonstrate the capability of the Remora to transfer, at atmospheric pressure (1 bar), crew from the Collins Class submarine to the surface recompression chamber suite. The ability to recover and transfer "injured" personnel from the submarine to the Remora and then to the RCC suite via a harness/pulley system was also demonstrated.

3 SURVIVEX: in order to demonstrate the Collins Class submarines can meet the 7 day survival requirement, the on board survival procedures were exercised as described in the Guard book (a set of cards providing escape and rescue instructions and held in each submarine escape compartment). The carbon dioxide level within the submarine was artificially raised to 2.5% and the crew were expected to follow procedures to measure the carbon dioxide and oxygen levels. Depending on the result, they had to decide whether to commence running the soda lime absorption units (SLAU), powered by 24 volt batteries in the event of a power failure, or burn oxygen candles. Trials to date have determined the SLAU meets the requirement for 46 men for 7 days; however the trials were not performed in accordance with guard book procedures and therefore not truly representative of an escape scenario. The SURVIVEX ran for 24 hours and calculations of usage rates of soda lime and oxygen candles will be extrapolated to 7 days. This should give accurate predictions of the stores required for 7 days.

The performance of Dräger tubes (used to measure carbon dioxide and oxygen levels) in the hyperbaric environment has been questioned in the past. Trials conducted led to a revision of practices and changes were made to guard book procedures. The SURVIVEX provided the opportunity to verify the guard book in a realistic situation.

The ELSS capability had not yet been conclusively demonstrated. Pods which weigh approximately 100 kg when fully laden with life support stores, food, water, medications etc. can be posted by ROV into the escape tower, providing extra time for the rescue forces to prepare. Difficulties have been noted when trialling the pods and a formal evaluation of the pod posting according to guard book procedures occurred during BLACK CARILLON 98.

Monitoring System

How does the RAN manage such a process? The RAN has implemented an internal 2 stage certification process addressing the material, engineering and operational aspects of the SERS with an additional annual audit of the system addressing these issues. The Remora is certified by the classification authority, Det Norske Veritas (DNV) for material safety with the recompression chamber suite currently undergoing this certification process.

The SUBSAFE Board Submarine Escape and Rescue Subgroup (comprising operational, medical and engineering representatives) is responsible for ensuring no hazard items represent an unacceptable risk prior to the conduct of these trials and in future operations.

Australian Defence Medical Ethics committee approval has been sought and granted for each phase of the exercises.

Summary

The RAN has developed and implemented a sophisticated escape and rescue organisation, the concept of which is being adopted by other major submarine nations around the world. The organisation includes not only the material hardware but a framework for review, accountability and progress. The Black Carillon exercise series will be followed by future exercises planned to maintain the momentum and in-house expertise in submarine escape and rescue.

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MILESTONES OF THE DEEP DIVING RESEARCH LABORATORY ZURICH

J Wendling, P Nussberger and B Schenk

Key Words

Decompression, deep diving, history, hyperbaric facilities, hyperbaric research, mixed gases, research, tables.

Abstract

Between 1959 and 1963 the deep diving pioneer Hannes Keller performed a series of depth records using heliox. He was assisted by the lung physiologist Professor A A Bühlmann of Zurich University. In 1961 application of a modified multi-tissue, perfusion limited, decompression algorithm for nitrogen and helium enabled an open sea dive to 305 m at Santa Catalina Island off California. However the price was a fatality. This dive was a break through for commercial diving, proving the feasibility of deep diving with helium.

A research contract with Shell, to develop decompression tables for offshore work, allowed the restructured research team at Zurich to construct a 100 ATA hyper- and hypobaric, multichamber, research and treatment facility, planned and directed by one of the authors (BS), an engineer. Experimental dives were continued down to 220 and 350 m at Alverstoke, UK, in 1969, and to 575 m in Zurich in 1981. The original decompression tables were empirically modified and became widely used. The problems of calculated tables and true reality will be discussed.

Altitude dive tables for scuba bounce diving were produced to meet the needs of military and police divers in Switzerland. Dive tables using the same algorithms as used for the deep dive experiments were calculated and tested for different altitude ranges. Bühlmann postulated a linear relationship of his supersaturation tolerance coefficients to the external pressure. In 1972 the first altitude table was produced using a 12-tissue model and in 1986 the actual set of tables was produced based on 16 tissues.

In a period of general rejection of any diving practices using computers as on-line dive planners, Bühlmann supported the adaptation of the Zurich tables for diving computers. The 1986 model has been further adapted to take into account workload, temperature, respiratory rate and inadequate decompression procedures specially considering the bubbles load of the lungs during certain phases.

The actual activities of the hyperbaric facility can be divided into the development of deep dive breathing apparatus and research into clinical hyperbaric oxygen (HBO) therapy.

Proving the feasibility of deep diving with helium (1959-1963)

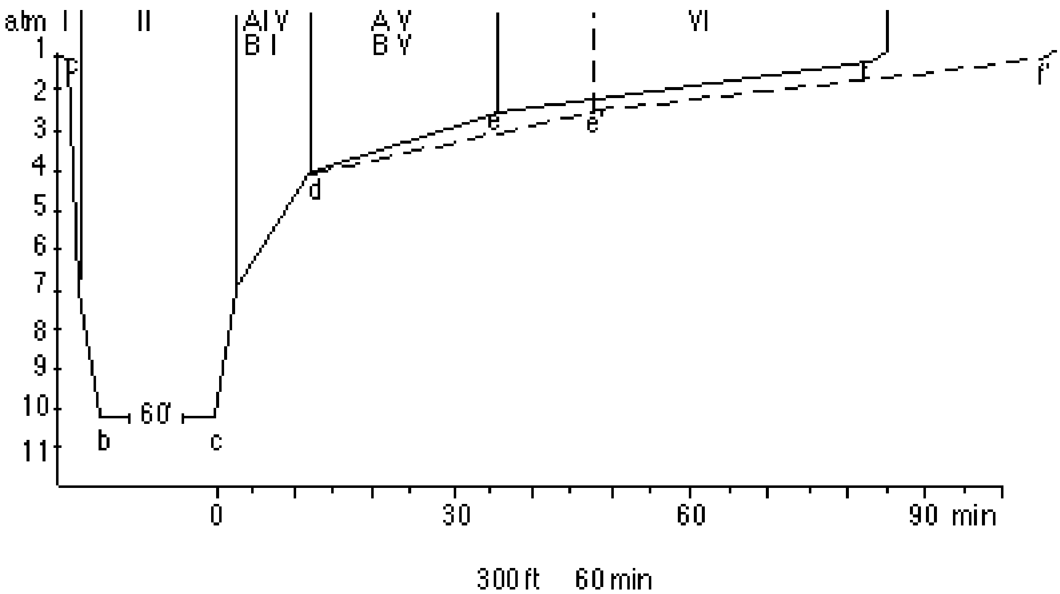
In 1958 the young mathematics teacher Hannes Keller, an enthusiastic sports diver, was fascinated by the idea of breaking the deep diving limits by optimising the known tricks and introducing some of his own ideas which he kept secret for many years. To get financial support, he had to consult a medical scientist , whom he found in Dr A A Bühlmann, a lung physiologist from Zurich University Medical Centre. Bühlmann had first to be convinced that helium is necessary to avoid nitrogen narcosis, which he believed to be a CO_2 retention effect. A trial in a monoplace chamber, with Bühlmann as the subject, convinced him.

Keller's secrets were:

- ability to calculate rapidly using his advanced experience with mathematics and the newly installed IBM computer in Zurich. Using the perfusion limited multi-tissue model (Haldane, Dwyer)[a,b] he calculated the decompression for the gas fractions of different gases.
- reduction of the gas load by ultra-rapid descent (20-50 m per minute)
- reduction of inert gas load by performing normo- and hyperbaric pre-oxygenation
- reduction of decompression time by multiple gas changes using the counter diffusion effect, which produces a temporary reduction of the total inert gas tension when changing to a gas with heavier molecular weight.
- reduction of decompression time by breathing with a PO_2 of up to 2.5 bar.

Using these principles he succeeded in several record dives (122 m in the Lake of Zurich 1959 and 222 m in Locarno 1960). However, technical support was minimal compared with similar tests performed by the US, French and British Navies.[1] Keller never used surface supplied underwater breathing apparatus, but developed handy tube valves that enabled refilling and gas changes of his scuba rebreather system on the diving platform.

The team achieved a 60 minute working time at 90 m depth with a total decompression time of only 85 minutes using six gas mixtures, two of them containing argon. (Fig 1)



A 85 min decompression time

	Gas	O_2	N_2	He	Arg.	min
A	I	21	79	-	-	-
	II	20	-	80	-	3+60=66
	IV	30	-	-	70	10
	V	50	-	-	50	24
	VI	100	-	-	-	50

B 110 min ibid

	Gas	O_2	N_2	He	Arg.	min
B	I	21	79	-	-	10
	II	8	-	92	-	3+60+3=66
	V	50	50	-	-	35
	VI	100	-	-	-	75

Figure 1. Compression and decompression profiles and gases used for a dive to 90 m (300 ft) for 60 minutes bottom time, nine subjects. (Figure 2 in Keller and Bühlmann[1]).

A dive of ten minutes bottom time at 220 m, followed by only 140 minutes of decompression, was planned using simulations in a monoplace chamber capable of 5 ATA by performing profiles with identical decompression ratios and gas mixes, going from 4.4 bar into hypobaric pressures up to 0.2 bar. The dive was demonstrated successfully in Toulon and Washington 1961 in a hyperbaric chamber. (Fig 2)

The deepest dive was 5 minutes to 305 m with a decompression totalling only 270 minutes (Fig 3). This dive was performed in the sea using a bell with a wet excursion at the bottom. The ascent was complicated by a tragedy. Keller's diving buddy died from hypoxia, due to missing gas reserves and because he failed to open his mask glass. Keller was in trouble, probably due to the high pressure nervous syndrome (HPNS), which resulted in loss of time and incorrect manipulation of the chamber. In addition a stand-by diver from the US Navy lost his life trying to close the chamber door in 60 m.

Development of decompression tables for off-shore work (1964-81)

Based on the success of the deep dive experiments, Shell Oil International signed a research contract with the Zurich team for the development of deep dive procedures that could be applied for diving operations on the

Figure 2. Hannes Keller (front) and Professor Bühlmann in the Toulon chamber before a 220 m chamber dive.

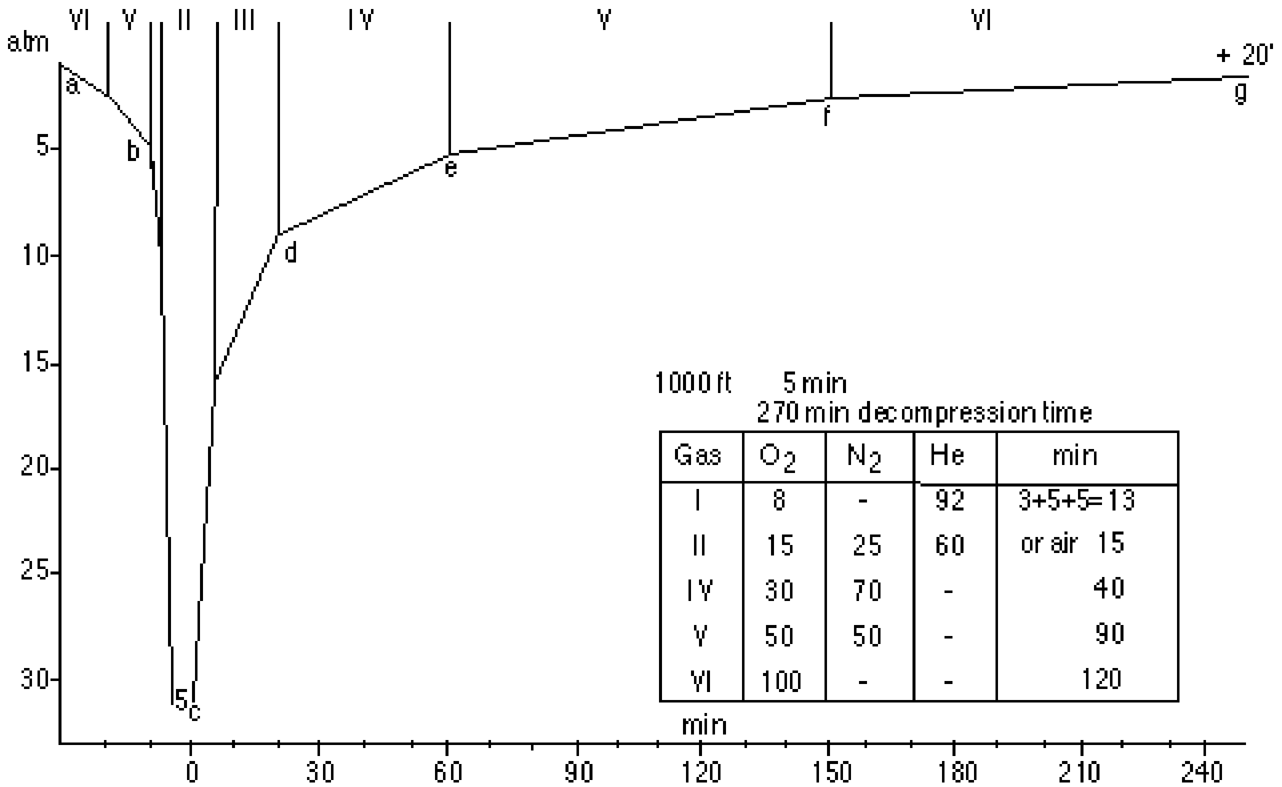


Figure 3. Compression and decompression profiles and gases used for a dive to 300 m (1,000 ft) for 5 minutes bottom time, two subjects. (Figure 6 in Keller and Bühlmann[1]).

continental shelf. As a result the diving bell "Atlantis", supplemented by a lock module and a detachable monoplace unit, was transformed into a 30 bar experimental living chamber.

The application of the usual algorithm used for the calculation of the deep bounce dives was now tested for longer bottom times up to saturation in 30 m simulation dives. This showed that much longer half times were needed (8 hours or 480 minutes for N_2 and 3 hours or 180 minutes for He, using the multi-tissue model). Ninety nine percent saturation was achieved after 64 hours (N_2) and 24 hours (He) respectively.[2]

The resulting long range and saturation diving tables were in use for many years in the diving company Micoperi or later SSOS (a Shell daughter company). During the subsequent experimental series the safe decompression limits for deeper dives, around 200 m, were tested using the experience of the early pioneer dives. These dives showed that all the advantages of the ultra rapid compression and multiple gas switches were lost when bottom time was increased. A new 100 bar chamber (Fig 4), a complex designed by Benno Schenk, who now acts as technical director, allowed simulations to much greater depths.

Although during the pioneer series HPNS was never observed, the somewhat longer and deeper dives showed tremor and other symptoms. For example, the 500 m experimental dive of 1977, using heliox, was not a success because the test subjects (divers) suffered badly from HPNS and their decompression had to be modified due to decompression sickness (DCS).

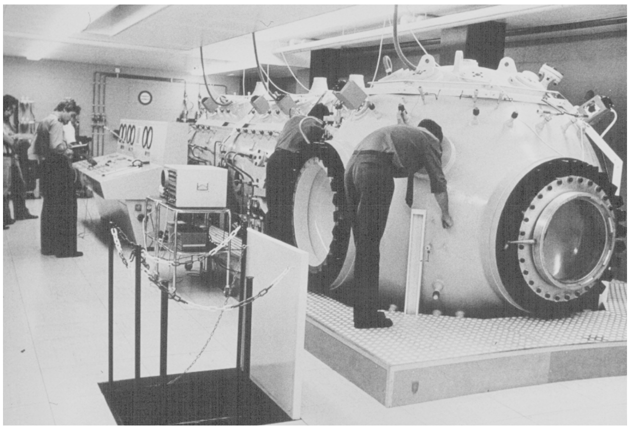


Figure 4. The three compartment research chamber at Zurich University.

After this, staged compression was introduced with good results. A 575 m chamber dive was achieved in 1981 with some HPNS in one subject and reduced working performance at maximum pressure (Table 1). Decompression from up to 300 m in the experiments resulted in newly

TABLE 1

OCCURRENCE OF HPNS WITH VARIOUS COMPRESSION PROCEDURES

A. Continuous compression, increasing with depth

215 m	in 3'	(20-50 m/'↓)	O_2-N_2-He	**HPNS -**	(n=2, 1961)
250 m	in 5',10'	(20-50 m/'↓)	O_2-N_2-He	**HPNS -**	(n=3, 1960/62)
300 m	in 16'	(20-50 m/'↓)	O_2-N_2-He	**HPNS (+)**	(n=5, 1961/62)

B. Continuous compression, constant

220 m	in 22'	(10 m/'↓)	O_2-He	**HPNS -**	(n=16, 1965-68)
250 m	in 25'	(10 m/'↓)	O_2-He	**HPNS +**	(n=11, 1967-80)
300 m	in 30'	(10 m/'↓)	O_2-He	**HPNS +**	(n=30, 1967-80)
350 m	in 35'	(10 m/'↓)	O_2-He	**HPNS ++**	(n= 6, 1977)
500 m	in 50'	(10 m/'↓)	O_2-He	**HPNS +++**	(n= 3, 1977)

C. Staged compression, continuous compression rate

300 m	in 155'	(10 m/'↓)	O_2-He	**HPNS (+)**	(n=6, 1978)
350 m	in 325'	(4 m/'↓)	O_2-He	**HPNS -**	(n=3, 1969)
400 m	in 255'	(10 m/'↓)	O_2-He	**HPNS ++**	(n=3, 1979)
400 m	in 415'	(10 m/'↓)	O_2-He	**HPNS -**	(n=3, 1981)
500 m	in 700'	(10 m/'↓)	O_2-He	**HPNS +**	(n=3, 1981)

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calculated tables using an algorithm that will be explained later.

However, diving contractors found it inconvenient to work with the safety level given by the Bühlmann tables and modified the decompression procedures on an empirical basis. Bühlmann however strongly believed that his algorithm (which resembles the Workman formula) reflected the physiological processes during a dive on the grounds that, since it had been successful experimentally, it *had* to be correct physiologically. This attitude, not always appreciated by the diving operator, together with Shell's fading interest in deep diving, were the reasons for the almost complete non-publication of the results of experimental dives by the Zurich investigators during that period.

The altitude dive tables for scuba bounce diving (1972 – 1986)

In spite of modest recognition by the deep diving industry of Bühlmann's ideas, the algorithm proposed by Bühlmann and Schenk was embraced by the sports diving community. By 1971, as computers offered more calculation capacity, the number of "tissues" (or more properly half-times) was increased to 16. The longest N_2 half-time represented a 635 minute (just under 11 hours) tissue. They found that, when using linear rather than exponential functions, it appeared that knowing the molecular weight of a gas was sufficient to deduce the a- and b- values.[3] These two parameters describe the tolerated supersaturation as a function of ambient pressure per tissue, represented by its half-time. Figure 5 shows Bühlmann's theoretical maximum tolerable partial pressures, on returning to 1 bar after exposure to pressure, calculated for different tissue half times. The experimentally determined limits are shown by dots, each is the occurrence of decompression sickness symptoms

With this formula it was easy to alter a particular experimental dive profile using a hand-held calculator. Validation experiments at various altitudes were performed. Reducing the decompression stops to cause an increase of about 10 % in the decompression stress resulted in a series of experimental dives with a 30 % incidence of DCS (these were immediately treated).

These studies were supported by the Swiss army and police divers. Extreme mountain lake validation dives at

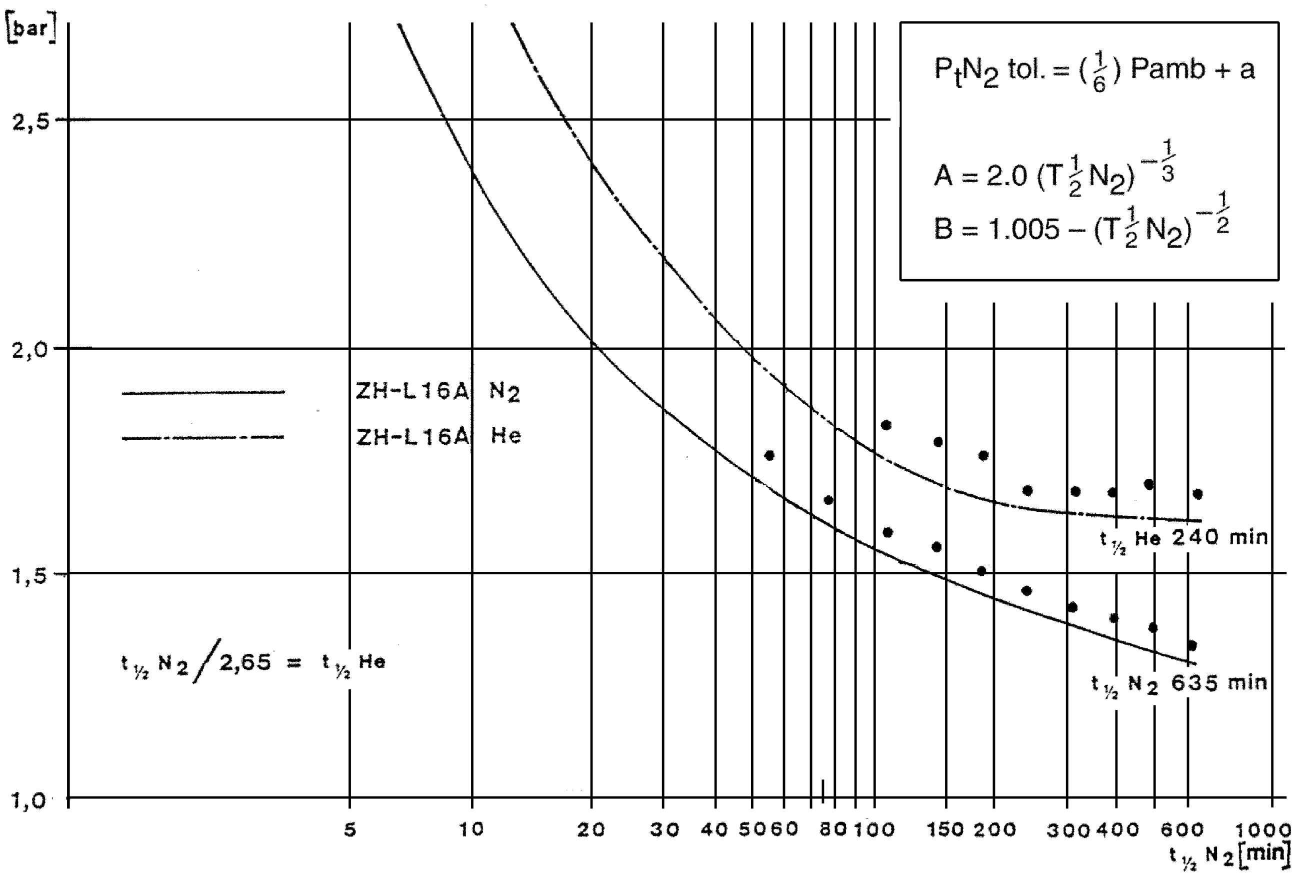

Figure 5. Bühlmann's theoretical maximum tolerable partial pressures, on returning to 1 bar after exposure to pressure, calculated for different tissue half times. The experimentally determined limits are shown by dots, each is the occurrence of decompression sickness symptoms (Redrawn from Bühlmann AA. Tauchmedizin (ISBN 3-540-58970-8) 1993).

Figure 6. W Keusen during an altitude dive at 4,780 m (Mt Kenya).

3,800 m (Lake Titicaca) and at 4,780 m (Mount Kenya, see Fig 6) proved the acceptable safety limits at these particular conditions.[4,5]

The results confirmed the calculated safety limits and gave further support to the general model. Bühlmann's hypothesis was that the algorithm had universal validity because it had been shown to be consistently successful with diving procedures when using helium, air, mixed gases for deep bounce dives as well as saturation dives.

Sports divers have successfully used the tables in various forms and in Switzerland the decompression of tunnel workers, using tables calculated for the particular altitude of the working site, has been successful.

Supporting development of dive-computers (1983-93)

When the first dive computers appeared, Bühlmann was asked to help develop a program containing the Zurich algorithm. He had never dived and considered recreational divers as foolhardy. At first he refused because he could not understand the enthusiasm of sports divers to be diving, when there was an increasing number of diving accidents in Swiss lakes.

He finally accepted the invitation having recognised that divers would use computers anyway so they might as well use his algorithm with its increased safety. He even found recreational divers interesting as research subjects for real time simulation of the tissue partial pressure of gases to get further validation of his algorithm.

For computers the tables were adapted to the specific characteristics of the hardware and software, adding the appropriate correction factors to the coefficients. Dive computers are now very popular in Europe and the DAN accident statistics do not show any increase of DCS incidence for computer users.

The next step was to study the cumulative effects of yo-yo and multi-level diving and flying after diving. Bühlmann supported the ideas of Ernst Voellm, a software-specialist and diving instructor, who wanted to modify the dive computer into an interactive monitor of various environmental and physiological parameters. The adaptive ZH16 model was born. It is influenced by the work-load of the diver, the (supposed) number of arterial bubbles and the temperature during the dive. Muscular work temporarily changes the halftime of that "tissue" resulting in a higher gas load. Bubbles slow down the elimination of nitrogen in the lungs. This is taken into account by assuming the start of bubble production when the supersaturation ratio is more than the threshold level. The correction applied is not changing the half-time coefficient, but temporarily adding a retardation factor according to the assumed quantity of bubbles as a function of time. The profiles can be downloaded into the PC and can be analysed by the divers immediately. (Fig 7)

The physiological parameters are taken by a sensor at the regulator valve and emitted to the dive computer through a radio-signal. In the same way the actual oxygen percentage will be monitored from mixed-gas rebreathers and then computed in a way to get a real time calculation of the theoretical gas tensions even during a Nitrox dive with semi-closed or closed systems.

The fact that 90% of Swiss divers and more than 80% of European divers use dive-computers, mostly with Bühlmann algorithms, without producing more accidents is an indirect validation of the algorithms used. In the future, prospective studies of the safety limits of the various Bühlmann algorithms, comparing the older ones with the most up-to-date modification, which certainly has more redundancy and would certainly allow shorter decompressions, should be performed. This project however is not financially viable if it is not sponsored by a Health and Safety Department or other interested organisation. A single individual would certainly not take the risk to reduce the coefficients.

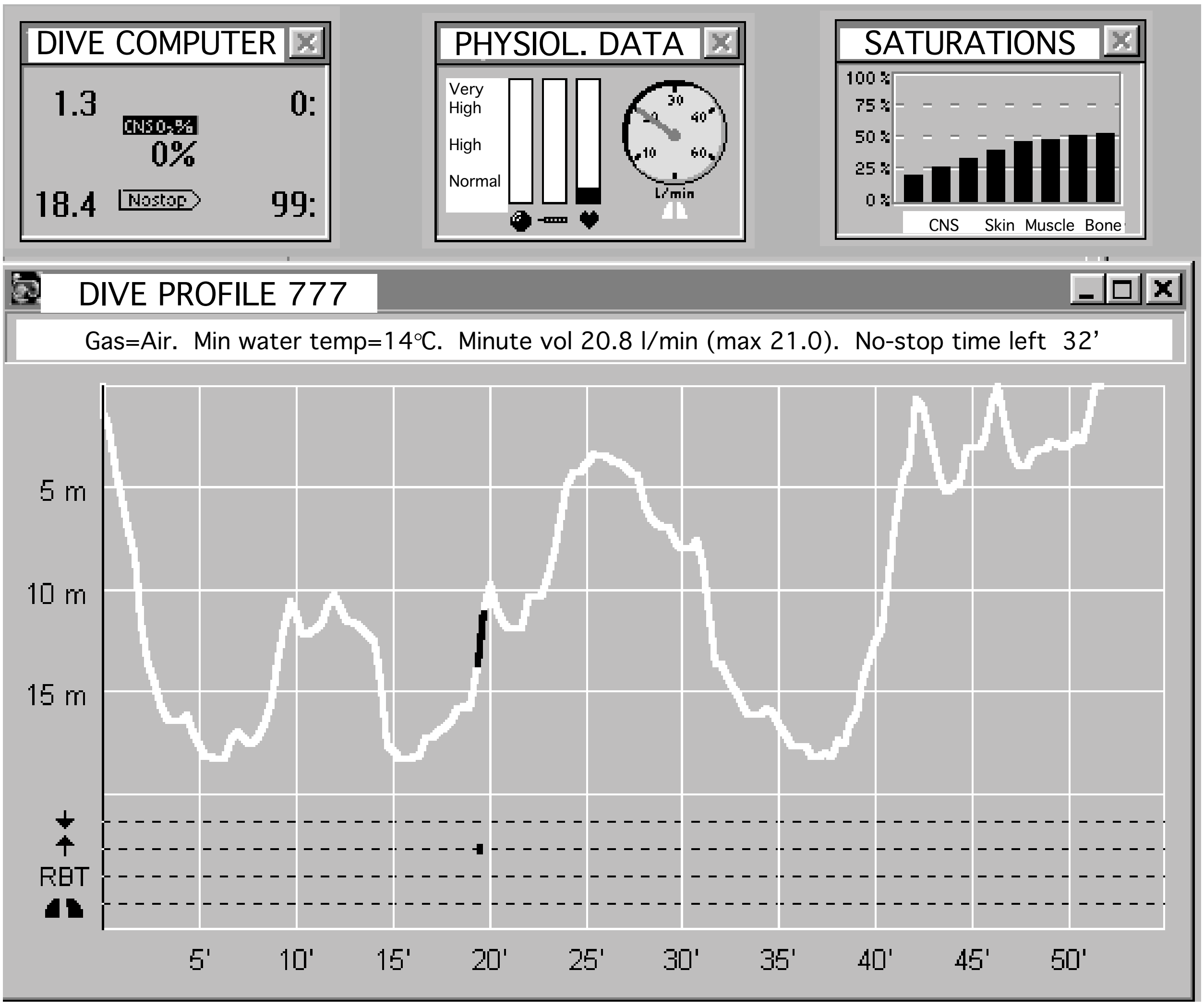

Fig 7. The graph, a screen capture, shows the time/depth profile of dive 777 taken from an Aladin-airX dive computer used by a diver. The black portion of the dive was when the diver ascended above the decompression stop requirement of the computer and the insufficient depth warning was sounded. Below the graph are four dotted lines. They are, from the top, the rapid ascent warning (arrow down), the too shallow warning (arrow up) with a black dot at the time it was activated, the alarm for insufficient remaining air to allow adequate decompression (RBT) and the hyperventilation alarm (outline of heart and lungs). The three small boxes across the top show the dive computer's calculations at the position of the cursor on the profile. In the first, at the top on the left, the maximum oxygen partial pressure attained, CNS O_2% as oxygen toxicity units and the dive time remaining. At the bottom the maximum depth and the no-stop time remaining. In the second box the first column, with a symbolic bubble below it, shows the estimated change in tissue perfusion by arterial bubbles of pulmonary (venous bubble passage), intra-arterial or tissue origin, the second column, with a symbolic thermometer under it, shows the expected temperature induced augmentation of the half times and the third column, over a symbolic heart, shows the estimated change in tissue perfusion due to increased cardiac output (calculated for the respiratory rate and minute volume). The dial, with symbolic lungs under it, shows the actual minute volume. The third box shows the saturation of eight theoretical tissues, defined by their half times, at the moment corresponding to the position of the screen cursor on the profile. In this case the CNS saturation is 25%, the skin is 40%, muscle is about 48% and bone is 50% of the tolerated supersaturation. (Redrawn from Bühlmann AA. Tauchmedizin (ISBN 3-540-58970-8) 1993)

Conclusions

The Zurich research group has now become history. Professor Bühlmann died in 1994, Hannes Keller has stopped diving and become a software-specialist and Benno Schenk will retire soon. The chamber is still used as a HBO facility and fights, as many others do, with financial problems. The University no longer finances it and it is not very practical, and too expensive, for efficient clinical use.

Research is being continued with the development of a deep dive breathing apparatus (Schenk) which facilitates breathing at greater depths, up to 700 m, by high frequency jet ventilation and airway pressure assistance.

The Zurich group was never in the main stream but nevertheless was successful in stimulating others to think over current concepts and define new ones (open bell bounce diving techniques, Workman M-values, Lambertsen counter diffusion principle).

The tables are the official dive tables of numerous sports diving associations, the CMAS affiliated diving federations in Germany, Switzerland, Austria, Ireland and Portugal, the British Subaqua Association (BSA) in England and are officially endorsed by NAUI International. The altitude adapted tables for tunnel workers are still often requested. Dive computer development benefits more and more from the "untrue", but very handy, algorithm that continues to be safe in spite of the opinions of many experts.

Acknowledgements

We thank all that have contributed to the workup of the Zürich Laboratory History, especially Mr Th. Bühlmann, Prof David Elliott, Max Hahn, Hannes Keller, Walter Keusen, Ernst Voellm and others.

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A BRIEF HISTORY OF DIVING AND DECOMPRESSION ILLNESS

Chris Acott

Key Words

Decompression illness, history, occupational diving.

Abstract

The significant events in the history of diving and decompression illness (decompression sickness and cerebral arterial gas embolism) are listed in chronological order.

The early history of diving

4,500-3,200 BC

Archaeological evidence shows that breathhold divers harvested sponges, food, mother of pearl and coral.[1,2]

1,194-1,184 BC

Breathhold divers were used in the Trojan wars to sabotage ships. Counter measures were introduced.[1]

900 BC An Assyrian bas-relief that showed a swimmer using an air filled balloon was part of King Assur-Nasir-Pal's palace at Nineveh. This balloon was probably not an air reserve but an early buoyancy device. This bas-relief is displayed now at the British museum.[3]

460 BC Herodotus described a Greek diver, Scyllis, also called Syllias or Scyllos, salvaging treasure for the Persian king, Xexres. He was so successful that Xexres held him captive to continue diving. Scyllis escaped by swimming 9 miles to shore during a storm (probably not underwater as it was reported!). He sabotaged the salvage fleet by cutting its moorings.[4]

332 BC Alexander the Great used divers for underwater demolition during the Siege of Tyre. He was supposed to have dived in a diving bell named "Colimphax". This event was recorded in a French manuscript in 1,250 AD.[1-5]

384-322 BC Aristotle described the use of the snorkel. He also described tympanic membrane perforation in divers and the use of the diving bell by Alexander the Great.[3,5] Reed snorkels have been used throughout history even recently during World War 1 by Allied troops in observation positions and the Germans in World War 2 by the Germans during their retreat from the Battle for Kuban.[4] The snorkel was used by both the American Indians and the Australian Aborigines for hunting.[1]

215-212 BC Greek divers were used at the siege of Syracuse to construct defensive underwater obstacles. [2,3,6]

168 BC "Commercial diving" was operational in all Mediterranean harbours.[2]

77 AD Pliny's book "Historia Naturalis" mentioned military divers breathing through snorkels attached to surface floats.[3]

Renaissance diving equipment

1450 Mariano (also known as Taccola) described a diving device similar to a horse's nose bag.[3]

1500s Leonardo Da Vinci sketched a variety of diving rigs but did not develop any for practical use.[3,7,8]

Hooded snorkel designs were described by Vegetius (1511), Vallo (1524), Lorena (1535), Lorini (1597) and Fludd (1617).[3,9]

The Age of Enlightenment

1616 Franz Kessler designed a diving bell. The diver sat on an internal framework and looked through a series of small eye ports. There was no means of adjusting the bell's buoyancy. The bell was slightly negatively buoyant so the diver walked on the sea bed.[3,5]

1620 Cornelius Drebbel, a Dutch inventor, developed a diving bell which was probably the first submarine. It relied on a one atmosphere air supply and caustic potash was used as an absorbent for carbon dioxide. Twelve oars powered it and it was operational to 4.5 m (15 ft).[4,7]

1627 Robert Boyle (1627-1691) was born in Lismore, Ireland.[10]

1632 Blaise Pascal (1632-1662) was born in Clermont-Ferrand, France.[10,11]

1635 Robert Hooke (1635-1703) was born on the Isle of Wight, England.[10]

1640 Von Treileben and Peckell used a diving bell to salvage 42 cannon from the Swedish ship "Vasa" which sank on its maiden voyage. The bell's air supply was atmospheric. The divers worked at 40 m (132 ft). There were no recorded cases of decompression sickness.[4]

1649 This was probably the date of publication of Pascal's Principle.[10,11]

1650 Von Guericke developed the first effective air pump.[1,3]

1656 Edmond Halley (1656-1742) was born in Shoreditch, England.[10]

1662 Boyle's Law was published.[12]

Henshaw, an English clergyman, used compressed air to treat various medical conditions. The chamber was an air-tight room, which he named "Domicilium". It was pressurised by a large pair of bellows.[7,13]

1670 Boyle demonstrated that a reduction in ambient pressure could lead to bubble formation in living tissue, however, this was not appreciated for nearly 200 years; "*..The little Bubbles.....by choking up some passages, vitiating the figure of others, disturbe or hinder the due circulation of blood*". His description of the viper when it was placed in a vacuum was the first recorded description of decompression sickness.[14,15]

1677 The Cadaques bell was used to salvage treasure from 2 wrecks in the port of Cadaques, Spain. The bell measured 3.9 (13 ft) by 2.7 m (9 ft) across. Two divers were used.[3,5]

1680 Borelli, an Italian mathematician, developed a rebreathing diving set. The exhaled gas was passed through some copper tubing cooled by sea water to purify it. The brass helmet was 0.6 m (2 ft) in diameter and had a glass window. The air supply was atmospheric. A piston device was used for buoyancy control. The diver was illustrated with claw like fins which suggested that he was a swimmer rather than a bottom walker. This apparatus was probably never used or tested.[3,8,16]

1681-87 Sir William Phipp used a bell and a team of divers for treasure salvage from a wrecked Spanish galleon in the Caribbean. Little is known about the bell.[3,6]

1689 Dr Denis Papin suggested that force pumps or bellows could be used to keep a constant pressure within a diving bell to maintain a constant supply of fresh air to prolong the divers' underwater endurance. This idea was first used by Englishman, John Smeaton in 1789. Papin's design was not constructed.[4]

1690 Edmund Halley developed a diving bell. In 1716 this design was improved by the use of 2 weighted air-filled 36 gallon barrels to replenish the bell's air supply.[3-7]

1715 Becker designed a helmet with 3 snorkels. Apparently he stayed submerged in the Thames for an hour, the depth is unknown.[4]

1715 Lethbridge designed a "diving machine" There are no drawings of this only an artist's impression sketched from later descriptions, which shows it as a barrel with a window at the head end and the diver's arms penetrating the barrel.[3,17]

1733 Joseph Priestley (1733-1804) was born in England.[10,11]

1742 C Scheele (1742-1786) was born in Sweden.[10]

1743 A Lavoisier (1743-1794) was born in France.[10]

1746 Jacques Charles (1746-1827) was born in France.[10]

1749 Pierre-Simon Laplace (1749-1827) was born in Beaumount-en-Auge, France.[10,11]

1766 John Dalton (1766-1844) was born in Eaglesfield, England.[10,11]

1769 Giovani Battista Morgagni described the post mortem findings of 2 cases in which air was seen in the cerebral circulation. He surmised that death was due to this.[18,19]

1772 Nitrogen was recognised by a Scottish botanist, Daniel Rutherford.[10]

1772 Freminet, a French scientist, designed a diving rig similar to Borelli's. The copper helmet was connected to an air reservoir bag. Exhaled gas was passed to and fro from the reservoir through copper tubing cooled by sea water. A set of bellows mixed the air supply in the reservoir. This apparatus allowed a diver to stay submerged probably for about 10 minutes. Although the system of air purification was invalid, the concept of extending the diver's bottom time and mobility was becoming a reality.[3,7,8]

1772 Oxygen was discovered independently by Scheele in 1772 and Joseph Priestly in 1774. They were ignorant of the each other's work. Priestly called it "dephlogisticated air".[10,20,21]

1755 William Henry (1775-1836) was born in England.[10]

1781 Lavoisier named "dephlogisticated air" oxygen (meaning acid producer).[10]

1782 The ROYAL GEORGE (a 3 deck battleship commanded by Rear Admiral Kempenfeldt) capsized on August 29 in Spithead. There were 1,000 people on board at the time, including women and children. Only 200 were rescued, Admiral Kempenfeldt and a large number of the crew drowned. It was rumoured at the time that the Royal Navy did not want the ship salvaged because it would reveal that the ROYAL GEORGE should not have been in service at the time. It was thought that the hull split open causing her to sink.[4,9,22]

Between 1782 and 1783 William Tracey used a diving bell in several unsuccessful salvage attempts. Cables were attached around the hull in an endeavour to refloat her. Tracey became bankrupt because of these salvage attempts and was imprisoned. He was later bailed out and pensioned off.[3,22]

1783 Forfait designed a diving rig which gave the diver the appearance of a submarine sandwich man. Two boards were hinged at the diver's waist and had 2 springs attached at the diver's shoulders. A rope was attached to the diver's right foot. By foot movement the diver could move these boards and either allow air in or out thus altering buoyancy. The helmet used a candle as a light source. This apparatus was not used.[3]

1784 Laplace's Law was published.[10]

1787 Charles' Law was formulated but not published.[10]

1788 In 1788 John Smeaton probably designed the first modern diving bell. It was used during the repair of the foundations of the Hexham bridge but it was not intended to be submerged. A force pump on the roof provided workers with a continuous supply of fresh air. In 1790 he modified this design to enable it to be submerged. This was used to construct the breakwater at Ramsgate Harbour.[3]

Augustus Siebe (1788-1872) was born in Saxony.[22]

1789 Lavoisier and Sequin were the first to describe the pulmonary effects of a prolonged exposure to normobaric oxygen and so discouraged its use.[10,22]

1790 Nitrogen was named by French chemist, Jean-Antoine-Claude Chaptal.[10]

1794 Lavoisier was beheaded.[10]

1796 Beddes and Watt wrote the first book on the medical applications of oxygen.[7]

1797 Klingert, a German, designed two diving rigs. One was a modified version of Forfait's design with the helmet attached to a surface float by a pipe. He used it in a shallow dive in the Oder river. It was not suitable for deep diving. His second design enabled the diver to control his buoyancy. It consisted of a large cylindrical air-reservoir which had a platform attached to it. The diver stood on this platform and was connected to the reservoir by a pipe. A rope connected the air-reservoir's top to the surface. Ballast was in the bottom of the air-reservoir attached to a pulley system operated by the diver. By either raising or lowering the ballast the diver could alter his buoyancy. Although impressive for its time the diver air supply was atmospheric and the apparatus difficult to handle and transport.[3,4,9]

1801 Dalton's Gas Laws were published.[11]

1802 Forder designed a snorkelled helmet attached to a set of surface bellows.[3]

Fullarton (1805) and Drieberg (1808) also designed snorkelled helmeted diving rigs which had limited success.[3]

1803 Henry's law was published.[10]

1821 F Magendie described gas embolism during surgery.[18]

1825 William James's compressed air diving rig (pressurised to 30 atmospheres absolute or ATA) had its air reservoir attached to the diver's waist. The diver regulated his air supply with a hand operated valve. The exhaust air escaped through a valve on the crown of diver's helmet. This was probably the first self-contained diving dress.[4,8,23]

1826 Von Derschau described the use of compressed air to raise water.[3]

1828 D'Augerville, a French dentist, designed a self contained compressed air back mounted diving rig with a reservoir air bag on the diver's chest. A hand held valve regulated the air flow to the reservoir bag from the air reservoir. The mask was made of copper and lined with dental cement to provide a good seal. The diver's buoyancy was controlled by the air content of the reservoir bag and ballast weights which could be jettisoned. D'Augerville used this rig in a salvage attempt of the wreck *Bellona*. It was used in depths between 9-20 m.[23]

1829 Bichat demonstrated that venous gas embolism could be tolerated but was dependent on the dose of air and site of injection. Small amounts of air, however, if injected into the cerebral circulation were fatal.[18]

Charles Dean used his open helmet diving dress for salvage work on the *Carn Brae Castle*, the first recorded use of suited divers in salvage work.[22]

1830 Cochrane patented the concept of the caisson (the use of compressed air to raise water).[3]

1832 Charles Condert, an American machinist, dived to 6m (20 ft) using a compressed air diving rig. It was a similar design to that of William James. A horse shoe shaped air reservoir, made from 6 inch (150 mm) copper tubing, was suspended around the diver's waist by shoulder straps. Air was supplied to the helmet by a hand controlled valve, the exhaust air escaping from a hole in the helmet's crown. Condert made several dives in the East River, New York, using this rig but he drowned in 1832 when his air hose broke and he was unable to ditch his weight belt.[8,16,23]

1833 Paul Bert was born in Auxere, France.[10]

1834 Junod, a Frenchman, constructed a hyperbaric chamber and used hyperbaric air (2-4 ATA) to treat pulmonary disease.[7]

1834-6 Between 1834 and 1836 the Deane brothers (John and Charles) made several successful salvage dives on the ROYAL GEORGE using the their diving rig. They were able to salvage 30 cannon, however, the ROYAL GEORGE still remained a hazard to shipping.[3,4,9,22]

1836 William Henry committed suicide.[10]

1837 Pravaz, a Frenchman, used hyperbaric air to treat a variety of illnesses. Between 1837-77 various hyperbaric air chambers were constructed in Europe to treat a variety of medical conditions.[7]

1839 In August 1839 Colonel Palsey, of the Royal Engineers, was employed to destroy the wreck of the ROYAL GEORGE. His divers used both the Deane diving rig and the newer Siebe "closed rig" (which made the diver more mobile and had a better air supply). Gunpowder kegs were placed around the wreck and electricity used to explode them. Palsey recommended that the Royal Navy use the Siebe rig which became the so called "classical diving rig".[3,4,9,22]

1841 Triger, a Frenchman, constructed a caisson (caisse is a box in French). Triger is credited with the invention of the caisson although the concept of using compressed air to raise water was an idea of Von Derschau's in 1826 and patented by Cochrane in 1830. Triger's caisson consisted of 4 iron cylinders about 1 m in diameter and 5 to 6 m long. It was sunk to a depth of 20 m (66 ft). It was used to excavate a coal mine at Chalonnes and to penetrate quicksand under the Loire River.[7,14,24-26]

In his first report Triger (1845) noted ear pain during compression. He also noted at 3 ATA:

that candles burned brightly;
that it was impossible to whistle;
that voices had a nasal accent;
and that respiratory rates were decreased and less effort was required to perform tasks.

He recorded the first 2 cases of decompression sickness in 2 miners. One complained of a "very sharp pain" in his left arm, the other a pain in his knees and left shoulder. These miners had been working at 2.4 ATA for 4.25 hours. Alcohol was massaged over the affected areas and both men returned to work the next day. Apparently the pain had disappeared.[24,25]

In subsequent reports, Triger noted that ear pain was relieved by swallowing (he knew about the Eustachian Tube) and that a dog and bird had been kept alive in the caisson for many days.[24]

In 1852 he was awarded the Prix de Mechanique for the invention of the Caisson.[24]

1846 Blavier reported that some caisson workers (Douchy mines, France) complained of a post decompression "heavy head" and limb pains. These pains were relieved by local massage.[26]

1847 Pol and Wattelle (both Frenchmen) noted "several untoward symptoms" (unconsciousness, convulsions and death) after decompression in caisson workers at Lourdes. They noted that symptomatic relief was gained with recompression in one worker. Although this is thought to be the first reported case describing the effectiveness of recompression for treatment, ("*.... a sure and prompt means of relief would be to recompress immediately, then decompress very carefully*") there is no evidence that they used recompression routinely in their affected workers.[24,26,27]

They also observed that there was a relationship between symptoms, depth and duration of exposure and the rapidity of decompression and that fit 18 year olds were less susceptible to decompression sickness than older workers.

They concluded that workers should be between the ages of 18-26. These data were published in 1854.[24,26-28]

1850-51 Hughes, an Englishman, described similar observations to Triger's (except for decompression sickness) during the construction of the Medway bridge.[26]

1855 Littleton reported 25 cases of decompression sickness in caisson workers during the construction of the Tamar bridge. Limb pains, paralysis and unconsciousness were noted a few minutes after decompression. He thought that decompression sickness was due to "...extrication of air occasioning pressure on the brain....". He recommended a gradual application and reduction of pressure.[26]

1857 Hoppe-Seyler repeated Boyle's experiments. He thought that sudden death seen following decompression was due to the sudden release of intravascular gas.[1]

1860 John Scott Haldane (1860-1936) was born in Edinburgh, Scotland.[10]

1861 Bucquoy published an account of the hazards of compressed air work. He was probably the first to do so. He advised a slow decompression.[29]

1863 Foley recommended recompression as the "true specific" treatment for decompression sickness.[27]

1864 Roger, a French physician, described the collapse of an 8 year old girl following irrigation of her empyema cavity. He thought that this was caused by "pleural reflexes". In 1875 Raynard and colleagues tried to verify this experimentally but were unable to do so. Collapse following empyema irrigation was called "pleural eclampsia" by Bessnier (1874) and "pleural epilepsy" by Legnoux and Leprice (1875).[18]

1865 Rouquayrol and Denayrouze developed their demand valve and diving rig. A pressure regulator was connected to a compressed air reservoir carried on the diver's back. This was a major advance in diving technology as it increased the diver's mobility. Rouquayrol and Denayrouze's diving rig was referred to in Jules Verne's Book "20,000 Leagues under the Sea" (written in 1869, published in 1875). Later Rouquayrol designed a flexible diving dress with a metal three-bolted helmet.[3,9,16]

1866 Leonard Hill (1866-1952) was born.[4]

1868 Helium (from the Greek word for sun) was discovered surrounding the sun by two English astronomers, Lockyer and Frankland.[10]

Gal described a case of paraplegia in a Greek sponge diver. The diver made a spontaneous recovery over 2 weeks. This case report was not published until 1872 and may have been the first description of neurological decompression sickness in a diver.[30,31]

1870 Bauer published a report of 25 paralysed caisson workers. Four died but the majority recovered within 1 - 4 weeks.[28,32]

Between 1870 and 1910 all the salient features of decompression sickness were established. Early explanations included:

reflex spinal cord damage caused by either by exhaustion or cold;
frictional tissue electricity caused by compression;
or decompression induced organ congestion and vascular stasis.[24, 25, 27, 30, 32]

1871 The St Louis Eades bridge project employed 352 compressed air workers. Thirty of these workers were seriously injured, 12 died. Dr Alphonse Jaminet was the physician in charge. He developed decompression sickness following an exposure of 2.75 hours at 29 m with a decompression of 3.5 minutes. His symptoms were: dizziness, limb pain, paralysis of one arm and both legs and an inability to speak. He elevated his legs and drank rum and made a spontaneous recovery within a week. His personal description of these events were the first such recorded.[13,24]

1872 Friedburg noted:

- the similarity between severe decompression sickness and surgically induced gas embolism;
- the association between decompression sickness and inadequate decompression.

He thought that a rapid decompression released intravascular gas and so suggested:

- a slow compression and decompression (at least 15 minutes each);
- that shifts be limited to 4 hours;
- that 44.1 psig (4 ATA) should not be exceeded;
- and only healthy individuals be used.

He also recommended recompression for severe cases.[26]

1872 Gal published data which showed that paralysed patients either recovered spontaneously (over 5 days - 3 weeks) or died from septicaemia (complications of bed sores or cystitis).[31]

1873 The Brooklyn bridge project employed 600 workers. The caissons were to a depth of 78.5 feet (23.8 m. These caissons were steam heated because it was thought that decompression sickness was due to extreme cold. Andrew Smith, an ENT surgeon, was the physician in charge. He described 110 cases of decompression sickness which he considered serious enough to warrant his attention (there were 119 cases in total). Fourteen of these died. He was the first to use the term "caisson disease". He did not use recompression because he believed it to be a "*....heroic mode..*" of treatment. The chief engineer, Roebling, developed neurological decompression sickness (mainly spinal cord symptoms). He directed the project from his sick bed. He was not treated but made a slow spontaneous recovery.[13,24,26,33,34]

During this project the colloquial term "the bends" was used. "Doing the bend" was used to describe the posture of the caisson workers who suffered from decompression sickness. These workers walked with a stoop resembling a posture known as the "Grecian bend" affected by fashionable women. "Doing the bend" was later changed to being bent or the bends.[13,24]

Some of the caisson workers wore bimetallic or "galvanic" bands either to prevent or relieve the symptoms of decompression sickness.[13,24]

1875 Raynard and co-workers tried to verify that pleural reflexes were responsible for pleural "eclampsia" or "epilepsy".[18]

1877 L von Bremen developed a speaking tube which improved communication between the diver and his surface attendant. This tube was connected to the diver's helmet.[4]

1878 Paul Bert published "La Pression Barometrique". He described the acute toxic central nervous system effects of oxygen (acute oxygen toxicity or the "Paul Bert effect").[13,24,29,35]

He recommended recompression and the use of normobaric oxygen for treatment.

He not only demonstrated that nitrogen bubbles caused decompression sickness but also recognised the existence of "silent bubbles" following decompression. He described the association between obesity and an increased susceptibility to decompression sickness (he experimented on his pet dog. It had survived many decompressions from 7-8 ATA while thin, however it died when subjected to the same pressure exposures while obese).[13,14,24,35]

1880 Fleuss designed an oxygen rebreathing set. The absorbent was rope soaked in caustic potash. It was first used for diving, by Lambert, during the flooding of the Severn tunnel. Fleuss was the surface attendant.[3,9]

1880-1910 Additional safety devices were added to diving helmets. These included:

- a valve which regulated the amount of air in the helmet;
- a "chin button" which enabled the diver to release air from the helmet giving him some control over his buoyancy;
- a non-return valve which prevented air escaping up a damaged hose air hose or if there was an air pump failure;
- and a hand operated 'spitcock' for helmet defogging.[4]

1881 Woodward reported that the majority of "pain only" and some cases of neurological decompression sickness resolved spontaneously.[30,31]

1884 Nowak published a summary on the medical aspects of compressed air work.[26]

1889 E W Moir installed a medical lock during the construction of the Hudson river tunnel. He used recompression for treatment. When Moir became the superintendent the incidence of decompression sickness was high with a death rate of 25% from decompression sickness. Following the installation of the medical lock only 2 deaths occurred in the subsequent 120 cases. Moir did not publish these data until 1896 and they are probably the earliest reference to the routine use of recompression for treatment. Moir's recompression regime was to recompress to 1/2 -2/3rds the working pressure followed by a stay at this pressure for 25-30 minutes and a decompression of 1 psi per minute. Haldane used some of Moir's clinical data for his experiments.[2,13,24]

1892 John Burdon Sanderson Haldane (1892-1964) was born.[10,12]

1894 Buchanan and Gordon, two Australians, patented a deep diving suit. This was manufactured by Siebe Gorman. Another Australian, Hamilton, designed a diving suit, however, this was not used.[3]

1895 Ramsay discovered helium on Earth.[10]

Snell used recompression during the construction of the Blackwall Tunnel (he had had a medical lock installed). He was the first to describe the association between an increased risk of decompression sickness and an elevation in the atmospheric carbon dioxide tension due to inadequate caisson ventilation[36]

1897 Zuntz discussed the factors that controlled bubble size and resolution but overlooked the role of fat in the pathogenesis of decompression sickness. He used oxygen and recompression for treatment, however, this mode of treatment was unpopular due to the fear of acute oxygen toxicity.[30,37,38]

1900 L Hill demonstrated experimentally, in a frog, that decompression caused bubbles and that these cleared on recompression.[40]

Heller, Mager and von Schrotter recommended a linear decompression of 1 atmosphere per 20 minutes.[14,40]

1902 Construction restarted on the Hudson River tunnels.[26]

Albert Behnke (1902-1992) was born in Chicago, USA.[41]

1904 Greek and Swedish divers were diving to 58 m using air but the rate of decompression sickness was high.[3]

1905 The British Admiralty appointed Haldane to develop safe decompression procedures. The Royal Navy had a 100 ft (30 m) limit on air diving.[14]

1906 Von Schrotter suggested the use of oxygen with recompression but again the fear of acute oxygen toxicity thwarted its use.[28, 42]

Hill and Greenwood recommended a uniform decompression of 20 minutes per atmosphere, similar to Heller and von Schrotter. They also experimented on themselves. To discover the saturation of the body's 'fast' tissues (the kidneys were used as an example) they measured their urinary nitrogen content. They disregarded the effects of carbon dioxide on decompression sickness. These data were subsequently used by Haldane.[39]

1908 JS Haldane, Boycott and Damant published "The Prevention of Compressed Air Illness". They recommended staged decompression. These tables were accepted by the RN and were used for dives to 34 fathoms (204 ft or 61.2 m).[39]

1909 The German company, Dräger, developed their rebreather.[9]

Keays described 3,692 cases of decompression sickness. He established recompression as the treatment of choice. He showed that there was a persistence of symptoms in 14% of Caisson workers who were not recompressed compared with 0.5% in who were. However he admitted that recompression often failed in "serious" cases. These data were published again in 1912.[43, 44]

Blick described 200 cases of decompression sickness in the Australian pearl divers. He showed that in the majority of 'pain only' cases the symptoms resolved spontaneously. There were some cases of spontaneous improvement in neurological cases. The pearl divers often died because of the complications of paraplegia (septicaemia from urinary stasis and infection), hence, they carried metal urinary catheters with them while diving to treat the paraplegic bladder. At post mortem Blick described "*..teasing of the spinal cord..*" in divers who had died from spinal cord decompression sickness.[45]

1910 Jacques Cousteau (1919-1997) was born in France.[10,68]

Jacobs reported the medical problems associated with caisson work during the construction of the Hudson River tunnels. Between 1902 and 1910 there were 1575 cases of decompression sickness in 8400 workers. Three died.[26]

1911 Bassoe described chronic joint pain and stiffness in 11 out of 161 compressed air workers in Illinois, USA. The radiological description was reported as "arthritis deformans".[46]

Knowles reported 115 cases of decompression sickness in 100 caisson workers during the construction of the Boulac Bridge across the Nile. There were 4 deaths due to decompression sickness. These were the first repetitive cases of decompression sickness to be published.[26]

1911-1912 Borstein and Plate described 3 cases of joint disease in 500 compressed air workers employed in the construction of the Elbe Tunnel in Hamburg. One had a single hip lesion, another bilateral hip lesions and the third a lesion in his right shoulder. All had suffered from decompression sickness. The maximum pressure they had worked in was 3.4 ATA.[46]

1912 Kenneth Donald (1912-1994) was born.[47]

Hill emphasised the increased risk of permanent disability or death in compressed air workers.[48]

Ryan published a treatment regime which had limited acceptance. He advocated a return to 2/3rds the original pressure followed by a slow decompression.[59]

M Brandes described the post mortem finding of bismuth paste in a patient's cerebral arterial and venous circulation following its use in the irrigation of an empyema cavity.[18]

1913 L Brauer suggested that the symptoms and signs of "pleural shock" or "pleural eclampsia" could be explained by cerebral gas embolism. He was probably the first to use the term "arterial gas embolism".[18]

1915 The United States Navy (USN) Diving Tables were first published. These were a version of the original Haldane tables modified by French and Stillson. Maximum depth was 300 ft (90 m). They were used, in 1916, to salvage the submarine *F4* which sank to a depth of 306 ft (92 m).[51]

1917 Levy advocated a recompression regime of a return to the original pressure followed by a slow decompression. It had limited acceptance.[49]

Dräger developed a nitrox rebreather.[3,9]

1918 A Tokyo engineer, Watanabe Riichi, patented his self-contained diving apparatus. This was marketed under the name of "Ohgushi's Peerless Respirator". The diver controlled his own air supply with 2 levers in his helmet which he manipulated with his teeth. His air supply was either surface supplied or from two cylinders, containing 1,000 litres when pressurised to 150 atmospheres. The surface supplied version of the Ohgushi regulator was illustrated and described in a 1945 Russian Navy diving manual and was apparently still in use at this time.[23]

1919 Elihu Thompson suggested the use of helium to the US Department of Mines. He thought that the use of heliox would decrease breathing resistance and double diving depths. Nitrogen narcosis was unknown at this time.[14]

The RN and US Department of Mines began experimenting with heliox. They used air decompression schedules which gave a high incidence of decompression sickness. As a result heliox was abandoned.[14]

1921 **Dr O Cunningham used hyperbaric air to treat a variety of illnesses, including diabetes.[7]**

1922 K Schlaepfer suggested the Trendelenberg position for any collapse following irrigation of an empyema cavity.[51]

1924 The USN first published the first standard recompression procedure.[27]

1926 A French Naval officer, Yves Le Prieur, patented the Frenez-Le-Prieur self contained diving apparatus. It consisted of a back mounted Michelin air cylinder connected to a Frenez mouthpiece. The diver wore Frenez goggles and a nose clip. This apparatus was superseded in 1934 by the Le Prieur apparatus which used the same cylinder but mounted on the diver's chest. A hand controlled regulator fed a continuous stream of air to a full face mask.[8,23]

1927 Haldane proposed that bubble resolution could take over 24 hours.[52]

1928 Rukstinat and Le Count advised that any post mortem examination should be conducted under water if the cause of death was suspected to be a gas embolism.[53]

Cunningham's hyperbaric "Sphere" was constructed. It was 5 stories high and 64 feet in diameter. Each floor had 12 bedrooms. Cunningham published only one article on the use of hyperbaric air despite repeated requests from the American Medical Association. He was censured by the American Medical Association. His chamber was demolished in 1937 for scrap metal.[7,13]

1929 Van Allen's data on the head down posture and gas embolism was published. He also noted that gas was not trapped in the cerebral circulation.[18]

Joseph Peress designed his watertight joint to be used in his one atmosphere diving suit.[54]

The Davis decompression chamber was designed.[3,4,39]

1930 Peress trialled his one atmosphere diving suit, "Tritonia", in a tank at Byfleet, England. It was later trialled in Loch Ness, the diver was James Jarret, Peress's assistant.[17,54]

The RN Second Deep Diving Unit was formed. Successive chairmen were Captain FA Buckly RN, Captain (later Admiral Sir Francis) Pridham, Captain Robertson RN, Leonard Hill (later Sir) and Robert Davis (later Sir). Experimental work was delayed by World War Two but resumed again in 1946. The RN began experimenting with oxygen decompression from 60 ft (18 m) in air dives to 325 ft (98 m). The RN used the submersible Davis

Decompression chamber for their oxygen decompression. During the deep dive experiments Damant noted unpredictable behaviour in the divers at depth. Various reasons were proposed for this:

L Hill and A Phillip (1932) psychological causes;
JS Haldane (1935) oxygen toxicity;
Behnke (1935) the result of an increased partial pressure of nitrogen. These oxygen decompression experiments stimulated Behnke to start his oxygen tolerance experiments.[3,39,55]

Courlieu, a Frenchman, developed the rubber foot fin.[8]

In the 1930's the USN Submarine Escape Unit, particularly Behnke, recognised arterial gas embolism as a different disorder from decompression sickness.[24]

1931 Six submariners escaped from the RN Submarine HMS POSEIDON which had sunk in 100 ft (30 m) in the China Sea. Five survived the escape, one died from a head injury received while exiting the submarine. All of the survivors suffered from decompression sickness. Four were found to have dysbaric osteonecrosis 12 years later (1 was lost to follow up). Apparently this was their only exposure to compressed air.[3,56]

1932 The first snorkel was patented. The name snorkel was adapted from the air tube used in German U Boats.[3,8]

1934 Kagiyama's data showed divers could ascend from deeper depths without decompressing if the exposure time was limited.[14]

1935 Behnke and Shaw investigated the use of oxygen (to create a maximum elimination gradient and relieve bubble induced ischaemia) in the treatment of decompression sickness.[42]

James Jarret dived on the *Lusitania* (304 ft, 91 m) in "Tritonia" the one atmosphere diving suit.[17,54]

1937 Behnke and Shaw published their oxygen tables. These tables were not used because the USN Bureau of Medicine and Surgery decided that oxygen breathing in a chamber was not "sailor-proof" (fear of oxygen toxicity and fire).[27]

Behnke and Shaw restated Van Allen's posture recommendation to prevent cerebral embolisation by bubbles.[42]

Behnke introduced the "no-stop" decompression tables.[14]

1939 Yarborough and Behnke showed a 50% recurrence rate with USN recompression procedures. They suggested recompression to 165 ft (50 m) combined with the use of hyperbaric oxygen from 60 ft (18 m). This treatment regime was not adopted.[57]

Momsen and Wheland published the first operational heliox operational decompression schedules. Heliox was used in the salvage of the US submarine *Squalus* which had sunk in 240 fsw (73 m). Behnke supervised the diving. Thirty six men were rescued. None of the divers complained about any decrement in co-ordination and cognitive function, which verified Behnke's theory of nitrogen narcosis.[58]

1942-1945 Donald conducted his oxygen diving experiments.[4,55,59]

1942 JL Fulton was appointed the head of a committee to investigate decompression sickness in aviators. This committee included Behnke.[26]

1943 Emile Gagnan, an engineer, and J Cousteau adapted a gas pressure reducing valve for use underwater. The "aqua lung" was born. This valve had been previously evaluated by Gagnan for use in gas powered cars.[1,7,23]

1945 Van der Aue et al. developed the USN's Treatment Tables 1 - 4. Gas embolism was treated on either Tables 3 or 4. [60]

Zetterstrom, a Swedish engineer, died diving while using a hydrogen/oxygen mixture. He had previously demonstrated that the risks of hypoxia and explosion were reduced in hydrox diving if the diver used air to 30 m followed by a 4% nitrox mixture and then a 4% hydrox mixture. He died during ascent from a dive to 160 m using these combinations, apparently the ascent was too rapid due operator error.[1,4]

1946 The RN Deep Diving Unit resumed its activities under Commander Shelford RN, but it was renamed the Admiralty Experimental Diving Unit. It was mainly concerned with heliox diving.[4]

1947 Dr Edgar End began treating compressed air workers with 3 ATA oxygen. His treatment times varied between 30 minutes to one hour or more depending upon the rapidity of relief. Between 1947-67 he successfully treated 250 patients. Unfortunately, his work was not published.[24]

1950 Molumphy modified Momsen and Wheland's heliox tables. [54]

1955 Haymaker et al. published their post mortem data which showed that decompression sickness in divers, caisson workers and aviators was identical.[61]

1957 Des Granges produced the USN Repetitive Air Diving Tables, using tissue half times of 40, 80, 120 and 240 minutes. These tables were based on Dwyer's data.[58]

1957-1963 Dr G Bond conducted the "Genesis studies". These studies were the forerunner of saturation diving.[16,62]

1960 Golding et al. classified decompression sickness into Type 1 and 2. This view was supported historically by the USN classification of decompression sickness into mild (or pain only) and serious.[1,51,63]

The USN used the Des Granges repetitive air tables.[58]

1962 Hans Keller dived successfully to 305 m in the sea using a Hydrox mixture.[1,4]

1962-1978 Various underwater habitats were tried. Sixty five were built in total, 41 of these in Europe. The aquanauts, as they became known, either dived on air or a heliox mixture. Between 700 and 800 aquanauts were used including astronaut Scott Carpenter.[16,62]

1965 Goodman and Workman began their studies on minimal pressure oxygen tables.[27,31]

1967 The USN accepted the Goodman and Workman tables. These were published as Tables 5 and, 6 in the USN Diving Manual.[27]

Waite and Mazzone began to re-evaluate the treatment of cerebral arterial gas embolism in submarine escape trainees.[64]

1968 Waite and Van Gendren modified USN Tables 5 and 6 for the treatment of cerebral arterial air embolism. These tables were called Tables 5A and 6A.[65]

1976 Table 5A was abandoned because it was considered that there was insufficient time at 165 ft (50 m) to evaluate the diver.[66]

1985 The USN published an algorithm for examination of the Central Nervous System in its Diving Manual.[67]

1990 A meeting was held at Alverstoke, UK, to discuss the classification of decompression sickness. A change in terminology was proposed, the term decompression illness was to embrace both the maladies of decompression sickness and cerebral arterial gas embolism.

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THE DIVING HELMET

John Bevan

Key Words

Equipment, history.

Abstract

Safe and effective commercial diving did not become viable until the invention of the surface-supplied diving helmet. Though simple in principle of operation, the idea did not dawn until the early 1800s. In 1856, Robert Stevenson MP, President of the Institution of Civil Engineers remarked at a meeting chaired by Isambard Kingdom Brunel, "Nothing had so much contributed to extend and facilitate marine engineering, as the invention of the diving dress".[1] The honour for this invention falls on two lowly seamen who were brought up during the Napoleonic wars, in Deptford, a squalid dockland in the suburbs of London. This paper describes how brothers, John and Charles Deane, came upon the idea of the diving helmet and their uphill struggle to turn it into a commercial success. Their story inevitably covers "firsts" in many categories, including marine civil engineering, salvage, treasure hunting, military activities and of course, underwater medicine.

(This paper is based on the author's book *The Infernal Diver*. Submex Ltd, 1996, ISBN 0 9508242 1 6)

The earliest diving helmet

Charles Anthony Deane filed his patent for a smoke helmet and dress on 4 November 1823.[2] At this time he had given up his seafaring career with the Honourable East India Company and had settled down as a ship's caulker, working in a private ship-building yard in his home town of

Deptford, near London. Six months later, as was the custom, Charles Deane enrolled the full specifications of his patent. Then on 15 May 1824, just a few weeks later, he sold an Indenture of Assignment for the patent to his employer, the wealthy owner of the shipyard, Edward George Barnard for the considerable sum of £417.[3]

Figure 1. 1823 Smoke helmet, photographed at Siebe Gorman. This is the helmet patented in 1823 by Charles Anthony Deane and manufactured by Augustus Siebe. In 1829 it was used as the prototype for a diving helmet.

As with all inventions, the next step was to prove the most difficult, that is, turning it into a commercial success. Both Deane and Barnard worked closely together in the venture and they approached the Admiralty on 7 December 1824 and again on 15 March 1825 to try to gain its interest and support.[4,5] But the Admiralty could see no advantage in it and turned them away. The last recorded attempt to promote the smoke helmet and dress was in 1829 when the equipment was demonstrated at a meeting of the Society for Preventing Loss of Life by Fire at 18 Aldermanbury, London.[6]

That might have been the end of the matter, but the proceedings took a new and unexpected twist. While Charles Deane had been in London pursuing his caulking and smoke helmet venture, his younger brother John had been working with the expert salvagers of Whitstable, Kent. There, an exciting, challenging and potentially lucrative career could be obtained recovering lost anchors and their cables from the sea bed. There were also major bonuses when a stranded vessel could be saved or a valuable cargo recovered from a wreck. But the methods used were crude, involving long poles with tongs on the ends, worked from the surface. Even a small diving bell had been tried. When John and Charles Deane compared notes, the idea dawned. Charles's smoke helmet was really like a small diving bell. So the two brothers set about modifying a smoke helmet and made a prototype diving helmet. In 1828 they tested their idea in Croydon Canal, just half a mile from Charles's home in Deptford and the system was brought to "full perfection".[7]

Figure 2. 1830, Deane helmet (France), the first dedicated diving helmet.

They were ready for their first serious attempt at commercial exploitation by the following year. As if in answer to a prayer, the Honourable the East India Company ship *Carn Brea Castle* was wrecked in shallow water off the Isle of Wight on 5 July 1829. The Lloyds Underwriters routinely approached the Whitstable salvagers when such an event occurred and it is through them that the Deanes would have had the invitation and opportunity to try out their new technique. Despite the crude nature of the equipment, which included a "leathern headpiece" and air supplied by a bellows, the venture was a complete success and most of the valuable cargo of the ship was saved before the next storm smashed her to pieces.[8]

Augustus Siebe was then commissioned by the Deanes for the first time to manufacture the next generation of the Deanes' diving equipment. The first reports of the

Deanes using a piston, force pump, an open helmet and a Mackintosh waterproof diving dress came in 1830.[9] Figure 3 shows the princlple of an open helmet, which only has one air pipe. The disadvantage was that bending forward caused water to enter the suit at the neck and could cause loss of air from the helmet leading to flooding.

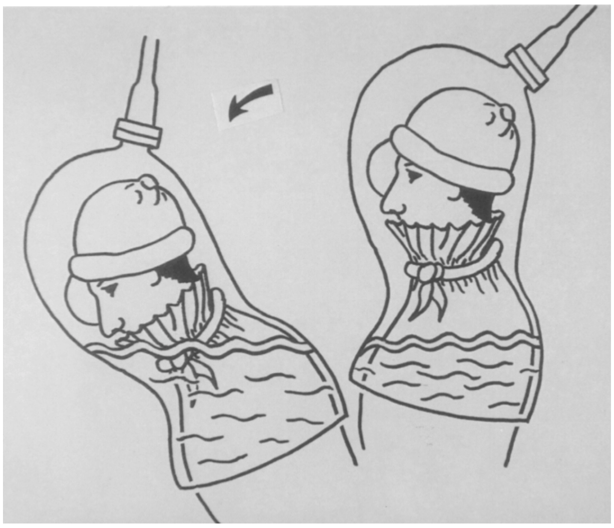

Figure 3. Open helmet principle. The helmet required only one air pipe, but bending forward caused water to enter the suit at neck and/or loss of air from helmet (flooding).

In 1830 John Parker Marsh, a commercial bell diver, first copied the Deane patented diving helmet. Barnard brought a case of patent infringement against Marsh in Chancery on 10 November 1831, but eventually lost it on 28 February 1833 because the patent was for a smoke helmet, not a diving helmet.

An undated drawing by Simon Goodrich shows what could have been the next developmental model of the Deane helmet and dress.[10] The helmet appears to have been negatively buoyant as it was not held down by any weights. The jacket and sleeves had been reduced, which removed the necessity to provide the helmet with an exhaust pipe. The excess air, together with the diver's exhaled air, would have escaped at the shoulders. The weights were attached to a separate belt around the waist.

In February and March 1832, Charles Deane carried out several dives for the Admiralty in the Medway and Thames, including the moorings of HMS FIORENZO, HMS IMPERIEUSE, the *Eveline* and HMS CHRISTIAN VII. The attention of the Deanes was then drawn to Portsmouth where the wrecks of HMS BOYNE and HMS ROYAL GEORGE were still causing chronic obstruction problems. The Deanes were, however, too late to get the rights to work on the BOYNE because a competitor named Henry Abbinett, to whom they had sold one of their obsolete sets of equipment, had beaten them to it. So Charles Deane opted for the rights to work on the ROYAL GEORGE, in the footsteps of Tracey, the Spaldings and Braithwaites. On 16 August 1832, Charles Deane landed on the deck of the ROYAL GEORGE at a depth of about 60 ft (18 m),[11] probably the deepest so far achieved in an open helmet. A notable change in his diving dress was that now he wore large weights on the front and back of his chest.

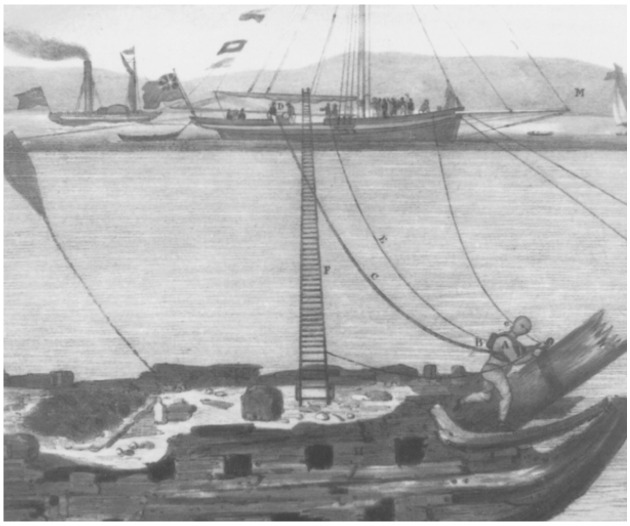

Figure 4. 1832, Charles Anthony Deane on HMS ROYAL GEORGE. He and his brother John salvaged several bronze cannons from this wreck.

The clearest description and illustration of the improvements of the open diving helmet, including the all-important exhaust pipe, appeared in August 1832.[12] This showed a flexible exhaust pipe lashed high on the side of the helmet. This is presumed to have been done whilst the helmet was not in use to keep the vulnerable pipe from being damaged. Also in August that year, John Deane was diving on the wreck of the *Guernsey Lily*, off the Norfolk coast, an ordnance transport vessel sunk in 1799. This was the first evidence of the Deane brothers working independently of each other.

The first use of the diving helmet in a civil engineering function happened in December 1832. The eminent civil engineers Walker and Burges of London had been commissioned to report on the structural integrity of the ageing Blackfriars Bridge across the Thames.[13] They employed Charles Deane to carry out the underwater survey and even tried out the equipment themselves.

The Whitstable salvagers were, by now, seriously impressed by the capabilities of the new diving helmet and they decided to try and get hold of the equipment for their operations. Thus Thomas Gann and George Bell of Whitstable, using their lawyer John Bethell of Lincolns Inn Fields, approached Barnard. Bethell also visited Augustus Siebe at Denmark Street, Soho to inspect the equipment. Barnard later accused Bethell of using this opportunity to spy on Siebe's manufacturing techniques because in 1834 Charles and John Deane discovered divers, using a diving helmet and dress made by Bethell, working on a wreck to which the Deanes had been given the rights by the underwriters. This was followed in 1835 by Bethell patenting his pattern for a diving helmet and dress.[14] Bethell's design was different in several respects. The main one was that it was a "tight" dress. That is, it completely sealed the diver from the water. It was made in two parts. The upper part consisted of the helmet attached to a jacket and the lower part was the trousers. A seal between the two halves was achieved around the waist where the jacket and trousers overlapped and were bound tight by twine tied over an inner metal ring. Bethell was successful in selling several units to the Royal Navy.

Yet another competitor appeared the same year. On 22 June 1835 John William Fraser filed a patent for an "Apparatus for Descending Under Water" but he failed to enrol a specification.[15] He made a second abortive attempt on 15 October with his patent for "Raising Weights from Below the Surface of the Water".[16] Success finally came on 14 November when he refiled his patent for a diving apparatus.[17] This equipment became the second major competitor to that of the Deanes. It was the second so-called tight dress and the main difference was in the attachment of a clever floating exhaust valve for the helmet.

Over the years 1834, 5 and 6, the Deanes worked on and off, on the ROYAL GEORGE. By 1835, they had raised 17 brass and 5 iron cannon from the wreck with a total value of £3,000. Their share must have been a healthy tonic for their bank balances because the following year, in 1836, both the brothers launched important publications. Charles published his "Submarine Researches on the Wrecks of His Majesty's late Ships ROYAL GEORGE, BOYNE and Others"[17] and John published the first ever diving manual which he called "Method of Using Deane's Patent Diving Apparatus".[18]

In 1836 the pickings on the ROYAL GEORGE were thinning out and John Deane, who by this stage seemed to be doing all the diving in partnership with William Edwards of Whitstable, was easily persuaded on 16 June 1836 to dive on a "foul" which had snagged some fishermen's nets. This turned out to be no less than the long lost wreck of the Tudor warship MARY ROSE, sunk in 1545. To the delight of the Admiralty, John instantly salvaged several unique pieces of ordnance which were around 300 years old even in the 1830s. The wreck was completely buried so he used gunpowder to excavate into the hull and to remove a 15-foot section of the ship's main mast, the first time explosives had been used in an underwater archaeological project.

Then towards the end of the year a third competitive diving dress patent appeared. William Bush filed his patent for "Improvements in the Means of and in the Apparatus for building and Working Under Water".[19] Bush was an eccentric civil engineer with bizarre ambitions to build light houses on the Goodwin Sands. His diving dress design included a diving suit which sealed around the waist (like Bethell's) but used a bolted flange to achieve water-tightness. This was an interesting improvement, superior to Bethell's arrangement and perhaps the inspiration for the later bolted flange seal at the corselet introduced by George Edwards. Bush also included a peculiar breathing system in his patent but it was completely impractical and would never have worked. Bush did however later become a major player in the diving salvage business.

1837 was an important year because this is when the disputed Deane smoke helmet patent came to the end of its 14 year life. Augustus Siebe, who presumably out of respect for Deane's patent, had not challenged it. But now the time was ripe to establish himself in his own right. On 22 May 1837 Siebe sent his first letter to the Admiralty offering his diving equipment which he stated he had been manufacturing for eight years and had sold 20 sets.[20] This equipment would of course have been the Deane open helmet and dress. The Admiralty still could not see any merit in it and turned it down again.

The Royal Engineers

The Royal Engineers, under the directorship of Colonel Charles William Pasley, were, on the other hand, an entirely different kettle of fish. Pasley was requested by the Lord Mayor of London to clear a shipwreck that was causing chaos in the navigation of the Thames, the brig *William* sunk in the middle of the fairway off Tilbury Fort, opposite to Gravesend in 1836. Pasley had been asked because he had a track record of setting off explosives in the Medway since 1812. Pasley had no experience with the application of the diving helmet at this time so he sought advice from everyone he could identify in the business. John Deane in partnership with William Edwards of Whitstable had offered his services free (expenses only) but Pasley had been misled by a jealous competitor (William Kemp) and he turned Deane's offer down. Pasley fell prey to Kemp's persuasion and was badly advised that he could use untrained Sappers and Miners as divers. This led to a fatal accident in a diving helmet when a diver became tangled in the wreck of the *William*.[21] He had been wearing a Fraser design of helmet and dress. But Pasley was later awarded the Freedom of London by the Lord Mayor for his successful removal of the *William*.[22]

Pasley's success coupled with his astute appreciation of the merits of the diving helmet led Pasley to seek out another opportunity to explore his new-found underwater mining skills. It was inevitable that this search led him directly to Portsmouth and the wreck of the ROYAL GEORGE which was still obstructing the Royal Navy's premier anchorage at Spithead. Pasley quickly discovered that the Admiralty had given the salvage rights to Charles Deane. But that did not stop Pasley. He pulled a few strings with friends in the Boards of the Admiralty and Ordnance back in London and the ROYAL GEORGE was duly removed from Charles Deane and handed to Pasley.[23] The news so stunned Deane that he ended up with an enforced stay in a lunatic asylum.[24] Charles Deane was never the same again and within another ten years he had taken his own life with a single fatal slice of a cut-throat razor.

In the meantime Pasley was at full gallop in his operations "against the ROYAL GEORGE". During the first year of his campaign, 1839, he hired two well known Whitstable divers named George Hall and Hiram London who used the Deane pattern diving equipment. Pasley however took the opportunity to get the Whitstable men to train some of his own men. The next year, Hall and London shared the diving work with some of Pasley's men. The third year saw the departure of the civilian divers back to Whitstable and the whole diving program was taken over by Pasley's newly-trained Sappers and Miners. Pasley had got what he wanted. By 1842 he had established a fully operational diving capability under his command in the Royal Engineers.

A milestone in the development of the diving helmet was set up on 26 June 1840 when the first Siebe "tight" diving dress (Figure 5) appeared on Pasley's ROYAL GEORGE operations.[25] The background to this event is important from the point of view of who should get credit for what. George Edwards, a noted civil engineer in charge of Lowestoft Harbour had purchased a Deane pattern open diving dress from Siebe in 1837. Edwards had disliked the tendency for water to enter the diving dress if the diver leaned forward so, in 1838, he came up with the idea to seal the helmet to the diving dress around the lower edge of the corselet. This he did using a "loose flange". He actually showed his idea to Siebe in London on 1 June 1838 and altruistically gave Siebe full and free use of the idea.[26] On 7 September 1838 Edwards asked Siebe to build him a diving helmet and dress incorporating his loose flange idea. Siebe said he would be happy to comply especially if Edwards could supply a full set of plans to "... save the expense and time of inventing".[27] In the end Edwards decided to have his first tight dress made in his home town of Lowestoft and he publicly demonstrated it on 15 March 1839 in Lowestoft Harbour. This was the fourth successful tight dress design to be produced.

About a year passed and Siebe was introduced to Pasley by George Hall, one of the Whitstable divers working on the ROYAL GEORGE. Siebe took the opportunity to suggest the tight dress design which Edwards had introduced the previous year. On 19 March 1840 the frugal Pasley gave the instruction that "The New Diving Dress not to be procured unless absolutely necessary. Estimate of Mr Siebe".[28] The big decision was eventually made and on 4 May 1840 the Storekeeper General placed the first order for a Siebe-manufactured tight diving dress which was delivered to Portsmouth on 26 June 1840.[29] Siebe's was therefore the fifth pattern of tight diving dress to be produced and certainly not the first, as was later claimed by his successors.

Figure 5. 1840, the new "tight" dress had a loose flange, designed by George Edwards, added to a Deane helmet manufactured by Augustus Siebe.

This first tight helmet from Siebe's manufactory at 5 Denmark Street in Soho, London, had been a one-piece arrangement. Siebe personally delivered his second tight helmet to Pasley in Portsmouth on 26 June 1840. Pasley noted in his diary "Mr Siebe arrives and brings with him his new diving dress of which the head unships".[30] This important design feature had been suggested to Siebe by Pasley and Siebe had been quick to take him up on it. The idea itself had of course originally been proposed back in 1823 in Charles Deane's smoke helmet patent specification.

At the close of 1840, Pasley produced an invaluable and detailed report describing the various diving suits used on the ROYAL GEORGE operations. After describing Siebe's tight dress he added "the details of this construction are not entirely Mr Siebe's invention, as he was assisted by Mr Edwards ... and part of it may also have been copied from other diving dresses ...".[32]

Siebe Gorman

After Siebe's death in 1872, his company was taken over by his son Henry and his son-in-law William Augustus Gorman. They moved to bigger premises and expanded the business. The company quickly consolidated itself as the world leader in diving equipment manufacturing. Part of this strategy was to promote themselves as the sole source of diving expertise and they set about removing the names of Deane and Edwards from their literature, substituting their founder, the late Augustus Siebe as the inventor of just about everything. This campaign was so successful that even today the popular opinion is that A Siebe invented the diving helmet and dress, and as early as 1819! Just about every encyclopaedia still carries this flawed version of the truth. Whoever said "Give a lie a good start and the truth will never catch up" knew what he was talking about.

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TUNA FARM DIVING IN SOUTH AUSTRALIA

David Doolette and Derek Craig

Key Words

Occupational diving, research, safety, training.

Abstract

Since 1990, in response to severe cuts in tuna catch quota, the South Australian tuna fishery has captured fish at sea, then fattened and harvested them at Port Lincoln. Divers are employed in all aspects of this tuna farming operation. In response to an alarming number of diving related injuries, a strategy designed to reduce the number and severity of accidents was implemented in 1995 by the South Australian Department for Industrial Affairs and WorkCover Corporation (the South Australian workers compensation authority) in collaboration with the Australian Tuna Boat Owners Association (representing the tuna farm owners). This strategy focused on raising diving safety to an acceptable occupational standard and resulted in a significant and almost immediate drop in the number of diving related accidents. A research project has been established at The University of Adelaide studying the nature and risk of decompression illness in this industry.

Tuna farming

In the early 1990s, in response to a 67% reduction in catch quota, the tuna fishing industry in Port Lincoln, South Australia began "farming" as a means of value adding to the fish. Through farming, tuna quality can be controlled and the Japanese sashimi market supplied on demand.

Each year, tuna are caught at sea in the Great Australian Bight and herded into semi-rigid tow cages. This cage is towed at approximately one knot towards Port Lincoln. A tow can last two or three weeks. The tuna are herded into stationary pens in the coastal waters near Port Lincoln. The tow cages and the pens are netted enclosures supported by circular pontoons. The tuna are fed on pilchards and during the next one to eight months the fish are carefully hand harvested so as to avoid damage to the flesh. Fish are slaughtered on site, then chilled and packed for shipping.

Tow cages, stationary pens and moorings are constructed, inspected and repaired by divers. Divers monitor the herding and feeding of the tuna and remove any dead fish from the enclosures. Occasionally sharks must also be removed. Divers and surface swimmers assist with the harvesting. The diving activities are relatively high risk.

Figure 1. Tuna pen in coastal water near Port Lincoln. The harvest net is being drawn in. Photograph by Derek Craig.

Dives are strenuous and often involve live boating and blue water diving. They may occur in adverse sea conditions and in conjunction with potentially dangerous equipment (nets, powerheads, cranes, suction pumps, high pressure jets). The divers are involved in repetitive and multi-day exposures.

Initially, the tuna farming process was developed by fishermen with little knowledge of safe working diving procedures who predominantly employed divers with recreational training. Work procedures were developed without due consideration being given to diving exposure, often resulting in provocative dive profiles with unnecessary multiple ascents. Despite the significant risk of entrapment working in contact with submerged nets, diver's air supply was often unreliable. Air was typically supplied from a petrol motor driven, low pressure compressor. Divers had neither secondary nor emergency (bail out) air supplies.

By early 1995, the Department for Industrial Affairs had raised concerns regarding diving operations with the tuna farming industry. WorkCover Corporation had received claims for 39 diving related injuries (at a total cost to date of over $Aust 1.5 million) and 17 divers had been treated for decompression illness (DCI) at the Hyperbaric Medicine Unit at the Royal Adelaide Hospital.

State government strategy

The Department for Industrial Affairs and WorkCover Corporation implemented a joint intervention strategy designed to improve tuna farm diving practice. The foundation of this strategy was to apply appropriate parts of the occupational diving standard (AS2299-1992) to tuna farm diving. Between February and December 1995 a series of on site audits of diving operations were conducted, training sessions were held for divers, supervisors and employers and assistance was given in developing safe operating procedures. With the co-operation of the employers, the Australian Tuna Boat Owners Association and the divers, the strategy produced a significant reduction in the number, severity and cost of injury claims. Despite the success of the strategy, the tragic diving death of a fisherman without diving training on a tuna farm in March 1996 served to highlight the disparity which continued to exist between the best and worst diving practices. In response the Government introduced the Approved Code of Practice for Tuna Farm Diving based on AS2299 - 1992 (gazetted 24 March 1997).

Since the implementation of the strategy and the introduction of the Code there has been an overall improvement in diving practice. All divers now have occupational training. Port Lincoln now has an occupational diver school accredited under the Australian Diver Accreditation Scheme. Divers use positive pressure full face masks, voice communications, surface supplied bottled gas with backup supply and bail out. Diving practices and equipment allow efficient diving procedures. For instance, a single diver with voice communication can direct the drying up of a net to allow harvest of fish from the surface. Many of the diving operations are now run very professionally and this is reflected in the recent safety performance.

Longitudinal health survey

Another strategy has been the introduction of a research project at the University of Adelaide, funded by WorkCover Corporation, investigating decompression risk and outcomes of tuna farm diving. One aspect of this research project is a longitudinal survey of the health of tuna farm divers. The objectives of this study are to collect objective diving exposure data and daily health data from tuna farm divers, to identify a decompression model that fits this data and to produce a computer-based decompression planning tool for tuna farm diving.

To collect diver health information and to identify DCI in the field, a psychometrically sound, self-administered brief health survey for daily use was needed. No such instrument has been reported in the literature so a single page, 10 item diver health survey has been developed. Seven items were developed from symptoms typical of DCI and from the prevalence of symptoms in those tuna farm divers presenting with DCI at the Royal Adelaide Hospital. Two items cover time of onset of any symptoms and general perception of health. Responses to each of these nine items is chosen from four semantic anchors representing scores of 0 through 3. One additional item supplies a brief history (name, date, number of dives, and hours since last dive) and there is space for unsolicited comments.

This diver health survey has now had extensive use in the tuna farming industry with over 250 surveys returned in 1997. Data is being collected to validate this survey including surveys completed by divers subsequently diagnosed with or without DCI at the Hyperbaric Medicine Units at the Royal Adelaide, Prince of Wales and Alfred Hospitals and surveys completed by non-diving tuna farm workers. So far, ten divers diagnosed with DCI have returned diver health surveys with a score of 10 ± 3 (mean $\pm$ SD) significantly different (t-test for independent samples, $p<0.0001$) from the first 100 tuna farm diver health surveys with a score of 3 ± 2 (mean $\pm$ SD), these latter presumably from divers without DCI. The area under the receiver operating characteristics curve (sensitivity versus 1-specificity) of this same data set is 0.97 indicating the diver health survey discriminates well between DCI and non-DCI; discriminating power improves as the area under the curve approaches unity. This curve also establishes the diver health survey cut-off score for DCI as 7.

Objective diving exposure data is obtained from dive depth/time profiles down loaded from diver decompression computers or recording watches. Diver heath surveys and dive profiles are managed using purpose designed database and analysis applications for reading dive profiles, matching health and exposure data, and analysis and reporting of probability of DCI. The probability of DCI is estimated using a linear-exponential kinetics (LE1) probabilistic decompression model[1] for initial feedback of higher risk (>0.01 probability of DCI) exposures to the tuna farming industry. The eventual aim of this study is identify a model of best fit to tuna farm diving exposure and health data using non-linear regression techniques.

Initial data collection from 17 divers occurred during 1997. Health surveys data and dive profiles were matched for 124 days of diving (187 dives). These included 67 single dive days and 57 repetitive dive days. 80% of exposures occurred in multi-day diving sequences of two to five days. The maximum depth of dives ranged from 3.7 to 22.4 m and total daily dive duration ranged from 4 to 190 minutes. All diving was within DCIEM air diving decompression limits. One dive resulted in serious DCI and retrieval to the Hyperbaric Medicine Unit at the Royal Adelaide Hospital. Four additional health surveys reported possible DCI (score ≥7).

The probability of DCI for all dives according to the LE1 model was 0.006 ± 0.003 (mean ± SD), 0.0006 - 0.0139 (range). Nine days exceeded 0.01 probability of DCI, all these were repetitive dives to 21 m. This prompted an examination of the probability of DCI for repetitive dive exposures (0.008 ± 0.002, mean ± SD) versus single dives (0.004 ± 0.002, mean ± SD); these were significantly different (t-test for independent samples, p <0.0001). However, this difference is apparently a result of deeper and longer diving exposure on repetitive dive days compared to single dives. On repetitive dive days the maximum depth of the deepest dive was 19.7 ± 2.9 m (mean ± SD), 10.7 - 22.4 m (range) and the combined time underwater was 44 ± 38 minutes (mean ± SD), 15 - 190 (range). In comparison, single dives were to a maximum depth of 17.5 ± 3.9 m (mean ± SD), 3.7 - 22.3 m (range) and dive duration was 33 ± 25 minutes (mean ± SD), 5 - 105 (range).

Summary

Tuna farm diving has evolved from an industry based on recreational divers to one based on occupational divers. The early experience of this industry with diver injuries illustrates the importance of adopting appropriate diving training and procedures. Historically, other fishing industries have experienced similar problems when developing diving capabilities. Future aquaculture industries, government and the diving community at large have a responsibility to break this cycle.

The longitudinal survey of health of tuna farm divers has developed instruments for diver health surveillance in aquaculture industries. These allow feedback to the tuna farm industry on the prevalent diving practices and outcomes and can be used to estimate the risks of tuna farm diving.

References

1 Thalmann ED, Parker EC, Survanshi SS and Weathersby PK. Improved probabilistic decompression model risk predictions using linear-exponential kinetics. *Undersea Hyperb.Med.* 1997; 24: 255-274.

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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

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

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

SCHOOL OF PUBLIC HEALTH AND TROPICAL MEDICINE JAMES COOK UNIVERSITY

COURSE IN DIVING AND MARINE MEDICINE

Tuesday 5th to Friday 8th of October 1999

For further details contact

Professor Peter Leggatt
School of Public Health and Tropical Medicine
James Cook University
Townsville
Queensland 4811

Telephone 07-4722-5700

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

July 1999

Unit 1	5/7/99	to	9/7/99
Unit 2	12/7/99	to	16/7/99
Unit 3	19/7/99	to	23/7/99

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)

July 1999
12/7/99 to 16/7/99

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
Adelaide, South Australia, 5000.

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

GLEANINGS FROM MEDICAL JOURNALS

SUBMARINE RESCUE

A decision aid for optimizing survival in a disabled submarine.

Wray DD, Francis TJR, Ryder SJ and Kargher RS. *Undersea Hyperbaric Med* 1998; 25 (Suppl): 41

Abstract

Background

Should a submarine become unable to surface under its own power, the crew are likely to spend a period of time in the boat before either having to make an escape to the surface or being rescued by another submersible. During this time they will endeavour to survive and maintain a breathable atmosphere with limited resources. The senior survivor will have to manage numerous tasks and solve many complex calculations at a time when he and his crew are under considerable psychological and physiological stress. The existing guidance on how to manage this situation is disseminated in a number of reference books.

Method

A computer program called SEAREX has been written in visual basic, to run on any PC running Microsoft Windows® 95™ and Microsoft® Internet Explorer. For each task which needs to be undertaken a determination has been made of the time the task will take to complete and the window in which this should occur. The program displays a "to do" list of the outstanding tasks as icons arranged in order of their urgency and impact on survival using a traffic light colour coding system. Tasks which are overdue are coloured red, those which need to be undertaken now are yellow and those which will need to be done shortly are coloured green. Routines are built in which request data and undertake repeated calculations to estimate the time before an escape needs to be undertaken. Other routines include those for maintaining the atmosphere, operating the escape trunk and scheduling the issue of food and water. Past readings and predictions of the submarine atmosphere composition are displayed as graphs. "Help" screens displaying current guidance are available in both a context-sensitive manner and as electronic, hypertext indexed reference manuals which can be accessed via the menu bar. Although the program is robust, it autosaves every five minutes to enable recovery should it crash.

Conclusion

Although formal field testing of the prototype program has yet to be undertaken, those who have tested the program have found the interface simple to use and the advice useful. The program format may be applicable to the management of other uncommon emergencies.

From

Naval Submarine Medical Research Laboratory, Groton, Connecticut 06349-5900 and Naval Undersea Warfare Center, Newport, Rhode Island 028481-1708, USA.

Key Words

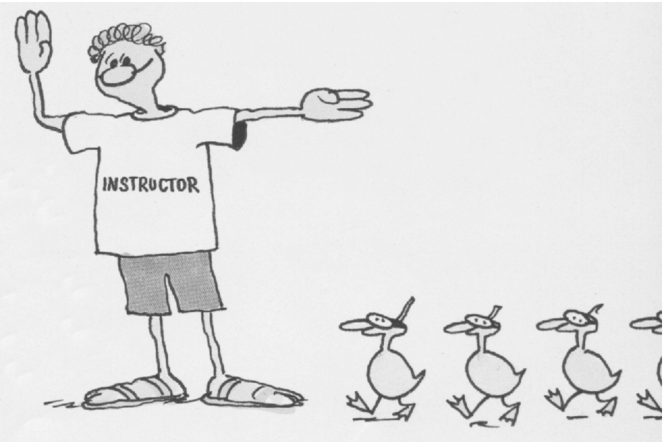
Rescue

THE SEA PEOPLE'S GUIDE TO DIVERS PART FIVE

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...

Thanks to the kindness of Rico, the cartoonist, and of Bernard Eaton, the Editor of DIVER, who have agreed to allow this series of typical divers to be reproduced in the SPUMS Journal. Although the featured diver types originated in the UK, we believe that most of them, at one time or another, have attended a SPUMS Annual Scientific Conference.



Plankton-Herder

The Plankton-Herder holds high rank in diving society; it is his noble office, also referred to as Training Officer, to oversee the myriad legions of hapless, floating novice divers. Blown like plankton by, the winds and the tides, these innocent larvae could fall victim to so many unheeding forces that without his vigilance many would not reach maturity. He is a matchmaker who many experienced divers avoid at buddy-up time. He arrives, a mother duck with his waddling charges, anxious to pair his fledglings with a caring foster-diver. He quickly learns to avoid the metal collectors and the Mayday Drifters, and usually ends up with the Moss Bros. This questionable solution to his problem often sees many a novice giving up in the despairing belief that all there is to diving is bladder wrack and *Eliminius modestus*.

Shoal Shepherd

In rank the Plankton-Herder is exceeded only by the Shoal Shepherd, the vessel of all the woes and responsibilities of the Branch. It is said that sharks can sense anxiety underwater. If this is so, the average great white could pick up a Diving Officer from a range of several miles on the worry-band. The DO must have the discipline of military office, tempered with the patience of a disaster counsellor. He must have the luck of Flash Gordon, the innovative flair of Batman, and the approachability of Mr Blobby. Without him, total anarchy would rule the diving fraternity, as opposed to the loosely bridled anarchy he helps to maintain. His heaviest burden is his ball and chain of example. While ordinary mortal divers need only thinly disguise their lifelong affair with disaster, the DO must be an unwavering moral model for the legions of loose cannons who litter the decks of the average dive club. One wrong step and his character is sullied for life. We must save for him our biggest salute, for in the example of his selfless responsibility lies the hope of Sea People in every ocean.

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