causes of accidents could be better identified, and diving safety would be enhanced.

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TRIAL OF IN-WATER OXYGEN RECOMPRESSION THERAPY IN ANTARCTICA

Peter Sullivan and Attila Vrana

Abstract

In recent years the Australian National Antarctic Research Expeditions have carried out several extensive diving programs in Antarctica. As access to a recompression chamber in this situation is usually impossible, a case of decompression sickness would present a major therapeutic problem. It has been suggested that, despite the extremely cold conditions, the technique of emergency recompression in water, using oxygen, may be applicable even in Antarctic waters. This paper presents the results of thermal monitoring carried out during two simulations of the technique under actual Antarctic conditions. The first trial had to be aborted after 90 minutes when one subject sustained a significant drop in his core temperature. In the second trial a heavier subject was able to maintain an acceptable rectal temperature for the entire 2 hours 36 minutes duration. From this it is concluded that, using current diving equipment, the technique cannot be adequately relied upon for the treatment of decompression sickness. For the technique to be safely used, even better thermal insulation than that currently in use would have to be employed.

Introduction

The concept of using oxygen underwater for the emergency treatment of decompression sickness in remote areas was first suggested by Edmonds in the early 1970's, although not published until 1976.[1] It was devised as the result of a number of cases of decompression sickness occurring in extremely isolated areas of the south-western Pacific, where evacuation to a recompression chamber would have involved a delay of many hours or even days. Originally, it was hoped that this technique would prove adequate for the treatment of minor cases, and prevent deterioration in serious cases until suitable transport could be arranged. Not only was it successful in these aims but, in a number of cases of neurological decompression sickness, the procedure resulted in dramatic improvement and even cure. Indeed, the technique has proven so effective that it has been approved, although only for emergency use in areas remote from a chamber, by the Royal Australian Navy[2] and in the 1979 Australian Diving Standards (AS 2299).[3] In recent years, the United States Navy approved a modified version of oxygen in-water recompression therapy, but only as an option of last resort.[4] At the Twentieth Undersea Medical Society Workshop on the Treatment of Decompression Sickness members concluded that while they could not recommend the widespread use of underwater oxygen treatment, they did note: "In remote conditions, with expert and experienced personnel, and when procedures have been fully planned and the proper equipment is at hand, workshop members recognize that the technique has value".[5]

Over the last decade the Australian National Antarctic Research Expeditions (ANARE) have carried out several extensive diving programs, particularly at Davis Station, Antarctica. This surely must be one of the most isolated dive locations in the world, located as it is some 220 km below the Antarctic Circle, cut off from shipping by sea-ice for nine months of the year, and lacking facilities for air transport. In the absence of a recompression chamber the dive team was acutely aware of the need for safe diving procedures. The dive tables (1972 RNPL/BS-AC) were modified accordingly by adding extra increments to both depth and time, and no dives requiring decompression were permitted. Even so, the possibility of decompression sickness could not be entirely excluded and the options for treating such a case had to be considered. One such option was the use of in-water oxygen recompression therapy.

Since this therapy takes between two and three hours (depending on the severity of the case and the rate of improvement), cold water is usually considered a contra-indication to the use of underwater oxygen therapy.[6] Even in the tropical waters of Central Queensland, one such treatment had to be abandoned when the patient reported that he was becoming too cold and insisted on terminating the dive.

In the summer of 1981/82 Carl Edmonds carried out a trial of the oxygen underwater equipment at Davis Station. One diver acted as the stationary "patient" and wore a dry suit, albeit an ill-fitting one, while the other wore a 9 mm wet suit and was free to swim about.

Neither diver was monitored and thermal stress was assessed purely on subjective grounds. The trial was terminated after 1 hour 15 minutes when the "patient" started to shiver and complained of feeling cold. Despite this result, Edmonds concluded that the underwater oxygen system could be employed in the Antarctic, provided that better thermal protection was used, such as a thin neoprene wet suit under a dry suit.[7]

The 1985 diving program was carried out on a considerably more sophisticated level: all members of the six-man dive team wore custom made dry suits and band masks; breathing gas was supplied from an air-bank kept in the warmed rear-section of one of the vehicles; and dives were carried out from a heated dive shelter (Figure 1).

In addition, real-time monitoring of both rectal and skin temperatures was able to be conducted. It was felt that, using this equipment, it might be possible toconduct a trial of a full underwater oxygen recompression therapy safely . Certainly we wished to carry out a monitored trial of the procedure rather than being forced to attempt it for the first time with a genuine case of decompression sickness.

Materials and methods

The technique of underwater oxygen therapy is as follows: the patient is lowered along a shot line to 9 m, breathing 100% oxygen from a surface supply. For comfort he should be slightly overweighted and resting in a harness or sling. Ascent is commenced after 30 minutes in mild cases, or 60 minutes in severe cases, if significant improvement has occurred. These times may be extended for another 30 minutes if no improvement has occurred. The ascent is made in steps of 1 m every 12 minutes. The patient should always wear a full face mask and must be accompanied by another diver at all times.

For the purposes of this trial the intermediate therapeutic profile was chosen,1 hour at 9 m and an ascent taking a further 1 hour 36 minutes. Although the risk of cerebral oxygen toxicity is minimal at this depth, for reasons of both safety and ease of implementation the trial was conducted using air rather than oxygen. It is considered that the difference in the thermal conductivity of the two gases would have no significant effect on the respiratory heat loss. However, the dive panel did have provision for a separate oxygen supply to the "patient", if required.

The anthropometric characteristics of the two divers who carried out the trials are listed in Table 1. The estimate of Mean Weighted Skinfold Thickness (MWST) was based on the work of Edwards,[8-9] such that:

$$MWST = 0.2_{\text{Biceps}} + 0.2_{\text{Triceps}} + 0.35_{\text{Subscapular}} + 0.25_{\text{Suprailiac}}.$$

Body surface area was estimated according to DuBois and DuBois[10] and percentage body fat was as calculated by Durnin and Womersley.[11]

Subject 1 had carried out 54 Antarctic dives within the previous year and Subject 2 had performed 24. Even if acclimatization to cold in Antarctic divers does occur (and there is some evidence to suggest that it does not [12]), it would appear unlikely to have contributed to any significant difference between the two divers.

Both divers wore the following: polypropylene underwear (which carried the thermistor leads in specially sewn-in channels), 3 mm (1/8") Thinsulite™ undergarments and boots, dry suits (CF200X, Diving Unlimited International Inc., San Diego, California), band masks (Kirby-Morgan), and three-fingered 6 mm (1/4") neoprene mitts. In each mitt were two 10 g magnesium-iron heat-bags. When working properly these bags generate heat by the exothermic reaction of the two metals in salt water.[13] However, in our experience their performance was quite variable. The band masks not only fulfilled the requirement for a full-face mask but also allowed for verbal communications throughout both trials.

The trial dives were carried out approximately 1 km

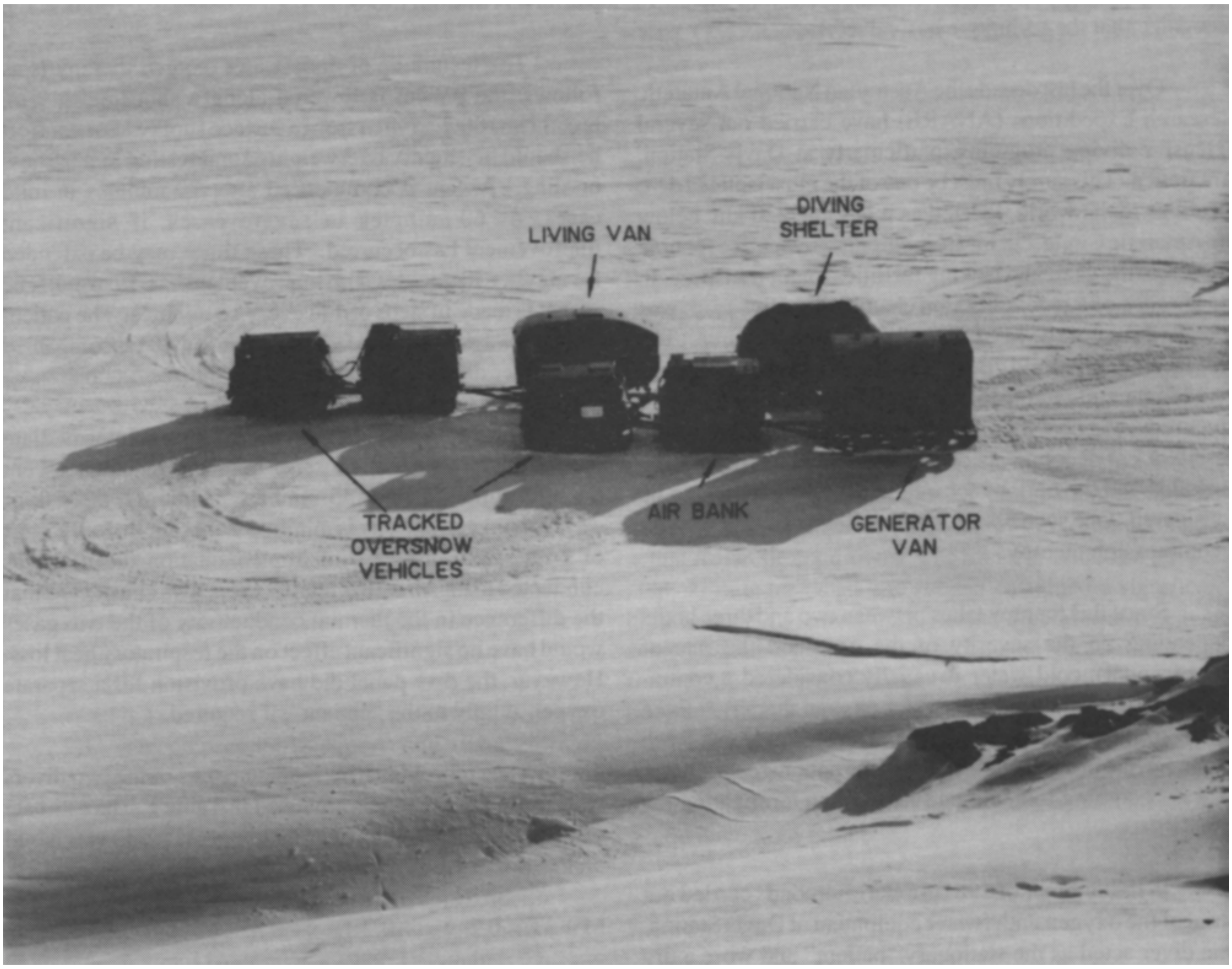

Figure 1. Diving convoy on the sea-ice in Antarctica.

TABLE 1

ANTHROPOMETRIC CHARACTERISTICS OF EXPERIMENTAL SUBJECTS

Subject	Age (years)	Height (cm)	Weight (kg)	MWST (mm)	Surface area (m^2)	Body fat (%)
1	30	178	70.1	7.4	1.87	15.6
2	42	189	92.5	9.0	2.20	21.0

from Davis Station in some 10 m of seawater. The sea-ice was 170 cm thick, enabling the warmed dive shelter to be parked directly over the dive-hole. The temperature of the seawater at the time of both trials was -1.4 °C.

Both subjects were instrumented with eight skin thermistors (YSI 409B, Yellow Springs Instrument Co., Yellow Springs, OH.) and a rectal probe (YSI 401) inserted 10 cm. Information from each of these thermistors (plus ECG and voice communication) was transferred via a 20-wire cable in the umbilical to the dive shelter. There the results were recorded every minute on a datalogger and transferred to a microcomputer. Scaled data were displayed on a video screen and printed out after each scan. The selection of thermistor sites was as per Adolfson, Sperling and Gustavsson.[14] (Figure 2).

Mean skin temperature (Tsk) was calculated as

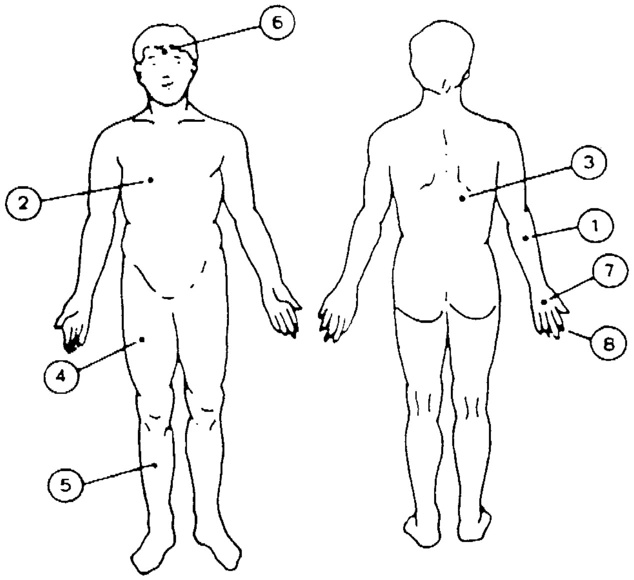

Figure 2. Thermistor locations

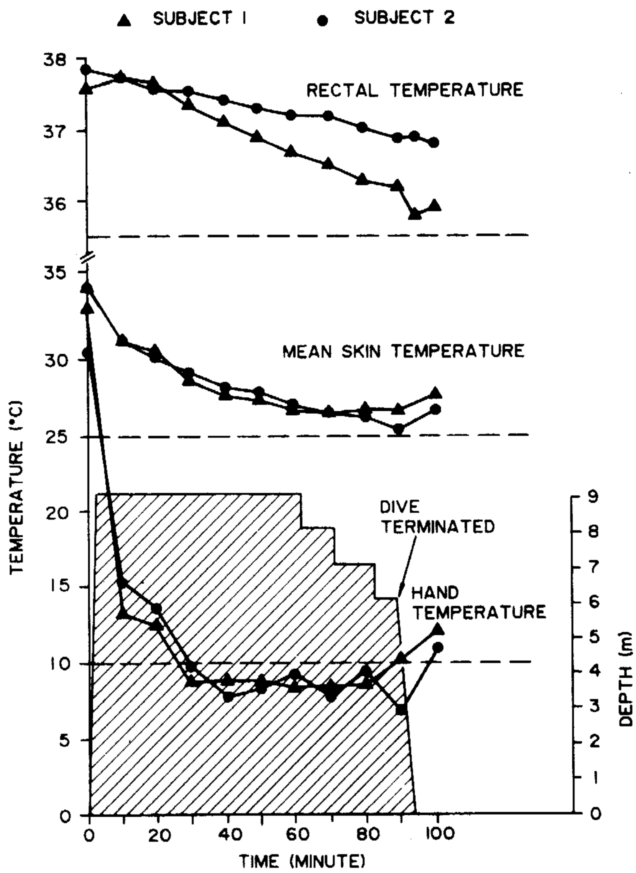

Figure 3. Trial 1 of oxygen in-water recompression therapy. The shaded area indicates the dive profile. The dotted lines indicate the UEG minimum acceptable temperatures. Subject 1 was the stationary "patient". The trial was aborted because of the fall in his rectal temperature.

follows:

$Tsk = 0.07\ T_6 + 0.175\ (T_2 + T_3\ + 0.05\ T_7 + 0.14\ T_1 + 0.19\ T_4 + 0.2\ T_5$. Mean hand temperature was calculated as the mean of T_7 and T_8.

For the trial to be considered successful it was intended that the "patient" should not only remain moderately comfortable throughout the full 2 hour 36 minutes of the treatment table, but that his thermal parameters should be within the limits established by the CIRIA/ UEG group.[15]

a Deep body core temperature should not fall below 35.5 °C.

b Mean skin and local head temperature should not fall below 25 °C with no local measurement below 20 °C except for hands and feet which should be maintained above 15 °C (for useful work in the fingers) and above 10 °C to prevent pain and possible cold injury over long dives.

Results

TRIAL ONE

In the first trial the smaller diver, Subject 1, acted as the stationary "patient" and Subject 2 was his attendant, maintaining the same depth but free to swim about. Both subjects started with a slightly elevated rectal temperature as a result of wearing their dry suits for some time inside the warmed dive shelter. Subject 1's rectal temperature fell steadily from the startt of the dive. After 90 minutes it seemed highly unlikely that he would be able to maintain a rectal temperature above 35.5 °C for the required 2 hours 36 minutes, so the trial was aborted. On leaving the water his rectal temperature suddenly dropped over a 2 min period from 36.2 °C to 35.8 °C, the familiar "after-drop" effect.

Subject 2 reported much less thermal discomfort and his rectal temperature demonstrated a much slower fall (Figure 3). Even after 90 minutes his core temperature had only fallen by 0.5 °C.

In spite of the difference in rectal temperature, both subjects maintained a very similar mean skin temperature, just above the minimum acceptable level. However, there was one noteworthy difference; after the first few minutes Subject 1 had a shin thermistor reading about 6 °C lower than Subject 2. This resulted from the stationary "patient," Subject 1, maintaining a vertical position with subsequent leg squeeze, while his attendant, Subject 2, swam about horizontally.

Despite the exothermic heat-bags the mean hand temperature of both subjects fell below the recommended minimum (10 °C) within 30 minutes of commencing the

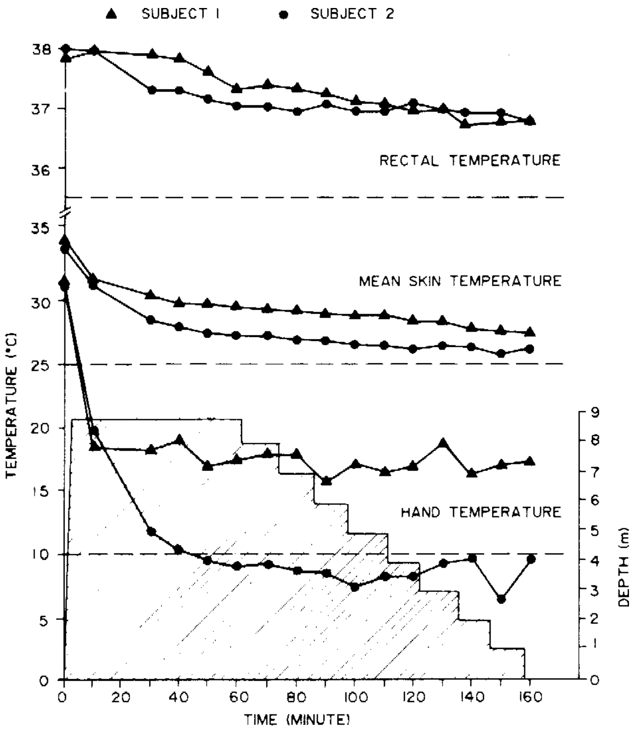

Figure 4. Trial 2 of oxygen in-water recompression therapy. The shaded area indicates the dive profile. The dotted lines indicate the UEG minimum acceptable temperatures. This time subject 2 was the stationary "patient" and maintained an acceptable rectal temperature. Data for the twenty minute mark is missing because of a temporary malfunction in the monitoring equipment.

dive.

TRIAL TWO

In the second trial it was the heavier diver, Subject 2, who took the role of the stationary "patient". As shown in Figure 4, he sustained a drop in rectal temperature of 0.8 °C during the first 30 minutes. From then on he was able to stabilise his core temperature at around 37.0 °C for the remaining 2 hours of the trial. Though not actually distressed by the cold he reported that it could not be considered as a particularly comfortable dive.

The attendant, Subject 1, was free to swim about and did so whenever he felt himself becoming cold. As a result he also was able to maintain an acceptable rectal temperature and fared much better than he had done on the first trial.

Again, both subjects were able to maintain a mean skin temperature above the recommended limit. However, unlike the first trial, where both subjects had very similar mean skin temperatures, this time Subject 1 consistently had a skin temperature 2-3 °C above that of Subject 2. This was partly a result of his considerably warmer hand temperature, and partly because, once again, the horizontal attendant had a significantly higher (8 °C) shin reading than did the vertical "patient".

Subject 2's decline in hand temperature followed much the same pattern as it did in Trial 1, and after approximately 40 minutes fell below 10 °C. However, neither on this dive, nor on any of the 150 other dives which were carried out during the year was there any evidence of non-freezing cold injury to the hands. Interestingly, Subject 1's right hand remained comparatively warm, about 17 °C, apparently because on this occasion the exothermic heat-bags worked adequately.

Discussion

It is not surprising to find that it was the heavier "patient" who was able to maintain an acceptable rectal temperature for 2.5 hours, while the thinner diver sustained a significant drop in his core temperature when in the "patient" role. This only confirms the importance of the insulating role of subcutaneous fat previously demonstrated by Keatinge, Webb and others.[16-17]

Also, the results of these two trials confirm the view expressed by Hayes[8] that a diver working in sub-zero water will need insulation of about 2 togs (1.3 Clo) to maintain comfort, (a solid neoprene dry suit with Thinsulite undergarments has an insulation value of 1.9 togs in water), but that once he stops working the requirement rapidly exceeds 4-5 togs.

One final point to consider is that in both trials the subjects were normothermic at the start of the "treatment". However, in a real-life situation it is quite possible that the dive which "bent" the diver might also have rendered him somewhat hypothermic.

Remembering that symptoms of decompression sickness often present within one hour of surfacing it is likely that the victim may not be adequately rewarmed at a time when the diving physician is considering subjecting him to a further 2 to 3 hours of immersion in sub-zero water. Ascertaining the patient's core temperature would be essential before even contemplating the use of in-water oxygen therapy in such conditions.

While it would be unwise to extrapolate too far on the basis of only two trials, these simulations of the underwater oxygen recompression technique demonstrate that, even using some of the best passive thermal protection equipment currently on the market, there still remain major problems concerning the risk of hypothermia and local cold injury. Although one large diver was able to undergo a full 2.5 hour "treatment", a smaller, indeed average sized, diver demonstrated a significant drop in core temperature after only 90 minutes and the "treatment" had to be abandoned. Therefore, the technique cannot be considered sufficiently reliable in such cold waters and a proper recompression facility should be provided for all future large-scale Antarctic diving programs.

Despite the above comments, in an extreme emergency, where access to a chamber is impossible, underwater oxygen recompression might still be worth attempting, especially if diver monitoring is available to increase the safety of the procedure. For even though a full 2 or 3 hour therapeutic profile may not be possible, it appears that at least an hour of oxygen at 2 ATA could normally be safely delivered and might well prove to be of considerable value.

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Keywords

Cold, diver monitoring, decompression sickness, recompression, hyperbaric oxygenation, skin temperature.

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CLINICAL REVIEW ROYAL ADELAIDE HOSPITAL HYPERBARIC MEDICINE UNIT 1990

Chris Acott

Introduction

Since its inception in 1986 the Royal Adelaide Hospital (RAH) Hyperbaric Medicine Unit has had a steady clinical work load (Table 1).

During 1990 the medical staff of the Unit was a full-time Director, four Specialists, a part-time General Practi-