DECOMPRESSION METERS
PHILOSOPHICAL AND OTHER OBJECTIONS

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The use of decompression meters (DCMs) is not new, and has involved a wide range of apparatus, from mechanical to electronic, and both diver-worn and remote. The Canadian Defence and Civil Institute of Environmental Medicine surface-based decompression computer represents one extreme of this development and has proved useful. However, the active marketing of a new range (not "new-generation" as is claimed) of diver-worn DCMs requires that the case against such devices be stated again.

Multi-level Diving

A major advantage claimed for DCMs is that they account for the multi-level nature of most recreational diving. Consequently, a DCM will "permit" a longer exposure to pressure, for a given multi-level dive, than that allowed by the traditional use of the same decompression schedule (which assumes that the entire exposure was at the maximum depth).

The number of cases of Decompression Sickness (DCS) presenting for treatment in Australia and New Zealand has increased since 1980 and has shown an alarming predominance of nervous symptom involvement. These episodes of neurological DCS often arise after dives that either were conducted in accordance with conventional tables (with and without fudging), or were within no-decompression limits (despite being multi-level).

Based on current treatment rates it is anticipated that in 1987 between 300 and 400 divers will be treated for DCS in Australasia. While this does not establish that the disease rate (eg. DCS/1000 diving hours) has increased, it is clear that the diving practice of the recreational diving community needs to become more conservative. This recommendation for safer diving is not consistent with the increased exposure possible with DCM-controlled multi-level diving.

Measurement of Exposure

While the marketing information released with each new batch of DCMs declares the arrival of a "new generation" of devices, this is simply not true. All devices that have been sold, and are about to be sold, measure depth and time, and not tissue nitrogen tensions. What does change with each new model is how the information is manipulated and presented. The expected body-tissue nitrogen tensions are calculated from this input, using one or more mathematical models. In general, these models are perfusion-based and do not account for the diffusion limits of intracellular fluid. Whatever the basis of calculation, it is important to understand that the kinetics of inert gas uptake and elimination have not been accurately described. Not surprisingly then, the accuracy of calculated tissue nitrogen tensions using these available mathematical models of decompression is quite poor.

This intrinsic inaccuracy of decompression models, and hence of DCMs, will remain until a DCM can directly measure an individual's tissue nitrogen tension (eg. using transcutaneous or implanted electrodes). Such a DCM would only then be a "new generation" device.

Electronic Reliability

An absolutely reliable electronic instrument has not and never will be built. Trials with all available DCMs have shown a real, although often small, failure rate (including total display loss). Obviously electronic diver-worn DCMs can never be used in isolation. Divers using DCMs should always carry and use a hard copy of suitable decompression tables.

Summary

Although DCMs are simple to use and account for multi-level diving, it is not possible to support or advocate total reliance on them. They may have a useful role in diving, but only in conjunction with a careful dive plan and concurrent use of a hard copy of decompression tables.

ASSESSMENT OF THE ORCA EDGE DIVE COMPUTER

Carl Edmonds and Tim Anderson

INTRODUCTION

The Royal Australian Navy School of Underwater Medicine first became interested in decompression meters used by divers during 1972. Many patients sought treatment for decompression sickness, following the use of the SOS decompression meter. A study of this meter showed that it indicated shorter decompression times than required by the US Navy decompression tables when used for repetitive dives, and for dives in excess of 60ft.[1] The Farrallon Multi-Tissue Decomputer was also studied[2] but was unacceptable because of its unreliability. The DECO-BRAIN suffered a similar fate when tested, approximately two years ago.

The senior author was involved in the treatment of a diver in 1986 who used an Orca EDGE for two dives to 87ft, after which she developed decompression sickness. It appeared that the meter had allowed a dive combination that would not be permitted by the US Navy tables. There were several possible explanations of this decompression incident: a chance occurrence because of the fallibility of the decompression tables, a misreading of the meter, a fault within the meter itself, or the meter programme permitted unsafe diving profiles.

It was against this background that it was decided to test the EDGE decompression meter's no-decompression repetitive dives and compare these with the established decompression tables.

PROMOTIONAL MATERIAL

The literature which accompanies the Orca EDGE meter makes the following statements:

> The dive computer is a compact submersible computer which gives information needed to plan dives and avoid bends. It is also a precision depth gauge, dive timer and surface interval timer. It takes care of repetitive as well as single dives.
>
> The programme provides a safer dive than the US Navy tables, while providing more dive time for Multi-Level dives. It makes allowance for altitude exposure, and is functional over a wide range of water temperatures.
>
> The US Navy tables were designed for single depth dives. Divers are required to use the maximum depth of any dive profile to calculate the decompression, as if the entire dive had occurred at that maximum depth. Many divers feel that they are penalised and limited by this procedure since they do not spend all the time at the deepest depth.
>
> The EDGE accounts for the absorption of less nitrogen at shallower depths, and typically divers using the EDGE get double the time allowed by the US Navy tables.
>
> Divers have sought new procedures for interpreting the US Navy dive tables to allow longer bottom times. The interpretations that gained the most acceptance in the diving community are Multi-Level dive procedures.
>
> Some diving authorities indicate that these or similar procedures have been tested and used in commercial or oil field diving, although little published data is available. Many hyperbaric physicians feel that the concept is valid and safe, if specific precautions are followed.
>
> The decompression calculations used in the meter are based on Multi-Level diving techniques adapted from the US Navy no-decompression tables, and the shorter no-decompression limits developed by Dr Merrill Spencer.
>
> The dive computer calculates divers' tissue and decompression status of 12 different tissue groups ranging from half times of 5 minutes to 480 minutes. At the present time, the EDGE is the best solution to decompression problems, providing long bottom times along with excellent safety.

Other claims made on behalf of the meter are worth of note.

The manufacturers claimed to have carried out a study to examine the effects of Multi-Level dives allowed by the EDGE decompression meter on human subjects. The results were said to have shown that the profiles tested were safe to all the divers exposed. The work referred to was presumably that supplied by the manufacturers in a paper entitled "Doppler Evaluation of Multi-Level Dive Profiles" by Carl E Huggins.[4] Doubts expressed by the same author, regarding the safety of multi-level diving were not reflected in the promotional material, even though this paper is quoted in the references.

It is stated in the manual that the EDGE is not a guarantee of avoiding the bends. It is claimed that the experience from thousands of dives indicates that the EDGE is a better bet than the US Navy tables. It is said that until August 1984, no cases of bends had been reported. The manual has been modified since then, but this quotation remains despite the manufacturers being aware of such cases.

A comparison of the no-decompression limits with both the US Navy tables and the Royal Navy tables at the end of the manual infer that the EDGE is more conservative or "safer" than the US Navy tables at all depths from 30-140ft. On the same page, a comparison of selected depths in metres shows the EDGE to be equal or more conservative than the Royal Navy no-decompression limits at all depths.

In the Questions and Answers section, the manufacturers suggest that it is a good idea for sport divers to add extra safety factors, eg. not getting closer than 5 or 10 minutes to no-decompression limits. This would presumably exclude all no-decompression dives in excess of 120ft, although the manufacturers do not draw this conclusion from their advice.

The brochure stresses the importance of dive planning, wearing back-up depth and time measuring devices and regular confirmations of the calibrations. There is a very clear disclaimer, without limitation, exonerating both the seller and the manufacturer from any liability for personal injury resulting from the use of EDGE.

Popular skindiving magazines, both in articles and by advertising, have supported the promotion of the EDGE. In 1985, Murphy[6] stated that the computer programme is based on entirely new technology. The article claims that "those who use on swear by it and the instrument's safety record is impressive". It quotes Dr Bruce Bassett as describing the EDGE as a "revolutionary electronic device that may change the destiny of divers". These authors would not contest the claim, but would point out that it is ambiguous.

There is some difference of opinion in the claims made for the EDGE software. Murphy states that "one thing that has not changed over the years is the software computer programme contained in the EDGE". In the documentation obtained from the manufacturer, it was clearly stated that those instruments shipped after 1 September 1986 have improved software called "Div 4", which gives a modified rate of ascent indicator plus two other small changes. The ascent rates now recommended are:

> 60ft (18m) per minute in the >120 ft (36m) range
> 40ft (12m) per minute in the 60-120ft (18-36m) range
> 20ft (6m) per minute in the 0-60ft (0-18m) range.

The temperature reading was converted to Fahrenheit rather than Celsius, and the limits of the slowest tissues were increased slightly.

In 1987, the Australian diving newsletter *In Depth*, in articles by Harper and Latimer, extolled the virtues of the meters and a report in *Undercurrent* [7] is complimentary to the EDGE. Like the other magazines, the support is made without recording any specific testing of dive profiles.

METHODS

The depth function of the meters was compared to the gauge readings on the main therapeutic recompression chamber. Agreement was within the claimed errors of the gauges. The clock function of the meters was checked against the Telecom time signal and found to be accurate (no errors were detected over a three hour period).

For all the following tests, the meter's depth readings and timings were used by the operators controlling the chamber, with the chamber's gauge and a chronometer as a check. No discrepancies in these functions were observed.

Four EDGE "dive computers" were available for assessment. These were:

Number 1452. This equipment had been used for many months, had shown no mechanical problems, and was regarded with high esteem by its owner. It had been used during a dive in which a diver had developed decompression sickness and required recompression therapy.

Numbers 4167 and 4170 were new and supplied direct from a potential Australian distributor.

Number 0085. This was an Orca EDGE decompression meter simulator. It allows a simulation of dives, without the necessity of a compression chamber and was found to accurately simulate the readings observed on the meters tested.

As an additional check, the three dive meters were subjected to the same hyperbaric exposure, and comparisons were made between the readings of maximum depth, dive time and no-decompression time, surface interval and the scrolling depth and time allowed for repetitive dives. As well as this, in the first series of dives, one of the meters was placed in an ice water bath before the hyperbaric exposure.

All the dives were carried out in a compression chamber, with direct observation by two or more researchers.

It was decided to restrict the dives to no-decompression exposures, and always to commence the ascent prior to the expiry of the no-decompression, as shown on the meter.

The descent rates were kept at 18m (60ft) per minute and the ascent rates were in accordance with the new, modified ascent recommended by the manufacturer as described above.

The depths chosen in the first series were constant, ie. there was no variation in the depth between the first and subsequent dives. The three depths chosen for testing were: 17m (56ft), 31m (102ft), and 43m (141ft), ie. depths halfway between table depths used in the RNPL/BSAC tables, in an attempt to reduce the bias in either direction.

The second series included repetitive dives to different depths.

The third series involved multi-level diving, ie. staying at different depths during the same dive. This duplicated the repetitive dive profile that caused decompression sickness in a diver, and led to the initiation of the project.

NONE of the dives tested required decompression according to the meter.

RESULTS

DIVE PARAMETERS

Dive parameters, including depths, maximum depth, durations, surface intervals and temperatures, were recorded accurately. No significant discrepancies between meters were observed.

SINGLE DEPTH DIVE

The no-decompression times permitted by the meters were compared to those depicted in the manual and seen during the "scrolling" of the meter on the surface. Only small discrepancies were noted.

Although the manual states that at 60ft the no-decompression time is 53 minutes, in practice it is 54. At 90ft it is stated to be 24 minutes, in practice it is over 25. At 120ft the no-decompression time is stated to be 11 minutes, whereas in practice it was 12. At 140ft the no-decompression time was stated to be seven minutes, whereas in practice it was nine. At 150ft, the no-decompression time was said to be seven minutes; in practice it was over eight.

REPETITIVE DIVES TO THE SAME DEPTH

Ten repetitive dive combinations were performed without requiring decompression according to the EDGE meter. These are reproduced as tables 1, 2 and 3.

In all the repetitive dive series performed above, decompression was omitted with the use of the EDGE meter, compared to the US Navy and RNPL/BSAC tables. However, in comparing the omitted decompression from both US Navy and RNPL/BSAC tables, two minutes extra decompression could be credited to the EDGE for each dive to make allowance for the slower ascent rate at the shallower depths. If this is done, the results are as follows:

> In the repetitive dive series to 17m (56ft) there was omitted decompression of between 10 and 46 minutes (US Navy) and between 66 and 302 minutes (RNPL/BSAC).

TABLE ONE - REPETITIVE 17M (56 FT) DIVES

DIVE NUMBER	BOTTOM TIME	SURFACE INTERVAL	OMITTED DECOMPRESSION STOPS US NAVY	RNPL/BSAC*
1a	60 mins	60 mins	0	10 mins
2a	45 mins	11 mins	14 mins	90 mins
3a	8 mins		26 mins	90 mins
1b	60 mins	120 mins	0	10 mins
2b	56 mins		14 mins	60 mins
1c	60 mins	60 mins	0	10 mins
2c	45 mins	11 mins	14 mins	90 mins
3c	8 mins	120 mins	26 mins	90 mins
4c	41 mins		14 mins	120 mins

* BSAC 18m table was used until the maximum tabulated bottom time was exceeded, then RNPL 20m table was used.

TABLE TWO - REPETITIVE 31M (102 FT) DIVES

DIVE NUMBER	BOTTOM TIME	SURFACE INTERVAL	OMITTED DECOMPRESSION STOPS US NAVY	RNPL/BSAC*
1a	17 mins	300 mins	0	0
2a	17 mins		3 mins	10 mins
1b	17 mins	120 mins	0	0
2b	17 mins	277 mins	7 mins	15 mins
3b	17 mine		7 mins	115 mins
1c	17 mins	60 mins	0	
2c	17 mins	37 mins	23 mins	30 mins
3c	15 mins	134 mins	54 mins	105 mins
4c **	17 mins		34 mins	155 mins
1d	18 mins	30 mins	0	0
2d	16 mins	30 mins	23 mins	30 mins
3d	13 mins	30 mins	54 mins	105 mins
4d	11 mins	30 mins	54 mins	125 mins
5d	8 mins		54 mins	155 mins

* BSAC 32m table was used until the maximum tabulated bottom time was exceeded, then RNPL 35m table was used.

In the repetitive dive series to 31 m (102ft) there was omitted decompression of between -1 and 175 minutes (US Navy) and between 6 and 315 minutes (RNPL/ BSAC).

In the repetitive dive series to 43m (141 ft) there was omitted decompression of between 20 and 275 minutes (US Navy) and between 112 minutes and "off the page" (RNPL/ BSAC).

REPETITIVE DIVES TO DIFFERENT DEPTHS

Repetitive dive combinations were performed which did not require decompression, according the EDGE meter. These are displayed in table 4 (page 125). Omitted decompression in this series was considerable, and far in excess of that which could be credited because of the slower ascent rate of the EDGE.

Table 5 shows an empirically unacceptable repetitive diving combination, which can be performed without any decompression according to the EDGE meter. The combination of dives would have required 100 minutes of decompression (including ascent times) according to the US Navy tables and over five hours according to the Royal Navy tables.

To avoid the safety factors inherent in "rounding up" of

TABLE THREE - REPETITIVE 31 M (102 FT) DIVES

DIVE NUMBER	BOTTOM TIME	SURFACE INTERVAL	OMITTED DECOMPRESSION STOPS US NAVY	RNPL/BSAC*
1a	7 mins	60 mins	1 min	0
2a	7 mins	105 mins	9 mins	10 mins
3a	7 mins	165 mins	9 mins	25 mins
4a **	7 mins		9 mins	85 mins
1b	7 mins	30 mins	1 min	0
2b	7 mins	30 mins	9 mins	10 mins
3b	7 mins	30 mins	32 mins	25 mins
4b	7 mins	30 mins	57 mins	185 mins
5b	7 mins	30 mins	57 mins	105 mins
1c	8 mins	60 mins	1 min	0
2c	8 mins	60 mins	9 mins	15 mins
3c	8 mins	60 mins	21 mins	55 mins
4c	8 mins	60 mins	32 mins	105 mins
5c	8 mins	60 mins	57 mins	115 mins
6c	8 mins	60 rains	57 mins	160 mins
7c	8 mins	60 mins	57 mins	off tables
8c	8 mins	60 mins	57 min	off tables

* BSAC 44m table was used until the maximum tabulated bottom time was exceeded, then RNPL 45m table was used.
** Dive combination 'a' was repeated twice; the same results being obtained each time.

TABLE FIVE

First dive	15m (49 ft)	duration 75 minutes	surface interval 3 hours
Second dive	25m (82 ft)	duration 25 minutes	surface interval 2 hours
Third dive	35m (115 ft)	duration 10 minutes	surface interval 1 hour
Fourth dive	45m (148 ft)	duration 8 minutes	

TABLE SIX

REPETITIVE DIVES CHOSEN TO AVOID ANY SAFETY FACTORS FAVOURING THE TABLES COMPARED TO THE EDGE DUE TO THE ROUNDING-UP OF DEPTHS, DURATIONS OR SURFACE INTERVALS

DIVE NUMBER	DIVE DEPTH	BOTTOM TIME	SURFACE INTERVAL	OMITTED DECOMPRESSION STOPS US NAVY	RNPL/BSAC*
1a	70 ft	40 mins	67 mins	1 min 10 sec	3 min 15 sec
2a	110 ft	10 mins	32 mins	8 min 50 sec	4 min 15 sec
3a	70 ft	30 mins		19 min 10 sec	3 min 15 sec
			TOTAL:	29 min 10 sec	10 min 45 sec
1b	120 ft	15 mins	46 mins	2 mins	4 min 30 sec
2b	120 ft	10 mins	34 mins	8 mins	4 min 30 sec
3b	120 ft	15 mins	27 mins	32 mins	4 min 30 sec
4b	120 ft	5 mins		32 mins	4 min 30 sec
			TOTAL:	74 mins	18 mins

TABLE FOUR - REPETITIVE DIVES TO DIFFERENT DEPTHS

DIVE NO.	DIVE DEPTH ft	m	BOTTOM TIME	SURFACE INTERVAL	OMITTED DECOMPRESSION STOPS US NAVY	RNPL/BSAC*
1a	56	17	60 mins	30 mins	0	10 mins
2a	108	33	12 mins	102 mins	34 mins	155 mins
3a	56	17	38 mins		4 mins	off tables
1b	102	31	16 mins	219 mins	0	0
2b	122	37	10 mins	14 mins	4 mins	10 mins
3b	132	40	6 mins		26 mins	85 mins
1c	62	19	50 mins	30 mins		10 mins
2c	102	31	11 mins	180 mins	34 mins	155 mins
3c	102	31	13 mins	30 mins	23 mins	155 mins
4c	62	19	35 mins		33 mins	off tables
1d	55	17	60 mins	60 mins	0	10 mins
2d	115	35	10 mins	60 mins	30 mins	155 mins
3d	55	17	45 mins	60 mins	26 mins	off tables
4d	115	35	5 mins	60 mins	30 mins	off tables
5d	115	35	10 mins	60 mins	46 mins	off tables
6d	115	35	0 mins		46 mins	off tables
1e	49	15	75 mins	180 mins	0	10 mins
2e	82	25	25 mins	120 mins	18 mins	85 mins
3e	115	35	10 rains	60 mins	30 mins	off tables
4e	148	45	8 mins		57 mins	off tables

* BSAC tables were used until maximum tabulated bottom time was exceeded, then RNPL tables used.
"Off tables" indicates that bottom exceeds the bottom times permitted by the table.

depths, durations and surface intervals with the use of the US Navy tables, two repetitive dive series (Table 6, page 124) were carefully chosen so as to avoid such safety factors.

With these two exposures, the EDGE omitted decompression and ascent time of 19 and 56 minutes compared to the US Navy table.

MULTI-LEVEL DIVING

The acceptability of single multi-level dives could not be assessed in the absence of any tested authoritative standards for comparison, however, it is considered that repetitive multi-level diving would have at least similar problems to repetitive fixed level diving, using the meter.

A multi-level repetitive dive profile was performed without requiring decompression according to the EDGE meter. It is shown as table 7 on page 126.

Converting time at different depths using the US Navy residual nitrogen proposed by Graver[8] indicates a stop of 14 minutes at 10ft (3m) on the second dive. The EDGE ascent rate (4 mins from 90ft) constituted some decompression for each dive.

This was a reconstruction of a dive schedule in which a diver using the EDGE meter was "bent" and required recompression treatment. The dive was considered safe according to the meter, but unsafe according to the US Navy tables (omitted decompression of over 30 minutes). Using multi-level dive calculations by Graver,[8] there was an omitted decompression of 14 minutes by the residual nitrogen method.

DISCUSSION

This study compared the EDGE to the established tables, as stipulated in the diving manuals, to determine its relative safety. No judgement is made of its adherence to the theoretical principles on which it or the tables were originally based. The US Navy and Royal Navy/BSAC tables have been tested, and have an acknowledged decompression prevalence. The relevance of theories of Haldane and others, including the half times, number of tissues, Doppler data, etc. is conjectural and still requires clarification.

The results showed that the meters were less conservative than the tables, and would result in repetitive dives which proponents of the established decompression tables would consider unacceptable.

TABLE SEVEN - REPETITIVE MULTI-LEVEL DIVES

DIVE ONE

87ft (26.5m) for 15 minutes bottom time. Ascend to 60ft (18m) in one minute, and remain for 15 minutes. Ascend to surface in six minutes with a precautionary stop at 10ft (3m) for three minutes included in ascent time.

Surface interval of 90 minutes.

DIVE TWO

87ft (26.5m) for 15 minutes bottom time. Ascend to 60ft (18m) in one minute, and remain for 18 minutes. Ascend to surface in six minutes with a precautionary stop at 10ft (3m) for three minutes included in ascent time.

Apart from the observations that the EDGE allows diving protocols that appear both radical and dangerous, there are many promotional claims and theoretical arguments that are contentious.

SINGLE DIVES

On the surface, scrolling of the no-decompression times for the EDGE for any depth ("bottom time") is usually an underestimate of the actual time that is available to the diver using the meter, probably because less nitrogen is absorbed during the descent than while at maximum depth. The "bottom time" is, by convention, a summation of these times.

The "bottom time" recorded in the EDGE manual and used for favourable comparison with other dive tables' no-decompression times is misleading. It does not include the time taken to reach depth. Descent rate is conventionally accepted as 60ft or 18m per minute. To obtain the bottom times used in the manual, it appears that the manufacturers have presumed that the diver is instantaneously transported to that particular depth. The result is that the more gradual nitrogen load experienced with descent, when added to the actual time at the bottom, gives a greater "bottom time" for the EDGE than the manual or scrolling depicts.

The manufacturer's selection of depths to compare the EDGE with US Navy and the RNPL/BSAC tables resulted in the "rounded up" depths being used, thereby showing the EDGE in a more favourable light than if random depths were chosen, ie. if a depth of 18m or 60ft is chosen, then the EDGE looks more conservative than the US Navy tables, or the RNPL/BSAC tables. If, however, a depth of 141 ft or 43m is chosen, then the advantage of the EDGE decompression is immediately lost, as the decompression according to the US Navy tables has to be carried out as if the dive was at 150ft, and with the RNPL/BSAC tables as if the dive was at 44m. In these cases, the no-decompression limits are more conservative with the established tables than with the EDGE. Thus the depths chosen for comparison will have a great bearing on the apparent safety of one procedure compared to another.

The same anomaly is found with no-decompression durations, ie. with a no-decompression dive for 20 minutes, the US Navy will permit a dive to 100ft, the RNPL/BSAC table allows no-decompression to 30m, and with this duration the EDGE compares favourably with the other tables. If, however, a six minute maximum depth no-decompression time is chosen, then the EDGE would allow 160ft depth, whereas the US Navy allows only 140ft. If a maximum depth no-decompression dive of 24 minutes was chosen, the EDGE would compare less favourably and allow a greater depth than the RNPL/BSAC tables.

When one considers these three factors, and modifies the EDGE no-decompression limits accordingly, it is evident that the EDGE no-decompression fixed level diving is less conservative than both Bassett and Spencer tables, although both these are quoted in the manual.

Even without such corrections, the comparison of Spencer's no-decompression limits with those of the EDGE, does not really lend support to the claim that the EDGE is based on Spencer's figures. In the 30-80ft range, the EDGE allows the same or more time without imposing decompression requirements. Spencer's exposures do not exceed 130ft, but at that depth the EDGE allows almost twice as much time as Spencer. Although Spencer's work is quoted on many occasions in the manual, the manner in which the two are related is not clear.

SAFETY FACTORS WITH ESTABLISHED TABLES

With the use of diving tables, there is no possibility of the tables encompassing the vast numbers of combinations of depths and durations available with the EDGE meter. The tables use increments of water depth and time segments, thereby compelling the diver to "pigeon hole" his dive into one of the established depth/duration "boxes".

One of the most obvious safety factors is the "rounding up" of the depth and duration so as to decompress according to a greater depth and greater duration. Thus, if a diver descends to a depth of 17m (56ft) for a period of 62 minutes, he will decompress as if he has been to 18m for 66 minutes (RNPL/BSAC tables), 20m for 65 minutes (RN 1972 tables), or 60ft for 70 minutes (US Navy tables).

This rounding up results in a safety factor in favour of the established tables. In each case, as one approaches the designated depths and durations, the less safe the dive will be, as more inert gas is absorbed into the tissues for the same decompression obligation.

This safety factor contributes to the relatively acceptable results when divers use these tables. Attempts to use the maximum depth/duration to approach the no-decompression limits, have resulted in unacceptable incidences of decompression sickness.[9,10] As it calculates decompression requirements for the precise depth and time, this safety factor is omitted with the EDGE diving computer.

Although the slower ascent rate with EDGE may be of benefit in reducing the danger of pulmonary overload with venous gas emboli, it will also add to the nitrogen load in the tissues, when performing repetitive dives.

MULTI-LEVEL DIVING

Huggins' report[4] receives acknowledgment by the manufacturer as a theoretical basis of the meter's development. Four of the ten profiles Huggins used finished with significant stops at 25ft or 30ft (8 or 9m). These would act as decompression stops. Huggins states "[t]his study is only the first step in validating the Multi-Level diving procedures. More research needs to be conducted to increase sample size". An interest in the Multi-Level tables has been expressed by the US Navy, and perhaps trials by this group may clarify the issues.

Huggins' dive schedules could confuse the effect of repetitive dives with multi-level dives. It seems that there is little sound experimental evidence for any multi-level calculation system.

For a single multi-level dive in which the depth plateaus are gradually diminishing, ie. five minutes at 120ft, 20 minutes at 60ft and 30 minutes at 30ft, decompression would not be considered necessary by most authorities and was not required by the meter.

If, however, the opposite situation is produced, ie. the dive gets deeper as it progresses then the nitrogen load in the "slower" tissues is likely to contribute more than usual to bubbles which are subsequently developed in the "fast" or "medium" tissues during or following ascent. These multi-level tables have yet to be competently tested.

REPETITIVE DIVES

"Rounding up" of surface intervals with the US Navy tables also adds a safety factor over the EDGE, with repetitive diving. A dive to 60ft (18m) for 20 minutes would be interpreted as moving into repetitive group D according to the US Navy manual, and therefore a surface interval of, say, five hours, would be calculated in the US Navy diving tables to be equivalent to a surface interval of two hours and 39 minutes, ie. moving into group B. According to the RNPL/BSAC tables, it would be calculated as a four-hour surface interval. With the EDGE, it is evaluated strictly as a five-hour surface interval, ie. the EDGE loses the safety factor applied in both other tables.

Because of the loss of safety factors involved in "rounding up" depths, durations and surface intervals, the EDGE is likely to require much less decompression time with most arbitrarily chosen repetitive dive profiles. This must make it more dangerous to use than the tables, which incorporate these safety factors.

Even when dives are chosen specifically to avoid the safety factors inherent in the US Navy tables, the EDGE still allows much greater durations for repetitive dives. This is demonstrated by the dive series in Table Six.

The more radical nature of the EDGE can also be demonstrated by recalculating the 102 or 141 ft dive series of Tables Two and Three. The US Navy tables still require decompression stops, even when the next shallower depth, the next shorter bottom time, and the next longer surface interval are used. Because of this, the EDGE must be considered unsuitable for repetitive dives.

FUTURE METERS

It is considered that the programme of the decompression computer should incorporate:

1. A safety margin in the model equivalent to the "rounding up" of depths and durations to those designated in the established tables, eg. 64ft depth should be read by the computer as 70ft. This would ensure that the meter does not exceed the durations allowed by the tables, and thereby increase the likelihood of decompression sickness.

2. In repetitive diving, the meter should be at least as restrictive as the US Navy tables.

3. Once descent has been completed in the multi-level dives, no subsequent descents should be permitted from that or any other plateau depth, until multi-level diving is better researched.

CONCLUSIONS

<u>Single fixed-depth no-decompression</u> dives allowed by the EDGE are comparable to the established US Navy and RNPL/BSAC tables. In some instances, the bottom times are more conservative than the tables; at other times, they are more radical. The comparisons, as quoted in the Instruction Manual, give an impression of safety with the EDGE meter, which is somewhat misleading.

The acceptance of the EDGE in the use of a <u>single multi-level</u> dive, depends on one's philosophy or approach to these theoretical dive tables. The EDGE meter, used on certain multi-level single dives, may give greater durations without greater decompression stress, eg. when the dive is performed in such a way that the depth lessens as the dive progresses.

For <u>repetitive dives</u> with either single or different depths, and using either the US Navy tables or the Royal Navy tables as a minimal acceptable standard for decompression, the EDGE meter could not be classified as either safe or acceptable. This is so even when the "rounding up" and safety factors are not applied.

SUMMARY

The EDGE seems suitable for measuring and recording the various dive parameters, such as depth, times, temperature, etc. It seems suitable for some single fixed depth dives and on some single multi-level dives, if sufficient care is taken to ensure a sensible dive plan, eg. diving from deep to shallow.

Its use in any repetitive dive situation, with either fixed or multi-level dives, should be discouraged.

REFERENCES

1. Quick DT. Evaluation of the Automatic Decompression Meter. *RAN SUM Report*. 1974; 2.

2. West D & Edmonds C. Evaluation of the Farallon Decompression Meter. *RAN SUM Report*. 1976; 1.

3. Le Sueur G. *Personal Communication of Investigations Carried out at the RAN SUM*. 1984.

4. Huggins KE. Doppler Evaluation of Multi-Level Dive Profiles. *Fourteenth International Conference on Underwater Education* MICHU-SG-84-300, 1983.

5. Huggins KE & Somers L. *Mathematical Evaluation of Multi-Level Diving. Michigan Sea Grant Programme* MICH-SG-81-207, 1981.

6. Murphy G. Orca Edge Update. *Skin Diver* 1985; 34: (11)

7. A Review of Two Decompression Computers. *Undercurrent* Part I, October 1986; Part II, November/ December 1986.

8. Graver D. Using the US Navy Dive Tables for Sport Diving. *Decompression in Depth* (A seminar sponsored by PADI, Santa Ana, California), 1979.

9. Bassett B. The Safety of the US Navy Decompression Tables and Recommendations for Sports Divers. *SPUMS J* 1982; 15: (3).

10. Hamilton RW. Sports Diving Session Looks at Decompression. *Pressure* August 1985; 13.

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DIVER NAVIGATION BY MEANS OF ACOUSTIC BEACONS

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SUMMARY

Divers traditionally have difficulty navigating underwater. In air, they have vision plus all types of sensory cues to accomplish this task. However, when submerged, the diver's visual modality is sharply impaired and in a sense, he or she is left virtually blind. Ordinarily divers attempt to navigate by compass (dead reckoning) but research has demonstrated that this approach leads to unacceptable errors. Some other approach, then, needs to be developed. In this regard, we have carried out and reported a number of experiments focused on the abilities of divers to navigate by means of programmed acoustic signals. It has been found that sound which "moves" underwater (ie. via the UAPP or Underwater Auditory Phi Phenomena) greatly aids sound localization and, ultimately, navigation. Indeed, for diver retrieval this phenomena is so powerful that no subject in any of our experiments has ever swum to an area except that containing the signal source. Previously published data will be reviewed briefly and new data on the effects of experience and/or training on diver navigation by acoustic signal will be presented.

INTRODUCTION

Diver navigation and retrieval of personnel continues to be a very serious problem. At present, only a very few partially developed systems are available (explosives, dead reckoning, beacons, etc.) that will permit even the most limited (controlled) travel underwater. This situation results from the fact that, when a person is submerged, there are very few (to no) location markers and his or her vision is sharply limited. That is, in the normal situation (ie. in air), humans utilize their vision for observing markers, localizing objects and moving from place-to-place. Underwater, however, human vision is greatly limited, the diver quite often is functionally blind or close to being so. As stated, the consequences of this condition are quite serious; divers often are unable to locate objects or team members, swim to desired locations/targets and/or find their way "home". This latter problem can be a pretty grim one if the diver is saturated. Traditionally, the solution to the problem has been the use of an underwater compass with the diver navigating by "dead reckoning". However, Anderson[1] has reported an experiment wherein he states that "even for well-trained subjects ... the average performance accuracy ... was plus or minus 53 feet from the centerline of the measurement array or 3.98 degrees in compass error ... in an operational situation when a diver might be engaged in an underwater search task or in accurate placement of underwater sensors, this level of performance would be marginal." Indeed so. A navigational error of this magnitude would become crucial, and possibly fatal, for saturated divers or divers attempting to find a moving vehicle. To illustrate, if a saturated diver made an error in navigating back to the underwater habitat as large as that reported by Anderson, he could easily miss it, and