## EFFECTS OF DIVING ON THE HUMAN COCHLEOVESTIBULAR SYSTEM

Otto Inge Molvaer

### Dissertation abstract

Cochleovestibular barotrauma was seen in all types of divers. A retrospective analysis of 76 cases (83 injured ears) is reported. It is hypothesized that middle ear gas may enter the perilymphatic space of the inner ear during ascent in cases of perilymphatic fistulae. The cochlear injury was classified as permanent in 58% of the cases.

The sound pressure level from the breathing gas in standard hard hats was measured to about 96 dB(A) (re 20uPa), while the level from high pressure water jet lances reached about 145 dB(A) close to the divers' head gear. In living chambers for saturation diving sound pressure levels reached about 106 dB(A). After the environmental control units were moved to the outside of the chambers the highest recorded levels were about 96 dB(A).

Significant temporary hearing threshold shifts were demonstrated in divers participating in two saturation dives of 19 and 34 days duration to 300 and 500 msw respectively. The recovery took up to three days post-dive.

Young, highly selected professional divers had lower hearing thresholds than age-matched randomly selected (standard) controls, but higher than the normality curves of the International Organisation of Standardisation. However, divers in their fourth decade of life had thresholds comparable to the standard controls. Divers who smoked had significantly higher thresholds than their non-smoking colleagues. After an observation period of about six years the divers' hearing had deteriorated faster than that of both otologically normal subjects and of the unscreened controls.

Transient vestibular imbalance was detected by ENG in 25% of the divers participating in four dives to 300-350 msw, but normalisation occurred within a year. The vestibulo-ocular reactivity to bithermal caloric stimulation was significantly reduced in six divers at 250 msw as compared to surface values. Alternobaric vertigo was reported by 33% of 194 professional divers. Although the symptoms usually were mild, in some cases they caused serious disorientation, nausea and vomiting.

*By Ed. SPUMS J*

*The above is the abstract of a doctoral dissertation which was successfully defended by Dr Molvaer (a member of SPUMS) on September 30th, 1988. Readers wishing for further information should contact Dr Molvaer whose address is the Norwegian Underwater Technology Centre A/S (NUTEC), P.O. Box 6, N-5034 Ytre Laksevag, Norway.*

## DIVE COMPUTERS

**John Lippmann**

Since decompression sickness in humans first reared its ugly head back in the mid-1800s, scientists and others have sought ways to improve and simplify decompression calculations and procedures.

Haldane introduced his model and schedules at the beginning of this century, and since then many decompression tables have been published. Although some of the very latest tables include methods for compensating for parts of a dive spent shallower than the maximum depth, most tables require a diver to choose a no-decompression or decompression schedule according to the maximum depth and bottom time of a dive. The calculation assumes that the entire bottom time was spent at the maximum depth, and that the diver's body has absorbed the associated amount of nitrogen. However many dives do not follow that pattern. A scuba diver's depth normally varies throughout a dive, and often very little of the bottom time is actually spent at the maximum depth. In this case a diver's body should theoretically contain far less dissolved nitrogen than is assumed to be present when using the tables in the conventional manner. Some divers feel penalised for the time of the dive not spent at the maximum depth.

The ideal situation is to have a device that tracks the exact dive profile and then calculates the decompression requirement according to the actual dive done. Such devices have emerged since the mid-1950's, some gaining some notoriety.

Probably the best known of the early decompression meters is the *SOS decompression meter* which was designed in 1959 and emerged in the early 1960s. The meter, which is still currently available, appears to represent a diver's body as one tissue. It contains a ceramic resistor through which gas is absorbed before passing into a constant volume chamber. Within the chamber is a bourdon tube which bends as the pressure changes, and the pressure level, which represents the amount of absorbed gas, is displayed on an attached gauge. On ascent gas escapes back through the resistor and eventually, when enough gas has escaped, the gauge will indicate that a safe (supposedly) ascent is possible. A number of problems arise with the use of the SOS meter. Individual meters often vary greatly, and the no-decompression times for dives deeper than 60 ft (18 m) exceed the US Navy no-decompression limits (NDLs). The meters give inadequate decompression for repetitive dives when compared to the USN and most other tables. In 1971, the first six divers requiring treatment at the Royal Australian Navy School of Underwater Medicine chamber were divers who had ascended according to SOS decompression meters.[1]

The Defence and Civil Institute of Environmental Medicine (DCIEM) of Canada developed a decompression meter in 1962. It utilised four resistor-compartments to simulate nitrogen uptake and elimination in a diver. Initially the compartments were set up in parallel so that each compartment was exposed to ambient pressure and thus absorbed gas simultaneously. When tested, this configuration produced an unacceptable bends incidence. The four units were then re-arranged in a series arrangement, so that only the first was exposed to ambient pressure and gas passed from one compartment into the next. This configuration was tested on almost 4,000 test dives and produced a very low incidence of bends.[1]

The meter gave effective half-times from five to more than 300 minutes, and it indicated current depth and safe ascent depth. The DCIEM unit never became available to sport divers as it would have proved to be very expensive and would have required extensive and costly maintenance.

In 1975 Farallon released its *Multi-Tissue Decomputer* which was designed to be a no-decompression meter. It consisted of four permeable membranes, two of which absorbed gas and two which released it. The Royal Australian Navy tested two meters in 1976 and found them to give very divergent results. One became more conservative while the other became more radical. In addition, various mechanical problems eventuated. Tests done in the USA confirmed that the NDLs given by the meter often greatly exceeded those of the USN tables.

Over the past ten years or so, various methods of extrapolating the USN (and some other) tables to credit a diver for the shallower portions of a multi-level dive have emerged. These methods require manipulations that are too complex for many divers and require the dive plan to be known in advance and rigidly followed. They are generally unvalidated, and their safety is a subject of dispute. In addition, if time is spent at more than two or three levels the calculations become prohibitively complex.

By the mid-1970s with the advance in microprocessors (a chip which can contain a series of pre-programmed instructions) it became possible to construct a small computer capable of doing very complex multi-level calculations. Recent technological innovations have overcome some of the early technical restraints and the scuba diver now has access to the convenience of automatic and more accurate depth and time recording, together with accurately computed multi-level decompression schedules, at far more affordable prices.

A microprocessor is capable of reading a pressure transducer (which converts pressure into electrical impulses) very rapidly and can apply nitrogen uptake and elimination algorithms (the mathematical equations which represent gas uptake and release) to this information every few seconds. These computers can therefore track a diver's exact profile and calculate decompression requirements according to it, rather than by the "rounded-off" profile which is used with decompression tables.

Despite, and in some cases because of, these features, some reputable diving scientists, doctors and educators remain very critical of these devices. Some argue that a diver will become too machine-dependent and would be at a loss and in a potentially dangerous situation if his computer failed while in use. However some diving instructors feel that modern decompression computers are less likely to fail than divers are while reading the tables and that there are some reasonable bail-out procedures in case of meter failure. *Probably the major fear of the computer critics is that some computers bring a diver far too close to, or beyond, the limits of safe diving, especially during repetitive dives.*

The decompression models programmed into the model-based computers are designed to simulate nitrogen uptake and release in a diver's body. However they are just models and cannot completely predict the gas flow in and out of our actual tissues. Our physiology is not always so predictable as many factors influence the rate of gas uptake and elimination and the possibility of consequent decompression sickness. So even though the computers follow their models exactly and the theoretical tissues programmed into the computer load and unload as expected, our bodies might not be behaving quite so predictably. There is no safety margin built into most computers which substantially compensates for this difference. Tables, on the other hand, usually contain an inherent safety margin and, in addition, since we must "round-up" any intermediate depth and/or time to the nearest higher or longer tabled depth and/ or time, we partly, but not always fully, compensate for our own body's deviation from the model.

A table-based non-multi-level computer retains any inherent and/or "round-up" safety margin of the table, a table-based multi-level computer retains a small amount of the margin and a model-based computer retains no margin at all unless it is built into the model itself.

## COMPARING COMPUTERS TO TABLES FOR NO-DECOMPRESSION DIVES

When no-decompression times allowed by various computers are compared to those allowed by various tables (even those based on the same model) for the same dive, vast differences often appear. These differences become greater for repetitive dives. Tables 1 and 2 compare the times allowed by various computers and tables for two series of repetitive dives that I carried out in a water-filled pressure chamber. I have conducted a variety of other simulated and real dives with similar results. Some of the reasons for these differences will be discussed in this section.

### Single Dives

Table 3, below, compares the single dive NDLs of various computers to those of the USN and Buehlmann (1986) tables.

### Single Rectangular Dives

It can be seen from Table 3 that the single dive No-Decompression Limits of the computers are more conservative than the USN limits and are generally similar to the limits of the Buehlmann Table. Therefore *for a single rectangular dive these computers will usually give a more conservative no-decompression time than the USN Tables.*

It has been shown experimentally that divers who dive right to some of the USN NDLs will be quite likely to bubble during or after the ascent. By shortening the initial NDLs and in some cases slowing down the ascent, these computers (and modern tables) attempt to minimise bubble formation during or after a dive.

### Single Multi-Level Dives

*On a multi-level dive the computers will normally extend the allowable no-decompression dive time far beyond that allowed by the tables.*

This occurs because the computer constantly calculates the (theoretical) gas uptake or release at all levels of the dive, rather than just at the maximum depth as tables do. This function is demonstrated in Figure 1 which shows a dive profile allowed by a Suunto SME-ML. At each level of the dive there was one minute of no-decompression time left when the ascent was commenced to the next level.

This single dive required no decompression according to the computer, but required decompression of 15 minutes at six metres and 31 minutes at three metres according to the USN Tables.

On a single multi-level dive of 30 m for five minutes, followed by 20m for 10 minutes, followed by ascent to 15m, the Suunto SME-ML allows a further 46 minutes of dive time at 15m before a decompression stop is required. The Huggins table allows 25 minutes at the 15m level before requiring decompression.

### Repetitive Dives

The dives shown in Tables 1 and 2 were rectangular dives so that the multi-level capability of the computers was minimised and the times allowed by the computers could be compared to the times allowed by the tables.

It is obvious that the computers allowed substantially more time for these repetitive dives than the tables would give. We know that it is unwise, and at times hazardous, to dive the USN Tables to their limits, especially on repetitive rectangular dives. How then can the generous times given by these computers be justified?

As previously mentioned, divers who dive right to some of the USN limits will be quite likely to bubble during or after the ascent. Some of these divers will develop manifestations of bends, but most will be asymptomatic. In either case these bubbles will slow down the out-gassing process and give rise to more residual nitrogen for repetitive dives than there would be if no bubbling had occurred.

By shortening the initial NDLs and slowing down the ascent rate, these computers attempt to minimise the bubble formation after the initial dive. This should enhance out-gassing, reduce residual nitrogen and thus enable longer no-decompression bottom times for repetitive dives. The Buehlmann Table works on this premise. It utilises shorter initial NDLs than the USN Table, followed by a slow ascent, and this is why it sometimes allows longer no-decompression bottom times than given by the USN Table for repetitive dives. However, as you can see from the examples, using the Buehlmann Table for repetitive dives is still more conservative than using most computers.

Because most tables are based on the off-gassing of a single slow tissue during the surface interval they often have a safety margin built into them, whereas the computers carry no such margin. Repetitive Groups and Residual Nitrogen Times given in tables are designed to account for the highest gas loading that is theoretically possible and are usually based on a single tissue compartment only. Since this tissue is a "slow" tissue it out-gasses slowly on the

**FIGURE 1**

***The times given are in minutes unless otherwise specified.***

**Dive 1**

| | |
|---|---|
| **Depth** | 36 m |
| **Allowable no-decompression bottom time** | |
| Aladin | 8 |
| Microbrain | 8 |
| Edge | 11 |
| Skinnydipper | 10 |
| SME-ML | 10 |
| USN Table | 15 |
| Buehlmann Table | 12 |
| **Bottom time (actual)** | 10 |
| **Decompression time required** | none |
| **Ascent time** | 1.3 minutes |

**Dive 2.**

| | |
|---|---|
| **Surface interval** | 60 |
| **Depth** | 30 m |
| **Allowable no-decompression bottom time** | |
| Aladin | 14 |
| Microbrain | 13 |
| Edge | 19 |
| Skinnydipper | 19 |
| SME-ML | 19 |
| USN Table | 11 |
| Buehlmann Table | 8 |
| **Bottom time (actual)** | 18 |
| **Decompression time required** | |
| Aladin | 40 seconds at 3 m |
| Microbrain | 2 min at 3 m |
| Edge | none |
| Skinnydipper | none |
| SME-ML | none |
| USN Table | 15 min at 3 m |
| Buehlmann Table | 2 min at 6 m and 7 min at 3 m |
| **Ascent time** | 2.3 minutes |

**FIGURE 2**

***The times given are in minutes unless otherwise specified.***

**Dive 1**

| | |
|---|---|
| **Depth** | 27 m |
| **Allowable no-decompression bottom times** | |
| Aladin | 19 |
| Microbrain | 18 |
| SME-ML | 22 |
| USN Table | 30 |
| Buehlmann Table | 20 |
| **Bottom time (actual)** | 18 |
| **Decompression time required** | none |
| **Ascent time** | 3.5 minutes |

**Dive 2**

| | |
|---|---|
| **Surface interval** | 32 minutes |
| **Depth** | 30 m |
| **Allowable no-decompression bottom times** | |
| Aladin | 14 |
| Microbrain | 14 |
| SME-ML | 16 |
| USN Table | 3 |
| Buehlmann Table | 6 |
| **Bottom time (actual)** | 16 |
| **Decompression time required** | |
| Aladin | 4 min at 3 m |
| Microbrain | 4 min at 3 m |
| SME-ML | none |
| USN Table | 15 min at 3 m |
| Buehlmann Table | 2 min at 6 m and 7 min at 3 m |
| **Ascent time** | 2.5 min to 3 m |
| **Decompression done** | 4 min at 3 m |

*The rest of this table is to be found on page 130*

surface. The tables assume that all of the tissue compartments are unloading at this rate and so may over-estimate the theoretical gas loads of the faster tissue compartments. This results in shorter repetitive dive times than would be allowed if the actual (theoretical) gas load in the faster compartments was considered. So this crudeness of the table's calculations may lead to longer surface intervals than are required by the model, but introduces a margin of safety by assuming the diver has more residual nitrogen than the model dictates. However many depth and time combinations may lead to the same Repetitive Group although, in reality, the nitrogen contents in the various body tissues are quite different.

Computers calculate repetitive dive times according to the exact (rather than the maximum possible) gas loading given by the model, taking into account all the tissues used in the model. This usually allows more dive time for repetitive dives than is allowed by tables. However in some situations the times can be similar. The deeper NDLs are determined by fast tissues which absorb gas rapidly and which off-gas rapidly at the surface. Repetitive Groups are based on slower tissues. If repetitive dives are compared for NDLs in the depth range where the Repetitive Group tissue controls the NDL (i.e. shallow to moderate depths), then the limits given by the tables and the computer should be close.

On some long dive sequences or in situations where repetitive dives are done over many consecutive days, the computers are sometimes slower to unload as they are programmed with slower tissues than are used to determine

**Dive 3**

| | |
|---|---|
| **Surface interval** | 32 minutes |
| **Depth** | 36 m |
| **Allowable no-decompression bottom time** | |
| Aladin | 7 |
| Microbrain | 8 |
| SME-ML | 10 |
| USN Table | none |
| Buehlmann Table | none |
| **Bottom time (actual)** | 10 |
| **Decompression time required:** | |
| Aladin, decompression was indicated but cleared during (rapid) ascent | |
| Microbrain | 5 min at 3 m |
| SME-ML | none |
| USN Table | 15 min at 6 m and 31 min at 3 m |
| Buehlmann Table | 4 min at 6 m and 9 min at 3 m |
| **Ascent time** | 1 minute |



the repetitive groups in tables. This may lead to the situation where the tables will allow you to begin a new days diving without considering residual nitrogen from the previous day's diving, whereas a computer may still carry over a penalty. *This will normally only apply to the first dive of the day and the computer will then allow longer bottom times for the following dives that day.*

## ARE THE COMPUTERS SAFE?

The safety of these devices is still the subject of many a heated debate.

The main criticisms focus on the following arguments:

1. The models on which the computers are based are not completely accurate. Decompression computers will retain inaccuracies until the devices can directly measure an individual's actual tissue nitrogen levels.

2. The inherent safety margin of the tables as well as the extra security gained by "rounding-off" the tables is lost in the computers. This will give a diver more time, but will at times put him more at risk.

3. Although some of the models on which the tables are based have been well-tested for fixed-depth dives, there have only been a few well-controlled, documented tests of the validity of the multi-level applications. The number of these tests has been insufficient to determine the validity of the multi-level applications with any statistical significance.

Before releasing the "Edge" in 1983, Orca Industries conducted a study to evaluate the safety of the algorithm programmed into the "Edge". Twelve divers did a series of ten "chamber dives". Nine of the profiles were multi-level no-decompression profiles, and the tenth required decompression. The divers were monitored with Doppler bubble detectors. In the 119 profiles completed, bubbles were detected in one diver and were the lowest grade of bubbles.[2] None of the divers showed definite signs of bends. Two divers were slightly fatigued, one had some skin itchiness (which often occurs in chamber dives) and another had slight tingling in one leg. Tingling was a condition this subject often had after diving but it was reported as it was stronger than usual. No conclusions could be drawn as to whether the manifestations of fatigue and tingling were due to decompression stress or other factors. However significantly more dives are needed to establish the risk of decompression sickness for the various schedules. For example, for each schedule a minimum of 35 dives without bends is needed before a bends rate of less than two per cent can be claimed with 95% confidence.[3]

Orca Industries report that more than 500,000 dives have been done by divers using the "Edge" (to my knowledge at the time of writing, the vast majority of these dives have not been documented or validated) and that 14 cases of bends in divers "properly" using the "Edge" had been reported to Orca and the Divers Alert Network (DAN) by the end of 1987.[4]

Uwatec, the manufacturers of the "Aladin" ("Guide"), report that between 50,000 and 100,000 incident-free dives have been done using the "Aladin" (to my knowledge at the time of writing, the vast majority of these dives have not been documented or validated) by the end of October, 1987. These dives included 290 well-documented dives done, by a British scientific expedition, in Lake Titicaca, 12,580 feet (3,812 m) above sea-level.[5]

With well over half a million apparently safe dives carried out by computer-users, it might appear that the computers are indeed safe devices. However, as with tables, it is difficult to determine whether it is the computers themselves that are safe, or if the apparent safety lies in how divers are using them and the type of dives that they are normally using them on. Since most of the 500,000 plus dives were undocumented, it is not known whether or not the divers dived to the limits given by their computers. If the units are not dived to their limits then we still do not know how safe the actual limits are. This is especially relevant to multi-level and repetitive dives.

More than 200 divers were treated for bends in Australasia in 1987. The vast majority of cases displayed neurological effects. These cases often arose after dives, often repetitive dives, that were conducted in accordance, and at times well within, conventional tables. Some had done a multi-level dive but had surfaced within the NDL specified by the table for the maximum depth.[6]

With such a high incidence of bends when diving within conventional limits, some fear that more cases might be expected to occur when the limits are extended, especially for repetitive dives. As computers become more and more common a better understanding should emerge.

By mid 1988, 79 cases of bends in divers using computers had been reported to DAN. In England in 1987, 16% (11/69) of the divers treated for bends had been using a diver computer.[7] Recent (as yet unpublished) figures from Aberdeen show a substantial bends incidence in divers who used computers for multi-day repetitive diving.

I believe that to a large extent the bends rate in dive computer users will depend on how divers dive when they use their computers, on the type of dive profile and on their rate of ascent.

It appears that a diver who ascends slowly will have less chance of getting bends, especially neurological bends, than one who ascends more rapidly. I believe that a diver should ascend no faster than about 10 m/minute when shallower than 30 m. Many computers include a warning to tell a diver when he is exceeding the recommended ascent rate. The rate varies between computers, but I believe it should roughly equate with the above recommendation. This function is a highly desirable, if not essential, function of any dive computer.

*If you exceed the recommended ascent rate at any stage during a dive, especially at or near the end of a dive, reduce your dive time substantially from that given by the computer for the rest of that dive and for repetitive dives. If bubbles form as a result of the faster ascent, they will slow down out-gassing and make the times given by the computer far less realistic.*

*I also highly recommend that a diver goes to the maximum depth early in the dive and then gradually works shallower.* If a diver begins a dive in the shallows and then progressively gets deeper and deeper before ascending to the surface, the nitrogen load in the "slower" tissues is likely to contribute more than usual to bubbles which are subsequently formed in the "fast" or "medium" tissues during or following ascent.

If you are using a dive computer I believe that you should:

Ascend slowly. Never exceed the recommended ascent rate and generally ascend at about 10 m/minute or slower.

Go to the maximum depth early in the dive and progressively and slowly work shallower. End the dive with *profiles.*

Do not dive right to the limits given by the computers. They do not cater for individual susceptibility to bends.

Avoid using the computer for deep repetitive dives, especially those with rectangular profiles (in fact avoid doing deep repetitive dives!).

In the event of a computer failure, ascend slowly to 3-6 m (nearer to 6 m if possible) and spend as much time as possible there before surfacing.

**THE FUTURE**

It appears that dive computers are here to stay and they will develop enormously as knowledge and technology advance. The current models are based only on depth and time, but future computers might be programmed to include other variables such as degrees of individual susceptibility to bends, exertion, water temperature and delayed out-gassing due to a rapid ascent. I am told that a computer which will do the latter is currently nearing completion and I believe this to be a large step towards improving computer safety.

The ultimate computer would measure the nitrogen level within an individual diver's tissues. I have put my order in already!

**SUMMARY**

Dive computers are designed to calculate the decompression requirement for the actual dive profile, rather than for the "rounded-off" profile which is used with tables.

Most current computers are programmed with an actual decompression model rather than with tables.

Computers eliminate errors in table calculations, and usually provide much more bottom time than is given by the tables.

Tables include inherent or added margins which provide a degree of safety if our body absorbs more nitrogen than predicted by the model. Computers do not include such margins as they follow the model exactly.

For single rectangular dives the computers usually give more conservative NDLs than the tables.

On a multi-level dive the computers will normally extend the allowable no-decompression bottom time far beyond that allowed by the tables.

The computers usually allow far more time for repetitive dives than is allowed by tables. This is an area of risk for the computers as is multi-day diving.

at least five minutes at 3-6 m. *Avoid rectangular dive* The safety of dive computers has not been determined as too few validated tests have been done to determine the bends risk associated with their use. However, this is also true for most decompression tables!

The computers generally rely on a slow ascent rate and the times given are less valid if a diver has ascended faster than recommended.

Computers can and do fail and the diver must have an appropriate back-up procedure.

If using a computer it is important to:

Go to depth early and then work shallower throughout the dive. Ascend at the appropriate rate. Do not dive right to the limits. Allow for predisposing factors of bends. End all dives with a few minutes at 3-6 m.

For multi-day diving rest every third day.

*The above article is taken from a book relating to various aspects of diving which John Lippmann is currently finalising for publication in 1989. No part of this article may be reproduced without the prior consent of the author.*

**REFERENCES**


1. Edmonds, C., "Bendomatic Decompression Meters". *SCUBA Diver*; October 1987: 22-27.
2. Huggins, "Microprocessor Applications to Multi-Level Air Decompression Problems". *Michigan Sea Grant College Program Report No. MICHU-SG-87-201*. Michigan Sea Grant Publications; 1987.
3. Shields, T., "Re-trial at sea of 70 and 80 metre 15 minute Trimix decompression schedules", *AMTE(E) R82-409*; 1982.
4. Barshinger, C., "Decompression Computers". Skin Diver; 1988; 37(2): 32.
5. Buehlmann, A., "Diving At Altitude and Flying After Diving", UHMS Symposium, The Physiological Basis of Decompression, Duke University Medical Centre, 1987.
6. Gorman, D. and Parsons, D., "Decompression Meters - Philosophical and Other Objections". *SPUMS J* . 1987; 17(3): 119.
7. Shaw, D., "NDC Diving Incidents Report". *Proceedings of Diving Officers Conference*. BSAC, London, 1987.


**Other Sources**


Chadwell, C., "Multi-Level Diving - Instructor Guide". Sea Quest, California, 1988.

Divers Alert Network, "Preliminary Report on Diving Accidents". Divers Alert Network, 1988.

Douglas, D., "Time to reflect on diving in the computer age". *Diver;* 1987, 32(7): 5.

Edmonds, C. and Anderson, T., "Assessment of the Orca EDGE Dive Computer". SPUMS J;. 1987; 17 (3): 119-127.

Ellerby, D., "Decompression Computers - Their Use". P*roceedings of Diving Officer's Conference.*. BSAC, London, 1987.

Ellerby, D., "Decompression - BC and AC". NDC B*ulletin*. 1987; 11: 1-3.

Ellerby, D., "Budget Brain". Div*er*. 1987; 32(7): 24-25.

Ellerby, D. and Todd, M., "Which Dive Computer?" Dive*r*. 1988; 33(3): 15-17.

Fulton, J., "Orca Industries stands by its EDGE". SCU*BA Diver*. October 1987: 22-27.

Graver, D., "Electronic Dive Monitors" NAUI *News*. May 1988: 33-37.

Huggins, K., and Somers, L., "Mathematical Evaluation of Multi-Level Diving". *Report No. MICHU-SG-81-207*. Michigan Sea Grant Publications. 1981.

Huggins, K., "Doppler Evaluation of Multi-Level Diving Profiles". *Report No. MICHU-SG-84-300.* Michigan Sea Grant Publications. 1983.

Huggins, K., "Multi-Level Diving, How Safe Is It?". Proceedings of International Conference on Underwater Education,. I.Q. 85, NAUI, California. 1985.

Huggins, K., "History of Decompression Devices". NAUI News;. May 1988: 22-30.

Huggins, K., "History of Decompression Devices - Part 2". *NAUI News*. July 1988: 49-51.

Murphy, G., "The SME-ML". *Skin Diver*. 1987; 36(6): 37.

Murphy, G., "Datamaster 2". Ski*n Diver*. 1987; 36(7): 101.

Murphy, G., "The GUIDE". Skin Div*er*. 1987; 36(8): 57.

Murphy, G., "Skinnydipper". *Skin Diver*. 1987; 36 (9): 56.

Murphey, M., "Subaquatic Computers Compared". *NAUI News.* May 1988: 31-32.

West, D. and Edmonds, C., "Evaluation of the Farallon Decompression Meter". RAM SUM Report. 1976; 1.

**Personal Correspondence**

Bennett, P., Personal Correspondence, 1988.

Buehlmann, A., Personal Correspondence, 1987, 1988.

Hahn, M., Personal Correspondence, 1988.

Hermann, J., Personal Correspondence, 1988.

Huggins, K., Personal Correspondences, 1987, 1988.

Moody, M., Personal Correspondence, 1988.

Nikkola, A., Personal Correspondence, 1987.

Vollm, E., Personal Correspondence, 1987.

*John Lippmann's address is: P.O. Box 381, Carnegie, Victoria, Australia. 3163.*

## LIMBO DIVING - THE DANGERS OF FREE DESCENT
## CASE REPORTS OF TWO FATALITIES

Douglas Walker

### SUMMARY

The dangers associated with scuba diving are well documented and the region of maximum danger has been identified as the surface itself. The critical factors influencing the course and outcome of all dives are discussed in all diving manuals and by all who instruct others, but all make the unstated assumption that the diver and his buddy are well orientated in regard to their surroundings. This assumption does not hold true where the descent is made in deep open water in the absence of either a direct sighting of the sea bed below or close contact with some other fixed and recognised object, such as a descent line. Most divers in such circumstances would discover that they were untrained to accommodate to such conditions and would experience a degree of orientation and stress which would impair their responses to the problems they faced. Inappropriate responses due to diver error can very rapidly cascade into a situation of increasing danger. Two fatalities occurring in dives under such circumstances are presented.

### Case Reports

**Case 1.**

All the divers taking part in this club-organised boat dive were trained and had some experience, though not necessarily of this type of dive. The two divers involved in this incident were probationary members of the club but had shown evidence of their training and had been watched during a dive that morning to 18m (60 fsw) for 44 minutes and judged to perform correctly. The afternoon dive was off a rocky reef, in calm water and fine weather. The dive boat had its anchor in 19.5m (65 fsw) deep water a little off the reef and the depth under its stern was 24-25.5m (80-85 feet). As there was some current flowing from the reef towards the boat the divers were advised to swim underwater towards the reef after making their water entry, they were also advised to limit their dive depth to no more than 18m (60 fsw).

The victim and her buddy were the last pair to enter the water and although the dive marshal suggested that they descend down the anchor line it is probable that they failed to follow this advice and made an open water "free descent". As they entered the water the first pair of divers surfaced, having aborted their dive after only 13 minutes, and reported the presence of a down-current which had swept them into 24m (80 fsw) deep water while they were adjusting their equipment underwater. They also mentioned that visibility was so poor that they did not see the sea bed until they reached it. Unfortunately the victim and her buddy probably never heard this report of the conditions they were to experience.

It is not known exactly what happened but it is apparent from the buddy's account that they found themselves forced down by this current, initially to 30m (100 fsw) depth and then deeper still until they found themselves on the sea bed at a depth of 39-42m (130-140 feet). Here the victim seemed to be experiencing a problem with her breathing and gave an "out of air" signal. Buddy-breathing was initiated but shortly afterwards the victim "blacked out" and the buddy "shot to the surface" and called for help. A surface search was maintained but the victim never surfaced, and subsequent underwater searches failed to find any trace of either the victim or her equipment. There was no immediate underwater search because it was recognised that there was no chance of finding the victim alive, and minimal chance of locating her in the low visibility conditions in the presence of the current and depth-dictated short dive time allowable. The duration of the dive had been 8 minutes.