# Chapter 14

# DECOMPRESSION TABLES & METERS

Since the work of J.S.**Haldane** (a British physiologist) early last century, decompression tables have been based on mathematical models of gas uptake and elimination in the body. He believed (wrongly) that the exponential rates of uptake and elimination of gases would be equal, and that body tissues could tolerate a supersaturation pressure gradient of air equal to 2:1, without causing bubble formation. He experimented on goats – the closest animal model that he could get to the diver – to determine this gradient. Thus a goat could tolerate 2 ATA of air pressure in its tissues, even when walking around at 1 ATA! Or, it could ascend from 6 to 3 ATA, 4 to 2 ATA and from 2 to 1 ATA, without bubble formation.

Haldane devised mathematical equations (later referred to as models or algorithms) that would represent a diver, and applied this to dive exposures. He postulated 5 hypothetical tissues (with half-times of 5, 10, 20, 40, 75 min) and decompressed the diver so that the supersaturation gradient in each of these 5 tissues would never exceed 2:1. Once any tissue reached that ratio, the diver would stop his ascent and "stage" there until the tissue "off-gassed" to allow him to ascend to the next stop. Thus bubble formation would be avoided by this decompression.

Although used by the Royal Navy for 50+ years, it was evident that some of Haldane's dive stops, or stagings, were too conservative and others too radical. Also, the assumptions on which the procedure was based were wrong.

The acclaimed 1957 **U.S. Navy Tables** are based on Haldane's theories. These include equal exponential uptake and elimination of inert gases and supersaturation gradients – as described in Chapters 1 and 13 – but have been modified by experimental trials and practical diving experience. In an attempt to overcome the flaws in Haldane's tables and to make decompression safer, they increased the number of hypothetical tissues to 6 (5, 10, 20, 40, 80 and 120 minutes), and calculated different maximum safe supersaturation ratios (now called M values) for the different tissues at different depths.

Following experiments and reviewing of the established decompression tables, between 1960 and 2000 a whole series of innovations and modifications were introduced. Dr Bruce Bassett (a USAF physiologist) concluded that the US Navy Tables resulted in an excessive incidence of about 6% DCS, when pushed to the no-decompression limits. Merrill Spencer in Seattle verified this observation and supported it with extensive Doppler monitoring, showing that bubbles developed in many routine dives – implying inadequate decompression. Many others observed similar inadequacies and in an attempt to cope with this new information, tables based on modified Haldane principles were developed by Bassett, Huggins, NAUI, PADI, and many others.

The main alterations to improve safety were in;

- reducing the acceptable no-decompression times by 10-20%
- reducing ascent rates from 18 m/min to 9-10 m/min (at least in the top 30m)
- Adding a "safety stop" of 3-5 min at 3-5 m.

The Swiss decompression expert, Professor **Buhlmann** produced the Swiss model, which includes 16 theoretical tissue compartments with widely ranging half-times. The testing of these tables at altitude became more extensive than for most other tables, and he extended the concept into repetitive dives. Much later the US Navy E/L model assumed an exponential uptake of gas and a linear loss to eliminate gas

In the UK, Hempleman introduced a slab diffusion concept, which later evolved into the RNPL/BSAC tables. A cylinder of tissue was used by Hills in Australia. Other groups assumed the presence of bubbles or bubble forming nuclei, bypassing the traditional gas-in-solution supersaturation concepts, and decompressed in such a way as to keep the bubbles at a tolerable level. These are sometimes referred to as "**bubble models**"

Yount in Hawaii developed tables designed to keep gas nuclei from forming larger bubbles, and the allowable pressure gradients across these nuclei were less than Haldane's supersaturation ratios. Thus the no-decompression times were less, the initial decompression stops were deeper and the ascent rates were slower. Weinke developed these concepts further in the Reduced Gradient Bubble Model, and has collected some diving data based on these tables.

The Canadians (**DCIEM**) considered the transfer of gas between adjoining tissues as a major principle, and produced a very well researched table, popular amongst conservative recreational divers. Although based on decompression theory, it has been modified by extensive human testing in cold water and hard working conditions, with Doppler (ultrasound) monitoring. The single no-decompression times, and most repetitive dives, are more conservative than the US Navy tables and are often recommended for recreational diving.

Another approach involves the collecting of a vast number of well-documented dive profiles, some safe and some unsafe, and letting the computer devise the safe tables. Extending this concept, the US Navy, and now DAN, use such statistical analyses to determine the probable DCS disk with each dive profile and so "probabilistic" tables that accept a defined DCS incidence of 1%, 2.3% or 5% can be derived – in theory.

When the formal tables were pushed to the limits (decompression diving, deep diving and dives approaching non-decompression limits), there was an unacceptable 1–5% incidence of DCS. Even in divers who appeared unaffected, Doppler (ultrasound) studies often showed bubbles in the major veins during decompression. Nevertheless, in both recreational and navy diving there is only a 1/5,000 to 1/10,000 incidence of clinical DCS. This paradox is explained by the fact that most dives do not approach decompression or depth limits and so do not really test the tables. Also, divers include conservative modifications or "fudge factors", making their diving safer. Even the US Navy has modified its "gold-standard" table by reducing ascent rates and incorporating safety stops, making it marginally safer than it was.

It is not possible to make a perfect mathematical model of the decompressing human body. Even under normal conditions, the blood flow to some capillary beds shuts off from time to time, while flow to other areas increases. During decompression, nitrogen elimination will virtually cease from an area of shutdown capillaries. As decompression proceeds, this area will have a much higher $N_2$ concentration than predicted. No mathematical model can predict biological phenomena such as this.

When one considers the ill-defined complexities of gas transport through the range of different tissues, all with different solubilities, different supersaturation tolerances, different nuclei quantity and location - all at different depths, durations and ascent rates - the accurate representation of bubble development with mathematical equations, models or algorithms, is impossible at this time. Even if one could so define the evolution of bubbles, there are many other problematic biochemical and haematological sequelae, as well as individual susceptabilities, in the development of DCS manifestations, that reliable modeling is not yet likely

Any decompression table or computer algorithm that offers longer durations underwater, deeper or more dives, will result in a greater incidence of decompression illness, unless compensated for with slower ascent rates and longer decompression.

The imminent release of brilliant "new" tables is a permanent rumour. The difficulty in producing mathematical models which truly reflect human decompression physiology upon which to base the tables or computers, as well as the difficulty and expense of testing them, makes the development and validation of tables based on truly new models unlikely. However, tables and computers based on recycled mathematical models do frequently arise and often there is an amalgamation of decompression theories.

Towards the end of last century recreational diving involved more repetitive dives and multi-level diving. It reflected the interests of recreational divers, taking diving holidays, on live-aboard boats, exploring reefs and drop-offs. This was considerably different to the pre-planned single-depth/designated-duration dives of navies and commercial divers. With much recreational diving, relatively little time is spent at the maximum depth. Attempts to accommodate for these different diving profiles were attempted, with ingenious innovations by Graver, Huggins, the PADI RDP and Wheel, etc., with variable success. Others, such as the Buhlmann tables were more easily modified to incorporate the greater number of variables with multi-level and repetitive diving.

For any given nitrogen loading, multi-level diving from deep to shallow should produce less DCS than the single-depth dives documented in the formal dive tables. However, decompression from the infinitely variable multi-level diving is almost totally based on theory**.** There have been no adequate and comprehensive trials performed to show the tables reliability.

For both theoretical and practical reasons, most dive authorities advised divers to dive to progressively shallower depths, when repetitive or multi-level diving. This is referred to as a “Forward Dive Profile”. About a decade ago there was a misplaced academic campaign to accept “Reverse Dive Profiles” as having equivalent decompression obligations, as an acceptable diving practice, without incurring decompression penalties. Both experimental evidence and diving experience subsequently showed that the traditional “deep dive first” concept is correct, in both multi-level and repetitive diving. If reverse dive profiles are to be used, they will require new decompression schedules, often with longer decompression requiremts.

# DECOMPRESSION METERS
# and COMPUTERS

With the preponderance of multi-level diving, repetitive diving and multi-day diving, the expedient introduction of decompression meters (DCM) and decompression computers (DC) resulted in a gradual reduction in the use of established tables and an acceptance of the new technology.

These meters are based on three different principles:

## ❑ Mechanical models of gas transfer. Decompression meters. (DCM)

The early meters in the 1960s relied on the movement of gas through small orifices to simulate uptake and elimination of nitrogen by compartments of the body. They are obviously a gross oversimplification of the gas transfer in divers but one, the **SOS meter**, was moderately safe for single shallow non-decompression dives to less than 24 metres.

## ❑ Electronic decompression models of existing tables.

These devices of the 1970s recorded the depth and time of a dive and related this to one of the existing decompression tables which was stored in its memory. One was even incorporated into a wristwatch. They saved the diver the difficulty of recording his depth and time, reading and remembering the tables.

These meters were not been very popular, because they did not offer any decrease in decompression obligation compared to the conventional tables and represented quite an expense merely to save the diver the trouble of applying a decompression table.

## ❑ Decompression computers (DC)

These are electronic models based on decompression theory. Microprocessors developed for computer use were incorporated into the diving world with the Edge (USA) and Decobrain (Switzerland), in the 1970s. Instead of following the tables, with their inevitable rounding up of depths and durations and the associated safety factors involved in overestimating pressure exposure, they were far more precise in their measurements and calculations. This meant that they could meticulously track the dive exposure and use algorithms to calculate in real time the nitrogen uptake and decompression required, according to any predetermined decompression theory. The safety of the DC then depends on the validity of the theory.

**Fig. 14.1**

DCs are of great value to divers, if they are used correctly. They have more accurate gauges (depth, duration) than previously available and this information is stored in a more reliable computer than the divers' narcotised memory. The incorporation of an ascent meter and alarm is invaluable in warning of rapid ascents.

These meters are programmed with one of the mathematical models (theories) on which the conventional tables have been based (usually the US Navy, Buhlmann or “bubble” tables) and this allows for multi-level and repetitive diving calculations. Because of this, and the avoidance of the rounding-up safety features inherent in the tables, the DCs usually permit longer dive durations, more flexibility in dive depths and repetitive dives, shorter surface intervals and less intellectual demand than “table diving”. There are currently over a dozen different algorithms determining decompression in DCs. In general medicine, there is an axiom that the more treatments that there are available, the less likely it is that any work well. Same with diving medicine and DCs .

Flexibility can be incorporated and with the more advanced DCs, there are optional safety factors and restrictions. One can determine whether the DC behaves more conservatively than the theoretical algorithm normally calculates, allowing for increased age, weight, importance etc – but at the inevitable cost of a reduced dive duration. Many also indicate altitude (flying) restrictions post dive.

Most cases of DCS treated nowadays occur in divers who have correctly followed the instructions computed by their DCs. Probably over 90% of divers now use DCs instead of decompression tables, and considering the poor comprehension of the tables, this is probably a good thing. It certainly means that when an accident does occur, a comprehensive dive profile can be downloaded onto another computer for analysis, in retrospect – and sometimes to the embarrassment of the diver who pleads innocence of his misdemeanours.

## ☐ Disadvantages of decompression computers.

Sophisticated electronics, batteries and sea water are sometimes not compatible. Machines and technology sometimes fail. Back up plans are advisable.

The price to be paid for more dives and longer durations, without longer decompression, is increased DCS.

Most DCs employ algorithms that have not been adequately validated. When each of the conventional decompression tables was first formulated from a theoretical model, it had to be extensively modified based on human testing. Essentially, the DCs are offering the tables as they were, before they were modified with safety factors. With the removal of the tables rounding-up safety factors, the price divers pay for their extended underwater durations is that they can dive much closer to the DCS margin.

Most of the new DCs are (like the old SOS meters) conservative for short single, shallow dives. The dangers increase with longer, repetitive or deeper diving. They are also probably less safe with some multi-level profiles, if reverse profiles are used.

Nevertheless, DCs are popular and deservedly so. They are perceived as an alternative to personal responsibility in coping with a difficult problem (decompression table calculations). Unfortunately, to question the value of any specific computer can be interpreted as blasphemy, casting aspersions on the owners, bringing a deluge of unsolicited testimonials and threats of legal action by the manufacturers.

### ☐ **Safety suggestions** (the **DC Ten Commandments**).

If you rely on DCs, the following recommendations are made:

1. Do not dive in the 24 hours before using the DC.
2. The DC should be used on **all** dives, if it is used on **any**.
3. Ensure a back-up documentation of the dive profile and details.
4. In multi-level dives, the depths should be progressively shallower.
5. Repetitive dives (on the same day) should be progressively shallower.
6. Repetitive dives should have surface intervals of at least 2 – 4 hours (longer with greater depths and longer dives).
7. With multiple days diving, every fourth day should be non-diving.
8. Add an extra decompression safety stop for 5 minutes at 5 metres, on each dive in excess of 15 metres depth, if practicable.
9. Do not do dives that require decompression or go into the decompression mode. Stay as far away from those dives as possible.
10. Do not presume that the DC is accurate for diving at altitude or for altitude exposure (flying).

DCs are preferably used at depths of less than 30 metres and definitely depths of less than 40 metres. Pseudo-science accompanied the technology in the promotion of these DCs, and many claims of excellence were more applicable to the colour brochures and marketing than any research or development activities.

For those divers who are more important, or are more susceptible to DCS (age, gender, fitness, weight, medications, injuries, DCS history, etc.) or undertaking more hazardous dives (depth, duration, decompression obligation, temperature, currents, repetitive, multiple ascents, etc), the more conservative modes on the DC should be chosen.

## PREVENTION of DCS

See the last page of Chapter 16