DECOMPRESSION TABLES, THEIR USE AND PROBLEMS

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Introduction

The decompression of divers, caisson workers, aviators and astronauts is occasionally complicated by dysbaric illnesses, including barotraumata, decompression sickness (DCS) and arterial gas embolism. To limit the occurrence of DCS, these decompressions are usually performed in accordance with a set of depth-time rules, a decompression table. It is hoped that by using these tables the rate of excretion of inert gases from the lungs will prevent gas bubbles from forming in tissues and in venous blood, and hence that DCS will be avoided. The frequent occurrence of DCS in all of these groups demonstrates that either available decompression tables cannot prevent DCS or that none of these groups can adequately comply with available tables. It is most likely that virtually any decompression can generate gas bubbles, that the response to such bubbles varies in an individual considerably from day to day and is a major determinant of the outcome of any decompression, and that conservative decompression practice only reduces the probability of DCS and can never totally prevent it. A risk-benefit approach to activities such as diving is obviously then the most appropriate one, and the concept of a "safe" decompression table is almost certainly naive.

The History of Decompression Tables

Although diving is an ancient occupation, the first recognised decompression table was only prepared for the British Admiralty in 1908.[1] This table was based on experiments performed on goats using an end point of symptomatic DCS. The significant probability of DCS associated with use of this original table for deep long dives was in part due to limitations with the experimental design, but largely due to the insensitivity of the chosen end point, clinical DCS. It would appear that bone, brain, and spinal cord damage can occur without overt focal symptoms.[23] The sensitivity of decompression testing has subsequently been increased by the use of ultrasonic bubble detection which has been able to detect mobile venous bubbles before symptoms of DCS emerge.[4] However, the Doppler apparatus used in these experiments only detects moving bubbles, cannot identify their source, and both the identification of bubbles and the determination of bubble frequencies is subjective. There is also an increasing belief that stationary tissue bubbles may be pivotal to the development of both tissue damage and dysfunction after diving. The simple problem is that the characteristics of the critical bubble whose formation has to be avoided in a decompression are yet to be described. Similarly, the pivotal role of complement protein activity in an animal model of DCS,[5] the cycling of blood vessels through open and closed phases,[6] the inability of single function exponential statements to describe gas kinetics,[7-9] and the extremely slow elimination of inert gases in comparison to their uptake,[10] all explain why existing "physiologically based" decompression tables, which do not take these phenomena into account, cannot describe actual events in a diver. The science of decompression table development has consequently become empirical, and since 1908, although they have been hidden behind physiological theorems, the modification of the original decompression table and the development of new tables has been a pragmatic exercise. It follows that testing of decompression tables in the field to a level of statistical significance should be the yardstick by which tables are measured and not the attractiveness of the underlying theory.

The original 1908 decompression table theory[1] incorporated the concepts that uptake and elimination of inert gases were mirror images of each other, that both of these processes were primarily influenced by the blood flow to a tissue and the solubility of the inert gas involved in that tissue, and that gas bubbles did not form in tissues until a critical super-saturation of tissue inert gas was reached. Almost certainly none of these assumptions are valid, but nevertheless, with the exception of some British decompression tables which were based on diffusion-limited uptake and a set of thermodynamic equilibrium tables,[6] similar assumptions are intrinsic to those tables being developed currently. What has been changed in these calculations is the number of tissues thought to be critical in the development of DCS, and the nature of the tolerable inert gas supersaturation.

Problems in Decompression Table Development

In two separate experiments,[11,12] gas bubble formation has been shown to significantly inhibit inert gas elimination. There are two immediate consequences of this observation. Firstly, the ideal decompression is that which creates the greatest possible gradient for inert gas elimination from a tissue without causing bubbles to form. Secondly, repetitive diving, multiples ascents within a single dive, and surface decompression procedures must be (and are) significant risk factors for DCS.[13] The fundamental problem in decompression table design is that the rules that govern a single dive and ascent are not applicable for circumstances when some tissue bubbles exist, as inert gas elimination will be slower and smaller decompressions will result in DCS. Surface decompression procedures (when a staged decompression is interrupted by decompression to the surface with subsequent recompression in a recompression chamber and then resumption of the original decompression, usually from a slightly greater depth than that from which the decompression was interrupted) in particular are thought, with some justification, to be "semi-controlled accidents".

Although considerable attention has been given, in both recent decompression table development and decompression-meter manufacture and marketing, to increasing allowable diving exposures by measuring the real depth-time exposure, rather than assuming the entire dive is spent at the maximum depth of the dive, it is the consequences of bubble formation that are critical to future decompression table design. In addition, this increased allowance for diving exposures by real depth-time monitoring must increase the frequency of DCS for any given decompression table.

A common practice now is to perform "safety" stops at 3 msw (10 fsw) even when the decompression table being used does not require any decompression stops. Such stops will have little benefit if bubbles have already formed, but should on their own do little harm. A more acceptable procedure is to perform those stops required of the first time interval for the greatest depth of the dive which does require a staged decompression to the surface. This is especially relevant for dives beyond 30 msw, where available risk data show that it is probably impossible to do a no-decompression dive (no decompression stages) and still have a subsequent probability of decompression sickness of less than one percent.[14]

The final difficulty in decompression table development is establishing the probability of decompression sickness associated for the individual depth-time formats and in each of the special procedures (repetitive diving, surface decompression). To do this with 95 percent confidence is practically impossible for all of the potential combinations, so a series of selected dives should be tested across the range of possible exposures to this level of significance. A sequential analysis[15] (35 dives without DCS needed before a DCS rate of less than 2 percent can be claimed) or a binomial distribution approach[16] (60 dives without DCS needed before a DCS rate of less than 5 percent can be claimed) are suitable techniques for such testing. With the possible exception of the Canadian Defence and Civil Institute of Environmental Medicine Tables,[17] none of the available decompression tables have been tested to this degree. For example, a common procedure has been to consider a table safe if 10 dives were performed for a particular depth-time combination without incident. In fact such an outcome only determines that there is a 35 percent chance that the associated probability of decompression sickness is less than 10 percent. In addition, it is essential that this testing be done in the ocean and involve real work, as both will significantly increase the rate of DCS in comparison to dives in recompression chambers of any sort or resting dives.[15,16,18,19]

Summary

It follows then, that although thee has been considerable experience in the use of decompression tables since 1908, that there has been little or no advance in real understanding. It also follows that until a new understanding is developed by the application of modern pharmaco-kinetic principles to gas-kinetic studies that decompression tables should be selected on the basis of their proven efficiency in avoiding DCS, and that procedures such as repetitive diving, multiple ascents within a single dive and surface decompressions should be avoided if at all possible.

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ARCHAEOLOGICAL DIVING IN AUSTRALIA A MEDICAL PERSPECTIVE

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Introduction

Why do students, a Qantas pilot, a customs agent and others want to spend two weeks training in archaeological diving? For some amateur (defined here as one who loves a field[1]) divers there is more than the lure of treasure hunting or the sport of wreck diving. In common with the underwater archaeologist, they share a fascination with the past and its reconstruction. The exploration of Australia has left our coast littered with hundreds of underwater time capsules. Until now, no formal training in scientific diving (archaeologist, biologist, oceanographer) has been available in Australia. Eight amateur divers and one professional underwater archaeologist recently undertook the first NAUI/CMAS Divemaster-Scientific Diver Training Course conducted by Sci Dive Australia in Far North Queensland from March 31st to April 15th, 1989.

This article will discuss aspects of such training and the role of the diving physician on such an expedition, which culminated with work on what is probably Australia's most important shipwreck, HMS Pandora.

Underwater archaeology is a relatively new discipline. Pioneering work in Australia commenced in 1969 with members of the Western Australian Maritime Museum inspecting, and later excavating the Dutch East Indiaman, Batavia, (wrecked on the Abrolhos Islands, West Australia, in June 1629)[2,3]. Artefacts raised from this vessel have included sufficient timbers to allow partial reconstruction of the vessel and many items of her extraordinary cargo. These have included a selection of silverware, stoneware jugs, smoking pipes, astrolabes, a pocket sundial and even a portico facade destined for the gateway to the company's castle in Batavia (now Jakarta, Indonesia).

Since then many thousands of archaeological dives have been undertaken on shipwreck sites around Australia, the Indian Ocean, south east Asia and the Pacific Ocean. Also many dives have occurred on wreck sites by sport divers and treasure hunting divers. Archaeological diving will be emphasised in this article.

As in other scientific diving disciplines (biology, oceanography, etc.) formal archaeological training is required for a systematic approach so that the maximum amount of information can be uncovered. The reconstruction of our past through maritime archaeology is a precise, time consuming discipline. Thus the 30 or so professional archaeologists now working around Australia have required hundreds of enthusiastic volunteers to help in their work. Lured by the romance of underwater archaeology, they are then faced with the reality of long arduous days in remote sites, diving at times in hazardous conditions, as shipwrecks are not noted for occurring off calm, balmy white beaches. On top of this there is new equipment and techniques to master. Despite this much valuable work has been done by amateur divers working with professional archaeologists with an excellent safety record.

In Western Australia over 10,000 archaeological dives have taken place[4] over the last 30 years at various sites along the coast. These include the wrecks of the Rapid, Batavia, Lively, Trial, Zuytdorp and Zeewijk to name a few. These sites are usually in less than 18 m, mostly in remote locations and many are exposed to surf (Lively, Trial and Sirius).

A medical officer has accompanied all major field trips in WA. So far no fatalities have occurred. No cases of decompression sickness (DCS) have been diagnosed. One case of cerebral arterial gas embolism (CAGE) has been successfully resuscitated, evacuated and rehabilitated. Three cases of severe marine stings, one stingray and two jelly fish, have occurred. While a number of minor illnesses and injuries have occurred, for example, a salt water aspiration syndrome like condition has been common in new divers to some sites, the safety record has been admirable.

The wreck of HMS Pandora, which sank in 1789, lies in 31-37 m of water on the outer Barrier Reef, at approximately 11°S 144°E. Surface conditions are relatively calm though the local reef configuration produces frequent and unpredictable changes in the ocean currents, even on the sea-bed. Water temperature is 14-16°C (average sea-bed), and