ROYAL ADELAIDE HOSPITAL

HYPERBARIC MEDICINE UNIT

Basic Course in Diving Medicine

Content Concentrates on the assessment of fitness of candidates for diving. HSE-approved course.
Dates Monday 8/2/99 to Friday 12/2/99
Monday 1/11/99 to Friday 5/11/99
Cost $Aust 750.00

Advanced Course in Diving and Hyperbaric Medicine

Content Discusses the diving-related, and other emergency indications for hyperbaric therapy.
Dates Monday 15/2/99 to Friday 19/2/99
Monday 8/11/99 to Friday 12/11/99
Cost $Aust 750.00
$Aust 1,300.00 for both courses taken back to back

For further information or to enrol contact
The Director, HMU,
Royal Adelaide Hospital, North Terrace
South Australia, 5000.

Telephone	Australia	(08) 8222 5116
	Overseas	+61 8 8222 5116
Fax	Australia	(08) 8232 4207
	Overseas	+61 8 8232 4207

DIVING MEDICAL CENTRE

SCUBA DIVING MEDICAL EXAMINER'S COURSES

A courses for doctors on diving medicine, sufficient to meet the Queensland Government requirements for recreational scuba diver assessment (AS4005.1), will be held by the Diving Medical Centre at:

Bond University,
Gold Coast, Queensland.
2nd-4th April 1999 (Easter Holidays)

Previous courses have been endorsed by the RACGP (QA&CE) for 3 Cat A CME Points per hour (total 69)

Phone Brisbane (07)-3376-1056 for further details

Information and application forms for courses can be obtained from

Dr Bob Thomas
Diving Medical Centre
132 Yallambee Road
Jindalee, Queensland 4047
Telephone (07) 3376 1056
Fax (07) 3376 4171

SPUMS ANNUAL SCIENTIFIC MEETING 1998

DECOMPRESSION THEORY IN THIRTY MINUTES

David Elliott

Key Words

Decompression illness, history, occupational diving, physiology, tables.

Introduction

The recognition of pressure-related illnesses in divers and compressed air workers and the first ideas on the control of those hazards evolved almost blindly and with little scientific direction during the 19th century. A long time passed after the publication of Paul Bert's work in 1878 before there was any real recognition of its message by the worldwide scientific community.[1] The pioneering applied science of John Scott Haldane began some 25 years later.[2] Haldane focussed upon the applied physiology of diving while, at the same time, Sir Leonard Hill was making the first quantitative analyses of nitrogen in blood and urine at pressure.[3] Hill favoured the ΔP concept, a constant pressure difference for the linear decompression of caisson workers. Each physiologist made contributions to both diving and compressed air work but, in spite of arising from a common stem, the subsequent development of safe decompression procedures for the shallow but prolonged dry exposures of compressed air workers has followed a different path from that for divers. The lessons to be learned by divers from caisson work today are few and, if anything, the transfer is now in the other direction. It is therefore the purpose of this brief review to focus on aspects of the development of decompression theory and confine that to only diving. And somehow all this has to be done in a time slot that would make a single evening for the condensed performance of all Shakespeare's plays seem generous.

To maximise the benefit, if any, from such a speedy approach it might be helpful to sketch out the route now be followed and identify some of the features to be spotlighted. Those who then wish to read more deeply in this subject with either a detailed research review,[4-7] or simply an advanced instructional text,[8] can use this brief overview as a guide to some practical difficulties that often seem overshadowed by computational wizardry.

Impossible variables

Decompression theory is readily amenable to mathematical modelling but the reality of trying to apply this theory is the basic problem which has bedevilled all research in this field, that of inter-individual and intra-individual variation. An example of the first is that "4% of the workforce get 50% of the bends"[9] and of the second is the common observation of a diver getting "hit" on a much safer profile than usually dived. What Haldane and his successors have done so effectively over the last 90 years for the safety of the diving population as a whole does not necessarily hold true for you on your next dive.

The presence of biological variation was acknowledged in some of the early studies but, at the beginning of this century, the morbidity was so gross that such subtle considerations were not necessary in order to make considerable progress. In later years, decompression scientists have reviewed some of the relevant factors but have not been able to integrate them into their mathematical models. Not surprising when one has to consider not only the effects of exercise at depth and during decompression, of hot water at depth and cold during decompression upon gas dynamics, but also all the individual factors, from age to hydration that may be related to susceptibility. Indeed, the pessimist can reach the conclusion that one mathematical model, however complex, for all divers is an impossible target, just on the basis of no more than the evidence of one case of a successful response to therapeutic recompression of a knee "bend" which followed some 30 min after a 5-minute bottom time dive to 100 feet (30 m). That bend, and there are many like it, is outside the predictive models used for regular tables and has to be handled in some other way. Probabilistic tables can cope with this extreme phenomenon but, of course, may be too long to be practical and of no consolation to the one diver who does get hit. Figure 1 (on page 211) shows the wide variability of no-stop curves (mild bends end point) in goats.[5]

Another underlying problem can be summarised by the title chosen by Nashimoto for a UHMS Workshop:[10] *"What is Bends?"*. There are no internationally accepted criteria to define the boundary between a dive that is clean and one that is not. What indeed was meant by different authors by the term "bend" when one reads reports on the bends incidence of different decompression procedures at different times and in different locations? Until Nashimoto's question *"What is bends?" can* be answered precisely, there is also no answer to the one question which is the foundation of today's quest for decompression safety, *"What is a safe decompression?"*

The main end-points that have been used in decompression studies in man over the years have included:

1 **reported symptoms, and physical signs** if detected, but these are largely dependent on the individual diver's reporting threshold. Severity ranges from vague "niggles" in the joints to a life-threatening illness, so where is the end-point to be defined?

2 **bubble counts in man**. Used successfully for the comparative testing of the Canadian tables[11,12] but not always reliable for diagnosing decompression illness.[13]

3 **recompressions**. Where a chamber is readily available, this is a definite event but, in addition to the reporting threshold of the diver, recompression is dependent also on the interpretation of the diver's symptoms by the chamber operator and/or diving doctor,

4 **long term outcome**:[14] ranging from neurological residua to bone necrosis.

Also to be considered in the development of decompression tables are the methods by which they were evaluated, with what subjects, under what circumstances and, again, how the end-point was assessed. Early naval tables were tested by sample profiles being dived under careful supervision by a relatively small team of fit young divers, well acclimatised to this type of diving. The target at RNPL in the development of deep helium bounce and repetitive air dives in the 1960s was to achieve "10 clear dives", defined by no recompressions. It was later calculated by Homer and Weathersby that as many as 40 dives might not indicate anything more precise than a bends risk for the dive of somewhere between 17 and <1%.[15]

Even when using a consistent end-point, the "bends percentage" is potentially misleading. If 10 men each perform 100 dives on a specified schedule and between them, in those 1,000 dives, there are 10 episodes of bends, then there can be alternative ways of presenting this 1% exposure rate.[9] By most table and probability assumptions, this risk is considered to be evenly distributed among the diving population. This means that at some time each diver would have had one bend and so this would be, for the 10 men involved, a 100% bends rate. Given the association between a history of recompression and the later development of osteonecrosis, this could be a more meaningful figure. If, at the extreme of biological variation, one susceptible man had all 10 bends then the best figure for this trial is that 10% of the divers were affected, but it is still 1% of exposures, the most commonly used index.

After the acceptance of a "tested" naval table into use, the subsequent reported bends incidence at sea may be different and this may be a reflection of procedural differences between the meticulous testing of the printed tables and the way in which operational dives are actually performed. Indeed, the tables may be safer "as used" because of the introduction of additional safety factors on site when estimating depth and duration.

Decompression table testing

In place of the linear decompressions recommended by Bert and von Schrotter,[1,16] a staged decompression was introduced by Haldane[2,17] based on 5 hypothetical compartments in the body (misleadingly called "tissues") with half times for gas uptake or elimination of 5, 10, 20, 40 and 75 minutes. The latter tissue was chosen because a 75-min tissue becomes 95% saturated in 5 hours and, as advised by E S Moir, compressed air workers did not appear to get an increased number of bends once they exceeded 5 hours at pressure. Haldane recommended an initial decompression, provided that this was from less than 6 atmospheres absolute (i.e., a depth of 50 m), to half the absolute pressure. This was then followed by the appropriate series of predetermined stops. In the same report it was recognised that an inadequate flow of air causes a build-up of carbon dioxide in the diver's helmet and that it was necessary to increase the minute volume in proportion to the increased pressure of depth. The Haldane tables were adopted by the Royal Navy in 1908 and subsequently adapted by the US Navy who added a 120-min half time compartment giving 98.5% saturation in 12 hours. Stillson also reduced the Haldane 2:1 ratio to 1.58:1 and included the option of oxygen decompression in these USN "Construction and Repair" Tables.[18]

In the UK , Damant and Davis also reduced the ratios and, for dives between 120 and 330 feet (36 and 100 m), introduced oxygen stoppages.[19] In the USA, Hawkins, Shilling and Hansen analysed several thousand dives and concluded that the faster compartments could tolerate higher ratios.[20] Their subjects made daily dives, 5 days a week, with 8 subjects at each depth and time of exposure. The stated end-point in each of these runs was the "production of caisson disease of severe enough nature to necessitate terminating the series".

Yarborough revised the Construction and Repair table,[21] eliminating the 5 and 10 minute tissues, and these resulted in a bends incidence of 1.1% but, as discussed, this percentage is not necessarily comparable with rates from other tables or other locations.

During the Second world War, there was much basic research on bubble nucleation and growth and on the patho-physiology of decompression in relation to high altitude and diving, excellent work that still repays reading.[22] After the war the Yarborough tables were reassessed and a very much higher bends incidence was found on deep dives. It was concluded that, to control decompression on the deeper stops, the 5 and 10 minute compartments should be reinstated.[23]

The US Navy also developed 'surface decompression' tables,[24,25] seemingly unaware of the experience of this procedure (*"crash surfacing"*) gained by Wotherspoon's divers in the cold waters of the St. Lawrence during salvage operations on *The Empress of Ireland* in 1914 and later by Damant during salvage of *Laurentic*.[26]

Behnke drew attention to a disequilibrium in gas tensions which he termed "the oxygen window".[27,28] US Navy tables were taken further by Workman who used half times of 5, 10, 20, 40, 80 and 120 minutes and revised values for the surfacing ratios.[29] These Workman tables are the basis of most tables which are in use today. To test these dives, 6 "clear" exposures were validated on each of the 88 computed schedules by naval divers exercising in water.[30] Workman subsequently developed the concept of M-values which defined the maximum tissue pressure (M-value) in feet of sea water for each tissue at each stop and for surfacing.[31]

In 1952, Hempleman questioned Haldane's concept of perfusion as the dominant factor for inert gas uptake and proposed a radical new approach:[32,33] a single tissue with diffusion as the rate-limiting factor. Essentially this suggests that the critical excess quantity of dissolved gas = $P\sqrt{t}$, and this provides, where t is less than 100 minutes, no-stop times which are very close to the US Navy's no-stop curve. Using this principle, the consequent RNPL 1968 Air Tables were relatively conservative and, although not popular for that reason among recreational divers, they were used successfully in the UK for deep and arduous working dives.

Hills continued the debate on what he called *"the perfusion diffusion confusion*" by using a thermodynamic model based on outward radial diffusion from a capillary perfusing the length of a hypothetical cylinder of tissue.[5] These and other aspects of his model were expressed in complex formulae, which I consistently failed to master, but his output was a series of ideas and pilot studies, each of which spotlighted contemporary controversial assumptions.[34] Also, in another laboratory while he was at RNPL, the unpredictable dynamics of flow and flow reversal within individual capillaries to be seen in a rabbit ear-chamber were a practical reminder that major individual variations can occur which may be concealed within the averages of large populations.

An exponential-linear uptake and elimination model was then used by the US Navy for the development of "constant PO_2' decompression profiles which have been successfully tested and are the basis for a decompression computer for air diving.[7,35]

Because the naval decompression tables were designed for "square wave dives", they are perceived as penalising the recreational diver by their inflexibility for multi-level dives. The recreational training agency PADI introduced tables with multi-level and repetitive procedures for their recreational divers, who are expected to stay within no-stop limits. Another recreational training agency, BSAC, produced their own tables designed for decompression diving. However, even in the no-stop range, the majority of recreational divers prefer to use personal diving computers for decompression safety. These provide immediate on-line guidance based on the actual pressure-time profile to that moment. A pioneering analogue computer was based on a mechanical series of compartments[36] but now all personal computers are digital and use a pressure transducer for input. A few computers are based on the established tables, such as those of the US Navy, but most now contain a pre-programmed mathematical decompression model selected by the manufacturer. There are many different computer models of inert gas uptake and elimination is use,[37] some based on modified Haldanean models, some developed by the late Professor Bühlmann (several using a 0.877 bar reference pressure for diving at altitude), some based on the mathematics of bubble growth and resolution, with a few based on yet other concepts, but all have one thing in common, like the tables before them, they cannot cater for the individual purchaser. Each internal computer program must cater for everybody with sufficient “padding” in the computer’s calculations to ensure a very low probability of decompression illness in the worldwide buying public.

Although, therefore, most computers will tend be oversafe for the majority of divers, even this may not be perceived by some divers to be safe enough. There may appear to be no obvious way of introducing additional safety factors for a susceptible diver but switching the computer into the altitude mode when diving at sea level merely shortens all the no-stop times, e.g. at 18 m with one computer to 39 minutes (from USN 60 min and DCIEM 50 minutes), and at 30m from 18 minutes in the same computer to 14 minutes (c.f. USN 25 minutes and DCIEM 15 minutes). This is not very popular with one’s buddy and, in any case, is merely an arbitrary change to the underlying mathematical model, not a logical one. A more acceptable alternative is to breathe nitrox (oxygen-enriched air; EANx) and then decompress as though on air, but this too says much about our scientific ignorance of determining the safe limits when it comes to planning a safe decompression for the individual.

For an experienced young and fit diver, who wants to avoid being penalised in terms of useful bottom time by what he may perceive as oversafe decompression models designed for the elderly and infirm, purchasing a personal computer with “improved algorithms” will not necessarily be the right answer. The phenomenon of acclimatisation to decompression stress is real but cannot be accounted for in a quantitative manner. Equally real is a fairly common observation that after many dozens of safe but extreme dives, suddenly and for no obvious reason, the same dive again is this time followed by devastating paralysis. Probability theory may be useful but, once the level of risk has been selected, there is little of predictive value about individual outcome that will influence the planning of the next dive.

Validation of the underlying models

Some years ago, factors related to bends-rates were analysed, in confidence, for the UK Department of Energy by Shields.[38] This project was dependent on the North Sea contractors providing the commercially sensitive paper records (logs) for each of many thousands of air dives. Verification of the data and elimination of some erroneous dive records from the analysis were conducted in accordance with predetermined criteria. They also provided their bends data which was reviewed by an independent and experienced consultant. Figure 2 (on page 210) shows two values of Shield’s index of decompression severity (P√t) plotted over a background of diving activity in the North Sea.[38]

On the public release of the results there was concern that the basis for this analysis, the use of P√t as a measure of potential decompression severity, was not valid for the subsequent decisions relating to decompression performance.[6] P√t was used as an index of only the gas loading at the end of the dive’s bottom time, assumed that the dive had been spent entirely at its maximum recorded depth, and so took no account of the decompression, which of the available commercial sets of decompression tables had been used, nor what additional safety factors of depth and duration had been introduced when the specific decompression profile for the actual depth and duration was selected, nor how well the actual decompression had been followed. For example, none of the contractors followed the published USN Surface Decompression tables but, because of bends experience, each contractor had introduced their own private extensions to the final oxygen decompression from 40 feet (12 m) to the surface. If that did not work maybe they modified them again, and so every table was different. Nor did P√t reflect deviations from the established maximum of a 5 minute surface interval in the surface decompression procedures.

Within the wide range of the different “proven” tables selected (but probably no “cowboy” tables) and the range of ways in which they are actually used, it is not surprising that it was said that there are no obvious differences between them in their gross effectiveness, as estimated on the basis of classifying all dives just by depth and bottom time. Because of commercial confidentiality, the HSE was not able to publish comparisons between company tables but has said informally that there were no detectable differences.

Thus it seems that all these different tables were so similar that any differences in bends rates between them were swamped by the other factors, such as the use of hot-water suits. Nevertheless, in spite of those deficiencies, which were due to decisions taken by the Department of Energy (later the Health and Safety Executive), the results of their recommendations were surprisingly effective and were based on the observation that distribution of

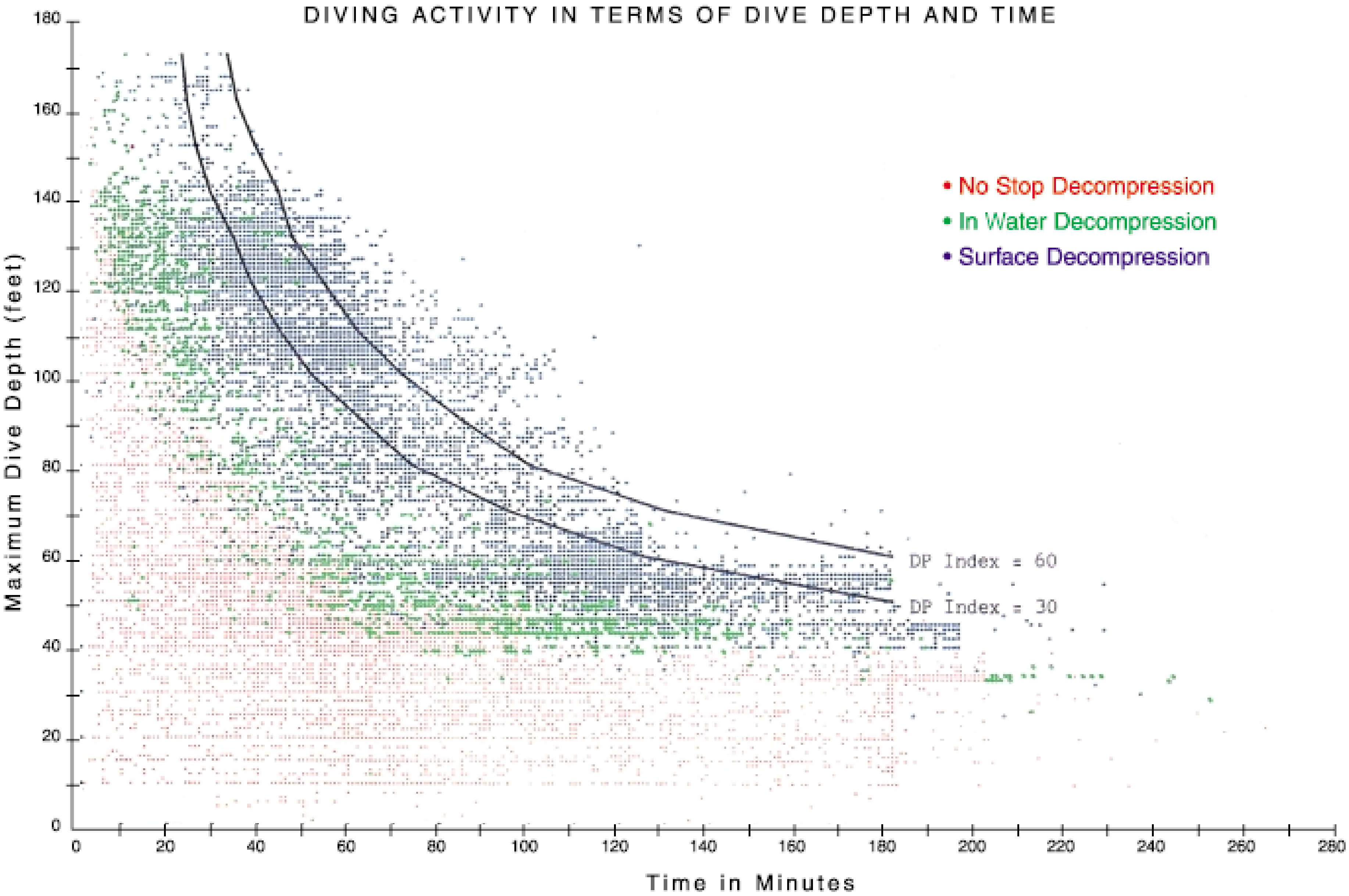

Figure 2. Two values of Shield’s index of decompression severity (plotted over a background of diving activity in the North Sea. No stop dives are red dots, in water decompression dives are in green dots and surface decompresssion dives are blue dots.

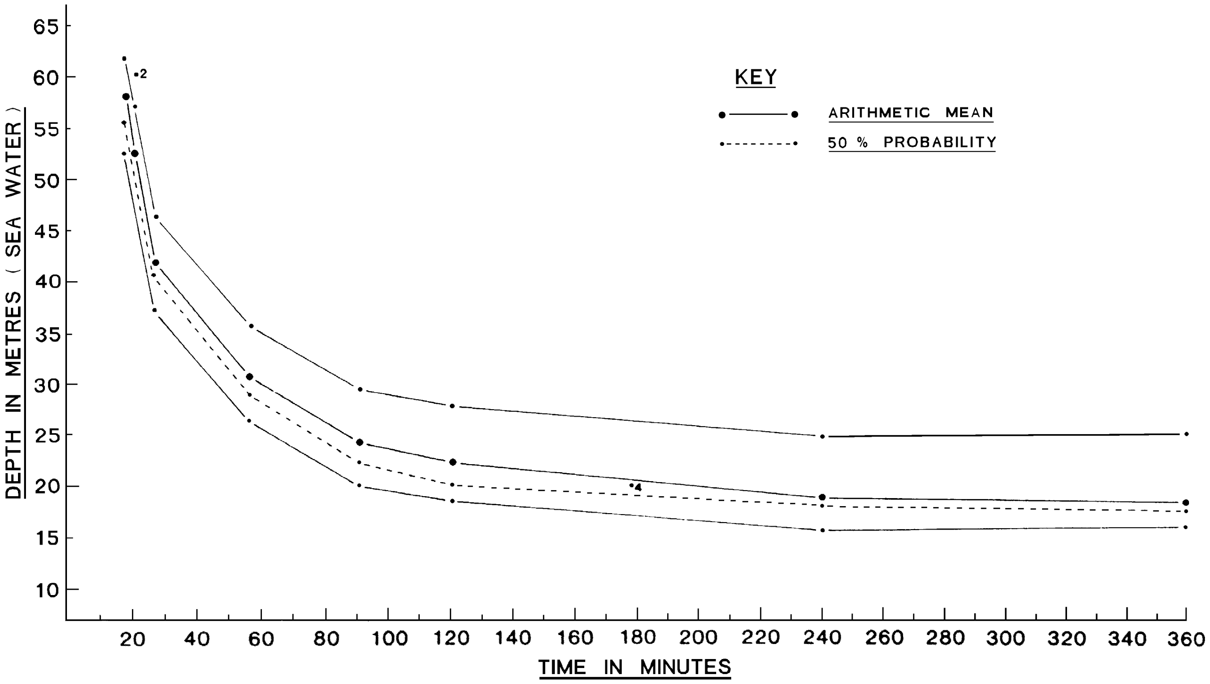

Figure 1. Hempleman's study of the wide variability of no-stop curves (mild bends end point) in goats. Below the bottom line no bends would be expected. Between the bottom and top lines only mild bends were recorded and it can also be seen that the distribution within these limits is not symmetrical but skewed. Above the top line severe bends would be expected. *Reprinted with permission from The Physiology and Medicine of Diving, 4th edition. Bennett PB and Elliott DH. Eds. London: Saunders, 1993; 355 [Fig. 13.5].*

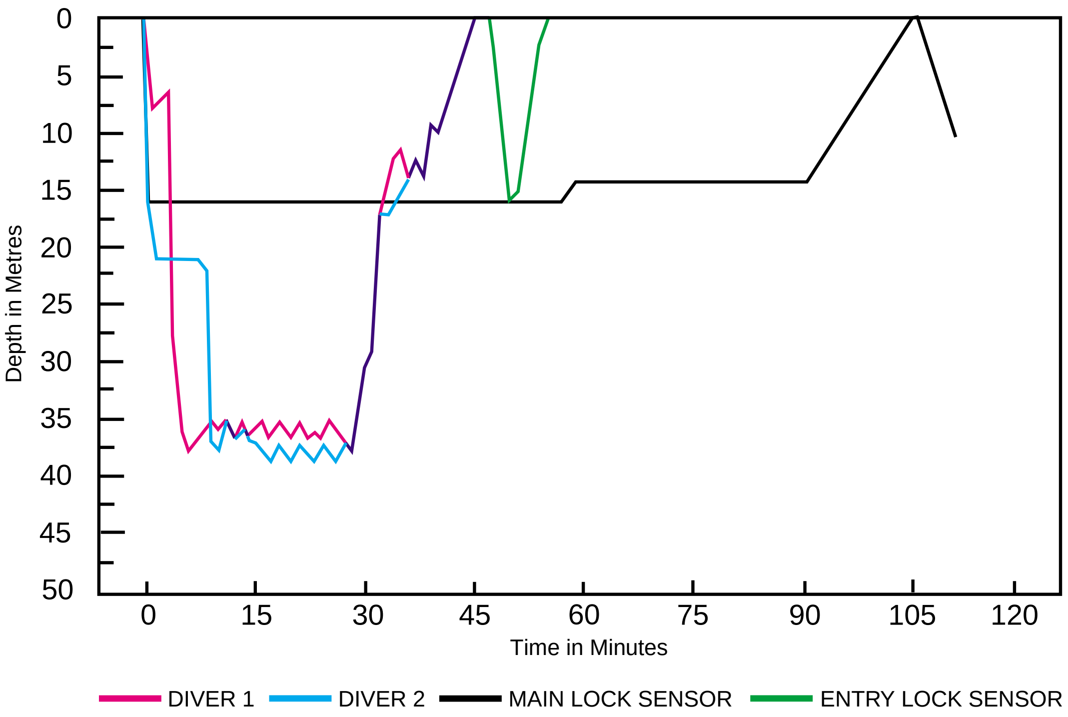

Figure 3. An illustration of depth-time recording. Diver Blue descends but waits until his buddy, Diver Red, has not only cleared his ears but has made it to the bottom before he continues down. These plots would be from on-line depth recorders which can be watched in real time by the surface supervisor. After a fairly erratic in-water stop they proceed to surface where the surface decompression chamber (black) is already at some 16 metres. The divers descend to it in the outer lock (green) which returns to surface after the divers have transferred to the main compartment and, after moving to 14 metres to complete their 40-min stop, they finally return to the surface.

decompression illness was predominantly related to the P√t index of dive severity. So, for air and nitrox diving, the UK Department of Energy issued a Safety Memorandum in 1988 introducing a "limiting line" and it has since been reissued by the UK Health and Safety Executive and adopted in the industry's Approved Codes of Practice.[39] This restriction is effective in reducing the bends rate simply by declaring dive exposures beyond the limit as possible only with a special HSE dispensation. The imposition of this limit on the diving industry brought the annual recompression rate for all air-range dives in the North Sea down to below 0.04% and, for two of these years at least, to zero.

Since then personal on-line depth-time recorders have been introduced for working dives in the North Sea. The recording of the depth and time at frequent intervals during the course of many actual dives and their decompressions are currently being collected, on-line from hose divers.[40] The acquired profile is detailed and even the effects of waves upon maintaining the depth of an in-water stop are capable of being quantified. Figure 3 (on page 211) is an illustration of depth/time recording of a dive with surface decompression following the depths achieved and the pressures in the two compartment chamber. The computerised records of these dives, together with other relevant details of each dive such as the gas breathed and the bends outcome, are to be available for central analysis, probably by the statistical method of maximum likelihood, in order to modify any inconsistencies within the diverse decompression models used for the generation of both tables and personal computer profiles. From the experience gained by this feedback, improvement of the underlying models may enable divers to approach the limiting line of the tables more safely, and then to venture beyond the present boundary of relatively safe dives towards the deeper and longer dives tables that retain the greater decompression risk unacceptable to industry. Paradoxically the future of the dive data recording study on working divers in the North Sea is threatened because there are "not enough bends", to the extent that it could take several decades to complete just a pilot study.

The future of this approach to validating the underlying decompression models lies with monitoring dives with potentially greater decompression risks. Studies on recreational divers, with post-dive down-loading from personal data loggers, are underway and will provide data from many thousands of actual dives which will be analysed to improve decompression safety.[41,42]

Personal decompression safety

However far the highly-refined decompression models of the future will enable divers to penetrate beyond the present limits of relative safety, none of this progress can change the fact of biological variation. Adaptation to decompression stress or the opposite, susceptibility, will still be unpredictable for the individual's next dive. Incorporating the user's physiological characteristics into a personalised decompression model would not control these or any other contributory factors on every dive. The use of Doppler also has practical limitations, not least because the detection of bubbles does not mean the onset of symptoms. The ultimate objective is some way of monitoring on-line the individual's potential during a dive for the development of the pathological effects of bubbles later.

But the story of that will have to be in some future historical account of decompression safety.

References

1 Bert P. *Barometric Pressure. Researches in experimental physiology. 1878.* Translated by Hitchcock MA and Hitchcock FA. Columbus, Ohio: College Book Company, 1943

2 Boycott AE, Damant GCC and Haldane JS. The prevention of compressed air illness. *J Hyg Camb* 1908; 8: 342-443

3 Hill L. *Caisson Sickness and the Physiology of Work in Compressed Air.* Arnold: London. 1912

4 Behnke AR. Some early studies of decompression. In *The Physiology and Medicine of Diving and Compressed Air Work.* Bennett PB and Elliott DH. Eds. London: Bailliere Tindall Cassell, 1969; 226-251

5 Hills BA. *Decompression Sickness Volume 1. The biophysical basis of prevention and treatment.* Chichester: Wiley-Interscience, 1977

6 Hempleman HV. History of decompression procedures. In *The Physiology and Medicine of Diving, 4th edition.* Bennett PB and Elliott DH. Eds. London: Saunders, 1993; 342-375

7 Vann RD and Thalmann ED. Decompression physiology and practice. In *The Physiology and Medicine of Diving, 4th edition.* PB Bennett and DH Elliott. Eds. Saunders: London. 1993; 376-432

8 Lippmann J. *Deeper into diving* Carnegie, Australia: J L Publications, 1990.

9 Hempleman HV. Experience and comparisons in diving. In *Decompression in surface based diving. Thirty-sixth UHMS Workshop.* Nashimoto I and Lanphier EH. Eds. Bethesda: UHMS, 1987; 2-6

10 Nashimoto I and Lanphier EH. Eds. *What is Bends? Forty-third UHMS Workshop.* Bethesda: UHMS. 1991

11 Nishi RY. The DCIEM decompression tables and procedures for air diving. In *Decompression in surface based diving. Thirty-sixth UHMS Workshop.* Nashimoto I and Lanphier EH. Eds. Bethesda: UHMS, 1987; 80-83

12 Nishi RY. Doppler and ultrasonic bubble detection. Pp In *The Physiology and Medicine of Diving, 4th edition.* PB Bennett and DH Elliott (eds). Saunders:

London. 1993; 433-453

13 Bayne CG, Hunt WS, Johanson DC, Flynn ET and Weathersby PK. Doppler bubble detection and decompression sickness: a prospective clinical trial. *Undersea Biomed Res* 1985; 12: 327-332

14 Schreiner HR and Hamilton RW. *Validation of decompression tables. Thirty-seventh UHMS Workshop.* Bethesda: UHMS. 1987

15 Homer LD and Weathersby PK. Statistical aspects of the design and testing of decompression tables. *Undersea Biomed. Res.* 1985; 12: 239-249

16 Schrotter, H von. *Der sauersstoff in der prophylaxe und therapie der luftdrucker- krankungen.* Berlin: Hirschwald, 1906

17 Admiralty Committee on Deep Water Diving (JS Haldane, AE Boycott, GCC Damant and AY Catto). *Parliamentary paper CN 1549.* London: HMSO, 1907

18 Stillson GD. *Report on Deep Diving Tests.* Washington, DC: U S Navy, Bureau of Construction and Repair, 1915

19 Admiralty Deep Diving and Ordinary Diving Committee (L Hill, RH Davis, GCC Damant and FA Buckley). *RN Diving Report.* London: HMSO, 1930

20 Hawkins JA, Shilling CW and Hansen RA. A suggested change in calculating decompression tables for diving. *U S Nav Med Bull* 1935; 33: 327-338

21 Yarborough OD. *Calculation of decompression tables. Research report, U S Navy Experimental Diving Unit.* Washington DC: Navy Department, 1937

22 Fulton JF. Ed. *Decompression sickness, Caisson sickness, Diver's and Flier's Bends and Related Syndromes. Compiled under the auspices of the Division of Medical Sciences, National Research Council, Washington DC.* Philadelphia: Saunders, 1951

23 Dwyer JV. *Calculation of Air Decompression Tables, NEDU Research Report 4-56.* Washington DC: U S Navy Experimental Diving Unit, 1956

24 Van der Aue OE, Brinton ES and Keller RJ. *Surface decompression : Derivation and testing of decompression tables with safety limits for certain depths and exposures. Research Report 5-45.* Washington DC: U S Navy Experimental Diving Unit, 1945

25 Van der Aue OE, Keller RJ, Brinton ES, Baron G, Gilliam HD and Jones RJ. *Calculation and testing of decompression tables for air dives employing the procedure of surface decompression and the use of oxygen. Research Report 13-51.* Washington DC: US Navy Experimental Diving Unit, 1951

26 Baker N. *Personal communication.* Historical Diving Society. 1998

27 Behnke AR. Decompression sickness following exposure to high pressures. In Fulton JF. Ed. *Decompression sickness, Caisson sickness, Diver's and Flier's Bends and Related Syndromes. Compiled under the auspices of the Division of Medical Sciences, National Research Council, Washington DC.* Philadelphia: Saunders, 1951; 53-89

28 Behnke AR. The isobaric (oxygen window) principle of decompression. In *Transactions of the Third Annual Conference of the Marine Technology Society.* Washington DC: Marine Technology Society, 1967 213-228

29 Workman RD. *Calculation of decompression schedules for nitrogen-oxygen and helium- oxygen dives. Research Report 6-65.* Washington DC: U S Navy Experimental Diving Unit, 1965

30 Des Granges M *Standard Air Decompression Table. NEDU Research Report 5-57.* Washington DC: U S Navy Experimental Diving Unit, 1957

31 Workman RD. American decompression theory. In *The Physiology and Medicine of Diving and Compressed Air Work.* Bennett PB and Elliott DH. Eds. London: Bailliere Tindall Cassell, 1969; 252-290

32 Hempleman HV. *Investigation into the diving tables. Report 111. R N Personnel Research Committee, UPS 131.* London: Medical Research Council, 1952

33 Hempleman HV. British decompression theory. In *The Physiology and Medicine of Diving and Compressed Air Work.* Bennett PB and Elliott DH. Eds. London: Bailliere Tindall Cassell, 1969; 291-318

34 Hills BA. Thermodynamic decompression: an approach based on the concept of phase equilibration in tissue. In *The Physiology and Medicine of Diving and Compressed Air Work.* Bennett PB and Elliott DH. Eds. London: Bailliere Tindall Cassell, 1969; 319-356

35 Thalman ED. Modelling used in developing US Navy decompression computer algorithms. In *Decompression in surface-based diving. Thirty-sixth UHMS Workshop*. Nashimoto I and Lanphier EH. Eds. Bethesda: UHMS, 1987; 64-69

36 Kidd DJ and Stubbs RA. The use of the pneumatic analogue computer for divers. In *The Physiology and Medicine of Diving and Compressed Air Work.* Bennett PB and Elliott DH. Eds. London: Bailliere Tindall Cassell, 1969; 386-413

37 Green NH and Woodward B. The evolution of divers' decompression computers. *Underwater Technology* 1993; 19: 9-23

38 Shields TG and Lee WB. *The incidence of decompression sickness arising commercial offshore diving operations in the UK sector of the North Sea during 1982/83. A report produced for the Department of Energy.* Aberdeen: Robert Gordon Institute of Technology, 1987

39 *Exposure limits for air diving operations. Diving Information Sheet No 5.* London: Health and Safety Executive, 1998.

40 Gardiner J. *The IMCA-HSE-UKOOA Dive Data Management System. Report.* Aberdeen: National

Hyperbaric Centre, 1997

41 D'Oliveira S. Project Dive Safety. *Alert diver.* 1996; March/April: 42-46

42 DAN project internet site: http://jshaldane.mc.duke.edu

Dr David H Elliott was one of the guest speakers at the SPUMS 1998 Annual Scientific Meeting. He is Co-Editor of The Physiology and Medicine of Diving, *which was first published in 1969, with the most recent edition in 1993 and is also the civilian consultant in diving medicine to the Royal Navy. His address is 40 Petworth Road, Haslemere, Surrey GU27 2HX, United Kingdom. Fax + 44-1428-658-678. E-mail 106101.1722@compuserve.com*

STRATEGIES FOR TREATING DECOMPRESSION SICKNESS.

Alf Brubakk

Key Words

Decompression illness, physiology, treatment,

Introduction

Decompression has generally been regarded as safe as long as it does not lead to clinical symptoms requiring treatment. Traditionally, the symptoms following decompression (dysbarism) has been distinguished according to where the main symptoms occur (Table 1).

This classification implies that the different categories are well defined disease entities and that there is reasonable agreement between doctors about the classification. Both the study of Smith et al.[1] and a study by Kemper et al.[2] demonstrate that there is considerable uncertainty between experts about classification. For instance, cerebral DCS cannot, in many cases, be distinguished from arterial gas embolism or vestibular barotrauma. Furthermore, several studies have shown that symptoms only from joints are quite rare, they are usually accompanied by central nervous symptoms,[3,4] Extreme fatigue can be classified as a harmless sign or be a sign of subclinical pulmonary embolism.[5] Francis et al.[6] therefore suggested the term decompression illness to include both decompression sickness and arterial gas embolism. They furthermore suggested that the disease should not classified as Type I and type II, but instead described according to clinical symptoms and their development. Using this classification scheme, a high degree of concordance between different doctors was reached .[7]

TABLE 1

CLASSIFICATION OF DECOMPRESSION DISORDERS (DYSBARISM)

Decompression sickness

Type I (mild)	Type II (serious)
Muscles and/or joints (bends, niggles)	Spinal
Skin	Cerebral
Lymph	Vestibular
Malaise/Fatigue ?	Cardiopulmonary (Chokes)

Arterial gas embolism

Barotrauma

Clinical diagnosis and reporting

> ***"The major symptoms and signs of decompression sickness are pain (bends), asphyxia (chokes) and paralysis. Minor effects are rash and fatigue. The parts of the body chiefly involved are the extremities (bends), cardiorespiratory system (chokes) and the spinal cord".[8]***

Even today, there is probably little to add to this description by Behnke in 1951, with the possible exception that we believe today that the brain may be more frequently involved and that extreme fatigue may be a more serious sign than previously thought.[5] However, it must be borne in mind that the symptoms can be slight and, as was described by one author, "as many as in syphilis and diabetes together".

In decompression disorders, the patients have to report their symptoms before treatment or investigations can be initiated. In many cases, the patients do not report their symptoms, either because they do not recognize them as being related to the dive or they feel reluctant to do so for many reasons.

There has been, for many years, anecdotal evidence that clinical symptoms of DCI are underreported to a considerable degree. We have recently asked a large group of Norwegian divers about this.[9] 19% of the sports divers, 50 % of the professional air divers and 63% of the saturation divers reported that they had symptoms that had not been treated, a majority of these symptoms were related to the CNS. Interestingly enough, there was a statistical relationship between this and later minor central nervous symptoms.

The incidence of decompression sickness.

There is probably little argument that severe violation of decompression procedures will lead to serious