ORIGINAL PAPERS

THE BS-AC '88 TABLES

John Lippmann

Background

A number of factors influenced the BS-AC's decision to replace the RNPL/BS-AC Table. Some of these are:

1 The high level of misunderstanding of decompression procedures amongst users and potential users of the table, and

2 The inherent inflexibility of the table itself. The BS-AC recognised that with the advent of the dive computer, the RNPL/BS-AC Table has become more unattractive to the user. The club wished to have a set of tables that approach the versatility of a computer, and that can comfortably co-exist alongside the computer.

The table designer, Dr Tom Hennessy, has worked alongside Dr Val Hempleman, the designer of the original RNPL model, for many years. Hennessy initially decided to base the new tables on the same decompression model as the RNPL/BS-AC Table, since the model on which that table is based had been tried and tested over a number of years. However, since the RNPL/BS-AC Table has not really had the facility to be used, and hence tested, over series of three or four dives per day, Hennessy had to first ensure that the model could be safely extended to cover these multiple diving situations. He believes that very long dives can produce a similar gas load in the tissues to that produced by multiple repetitive dives and, after receiving some data which indicated that the model might be marginal when used for very long, deep dives, Hennessy decided to modify the model slightly.

The RNPL/BS-AC Table assumes that it is safe to ascend directly to the surface from saturation at 9 m, but this is no longer believed to be true. There has been some evidence that the depth a safe direct ascent from saturation can occur from is around 7 m rather than 9 m. This ascent criterion is included in the BS-AC '88 Tables.

Hennessy also believes that bubbles form after every decompression, and that these bubbles affect the gas uptake and release for each subsequent dive. For example, if a diver who has nitrogen bubbles in his blood or tissues descends on a repetitive dive, the nitrogen in the bubbles is exposed to the entire ambient pressure. So at 10 m, the partial pressure of nitrogen in the bubble is 2 ATA, which is higher than the 1.6 ATA partial pressure of nitrogen at 10 m on an initial dive. This means that a diver may saturate more rapidly during the repetitive dive than during an initial dive of the same depth and duration. The total amount of nitrogen will be a combination of this redissolved nitrogen and the nitrogen already dissolved, as well as the normal uptake of nitrogen delivered by the blood during the new dive. The gas in the bubbles does not redissolve as soon as it is recompressed. It takes a certain depth and time before the gas will redissolve completely, and, only then, will the tissue revert to its normal state where uptake and elimination can be described by the model used for the first dive. Hence, the rates of gas uptake and elimination will alter from dive to dive, and it becomes necessary to treat the second, and subsequent, dives quite differently to the first when trying to predict safe decompression.

Most decompression models assume that gas uptake and elimination occur at the same rate during any dive, and the models assume that this rate is the same on a repetitive dive as it is on a single dive. This may be acceptable if significant bubbling has not occurred within the blood and tissues but, if bubbles are present, they will slow down off-gassing and the rates may differ. The original RNPL model assumes that off-gassing is at 2/3 the rate of uptake, and these new tables also assume an assymmetry in the rate of gas uptake and elimination. Hennessy set out to design a set of tables which become progressively more conservative as the number of dives, depth and duration increases.

The US Navy Tables depict the amount of nitrogen in a diver by a single letter code, the Repetitive Group Designator, which is supposed to represent the nitrogen level in the 120 minute theoretical tissue compartment. The system assumes that, after a surface interval of ten minutes, this tissue compartment has the highest nitrogen load and, therefore, controls the decompression. The code is then used to determine the amount of residual nitrogen still remaining in this theoretical tissue (and, therefore, in our entire body) before a repetitive dive, and the original single dive model is used to predict the decompression for the repetitive dive. In reality it has been shown that on a typical "deepish" dive, seven or eight different absorption rates may play a part in controlling the decompression. The US Navy's approach also assumes that dives which give the same code can be treated identically, whether a short, deep dive or a long, shallow one. It assumes that, because the amount of nitrogen that is theoretically dissolved in this one tissue compartment is the same, the dives can be treated equivalently. Unfortunately, our bodies do not work quite so simply. What is not accounted for is that the distribution of the gas load between the various tissues may be quite different in each of the cases, so simply adding some residual nitrogen to the level in one theoretical tissue, is often not sufficient.

To avoid using a single dive model to predict repetitive dives, Hennessy has created a number of different tables to be used for different dives. In all, the BS-AC '88 Tables consist of a set of seven separate tables, labelled Table A to Table G.

The first table, Table A, is used for the initial dive. After the dive the diver surfaces with a letter code (the Surfacing Code) which relates to the depth and time of the dive. Following a surface interval, the diver selects a new code (the Current Tissue Code) which relates to the nitrogen load in the tissues after the surface interval, and enters a new table (rather than the original table) which bears the same letter code. The minimum surface interval required to gain credit for off-gassing is 15 minutes, rather than the two hours previously used.

The new tables utilise depth increments of 3 m, rather than 2 m and, instead of giving bottom times, give the time from leaving the surface until arriving at 6 m during the ascent, or at 9 m on dives requiring a 9 m stop. The tables use initial No-Stop Times that are more conservative than those on the RNPL/BS-AC Table.

The BS-AC have not recommended a reduction in the 15 m/minute ascent rate, and have not included a safety stop after all "no-stop" dives, as is done on various other tables. Instead, the BS-AC '88 Tables require that the ascent to 6 m is at a maximum rate of 15 m/minute (which means that it may be slower than 15 m/minute), and the ascent from 6 m to the surface must take one minute (which means a rate of 6 m/minute).

Decompression stops are done at 9 m, 6 m *and at the surface*. It is stressed that a surface interval should in essence be treated as a decompression stop, and a diver's activities should be modified accordingly. No 3 m stops are given as they are too difficult to do successfully when there is wave action. Decompression times increase in increments of one minute, rather than five minutes as in the RNPL/BS-AC Table. The maximum decompression given is 22 minutes.

The BS-AC '88 Tables are presented in a compact, easy-to-read format *and do not require any calculations at all*, Tables A to G are supplied in a non-submersible but water resistant format, and Tables A, B and C are also printed, in an abbreviated form, on a submersible card, which should be carried by the diver and used in the event of a memory lapse or a change of dive plan. Presumably, Tables D to G are not included on the card due to the very restricted No-Stop Dive Times available to a diver with Current Tissue Codes of D to G.

The tables in their current form are presently untested but appear to be conservative when used for *NO-STOP DIVES.*

Comparing the BS-AC '88 tables to some other tables

When the BS-AC '88 Tables are compared to tables such as the US Navy Tables, the Buehlmann (1986) Tables, and the DCIEM Tables some trends appear to emerge. These are:

> The tables appear to be conservative for both single and multiple no-stop dives, with the initial NDLs comparable with those of the Buehlmann (1986) and DCIEM Tables. (Table 1)
>
> For single/initial dives requiring stops, the decompression given is often, but not always, more conservative than that given by the US Navy Tables, but is often less conservative than that suggested by the Buehlmann (1986) and DCIEM Tables.
>
> For repetitive dives requiring stops, the decompression given by the BS-AC '88 Tables is more conservative than that given by the US Navy Tables, and often comparable to that given by the Buehlmann (1986) and DCIEM Tables.

These trends are demonstrated in Table 2 and Figure 1.

Promoters of the BS-AC '88 Tables argue that even though the Total Decompression Time (TDT) given by these tables is sometimes shorter than that given by some other tables, the risk of decompression sickness is not only dependent on TDT. A longer decompression profile is not necessarily a safer one as other factors (procedural parameters) also affect the risk of bends. Some of these parameters are the ascent rate, the depth and duration of the initial stop, the ease of maintaining the depth of the required stops, the surface interval required before diving again (or flying) and the activities during the surface interval.

If one compares the ascent procedure suggested by the BS-AC '88 Tables to that given by the US Navy Tables, there are a number of differences which includes:- a slower ascent rate to 6 m, a longer stay at 6 m, a slower ascent rate from 6 m to the surface (although often a shorter ascent time) and a longer stay at the surface before diving again. Although these comparisons are valid for the US Navy Tables, they do not necessarily apply to other tables. When the BS-AC '88 Tables are compared to the Buehlmann (1986) and DCIEM Tables, especially for first/single dives, the BS-AC Tables often appear less conservative, not only with TDT but also with respect to some of the procedural parameters previously mentioned. Careful examination of Figure 1 will indicate this trend. Hennessy argues that the Buehlmann and DCIEM Tables are often overly conservative, but this is debatable. Although commercial divers may need to minimise decompression time for the sake of efficiency a recreational diver who decides to conduct a dive involving mandatory stops and who has planned the dive properly should have no reason not to use a conservative table to gain any extra security that it may provide.

The US Navy Tables, Buehlmann (1986) Tables and

TABLE 1
COMPARISON OF NO-STOP LIMITS
(Bottom Times)

Notes:
Times are in minutes unless otherwise specified
No-stop bottom time limits for the BS-AC '88 Tables are approximate
The ascent rate used by the US Navy Tables is 18 m (60 ft)/minute
The ascent rate used by the Buehlmann Tables is 10 m (33 ft)/minute
The ascent rate used by the DCIEM Tables is 15 m (50 ft)/minute

Depth feet	Depth m	BS-AC '88	RNPL/BS-AC	Buehlmann (1986)	DCIEM	US Navy
30	9	242	-	400	300	-
40	12	121	137	125	150	200
50	15	73	72	75	75	100
60	18	50	57	51	50	60
70	21	36	38	35	35	50
80	24	28	30	25	25	40
90	27	22	23	20	20	20
100	30	18	20	17	15	25
110	33	15	16	14	12	20
120	36	12	14	12	10	15
130	39	10	11	10	8	10
140	42	9	10	9	7	10

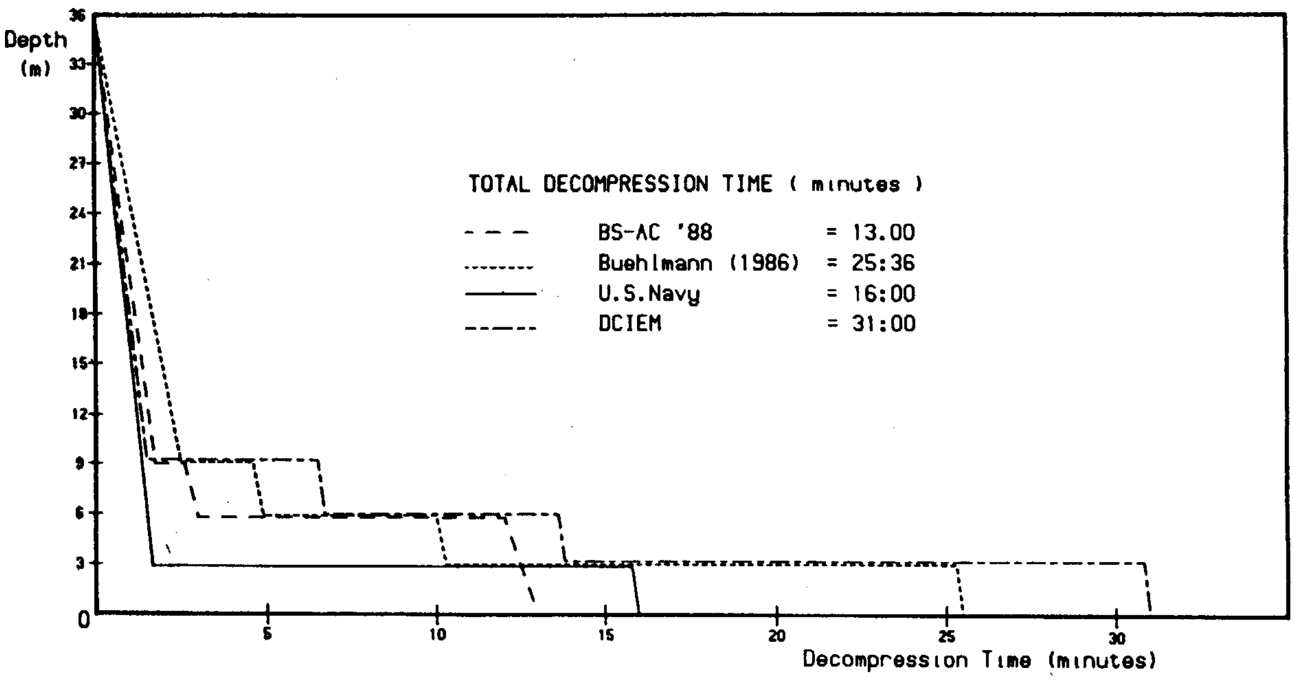

Figure 1 A comparison of the decompression profiles given by various tables for a dive to 36 m (120 ft) for a bottom time of 30 minutes.

TABLE 2

COMPARISON OF VARIOUS DIVE SCHEDULES WHEN USING BS-AC '88, US NAVY, BUEHLMANN AND DCIEM TABLES

Times are in minutes unless otherwise specified
No-stop bottom time limits for the BS-AC '88 Tables are approximate
The ascent rate used by the US Navy Tables is 18 m (60 ft)/minute, by the Buehlmann Tables is 10 m (33 ft)/minute and by the DCIEM Tables is 15 m (50 ft)/minute

EXAMPLE A

Dive 1 Max depth 33 m (110 ft) Actual Bottom time 25 minutes

	BS-AC '88	US Navy	Buehlmann	DCIEM
No-Stop (*Bottom* Time) Limit	15	20	14	12
Stops required	3 min at 6 m	3 min at 3 m	2 min at 6 m and 7 min at 3 m	10 min at 6 m and 10 minat 3 m

Surface Interval 2 hours

Dive 2 Max depth 21 m (70 ft) Actual Bottom time 18 minutes

	BS-AC '88	US Navy	Buehlmann	DCIEM
No-Stop (*Bottom* Time) Limit	9	24	23	17
Stops required	1 min at 6 m	None	None	5 min at 3 m

EXAMPLE B

Dive 1 Max depth 27 m (90 ft) Actual Bottom time 20 minutes

	BS-AC '88	US Navy	Buehlmann	DCIEM
No-Stop (*Bottom* Time) Limit	22.5	30	20	20
Stops required	None	None	None	None

Surface Interval 2 hours

Dive 2 Max depth 24 m (80 ft) Actual Bottom time 15 minutes

	BS-AC '88	US Navy	Buehlmann	DCIEM
No-Stop (*Bottom* Time) Limit	6.5	22	14	16
Stops required	3 min at 6 m	None	16 min at 3 m	None

Surface Interval 4 hours

Dive 3 Max depth 18 m (60 ft) Actual Bottom time 40 minutes

	BS-AC '88	US Navy	Buehlmann	DCIEM
No-Stop (*Bottom* Time) Limit	31	43	37	35
Stops required	1 min at 6 m	None	11 min at 3 m	5 min at 3 m

EXAMPLE C

Dive 1 Max depth 36 m (120 ft) Actual Bottom time 12 minutes

	BS-AC '88	US Navy	Buehlmann	DCIEM
No-Stop (<u>Bottom</u> Time) Limit	12	15	12	10
Stops required	None	None	None	5 min at 3 m

Surface Interval 1 hour 30 minutes

Dive 2 Max depth 30 m (100 ft) Actual Bottom time 14 minutes

	BS-AC '88	US Navy	Buehlmann	DCIEM
No-Stop (<u>Bottom</u> Time) Limit	No no-stop time available	11	8	10
Stops required	3 min at 6 m	3 min at 3 m	5 min at 3 m	10 min at 3 m

Surface Interval 8 hours

Dive 3 Max depth 27 m (90 ft) Actual Bottom time 20 minutes

	BS-AC '88	US Navy	Buehlmann	DCIEM
No-Stop (<u>Bottom</u> Time) Limit	13.5	23	20	14
Stops required	1 min at 6 m	None	None	10 min at 3 m

DCIEM Tables have been used for comparison with the BS-AC '88 Tables as they have all had a considerable amount of testing and/or usage. Although the basic model on which the BS-AC '88 Tables are based was tested and was used extensively, *the BS-AC '88 Tables are untested in their current form.*

The BS-AC considered mounting a series of trials using recreational divers, but it was decided that, since the bends incidence was expected to be low, unless a very large number of trials were conducted the results would not be statistically conclusive. The practical and financial constraints of a large test series proved prohibitive so, instead, a 4-month period of informal open-sea dives were conducted by a number of BS-AC members before the tables were released. No details of the profiles conducted and the number of dives have been released, but no cases of bends were reported during the period.

Although essentially untested, the BS-AC '88 Tables appear to be quite conservative for no-stop dives and should generally (but obviously not always) be reasonably safe for such dives. *However, divers who plan to use the BS-AC '88 Tables for dives requiring mandatory decompression stops are urged to do so very cautiously and conservatively as the tables are often less conservative in this area than some well-tested tables. Extensive testing needs to be done before the safety of these tables when used for dives involving mandatory stops is determined.*

A recent BS-AC report states that, in 1989 after the first full season of usage, there were 41 divers who developed bends after diving according to the BS-AC '88 Tables. Eleven of the divers had misused the tables, 22 had dived withn the tables and in the other eight cases there was insufficient information to determine whether the tables had been used correctly. The BS-AC estimate that possibly a million dives could have been conducted using the tables, which would yield an incident rate better than 1 in 10,000.[1] No information is currently available about how many of the bends cases occurred on dives involving mandatory stops and the number that occurred after no-stop dives.

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Recommended Further Reading

British Sub-Aqua Club Diver Training Material - Supplement to Sports Diver and Dive Leader Training Handbook (Lessons ST 6: ST 7: LT 6 using BS-AC '88 decompression tables with theory questions and answers). BS-AC, London, 1988

The author wishes to thank Dr Tom Hennessy for perusing the draft of this chapter and for the material and assistance he provided.

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AN ATYPICAL EPISODE OF DECOMPRESSION SICKNESS

Hamish Holland

Summary

A case is presented of a novice diver in whom symptoms consistent with decompression sickness developed after diving to a depth of 7 metres of sea water (msw). Resolution followed hyperbaric oxygen therapy.

Introduction

The diagnosis of decompression sickness (DCS) in divers is heavily dependent on the history with considerable weight given to the dive profile. Various "safe" decompression tables are published, and it is generally accepted that symptomatic DCS is extremely rare following exposure to pressures less than 2 ATA.[1]

A case is presented of a novice diver who developed symptoms after shallow training dives, in whom DCS is the only tenable diagnosis.

Case Report

The patient was a 16 year old girl, performing her first training dives in the open sea. The dive series commenced at 1300 hours, and consisted of two dives to a maximum of 7 metres for 15 minutes each, then a 30 minute break and four descents to 4 metres maximum over 40 minutes. The dive profile was confirmed by her instructor, and the dives were uneventful.

By 1800 hours, she reported aching knees and jaw, and a feeling as if her ears were not equalised. The pain continued overnight and was sufficient to disturb her sleep.

The next day, the jaw was easier but her knees had not improved. In addition, she had a headache, pins and needles in both legs, and occasional sharp pains in ankles, wrists, elbows and shoulders. She presented to her local hospital that day, and was transferred to the Royal Darwin Hospital (RDH) 2 days after her dives, arriving at 1330 hours.

On arrival at RDH, she still had aching knees, pain in her shoulders, and an occipital headache, but all other symptoms had resolved.

The patient stated she normally enjoyed good health apart from occasional attacks of tonsillitis. She had not noticed any fever, rash, weakness or lethargy although she had been resting in bed since the day of the dives. She had no abdominal pain, nausea or vomiting, and no urinary symptoms. She comes from an area where ciguatera occurs, and eats a large amount of fish, but no other family members reported any malaise. She has had no previous episodes of ciguatera.

On examination, she proved to be alert and fully orientated, with no nystagmus, no limb weakness, normal tone and no clonus. Reflexes, including plantars, were normal and no sensory loss was detectable. She was afebrile with no skin rash and no lymphadenopathy. Respiratory and cardiovascular examination was normal, as were her eardrums. Her joints displayed a full range of movement and did not show swelling, tenderness or localised warmth.