

- Am J Sports Med. 1979; 7(4): 260-261.
16. Plueckhahn VD. Alcohol and accidental drowning: a 25-year study. *Med J Aust.* 1984; 141: 22-25
 17. Strauss RH. Medical concerns in underwater sports. *Pediatr Clin North Am.* 1982; 29(6): 1431-1440.
 18. Ritchie BC. The physiology of drowning. *Med J Aust.* 1972; 2: 1187-1189.
 19. Halmagyi DFJ, Colebatch HJH. The drowned lung: a physiological approach to its mechanism and management. *Aust Ann Med.* 1972; 2: 1187-1189.
 20. Halmagyi DFJ, Colebatch HJH. Ventilation and circulation after fluid aspiration. *J Appl Physiol.* 1961; 16: 35-40.
 21. Pathophysiology of drowning. *Med J Aust.* 1985; 142: 586-588.
 22. Keatinge WR. Accidental immersion hypothermia and drowning. *Practitioner.* 1977; 219: 183-187.
 23. Cooperman EM, Hogg J, Thurlbeck WM. Mechanisms of death in shallow-water scuba diving. *Can Med Assoc J.* 1968; 99: 1128-1131.
 24. Smith FR. Air embolism as a cause of death in scuba diving in the Pacific Northwest. *Dis Chest.* 1967; 52: 15-20.
 25. Strauss RH, Pischop LD. Decompression sickness among scuba divers. *JAMA.* 1973; 223(6): 637-640.
 26. Goldhahn RT. Scuba diving deaths: a review and approach for the pathologist. *Legal Med Annual.* 1976-77; 109-132.
 27. Calder IM. An evaluation of the diatom test in deaths of professional divers. *Med Sci Law.* 1984; 24(1): 41-46.

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THE IDEAS BEHIND THE NEW USN TABLES

John Knight

The USN air decompression tables are used by sports divers around the world. No one really knows how good they are because no one knows how many dives are made to what schedule every year and how many cases of decompression sickness (DCS) result. These figures are not even reliable for the USN inspite of the requirement to record every dive and forward the figures to the Navy Safety Center. These are many cases of people getting bent using the USN no-decompression tables as they are written. That is straight to depth and staying there for the full bottom time and returning to the surface. Some will have ascended faster than 60 feet (18 metres) a minute, but others have kept to that limit. Looking at the testing that was done for these tables¹ there were 27 bends in 568 dives, with an average of 6 dives a schedule, covering 88 schedules. This gives a 4.75% incidence of DCS. So one could perhaps expect about 5% bends using the USN tables as they are written. Two thirds of the schedules were never tested!

Repetitive dives were even less thoroughly tested and later experience is much less than for single dives.

Dembert et al² published the 1981 USN statistics. There were 35 cases of DCS in 92,484 dives, approximately 0.038%, which is 100 times safer than

the acceptance trials and various other series where the USN no-decompression tables have been used. How can one explain the difference. Much of the air diving is shallow, and well within the no-decompression limits. For decompression dives USN divers seldom dive the dive in the book, they often add either a depth increment or a time increment, or both, to the dive and decompress for this fictitious dive. If they get close to the no-decompression limits they often decompress for the first decompression dive in the table.

In an effort to find out the incidence of decompression sickness the USN did a study of decompression dives, as being more likely to be recorded than no-decompression dives, and the incidence of DCS.³ The results, covering the years between 1 October 1971 and 30 November 1978 were published in January 1980. The overall incidence of DCS was 1.25%. The average incidence was 1.1% for the 43 schedules that were dived more than 100 times. Four schedules produced a statistically significant increased incidence, ranging from 3.1 to 4.8%. The conclusions were that there were a very limited number of schedules that were being used frequently, and that the incidence of DCS was very low (at 1.25%). There was a trend to an increase in DCS incidence with longer dives.

Weathersby et al have published a review of a large number of sets of experimental dives, including: A: the original testing of the current USN Table 1, B: the original testing of the exceptional exposure tables, C: Royal Navy submarine escape trials,⁶ D: dives at the Defence and Civil Institute of Environmental Medicine, Ontario, Canada,⁷ E: sea trials of a proposed Royal Navy decompression table,⁸ F: trials to see whether exercise during decompression affected the incidence of DCS,⁹ G: testing of surface decompression using oxygen,¹⁰ and H: a very conservative Royal Navy table which was not accepted for fleet use.¹¹

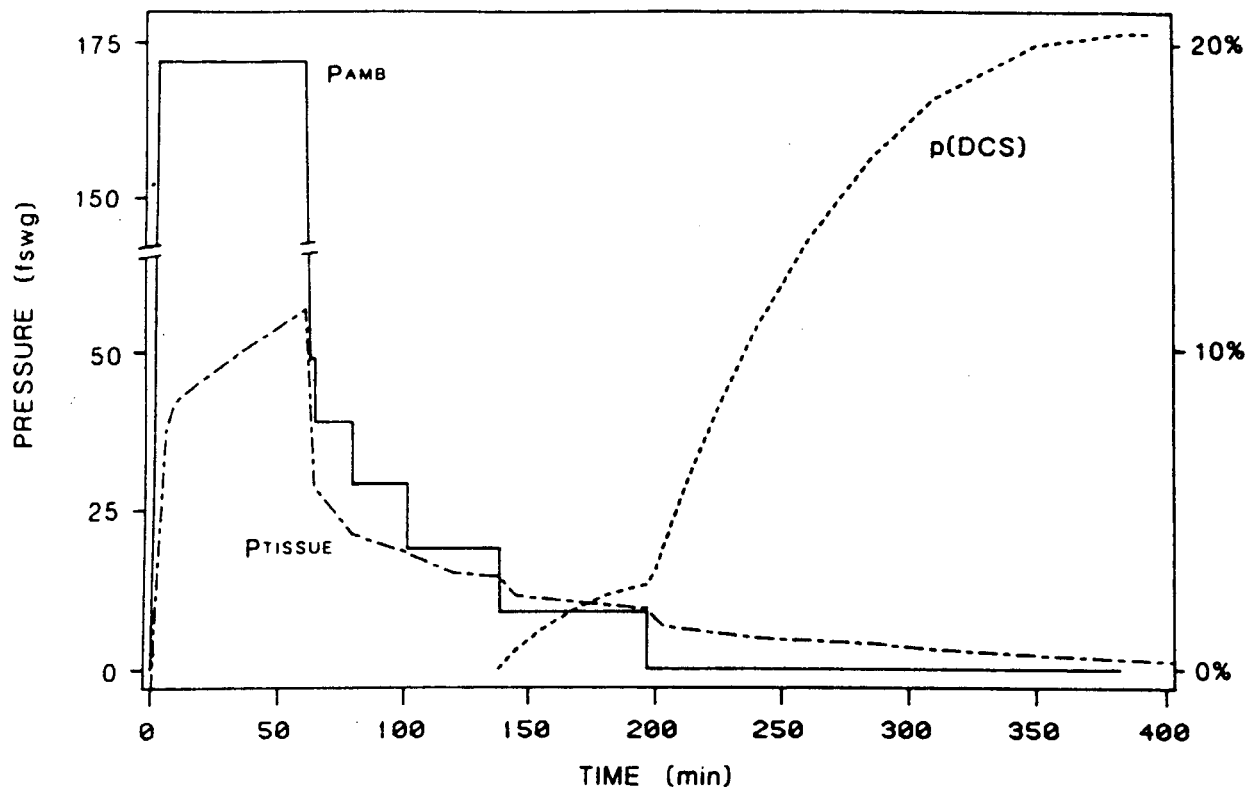
They predicted, using a relatively simple mathematical model, the probability of DCS in these dives of known profile and known DCS incidence. This allowed them to alter the values in the model to get best fits to the data. Their method of integrating risk over the course of an entire decompression differs fundamentally from the usual practice of trying to avoid a specific point, a given supersaturation ratio in the current USN tables and any supersaturation in Brian Hills' theories, all through the decompression. They assumed that a given decompression stress is more likely to produce symptoms of DCS the longer it lasts. This also means that a large number of different decompressions from the same dive may result, after integration, in the same probability of DCS. They did not invoke specific mechanisms of bubble formation, number, or growth. They assumed that when the computed inert gas partial pressure was less than ambient pressure there was no risk of DCS.

They used 6 models to examine their data. The first had one well mixed compartment for calculating the tissue partial pressure of inert gas. The second had a threshold of supersaturation, that had to be exceeded for symptoms, added. The third had two tissue compartments, which meant that the probability of no DCS was the joint probability of no DCS in both tissues. The Fourth was the third with a threshold added. The fifth was a two compartment model with three kinetic parameters rather than a single exponential for each compartment. The sixth was the same as the fifth with a threshold added.

FIGURE 1

Reprinted from reference 4

RISK ACCUMULATION IN 170/60 TRIAL
MODEL 5, DATA SET ABC



They calculated the tissue nitrogen partial pressure for the dive and sufficiently long afterwards for it to fall below 1 ATA as the time of onset of symptoms was not usually known. When the tissue nitrogen pressure exceeded ambient the risk of DCS started and increased for as long as tissue inert gas pressure exceeded ambient. Once they were the same the risk remained constant. Figure 1 shows the risk accumulation in a 170 feet for 60 minute dive using model 5 and the combined data from sets A, B and C. In this case the greatest risk accrued after surfacing.

Applying the various models to the different data sets showed that a single tissue model was adequate for prediction using set A, the acceptance trials of the present USN tables. In other words adding another tissue did not improve the fit. Set B, long dives, was also well predicted by a single tissue, and the time constant was close to that for set A. Set C, the submarine escape data, was also well predicted by the single tissue model but the time constants were shorter. So the three sets of data could not be combined and treated with a one compartment model.

The fit can be shown by a bar graph. Figure 2 compares the predicted and observed incidence of DCS using model 1 and data set A. The results were grouped into four categories depending on the prediction, 0-2%, 2-5%, 5-10% and >10%. The figures over the columns show to the right of the bar the number of dives predicted to be in that group. The

figures to the left of the bar are the number of cases that actually occurred. The bar is plotted at the predicted incidence and extends to the height of the actual percentage incidence. In the 2-5% group the model predicted 65 cases with an average incidence of 3.3%. In fact there were 3 cases of DCS which is 4.6% of 65. So the bar is at 3.3 on the predicted scale and rises to 4.7 on the observed scale. The thin vertical lines are the 95% confidence limits for the observed incidence. The dotted line is where the bar tops should be if observed and predicted were the same. The nearer the top of the bar is to the line the better the prediction.

The combined data needed a two compartment model with the two time constants similar to those found when the three sets were examined separately. When these models were applied to the Canadian dives the time constants, though similar to those using the combined data, were not quite so short nor quite so long, which is to be expected as the dives did not include the deep short ones or the long ones of sets C and B.

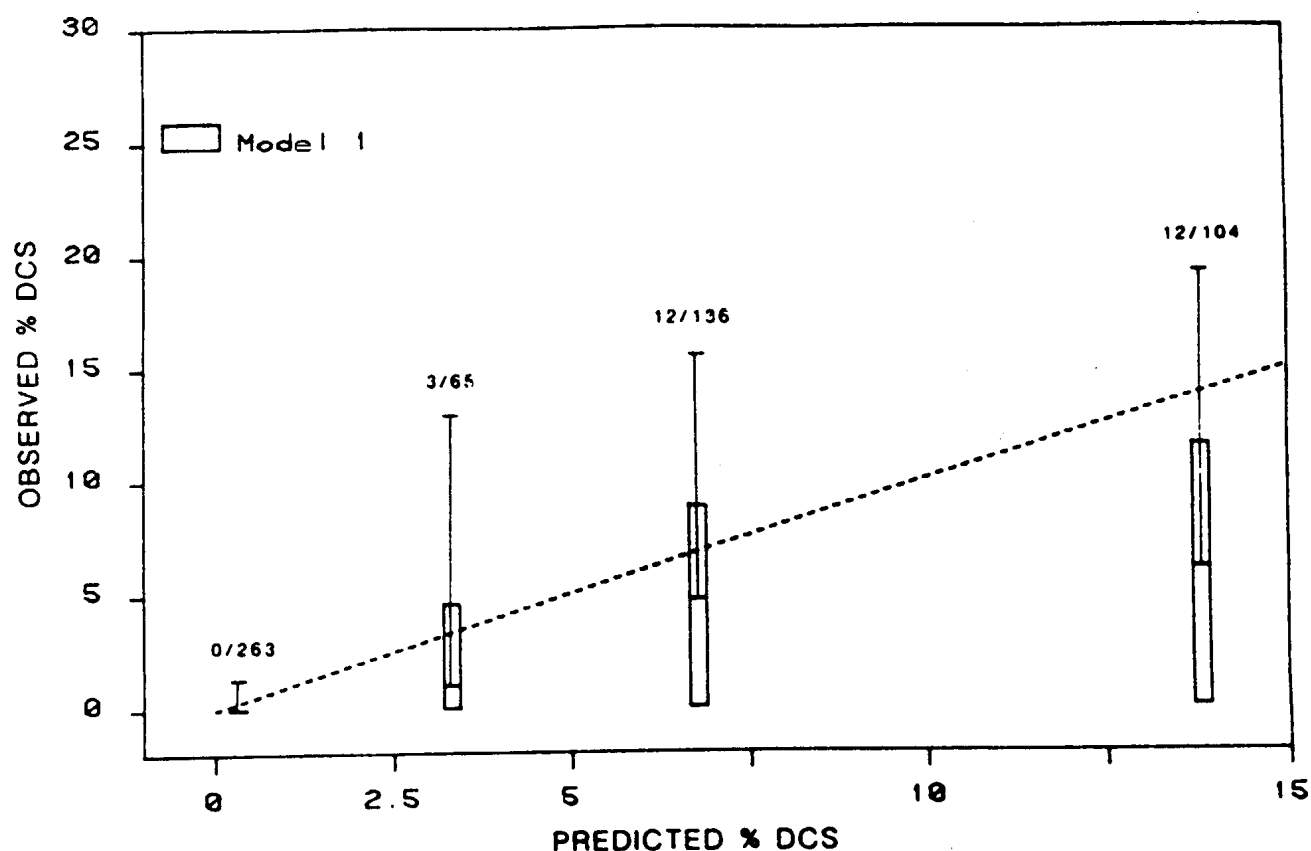
Then they examined the four sets combined. The result was not quite as good as with sets A and B. The results were much the same as for the four sets. So they decided to take the results from the data sets A, B, C and D and use them as their best summary of air diving risk.

FIGURE 2

Reprinted from reference 4

OBSERVED vs PREDICTED INCIDENCE

DATA SET A

TABLE 1
PROJECTION OF RISK IN ADDITIONAL DATA

Data Set	Dives	DCS Cases	Cases Predicted by Model/Data				
			1/AB	3/ABC	5/ABC	4/D	3/ABCD
E	50	9	0.8	0.8	0.7	1.8	0.8
F	141	42	3.9	3.6	4.3	7.3	3.4
G	143	9	0.9	1.1	1.3	7.5	1.7
H	192	1	3.2	3.7	3.9	5.5	3.8

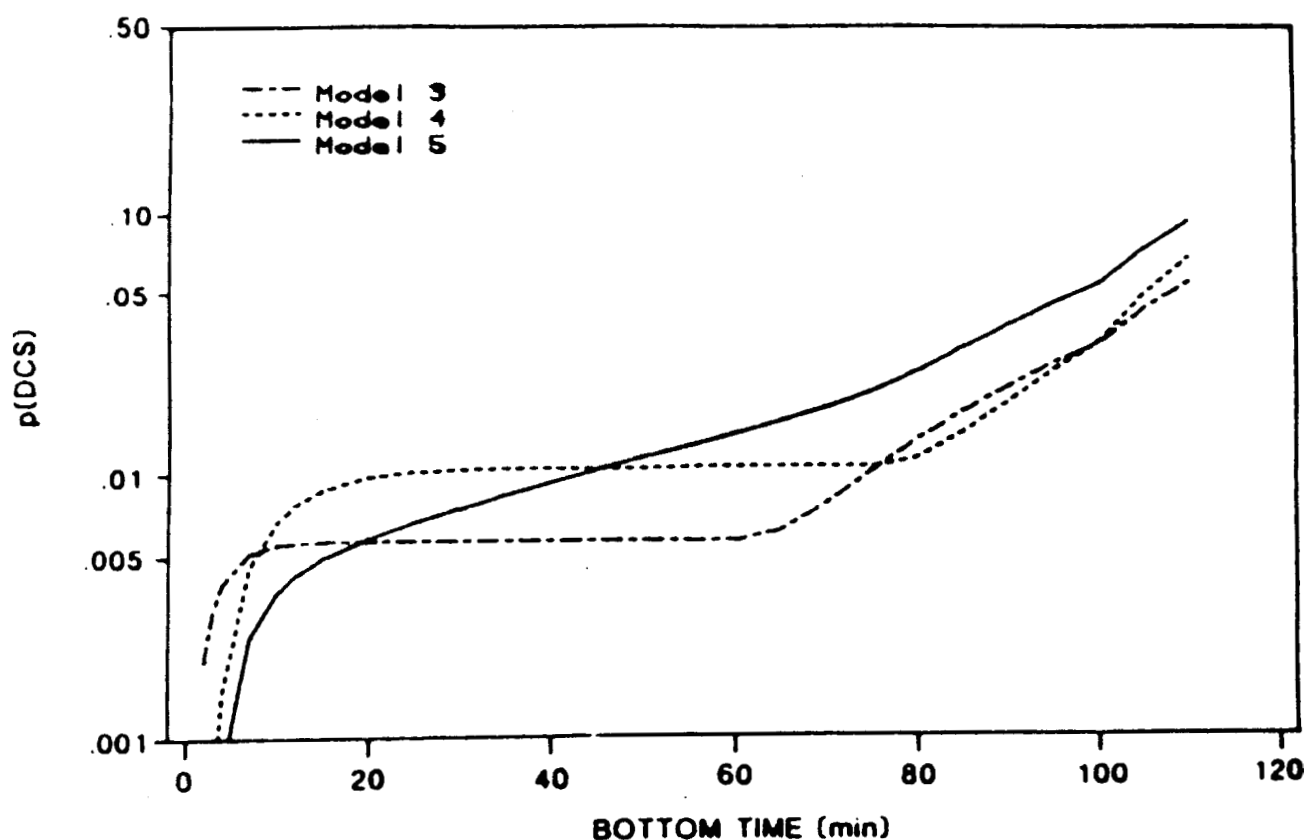
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Table 1 shows the predictions for data sets E: 1957 Royal Navy trials with shorter decompressions than US tables for the same depth, F: exercise during decompression which were intended to produce a 50% bends rate, G: surface decompression and H: a conservative Royal Navy table, both of which had depths, bottom times and decompressions in the range of those in A and D. It is not surprising that the predictions fit these two sets better than they do than they do E and F, although none of predictions is close to the results.

The predictions were applied to the current USN tables using the same models and data sets used in Table 1. Depending on the model and data set, the USN no-decompression limits, which are what interest sports divers, have predicted risks of 0 to 12% for model 1/AB, 0.3 to 12% for model 3/ABC, 0.4 to 12% for model 5/ABC, 1 to 8% for 4/D and 1 to 9% for 4/ABCD. The highest risk is for 310 minutes at 35 feet. Weathersby et al⁴ consider that air dives shallower than 150 feet and shorter than 40 minutes are quite safe, with a risk of DCS less than 0.5%, which depends

FIGURE 3

Reprinted from reference 12

NO-DECOMPRESSION DIVES TO 60 ft

Probability of DCS after dives to 60 ft for various bottom times followed by direct ascent to the surface. Results are plotted for three different models and parameters from Data Set ABCD.

on the model used as 4/D gives risks of 2 to 3% in this range. Dives lasting longer than 2 hours down to 80 feet, longer than 1.5 hours between 90 and 120 feet and longer than 40 to 60 minutes deeper than 120 feet should produce bends at least 10% of the time. Dives that are both deep and long should produce bends more often than not.

The companion report¹² gives the equal risk air diving decompression schedules. To calculate the no-decompression limits a time and depth profile is run through the various models. Models 3, 4 and 5 agree within a factor of two on the level of safety. The "two tissue" models (3 and 4) both produce a plateau where safety does not change with time for a while. These correspond to decompression after the first tissue (time constant) has reached its maximum effect but before the second has raised its PN₂ above 1 atmosphere. Model 5, with different kinetics, gives a smoother curve. Two sets of these curves are shown in Figures 3 and 4. Depending on which model is used the risk of 1% bends after a no-decompression dive to 60 feet starts at 20, 45 or 75 minutes. With the dive to 120 feet the 1% risk is reached at 4, 5 and 7 minutes. It is of interest that the models are not consistently fast or slow at the two depths. This depends on the time constants for the models; 3 and 4 have a short time constant which requires deeper stops, but they are brief.

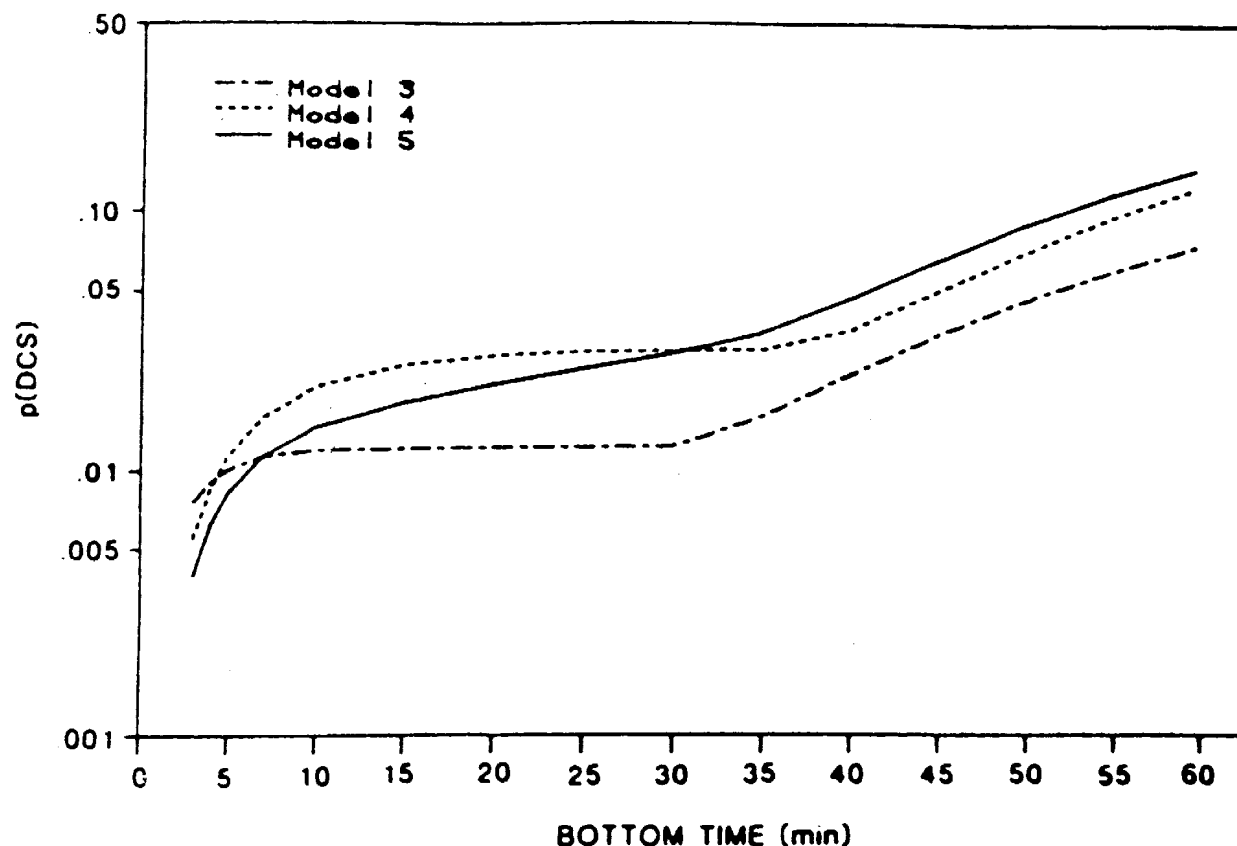
Model 5 was chosen for the tables as it gives a smoother curve for the no-decompression predictions and because it is a kinetic model. The tables have most of the decompression at 10 feet which is quite different to Brian Hills' thermodynamic theory decompression requirements.

The no-decompression limits calculated by three (3, 4 and 5) are set out in Table 2. The current USN no-decompression limits are in the more than 1% risk area in all three models at all depths except for 50, 60, 70, 80 and 90 feet, where only two models are over 1%. For 35 and 40 feet the current USN no-decompression limits are in the more than 5% risk area. The Bassett modification to the USN no-decompression limits is in a slightly better position. None of its limits are in the 5% risk area. At 40 and 50 feet only one model puts it in the over 1% range. At 30, 60, 70, 80 and 90 feet two models put it in the over 1% range. At 35, 100, 110, 120, 130 and 140 feet all three models put its times in the over 1% range which is true of the USN tables as well for these depths. Neither table has any time for any depth in the predicted 0.5% risk zone. In other words the least one can expect is to have a two to one risk of developing DCS after one dive in every hundred using the USN tables, if the models are reliable. (However those who use the Bassett tables with their slower ascent rate are allowing some extra decompression time during surface ascent, so although

FIGURE 4

Reprinted from reference 12

NO-DECOMPRESSION DIVES TO 120 ft



Probability of DCS after dives to 120 ft for various bottom times followed by direct ascent to the surface. Results are plotted for three different models and parameters from Data Set ABCD.

the bottom times, with a 60 foot a minute ascent rate would put the diver at the risks mentioned, the slower ascent reduces the risk as does the safety stop on all dives below 10m (30 feet).)

Various people in Australia have told me that the new USN tables will give longer bottom times for less decompression. From these reports^{4,12} this is not entirely true. Certainly the "5% incidence of DCS" table times are, deeper than 40 feet, 20 minutes longer than current USN times down to 180 feet where they are 15 minutes longer. But who really wants to get bent every twentieth dive?

The "1% incidence of DCS" table halves the no-stop times at 35 and 40 feet, knocks 30 minutes off at 50, 20 minutes come off at 60, 25 minutes of at 70 and 80, 20 minutes off at 90, 17 minutes off at 100, 13 minutes off at 110, 10 minutes off at 120, 5 minutes off at 130, 5 minutes off at 140, 1 minute comes off at 150 feet and below that depth there are only decompression dives. The limits for these two tables, the current USN tables and the Bassett tables are set out in Table 3.

These tables are untested. The history of testing tables is that in almost every instance the tables have to be modified to reduce the bends rate to an "acceptable" incidence. Chamber dives usually produce fewer cases of DCS than sea dives⁸ again leading to table modification. So what the final, tested, tables will be is anyone's guess. But it is pretty certain that they will not be identical with the first proposal.

The idea of decompression tables which allow you to pick the likely chance of DCS is a good one. What is doubtful is whether the equations used to predict the incidence are actually valid under all circumstances. Some of the data sets had to be excluded because the predictions did not fit the results at all well. A reliable prediction model should fit all the data. Weathersby et al¹² draw attention to this and to the unreliability of some of the data. They are troubled by the short decompression requirements for very deep but short dives. The USN had a nearly 10% incidence of DCS with short dives to 285 feet with longer decompressions than are suggested in the new tables. Another worry is whether the sudden decompression to shallow stops will cause problems. Only testing will give the answer.

TABLE 2

CALCULATED NO-DECOMPRESSION LIMITS

Reprinted, in part, from reference 12.

PROBABILITY OF DECOMPRESSION SICKNESS (%) WITH THREE MODELS
(CURRENT USN TIMES FOR COMPARISON)

DEPTH (FSW)	MODEL 3			MODEL 4			MODEL 5			USN
	0.5	1.0	5.0	0.5	1.0	5.0	0.5	1.0	5.0	
30	160	180	290	200	220	320	120	170	270	
35	130	140	230	160	170	240	85	130	200	310
40	110	120	190	130	140	190	60	100	170	200
50	80	90	140	10	100	140	30	65	120	100
60	7	75	110	7	25	110	15	40	95	60
70	4	60	95	5	10	90	7	25	80	50
80	3	50	80	4	7	75	5	15	65	40
90	2	40	70	4	5	65	5	10	55	30
100	2	15	60	3	5	55	4	8	50	25
110	2	5	55	3	5	50	3	7	45	20
120	-	4	50		4	45	3	5	40	15
130	-	4	45		4	40	3	5	35	10
140	-	3	40		3	35	-	4	30	10
150	-	3	35		3	30	-	4	30	5
160	-	3	35	3	30	-	3	25	5	
170	-	-	32	-	25	-	3	25	5	
180	-	-	31	-	25	-	3	23	5	
190	-	-	29	-	21	-	3	21	5	
200	-	-	27	-	18	-	-	20	-	

Time is in minutes. Descent rate of 75 ft/min. Ascent rate of 60 ft/min. Descent time counts as part of bottom time.

TABLE 3

NO STOP BOTTOM TIMES

Reprinted in part from reference 12

Depth in FSW	Predicted 5% DCS	Predicted 1% DCS	Current USN	Bassett times
30	240	170	310	220
40	170	100	200	120
50	120	70	100	70*
60	80	40	60	50*
70	80	25	50	40*
80	60	15	40	30*
90	50	10	30	25*
100	50	8	25	20*
110	40	7	20	15*
120	40	5	15	12*
130	30	5	10	10*
140	30	4	10	5*
150	30	4	5	-
160	25	-	5	-
170	25	-	5	-
180	20	-	5	-
190	20	-	5	-
200	20	-	-	-

Both predictions are made using Model 5 with data sets A,B,C and D.

*The Bassett tables require a 3 to 5 minute safety stop at 3 to 5 m on these dives.

REFERENCES

1. des Granges M. Standard air decompression table. Naval Experimental Diving Unit Report No. 5-57. Washington DC: Navy Experimental Diving Unit; 1956.
2. Dembert ML, Jekel JF and Mooney LW. Health risk factors for the development of decompression sickness among US Navy divers. Undersea Biomedical Research. 1984; 11(4): 395-406.
3. Berhage TE and Durman D. US Navy air decompression schedule risk analysis. Navy Medical Research Institute Report No. 80-1. Bethesda: Naval Medical Research Institute; 1980.
4. Weathersby PK, Survanshi SS, Homer LD et al. Statistically based decompression tables. 1. Analysis of standard air dives: 1950-1970. Naval Medical Research Institute Report No. 85-16. Bethesda: Naval Medical Research Institute; 1985.
5. Workman RD. Calculation of air saturation decompression tables. Naval Experimental Diving Unit Report No. 11-57. Washington DC: Navy Experimental Diving Unit; 1957.
6. Donald KW. A review of submarine escape trials from 1945 to 1970 with particular emphasis on decompression sickness. Medical Research Council Underwater Physiology Report No. 290. London: Her Majesty's Stationery Office; 1970.
7. Nishi R, Kuehn LA, Kidd DJ et al. Air dives done at Defence and Civil Institute of Environmental Medicine, Ontario, Canada. CANDID data base access numbers DDO453A to DDO814A.
8. Crocker WE. Investigation into the decompression tables. VII. Sea trials of proposed new diving tables. Royal Naval Physiological Laboratory Report No. 2-57. London: Her Majesty's Stationery Office; 1957.
9. Van der Aue OE, Kellar RJ and Brinton FS. The effect of exercise during decompression from increased barometric pressures on the incidence of decompression sickness in man. Naval Experimental Diving Unit Report No. 8-49. Washington DC: Navy Experimental Diving Unit; 1949.
10. Van der Aue OE, Kellar RJ, Brinton FS, Barton 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. Naval Experimental Diving Unit Report No. 13-51. Washington DC: Navy Experimental Diving Unit; 1951.
11. Crocker WE and Hempleman HV. Investigation into the decompression tables. A method of calculating decompression stages and the formulation of new diving tables. Royal Naval Physiological Laboratory Report III, Part B. London: Her Majesty's Stationery Office; 1952.
12. Weathersby PK, Hays JR, Survanshi SS et al. Statistically based decompression tables. II. Equal risk air diving decompression schedules. Naval Medical Research Institute Report 85-17. Bethesda: Naval Medical Research Institute; 1985.

RECOGNISING THE DISTRESSED DIVER

"There is no such thing as an accident. What we are seeing is an effect-from a cause which we do not see." (at the time)

Voltaire

This list has been sent to us by Wayne Williams and Dr John Williamson. It was compiled by a group of experienced Townsville instructors who had observed these problems over the years, with apprehensive pupils.

WARNING SIGNS OF IMPENDING TROUBLE IN NOVICE DIVERS

BEFORE THE DIVE

Vague symptoms to "cop out"
Stalling tactics
Super-quiet

KITTING UP

Errors of simple technique

ENTRY

Grasping boat lines high above the waterline
Inefficient finning
Wide eyed
Inappropriate concern about diving conditions
Reluctant to give up regulator for snorkel
Not following instructions

DESCENT

Equalisation problems -
where no previous problems existed
Buoyancy problems -
where no previous problems existed

THE DIVE

Buoyancy problems
Will not go to the bottom
Keeps off the bottom
Wide eyed
Poor observation of surroundings
Fails to obey pre-dive instructions
Works much harder than other divers
Rapid air consumption (sometimes)

THE 'UP' SYNDROME

A mental attitude where the solution to any problem is rushing to the surface

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