Workshop report

The use of deep tables in the treatment of decompression illness: The Hyperbaric Technicians and Nurses Association 2011 Workshop

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Abstract

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In August 2011, a one-day workshop was convened by the South Pacific Underwater Medicine Society and the Hyperbaric Technicians and Nurses Association to examine the use of deep recompression treatment tables for the treatment of decompression illness in Australia and New Zealand. The aim of the workshop was to develop a series of consensus statements to guide practice around the region. The workshop chose to focus the discussion on the use of 405 kPa (30 msw) maximum depth tables using helium-oxygen breathing periods, and covered indications, staffing and technical requirements. This report outlines the evidence basis for these discussions and summarises the series of consensus statements generated. These statements should assist hyperbaric facilities to develop and maintain appropriate policies and procedures for the use of such tables. We anticipate this work will lead to the formulation of a standard schedule for deep recompression to be developed at a future workshop.

Key words

Recompression, decompression illness, decompression sickness, heliox, treatment, hyperbaric facilities, safety, meetings

Introduction

This one-day workshop, jointly run by the South Pacific Underwater Medicine Society and the Hyperbaric Nurses and Technicians Association (HTNA) was held in August 2011. At the workshop, we proposed a series of statements concerning the use of deep treatment tables for decompression illness (DCI). These statements were broken up into three sections (medical, nursing and technical), each introduced by a formal presentation from an expert in the appropriate discipline. Following the presentation of each proposed statement, the joint chairs moderated an open discussion designed to modify the statement as required and seek a consensus. Following agreement on each statement, we moved to the next. The aim was to build through consensus a logical, comprehensive approach to the use of deep treatment schedules. In this report, the medical, nursing and technical background material is reported first, followed by 17 concensus statements with summaries of the discussions on each.

Summary of the evidence and medical considerations

For over a century, the 'standard of care' treatment for DCI has been recompression.[1] Early success using air breathing during recompression to the 'depth' (pressure) of the incident dive was enthusiastically reported in comparison to the previously common approach of masking symptoms with alcohol and morphia until they receded.[2] The use of formalised 'deep' treatment tables really begins with the development of US Navy (USN) Treatment Tables 1 to 4 by Van der Aue and others.[3] These tables were formally adopted by the USN in 1945 and were the preferred approach for the treatment of DCI until the 1960s. Over time, however, it became clear there were many problems with the use of long air recompression tables and in the 1950s and 60s, following the work of Behnke and others in the USN, the use of relatively low-pressure, short oxygen (O_2) tables achieved widespread acceptance. Today, the most commonly used recompression schedules for DCI worldwide involve compression to 284 kPa (18 metres' seawater (msw) equivalent) with 100% O_2 breathing (F_iO_2 = 1.0), followed by decompression according to the USN Treatment Table 6 (USN TT6) (see footnote) or the very similar Royal Navy Table 62 (RN62).[3,4] Several variations of these tables exist. The Divers Alert Network (DAN) reports suggest that about 80% of initial recompressions are delivered on one of these schedules, while less than 1% were clearly identified as 'deep' tables (0.7%) and 8% were simply classified as 'other'.[5]

The O_2 tables are highly successful, with resolution rates approaching 100% in some hands. The likelihood of success is related to the time delay to recompression – at least at the extremes. For example, Thalmann reported 97% resolution with prompt therapy, dropping to about 80% if treatment was

Footnote: The figures displaying the various treatment tables discussed at the Workshop are available separately to this article on the Journal and Society websites in a pdf file entitled: *Treatment tables for the Deep Tables Workshop*.

delayed for hours rather than minutes.[6] Outside the military sphere, Sayer et al reported 89.5% complete resolution or major improvement in a series of 194 Scottish divers.[7]

DEEP TABLES

'Deep' tables involve compression to pressures greater than 284 kPa (18 msw), the pressure beyond which it is unsafe to continue breathing 100% O_2. Two general forms exist, defined by the nature of the breathing gas. The first involves air or O_2-enriched air ('nitrox'), two examples being the USN TT4 and 6A, which involve excursions to 608 kPa (50 msw) whilst the patient breathes air.[3] The second involves the use of helium/oxygen (heliox) breathing mixtures. Probably the most commonly used of these is the Comex 30, which involves compression to a maximum pressure of 405 kPa (30 msw) while the patient breathes a 50:50 mixture of heliox. At the workshop, the participants defined the scope of the discussion, and it was quickly agreed that the primary interest was in the appropriate use of heliox tables, and this is reflected in the account that follows.

THE EVIDENCE

Vann et al. in a recent review of the treatment of DCI, acknowledge that 284 kPa O_2 tables have become the *de facto* standard of care, summarising the evidence for using deep tables thus: "*...supporting evidence is weak for depths greater than 18 m*[sw] *for initial recompression without a demonstrated need to go deeper, and no benefit has been shown in animal studies. Many recompression strategies ranging from pressures of 1.9–10.0 bar* [192 kPa to 1.01 MPa] *exist, but there are no human outcome studies for comparison of efficacy*".[8] Given this flimsy basis in support of deep tables, why are they still used? There are two principal arguments in favour of such tables. First, both physics and *in-vivo* animal experiments confirm that compression to greater pressure results in a more rapid reduction in bubble volume, particularly when heliox mixtures are employed.[9–11] Second, helium has a low lipid solubility, which may assist with denitrogenation of the tissues as there will be lower volumes of gas available for ingress into bubbles. Hyldegaard et al. have demonstrated more rapid resolution of bubbles with heliox and a transient increase in bubble size on compression while breathing 100% O_2.[10,11] They concluded: "*The clinical implication of these findings might be that heliox 50:50 is the mixture of choice for the treatment of decompression sickness.*"

Other animal model evidence has not shown a clear advantage for either heliox or deep recompression. Arieli et al compared DCS in a rat model using compression on O_2 (284 kPa) versus heliox (304 kPa) following a deep 'trimix' dive.[12] When treatment was delayed by 5 min after a provocative dive, the difference in death rate (25% with 100% O_2 versus 20% using heliox) was not statistically significant. In a dog model of cerebral arterial gas embolism, Leitch et al concluded that there was no advantage in preceding 284 kPa O_2 treatment with compression to 608 kPa on air.[13] They were also unable to demonstrate improved recovery in a dog spinal DCS model when the pressure was increased as the partial pressure of O_2 was held constant.[14]

The clinical evidence for the use of deep tables is largely anecdotal. In 1990, Thalmann described a number of cases where symptoms and signs refractory at 284 kPa resolved on deeper exposure.[15] In 1997, Shupak, in an historically controlled series of divers treated for spinal DCS, demonstrated no difference in outcome between USN TT6 or a heliox protocol.[16] However, this study was biased against the heliox treatment protocol because the severity score at presentation was significantly worse for that group ($P < 0.001$). Interestingly, of the 17 patients who were treated with the use of the O_2 tables, five deteriorated after the initial recompression. The authors also noted that two heliox patients had extensions of the Comex 30 and two further heliox patients went into saturation treatments, while in the other group, nine patients required an extended USN TT6. Shupak concluded: "*The results suggest an advantage of helium oxygen recompression therapy*".[16]

Following this report, there have been at least two attempts to perform randomised studies. Drewry et al reported in a meeting abstract on the first 88 patients enrolled in a trial comparing two complex algorithms based on heliox and nitrox breathing gases.[17] Patients in both groups started with compression to 284 kPa (18 msw) and could progress to 405 kPa (30 msw) on 50% O_2 if incompletely resolved after two 20-minute O_2 breathing periods. The odds of multiple recompressions was lower with the heliox table compared to the nitrox table (RR 0.56, 95% confidence interval (CI) 0.31 to 1.00, $P = 0.05$). Unfortunately, because of a failure to recruit divers early, the study was abandoned.[18] In 1999, a draft protocol by Hink to test the Comex 30 table against the standard USN TT6 never commenced formal recruitment.[19]

SUMMARY OF CURRENT OPINION

Little formal discussion has occurred over the last decade, with no clear consensus among experts. In 1998 Gorman and Moon summed up the situation as follows:[18]

Gorman: "*The 1995 attempt at consensus went no further than the 1990 attempt at consensus, which was pretty much the same as the 1979 consensus, and my advice then was, as it is now, get the old document, white out the date and just change* [it]."

Moon: "*The idea of using heliox as part of a recompression has been around now for 10 or 15 years, and slowly but surely, based on anecdotal reports and personal experience, it is becoming the de facto standard of care, unfortunately, I believe, without the necessary data. It may well be correct that helium-oxygen is more efficacious than oxygen or nitrox, but I think the danger of accepting this notion without the proper data is that a tremendous expense to chambers* *around the world would be incurred. I have seen a number of severe neurological bends referred to our medical centre after having received a treatment somewhere else, which either did nothing or actually appeared to make the patient worse. Those patients uniformly responded to* [oxygen] *recompression at our medical centre. I do not really understand why, it must have something to do with the natural history of the disease, but treatment a day later often is more efficacious than the initial treatment. If we had used helium-oxygen for those second treatments, we would be enthusiastically touting helium-oxygen. So, we must keep an open mind on heliox, but not accept it until the necessary observations have been made.*"

In 2011, little has changed. What follows is a pragmatic attempt to combine the Australasian experience and make some statements designed to guide those who may consider using deep tables in their clinical practice.

Some tables under consideration

There are many 'deep' tables from which to choose. Given that 100% O_2 breathing is unsafe beyond about 284 kPa, and that inert gases other than nitrogen and helium are not generally available (or necessarily useful), there are basically two approaches to deep tables, as noted above. For the workshop, the following representative tables were chosen, on which the participants could base their comments.

COMEX 30 (and COMEX 50)

These tables have a surprisingly difficult-to-define provenance. Since the workshop, it has been established that the Comex 30 table is an adaptation by Dr Xavier Fructus of an older nitrox table developed by Dr Barthelemy at the French Navy diving facility (GERS) in the late 1950s. The Comex table appeared for the first time in 1974 using either 50:50 nitrox or heliox (Imbert JP, personal communication 2012). The final version of the Comex 30 heliox table appeared in the 1986 Comex medical book. Since then it has been modified by many users, so that multiple similar versions are in use around the world. Today, there are many 30m heliox tables from which to choose.

Essentially the Comex 30 table involves an initial compression to 405 kPa (30 msw) for 60 minutes breathing a 50:50 heliox mixture, followed by decompression on the same mixture, with stops at 344 kPa (24 msw), 304 kPa (20 msw) and 223 kPa (12 msw), (total time 450 min). The Comex 50 table is very seldom used. It involves a period of 80:20 heliox breathing at 608 kPa (50 msw) before decompressing to 405 kPa (30 msw) and proceeding much as for a Comex 30 table.

Two versions of a Comex 30 in use in Australian hyperbaric units are shown in the pdf on the websites. These give instructions for locking in a second attendant on reaching 284 kPa (18 msw) during decompression. One of these tables is designed to convert a USN TT6 to a 405 kPa (30 msw) heliox table after failed symptom resolution at 284 kPa (a similar approach to the RNZN 1-alpha discussed below). Finally, an example of a 608 kPa (50 msw) modified Comex heliox table (developed by Dr. Robert Wong for the Fremantle Hyperbaric Service) is also shown on the websites.

RNZN 1-ALPHA

This table involves 50:50 heliox breathing initially at 284 kPa (18 msw), progressing to 405 kPa (30 msw) if there is less than 80% resolution after a period. It resembles a Comex 30 table but with an option to go no further than 18 msw if there is a good response, and with the shallowest stop pressure at 192 kPa (9 msw) instead of 223 kPa (12 msw). An additional feature is that all 'air' breaks are on 80:20 heliox.

HAWAIIAN TABLES

These deep air-breathing tables are unique to Hawaii.[20] They utilise an initial deep 'spike' to either 962 kPa (280 fsw; 85 msw; TT280), 780 kPa (220 fsw, 67 msw; TT220), or ~608 kPa (160 fsw, 49 msw; TT160) using nitrox mixes of 65:35 and/or 50:50. The Hawaiian physicians claim these tables are more successful than the 'standard' 284 kPa tables and some version of these tables is employed for 90% of DCI treatments. The rationale is that they take advantage of pressure to reduce bubble size and enhance dissolution, followed by a slow, staged decompression while providing therapeutic hyperbaric O_2, eventually transitioning to 100% O_2 at 284 kPa, and then a more gradual staged decompression rate compared to USN tables.

US NAVY TREATMENT TABLE 6A (USN TT6A)

This table was originally proposed for the treatment of arterial gas embolism on the basis that a high pressure spike to 608 kPa (50 msw) at the start would promote bubble resolution through Boyle's law.[3] After a period of 30 min (which includes the compression time) breathing air at 608 kPa (50 msw), the patient is decompressed to 284 kPa (18 msw), where a standard USN TT6 is commenced. There has been no clear validation of this table (see above) and it is now rarely used.

USN AND RN DEEP AIR TABLES

Both navies have published a series of air tables with deeper excursions than 284 kPa (18 msw).[3,4] They are largely historical, although they are still employed occasionally for resistant cases, particularly in facilities that have the ability to convert to a saturation protocol. They may also be used in unusual situations where O_2 is not available for recompression. The series includes:

USN TT2A (RN52): 11 hour table to 608 kPa (50 msw) (no O_2 available);
USN TT3 (RN53): 19 hour table to 608 kPa (50 msw) on air, then O_2 breathing at 284 kPa (18 msw);
USN TT 4 (RN54): 38 hour table to 608 kPa (50 msw) then O_2 breathing at 284 kPa (18 msw);
RN55, 72, 71: 43- to 48-hour tables with extended stops when no O_2 is available.

Nursing perspective on the use of deep tables

A small survey taken around Australia on nursing aspects of the use of deep treatment tables was reported. Thirteen nurses from four facilities where deep tables had been used responded. All used the Comex 30 schedule.

1. Were you looking forward to doing a Comex 30 treatment? About half said 'no' and cited the length of time in-chamber and concern about performance at depth due to nitrogen narcosis, with a sick patient in a small treatment area as the common reasons for this. The other half said they were looking forward to it, citing the opportunity to be involved in a rare experience, to practise what they had trained for and extend their deepest treatment table experience. A single responder was indifferent about such treatments.

2. After doing a Comex 30 table, what were your feelings about doing further Comex 30 tables? There were mixed responses and the strong implication was that the experience could be either strongly positive or negative. Some were now more confident to undertake further such treatments, while others were not at all keen to repeat the experience.

3. Describe any incidents during the treatment table that made it more difficult or challenging. Few responses concerned incidents directly related to patient care. Two respondents found the treatment highly challenging caring for critically ill, ventilated patients (near drowning plus DCI). Two noted the need to concentrate carefully on a single task at any one time because of the effects of nitrogen narcosis. Two also remarked on the problems of working in a confined space for such a long period of time, while one reported being very fatigued and having trouble staying awake. Finally, one nurse reported difficulties with equipment running out of battery power during the treatment.

4. Did you suffer any ill effects during or after the treatment? Four nurses reported no ill effects, while the remaining nine had some problems to report. Eight reported fatigue after the treatment for one to two days, described by one as very similar to 'jet lag'. Three nurses complained of chest pain or tightness with cough, which was attributed to O_2 toxicity or a long period of breathing dry gases. One nurse complained of feeling nauseated while on O_2.

5. If you did suffer from ill effects were these reported to anyone? Four of the nine nurses who described ill effects had reported these to the medical officer in attendance. Several remarked that fatigue was expected and did not warrant reporting, while the single episode of nausea was not reported as it resolved on ascent.

6. Did you feel that you were at increased risk relative to attending an RN62? Despite the majority of respondents reporting some ill effects, only six agreed with this proposition, citing the consequences of increased depth and length of this table. The remaining seven felt they were at no increased risk and one commented that she was confident that all safety requirements would be adhered to, thus keeping risk to a minimum.

7. What was the outcome for the patient? Six of the 13 patients treated were fully recovered and four almost fully recovered. Three patients had only partial improvement.

8. Did you use the toilet during the Comex 30 table? While 11 nurses urinated as required and freely, two did not urinate at all during the table due to embarrassment. These respondents worked in a chamber with no toilet available at pressure, and were required to use a bedpan. It was observed that, at times, nurses deliberately avoided liquids prior to compression in order to avoid this embarrassment.

9. Did you feel that you had adequate support from the outside staff? All respondents reported that the outside staff were very helpful and attentive.

10. Please let us know if you have any other thoughts about the Comex 30 treatment table. A number of free-text comments are paraphrased here:

- I dislike being on O_2 for so long as it leads to cough and chest pain.
- I had more concern for the patient than myself.
- I would prefer to split the duration between two attendants.
- It was a good experience!
- This table is much better if it is not late at night.
- It was good to be involved; all part of job.
- It was a unique experience, but I dislike the "endless" O_2; I will do it in the future if required. It was challenging with a sick patient, but there was a good outcome.
- The table would be more comfortable with a better-designed chamber and, in particular, a toilet.
- Outcomes for the patient are good, and I support the use of the table, but have reservations about the depth and time a single attendant spends inside.

While many issues are raised by this small survey, three were of particular interest to the nursing staff. First, it was noted that the usual staffing for these tables is a single doctor, technician, outside nurse and attendant. There may be a good case for a second attendant to lock in at some point and relieve the first attendant. The second relates to professional competencies. Many remarked that there were no such competencies specifically relating to deep tables, and this situation was contrasted with other areas, such as the treatment of ventilated patients. Finally, there was great interest in discussing the safety of such treatments for inside attendants. The workshop then generated some related consensus statements.

Technical aspects of the use of deep tables

There are a number of identifiable risks arising from the use of these tables. Some of these are considered below.

STAFF DECOMPRESSION

Computing appropriate decompression schedules for the attendant is problematic. While all recompression tables rely on approximations and empiricism, the more routine exposures have the great advantage of history on their side. In any busy hyperbaric facility there will be hundreds of staff decompressions every year, such that the incidence of even relatively rare complications (e.g., DCS) can be estimated with some accuracy. Deep tables are rarely required and our collective experience is little more than a handful of cases in a year. The true risks may take many years to emerge with any accuracy, and staff are at risk in the meantime. This is even more so when considering extended tables, those converting from 18 msw tables, or those where tables are 're-started' following relapse on decompression. It would be very difficult to truly validate these schedules in an ethical manner. For this reason, decompression schedules are generally very conservative in these situations. From time to time, deep tables will need to be aborted unexpectedly, and plans must be in place to manage the decompression of the attendant under such circumstances.

ENSURING THE CORRECT GAS IS DELIVERED

Each of these deep tables involves several gas switches at differing pressures. At each switch, there is a risk of delivering an incorrect gas mix which could lead to O_2 toxicity or DCS. Several methods exist for checking the gas mix at these times and a safe treatment cannot be delivered without careful consideration of what combination of checks is likely to work best for the individual facility. Examples of such checks include noting changes in the gas-flow tone or register of the voice and physically double-checking the O_2 content of gas. Any safe facility will have staff appropriately trained in switching procedures and a regimen of regular competency checks.

GAS SUPPLY

Deep treatment tables consume large volumes of gas. The technician must ensure there is ample gas available to safely complete treatment with a significant reserve. Where possible, the use of hoods should be avoided in favour of demand-style regulators (e.g., Scott masks) or closed/semi-closed anaesthetic circuits.

How much gas might be used in a typical treatment? Calculation of the volume of gas required can be made by multiplying the atmospheric pressure inside the chamber (P, measured in Atmospheres Absolute, ATA) by the time spent at that pressure (T, min) by the volume of gas used by the patient(s) and attendant(s) per minute ($\dot{V}$, L min^{-1}) and by an appropriate safety factor (SF). That is:

$$\text{Volume required} = P \times T \times \dot{V} \times SF \quad [1]$$

Table 1
Example calculation for gas supply requirements

Calculate the amount of O_2 required for a USN TT6 (RN62) (without extensions) for one patient and one attendant. This requires four separate equations [2–5] due to the linear decompression stages and the two different treatment pressures (284 kPa (2.8 ATA) and 192 kPa (1.9 ATA)).

For the 2.8 ATA section: *3 times 20 min O_2 breathing periods.*
2.8 x 60 (Mins) x 15 (L min^{-1}) x 1.25 (SF) = 3,150 L O_2 [2]
For the 2.8 – 1.9 ATA section: *As the decompression is linear, an average of the absolute pressure over the 30 min is appropriate (i.e., 2.35 ATA).*
2.35 x 30 x 15 x 1.25 = 1,322 L O_2 [3]
For the 1.9 ATA section: *2 times 60 minute breathing periods for the patient and the attendant breathes O_2 for the last 30 min*
1.9 x 150 x 15 x 1.25 = 5,343 L O_2 [4]
For the 1.9 ATA to surface pressure section: *As the decompression is linear, an average of the absolute pressure over the 30 minutes is appropriate (i.e., 1.45 ATA). The attendant needs to breath O_2 for the duration of this section, therefore, time is be calculated at 60 min.*
1.45 x 60 x 15 x 1.25 = 1,632 L O_2 [5]

Total O_2 required = 11,447 litres

Table 2
Volumes of treatment gas required to conduct commonly used 'deep' treatment tables; FHHS 50 – Fremantle Hospital Hyperbaric 50 msw schedule; USN6–Cx30 – initial USN TT6 converting to Comex 30 if poor response

Treatment table	Pressure (max., kPa)	Time (hr:min)	Volume of gas (L) (Heliox or Nitrox)		
			50:50	20:80	40:60
USN TT1A	304	6:20	7,358	--	--
Comex 30	304	7:40	9,281	--	--
FHHS 50	507	9:20	14,578	3,496	12,984
USN6–Cx30	304	9:35	14,100	750	--

The volume of gas used by the patient (and attendant) is assumed to be 15 L min^{-1} for a demand-supply mask (e.g., Scott mask; requirements may differ for alternative breathing systems). The 'slides' from one pressure to another are estimated using the pressure at the midpoint of the slide. The safety factor recommended is 1.25. That is, multiplying the calculated expected volume usage by 1.25. An example gas calculation is shown in Table 1. Using the formula above, Table 2 shows the volume of gas(es) required to complete some of the tables commonly used in Australia.

INCREASED RISK OF O_2 TOXICITY TO BOTH THE PATIENT AND THE ATTENDANT

During deep tables, the patient is exposed to a high PO_2 for relatively long periods, and, therefore, is at risk for both pulmonary and central nervous system O_2 toxicity. As with all recompression therapy, the risks and benefits need to be carefully weighed. During decompression, the attendant(s) also spends significant periods breathing at high PO_2. The true incidence of toxicity is unknown (for similar reasons discussed above in regard to DCS) but cases have been reported. This is one of the advantages of considering a second attendant to be locked in during the treatment schedule. Facilities will need to have carefully reasoned procedures for dealing with both patient and staff O_2 toxicity, and should practise emergency procedures with regularity in anticipation of such events.

ATTENDANT FATIGUE

The sole attendant is not only at risk of both nitrogen narcosis early in the treatment (see below), but also fatigue due to the extended treatment time. The operating procedures of the individual unit must allow for any local award considerations and rules regarding working hours. There are several related issues that can only be addressed at a local level. Mandated work breaks will need to be addressed, both within normal working hours and after hours.

In practice, it may be impossible to relieve the inside attendant, while the available 'relief' staff may not be suitably trained and qualified to act as outside attendants. Indeed, there is also the question of the competence of medical officers to act as outside attendants. Some units have implemented specific competencies for their medical staff in order that they may step into roles as outside attendant, inside attendant or even technician, as the need arises.

CHAMBER OPERATOR FATIGUE

Similar issues arise with the potential for reduced vigilance and performance of the lone technician during a long, deep table. There are several critical aspects to the safe conduct of these tables, and arguably, a single attendant may be adversely affected, particularly if the treatment begins in the evening after an already full day's work. Local award considerations need to be addressed and consideration given to making a second technician available at a suitable time during the conduct of the table. With respect to both the attendant and the technician, there will be considerable cost implications for the provision of 'back-up' staff.

NITROGEN NARCOSIS IN THE ATTENDANT

All deep tables require the attendant to breathe air at a pressure sufficient to induce some degree of nitrogen narcosis. Procedurally, someone in the team must be identified as the 'decision-maker' and, ideally, this person should not be exposed to a high PN_2. There may be legal implications for any individual or facility that contemplates putting the decision-maker into such a position. It is unclear what can mitigate this situation, apart from 'doubling-up' all personnel involved in the treatment at considerable cost. It may be possible to modify the breathing system to allow heliox breathing for the inside attendant(s), or to introduce testing procedures to ensure 'tolerant' individuals are chosen for such tasks. We know of no facilities where either of these options has been put into practice.

EQUIPMENT ISSUES

Any in-chamber equipment must perform to the manufacturer's standard while under pressure; however, most medical equipment will require some modification in order to achieve this. This is particularly so in relation to mechanical ventilation and drug delivery systems such as pumps and drip counters.[21–23] A thorough system for risk assessment is required, involving the local clinical engineering (or biomedical) department. Any equipment not tested adequately for safety and performance under the relevant conditions should be banned from the chamber.

EMERGENCY PROCEDURES

A guiding principle of safe chamber operation is the existence of appropriate and practised emergency procedures (EPs). Given the rare use of these tables, and the increased risks inherent in going deep and long, this is particularly relevant in relation to them. EPs must be developed to cover all the identified risks discussed above. Ideally, the local occupational health and safety officers should be invited to participate from an early stage to ensure the ultimate adoption within the hospital facility of these procedures. These EPs must be reviewed and practised at regular intervals, and all such activity should be carefully logged.

Workshop consensus statements

The workshop was opened for discussion based on a series of statements concerning the medical application of deeper tables for the treatment of DCI. Each statement was generally accepted after discussion and modification, and the debates are summarised following each statement.

STATEMENT ONE – SCOPE OF THE WORKSHOP

This workshop will limit the consideration of deeper treatment tables to those involving periods of heliox breathing at 405 kPa (30 msw) and 608 kPa (50 msw) only.

Deeper nitrox (including air) breathing tables are used extremely rarely and no participant had used such tables for many years. Therefore the focus should be on the use of heliox tables at 405 kPa (30 msw) and 608 kPa (50 msw).

STATEMENT TWO – EVIDENCE FOR 'STANDARD OF CARE' USE

The evidence supporting the use of deep recompressions using heliox as a treatment gas is relatively weak. Notwithstanding the following discussion, these treatments cannot and should not be considered a 'standard of care' for relevant DCI cases.

There was broad agreement with the summary evidence as presented above. While both experience and evidence suggests there is a place for the use of these tables, there is no justification for the adoption of these tables as 'standard of care' in any particular clinical situation.

STATEMENT THREE – SITUATIONS WHERE DEEP HELIOX TABLES MAY BE INDICATED

Deep treatment tables may be indicated for:

Significant neurological DCI where a period of oxygen breathing at 284 kPa (18 msw) has not resulted in improvement of the clinical condition; OR at the initial presentation of serious neurological DCI; OR other life threatening, serious, or rapidly progressive presentations.

Some time was spent discussing the potential indications for these tables. It was agreed that:

- Appropriate personnel, experience and equipment (as defined later in the workshop) were a necessary pre-requisite before considering the use of these tables.
- No definitive list of indications could be generated from the evidence, and no statement should attempt to restrict the use of these tables. The clinician should be able to assess each presenting diver on an individual basis, and to use their own clinical judgement as to the appropriate therapy. This statement is a guide to clinical practice rather than a statement of 'standard of care' or a recommended clinical pathway.
- Serious neurological presentation was overwhelmingly the most common situation where the use of a deep heliox table should be considered.
- There was no consensus on the relative merits of using a 284 kPa (18 msw) O_2 breathing period as the primary approach, with conversion to deep heliox if the response is inadequate (as with the RNZN 1-alpha table), or a deep heliox table as the primary recompression schedule.
- There was strong support for allowing that other serious presentations may also be indications for a deep heliox table at the discretion of the treating physician.

STATEMENT FOUR – WHICH TABLE?

There is no good evidence for recommending a particular deep treatment pressure. Consideration of 405 kPa (30 msw) vs 608 kPa (50 msw) (or other treatment pressures greater than 284 kPa (18 msw)) must be undertaken by each unit based on experience and logistic considerations.

While the experience of the participants was overwhelmingly with the use of the 'Comex 30' table in its various forms, there was no clinical evidence to support the choice of any particular heliox-breathing schedule. Many experienced clinicians made the point that experience with the chosen table was invaluable, while logistical support was a vital factor in making this decision.

STATEMENT FIVE – USE OF REPEAT DEEP EXPOSURES

There is no indication for a second deep treatment table in the event of incomplete symptom resolution following the first.

There was unanimous agreement there was no indication for a second deep treatment for residual symptoms and signs following an initial recompression. Administering more than one such treatment within a short space of time carries logistic difficulties in most clinical facilities, and there is no good evidence to support such a practice.

STATEMENT SIX – INSIDE ATTENDANT TRAINING

Any deep treatment table should involve the attendance in the chamber of appropriately trained staff.

There is no advantage attached to mandating a particular set of requirements for training as these are site specific. Each facility intending to use deep treatment tables should develop appropriate training modules and procedures to suit their own operations. Neither is this statement intended to imply that inside attendants must have entry qualifications in any particular discipline.

STATEMENT SEVEN – MEDICAL STAFFING

The minimum medical staffing for a deep treatment table is one experienced hyperbaric medical officer (HMO) dedicated to the immediate supervision of that treatment. Consideration should be given to calling on a second medical officer if the supervising HMO is required to be compressed.

An experienced HMO is required in attendance at a deep treatment table. While there was debate about the need for a second HMO trained in diving medicine if the primary HMO is required to enter the chamber, most experienced physicians considered there was no justification for a formal 'second call' roster to be developed. This situation occurs so rarely that it is best addressed by each unit individually.

STATEMENT EIGHT – NURSING/ATTENDANT STAFF

The minimum number of trained chamber attendants for a deep table is one inside attendant and one outside attendant.

The preferred number of trained chamber attendants for a deep table would allow a second inside attendant to take over care of the patient during the table.
The staffing level for chamber attendants during a deep table varies greatly between facilities. While it is highly desirable to reduce fatigue and the incidence of complications due both to pressure exposure and lengthy O_2 breathing periods, it may not always be logistically practical to ensure that an attendant change over can be achieved safely. Each facility should consider the possibility of such a change over. This is the preferred staffing arrangement.

STATEMENT NINE – HYDRATION AND TOILETING ARRANGEMENTS
The inside attendant in a deep treatment must ensure they maintain adequate fluid intake both before and during the exposure. Acceptable toileting facilities must be provided.
This requirement was unanimously agreed. While it is acceptable that some chambers will not have a standard toilet available at depth, there must be adequate facilities in place to ensure privacy and hygiene to allow comfortable and safe toileting.

STATEMENT TEN – ALTITUDE AND EXERCISE AFTER DEEP TABLES
The chamber attendant should not fly for at least 24 hours after a deep treatment table, and not undertake strenuous exercise (e.g., jogging, weights session, cycling) for 12 hours after such a table.
There is little evidence to guide such recommendations, and 'strenuous exercise' is difficult to define. Individual facilities are encouraged to refer to published standards with regard to altitude exposures (both flying and terrestrial) following individual treatment tables, while each facility should develop a policy regarding the permissible level of exercise following such exposures.

STATEMENT ELEVEN – ATTENDANT TIME TO SUBSEQUENT COMPRESSION
The chamber attendant should not be required to be compressed again for a minimum of 24 hours after completing a deep treatment table.
While this statement was widely accepted, it was allowed that, in the event of two attendants sharing the exposure (as recommended in statement eight above), a shorter period may be permissible for the second attendant. This will depend on the point at which the change over occurs and is at the discretion of individual facilities.

STATEMENT TWELVE – GAS SUPPLY
The minimum safe gas supply to allow for the performance of a deep table is to be calculated, and the correct volume of gas is to be immediately available and a written note made to that effect before starting the treatment.
The oxygen content of any heliox mixtures should be measured prior to use (see Table 1 above).

STATEMENT THIRTEEN – CHAMBER OPERATOR AVAILABILITY
The minimum safe technical staff level for a deep table is two.
The presence of two technicians was considered to be highly desirable, but some argued that such a provision would be very difficult in practice. After discussion, a show of hands was overwhelmingly in favour of including this statement.

Such an arrangement could be achieved 'ad hoc' rather than by a formal 'second on-call' roster. Two operators would not be required for the entire table, but rest relief or a change over as mandated by local practice rules was entirely appropriate. A number of attendees suggested that the inability to locate a second operator to provide such relief was a good reason to pursue an alternative, shorter table rather than persist with a single operator.

STATEMENT FOURTEEN – CHANGE-OVER TIME FOR INSIDE ATTENDANT
While it is acceptable practice to require a single attendant to complete a deep treatment table, if a change of attendants is considered necessary or desirable, a suitable time to make the change is on arrival at 223 kPa (12 msw) for a Comex 30 heliox (or similar) table, and on arrival at 284 kPa (18 msw) for a Comex 50 table.
These times are chosen on the basis that they are the points at which the first attendant is required to breath 100% O_2, and is therefore both at risk of O_2 toxicity, and less physically able to attend the patient. The second attendant will have minimal decompression obligation (particularly so with the 405 kPa (30 msw) tables) and will have a reduction in the time to recompression for future work.

STATEMENT FIFTEEN – ATTENDANT ON OXYGEN
The attendant(s) are required to hold on their mask during oxygen breathing periods during deep treatments.
While it is possible that any central nervous system toxicity will terminate equally as rapidly whether the O_2 mask is removed or not, the workshop was unanimous in the opinion that it remained good policy not to have the attendant use a mask strapped onto the head for decompression. A secondary advantage of this practice is that a dropped or removed mask, whether owing to fatigue or inattention, would bring the early attention of the operator and outside attendant to the fact that there may be a problem inside. If two attendants are inside, only one of whom is required to breathe O_2, then strapping to the head would be appropriate, if that was preferred by the individual.

STATEMENT SIXTEEN – GAS SWITCHING
Gas switching periods should be made safer by close, alarmed monitoring systems to ensure safe transitions.
Gas switching is a time of increased risk in the performance of all deep treatment tables. While there are physical signs of successful switching (e.g., voice timbre or gas-flow pitch) these are generally less reliable than appropriate monitoring systems with alarm limits. There are a number of alternative

monitoring systems available and the choice will depend on local considerations. Alarmed monitoring is mandatory for the safe conduct of deep treatment tables using heliox mixtures.

STATEMENT SEVENTEEN – ATTENDANT DECOMPRESSION FOLLOWING ABORTED DEEP TABLE

In the event that a deep treatment needs to be aborted, the attendants must have another chamber available (and to which they can transfer under pressure) in order to complete any decompression obligations.

It is acceptable that any attendant so affected can complete their decompression without themselves being attended.

There is a practical limit to the support that can be provided during the use of a deep table, and it is unreasonable to expect a third attendant to be on call in the unlikely event that a table is aborted, leaving two attendants with decompression requirements. In this case, it is reasonable to allow the attendant to decompress alone with observation only from outside the chamber. "Another chamber" here does not mandate a second, independent vessel, but that an independent compartment within the same vessel would be acceptable. What is required is the ability to more rapidly decompress the patient in the case of an abort, while still protecting the original attendant from decompression injury by allowing the planned decompression procedure in another chamber/compartment.

Conclusions

Deep treatment tables resembling the Comex 30, which utilise pressures higher than 284 kPa and heliox breathing, are used sporadically in Australia and New Zealand. There is sufficient evidence of efficacy to justify this practice, but insufficient evidence to establish such tables as a 'standard of care'. Nor is there an evidential basis for choosing one deep treatment regimen over another.

Hyperbaric units undertaking deep treatments must be appropriately equipped and staffed. 'Appropriately equipped' implies the presence of the required gas delivery and monitoring systems, sufficient supplies of all relevant gases, toileting facilities, and an externally accessible compartment into which attendants can transfer under pressure for decompression independent of the treatment compartment, if there is a requirement to abort the treatment in an emergency. Deep treatments should be attended by medical, nursing, chamber attendant and technical staff who are trained and experienced in their implementation.

The minimum staffing for a deep treatment is one medical officer, two nurses / attendants (one inside and one outside), and two technicians. There must be provision for the inside attendant to maintain hydration, including privacy for toileting. A lone inside attendant must hold the O_2 mask during O_2-breathing phases of the decompression. Inside attendants must not fly or be compressed again for at least 24 hours after completion of the treatment. Nor should they undertake strenuous exercise for at least 12 hours.

The workshop recommends recompression facilities in Australia and New Zealand should maintain a prospective database including all occasions when deep tables are used. The data set should include the indication for treatment, details of the conduct of the treatment including staffing and pressure profiles, any adverse effects on patients or staff, the number and nature of follow-up recompressions and the clinical outcome. Such information will be useful in further defining appropriate recompression schedule selection in the future. Consideration should be given to the development of an agreed deep recompression schedule, including recommended staffing levels, gas switching procedures, safety procedures and abort schedules.

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Editor's note:

Because of the considerable additional expense of reproducing a large number of colour images in the Journal, the several treatment tables discussed at the Workshop are gathered together on the Journal and Society websites in a pdf file entitled: *Treatment tables for the Deep Tables Workshop*. This may be found in the journal sections on the EUBS and SPUMS websites and in the featured article on the Journal website.

Diving and Hyperbaric Medicine – 5-year Impact Factor

Diving and Hyperbaric Medicine has now been indexed on the Thomson-Reuters database SciSearch® for five years. The five-year Impact Factor is shown in Figure 1. Note that no IF is given until after the first two years of indexation, so 2009 was the first year in which an IF was calculated.

Much of the level of the IF is the result of self-citation (that is, articles in DHM referring to other articles within the same journal). However, with back-indexing of the years 2008–2010 on PubMed, one would expect to see a further rise in the journal's IF over the next few years.

As the IF of a publication is generally regarded as a proxy for its relative importance within its field, the message is clear - please support your Journal!

Figure 1
Impact Factors for *Diving and Hyperbaric Medicine*