Review article

Monoplace chamber treatment of decompression illness: Review and commentary

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Abstract

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This paper summarises the history and capabilities of monoplace chambers in treatment of decompression illness (DCI); both in support of diving operations and in the hospital setting. In the field, monoplace hyperbaric chambers provide victims of DCI immediate access to recompression in settings where traditional multiplace chambers are not available. Alternatively, they may facilitate pressurised transport to a multiplace chamber for continued management. Recently, collapsible lightweight versions have improved suitability for field deployment aboard small vessels in remote settings, and for use by less technically capable military, occupational and civilian operators. The resulting elimination of treatment delays may prove lifesaving and central nervous system sparing, and avoid subsequent diving fitness disqualification. Monoplace chambers thus facilitate diving operations that would otherwise be difficult to condone on health and safety grounds. The 1960s saw the introduction of multiplace hyperbaric chambers into the hospital setting, as a number of non-diving conditions appeared to benefit from hyperbaric oxygen. This coincided with interest in hyperbaric oxygen as a solid tumour radiation sensitiser. Development of a novel acrylic-hulled single occupancy chamber enabled patients to undergo radiotherapy while pressurised within its oxygen atmosphere. Increasing numbers of health care facilities adopted this chamber type as a more economical, less complex alternative to the multiplace chamber. Incorporation of relevant biomedical technologies have allowed monoplace chambers to support increasingly complex patients in a safe, effective manner. Despite these advances, criticism of medical centre-based monoplace chamber treatment of DCI exists. This paper evaluates this controversy and presents relevant counter-arguments.

Introduction

Therapeutic recompression has long represented standard care for those suffering decompression illness (DCI). It was proposed in 1854,[1] then first employed in a systematic fashion during excavation of the Hudson River tunnel.[2,3] By the early twentieth century, an on-site recompression or hyperbaric chamber was increasingly considered essential support for compressed air operations.[4,5] Constructed of steel, it was large enough to accommodate several occupants. This afforded immediate and simultaneous treatment of multiple patients, given large 'at risk' populations employed within pressurised bridge caissons and mass transit tunnels. Connected to the chamber was an entry compartment, or air lock, to facilitate transfer of patients and support personnel into and from the main compartment while it remained pressurised. The chamber's principal therapeutic basis was that of Boyle's Law; namely, air pressure increases proportionally decrease the volume of gas emboli.

On-site recompression chambers were soon associated with naval and civilian diving operations. In contrast to referenced fixed location civil engineering projects, diving worksites involved fewer at-risk personnel, occasionally operated from water-borne platforms, and were increasingly remote. To support this form of compressed air work, traditional large permanently emplaced multiplace chamber design evolved to one that was smaller and relatively transportable. Subsequent use of aluminum alloy further decreased weight and enhanced transportability.

Growth in demand for underwater work, occasional space limitations, increasingly remote worksites and certain economic constraints led to the introduction of a single occupancy 'monoplace' chamber. Air remained the compression gas and operating pressures of early models equalled many of their multiplace counterparts.[6,7] In due course, oxygen, delivered by facemask, became an important therapeutic adjunct, as it did for the multiplace chamber.

Monoplace chamber support of diving operations commonly involves two distinct strategies. One is to effect treatment while the chamber remains at the dive site, thereby ensuring its continued availability during ongoing underwater activities. The alternative is a transportable system, although chamber designs are not mutually exclusive. In this second example, and upon initiation of on-site recompression, transfer of the pressurised diver to a regional multiplace chamber occurs by whatever expedited means planned or available. Upon arrival, the patient relocates to the multiplace chamber. Several factors dictate how this is accomplished. If the monoplace is equipped with a flange coupling compatible with the multiplace, transfer under pressure takes place by physical connection of the two chambers.[8] Once attached, compression of the multiplace chamber to equal monoplace pressure occurs, at which point multiplace inside attendants (IAs) open interconnecting hatches and assist the patient into the multiplace compartment for continued treatment. Monoplace chamber design tends to be narrower and lighter in order to accommodate this transfer method. In the absence of a physical connection capability, and size constraints permitting, support personnel place the monoplace into the unpressurized multiplace chamber.[9] The multiplace is then compressed to monoplace pressure and the patient relocated as before. Failing the ability to effect either option, one may elect to complete treatment in the monoplace or decompress it and promptly recompress the patient in the multiplace. Various clinical circumstances, operational constraints and environmental factors dictate which of these decisions would best apply.

In the 1980s a fabric-hulled compressed air monoplace chamber was introduced.[10] Exceptionally lightweight, it is readily transportable in carrying cases. Although it lacks the degree of pressurisation inherent in earlier monoplace designs, it has an oxygen delivery system so is capable of providing US Navy Treatment Table 6 (USN TT6); an essential DCI standard of care.[11] Such chambers presently support unique military needs,[12] civilian professional, marine science[13] and recreational diving communities,[14] and have proven an effective on-site option to reduce inherent treatment delays.[13,14]

There has been little criticism of monoplace chamber support of a wide range of diving activities and its transfer under pressure capability.[15–18] On the contrary, its increased acquisition in recent years appears testament to its perceived lifesaving and central nervous system-sparing potential, and avoidance of outcomes that result in career-ending diving medical disqualification. Monoplace chambers support diving operations that would otherwise be difficult or impossible to condone on health and safety grounds. This is certainly the case in remote settings where injured diver retrieval can be complex, lengthy, hazardous and expensive. Cocos Island, essentially a rocky outcrop off Costa Rica and popular for cage diving among great white sharks, is one example. It is only accessible by boat so injured divers must endure the 30-hour return trip to the mainland for care. Fixed wing aircraft cannot land and the island is well beyond helicopter range. 'Fast boat' recovery attempts are dangerous and may be thwarted by unpredictable weather conditions that far into the Pacific. The author was recently involved in a 28-hour retrieval of a diver from San Benitos Island, off Baja California, Mexico.

The 1960s saw the introduction of hospital-based multiplace hyperbaric chambers as several other conditions appeared to benefit from their use. This same period coincided with considerable interest in hyperbaric oxygen (HBO) as a solid tumour radio-sensitizer.[19,20] A newly designed acrylic-hulled monoplace chamber facilitated this novel approach; one that enabled patients to undergo radiotherapy while pressurised within its oxygen atmosphere.[21] Hospitals increasingly adopted this chamber type as a more economical and operationally less complex alternative to the multiplace chamber for provision of HBO treatment (HBOT). Over the ensuing years, several biomedical technologies have been developed or adapted to allow monoplace chamber support of increasingly complex cases.[22–28] Today, it affords safe and effective therapy across the full range of patient states, from ambulatory cases to those critically ill and dependent upon mechanical ventilation.

In contrast to its on-site support role, the hospital based monoplace chamber enjoys a practice setting readily supported by advanced diagnostic capabilities, complementary therapies and multidisciplinary expertise. Given this optimal clinical environment, given that the monoplace meets US Navy minimum hardware capabilities for recompression therapy,[29] given that it has been successfully employed over several decades,[30–34] and given that it is considered appropriate for treatment of DCI in authoritative reviews,[11,35] it is surprising that there has been criticism of its use for this purpose in the hospital setting.[32,36,37]

Monoplace chamber perceived limitations addressed

Criticisms of the monoplace chamber in general and its use to treat DCI in particular can be summarised as patient isolation, lack of an air break delivery system, inability to support critically ill patients, limited pressurisation capability, heightened fire risk, impact of decompression on an existing pneumothorax and management of excreta. What follows is a review of the monoplace chamber's current capabilities in the context of these criticisms. It should enlighten those not familiar with, or have a dated understanding of the scope of the monoplace hyperbaric delivery system's technical arrangements and operational standards, the sum of which should serve to dispel much negative dogmatism.

PATIENT ISOLATION

The principal advantage of the multiplace chamber is the ability to accompany patients during treatment. For the

injured diver, this affords objective assessment of treatment response to guide subsequent management decisions. Typically today, this will centre on whether to extend the USN TT6. Historically, treatment decisions based upon clinical response were more impactful given a multitude of recompression approaches, therapeutic gas choices, saturation storage options and subsequent decompression table selection.

Should the diver exit the multiplace chamber incompletely recovered, follow-up treatments using USN TT5, 6, or 9, are commonly rendered until resolution, or no sustained improvement following two consecutive treatments.[38] There is no credible evidence to indicate that this 'simplified' approach is any less effective than deeper, longer and operationally more complex options, most of which have since been abandoned.

Appropriately equipped and knowledgably staffed monoplace chambers readily support a USN TT 6. The key 'monoplace' decision is how to address the issue of medically necessary extensions in the absence of objective guidance. For more than three decades, the hyperbaric medicine programme at the author's institution has successfully employed one such approach. It involves table extension determination at the beginning rather than the end of the third oxygen breathing cycle at 284 kPa (2.8 atmospheres absolute [atm abs]). If the patient reports being asymptomatic at this time point, the USN TT6 is continued without extension(s). Should a residual undetected deficit exist, it has the therapeutic benefit of oxygen for 20 more minutes at 284 kPa and several additional hours during delivery of the remainder of the table. Should a post-treatment assessment determine incomplete relief, serial follow-up treatments occur consistent with multiplace operations. If the patient remains symptomatic at the beginning of the third oxygen cycle at 284 kPa, extension(s) occurs at that pressure. Assessment also takes place at 192 kPa (1.9 atm abs), in determining any additional extensions. Employment of all four extensions resulting in an 8-hour chamber exposure has been uneventfully administered.

Evaluating the patient's oxygen delivery system for good fit, and its management should central nervous system (CNS) oxygen toxicity develop is another important multiplace chamber inside attendant function. During monoplace operations, the patient breathes directly from the chamber's oxygen atmosphere so the potential multiplace chamber mismatch between chamber pressure and oxygen pressure when using an oral nasal mask does not exist.[39,40] As patients are readily visible from the monoplace control panel, any suggestion of oxygen intolerance prompts instruction to the patient to begin breathing air. Air delivery systems for the full range of patient states and are discussed in the next section.

If the chamber operator misses premonitory events and/or seizure occurs, chamber pressure remains unchanged until seizure activity has ceased. Even though the patient remains in a pressurized oxygen atmosphere, seizure latency is similar to patients immediately converted to air breathing, as would occur in a multiplace chamber. This has been a consistent observation during many decades of monoplace operations; namely, it is not necessary to interrupt oxygen breathing to halt an oxygen-induced seizure. Some may find this counter-intuitive as in their experience removal of the multiplace patient oxygen delivery system was associated with seizure cessation. The seizure would have ceased if mask/hood oxygen breathing continued, as oxygen is metabolized to sub toxic levels. For a patient to remain exposed to hyperbaric oxygen following a seizure, however, invites a second episode. Therefore, once all seizure activity has ended and the patient appears to be ventilating spontaneously, the monoplace chamber is decompressed.

Should a sudden change in patient status take precedence, decompression of the monoplace chamber from its highest operating pressure will take no more than approximately 120 seconds. This represents a distinct advantage over multiplace operations in terms of time of access to advanced care and related inside attendant decompression risk. Several cases of inside attendant DCI secondary to such multiplace chamber 'aborts' were included in a recent attendant DCI review.[41] One involved treatment of a complex CAGE patient who developed ventricular fibrillation during the latter stages of a USN TT6A. Defibrillation was urgently required and considered inherently dangerous under hyperbaric conditions,[42] and chambers 'must be surfaced to perform defibrillation' in accordance with US Navy policy.[38] Subsequent accelerated decompression resulted in a significant inside attendant decompression injury, with permanent and career-ending sequelae. Conceivably, a replacement IA could rapidly enter the chamber as it is decompressed in order to assume patient management, thereby allowing the original IA to undergo scheduled decompression in a separate lock. Time and resources did not permit such substitution in the referenced cases. In cases of multiplace chamber cardiopulmonary arrest, CPR can and is likely to be administered during emergent decompression, something not, of course, available in a monoplace chamber.

LACK OF AIR BREAKS

The original design of the monoplace chamber was to deliver 100% oxygen in a continuous manner. As such, there was no consideration to equip it with an intermittent air breathing capability, thus preventing treatment of DCI in accordance with typical US Navy protocols. This prompted development of a monoplace-specific treatment table that did not require air breaks, since proven effective for both acute and delayed DCI presentations.[31,32,34]

In 1984, the author incorporated the aviator type oro-nasal mask in common use during multiplace chamber use at the time into monoplace operations, thereby allowing administration of USN TT5 and 6. It eventually became the position of the National Board of Diving and Hyperbaric

Medical Technology that all hyperbaric chambers, regardless of type, should be equipped with an air break capability.[43] This position has more to do with CNS oxygen toxicity prophylaxis and management of any premonitory events than treatment of DCI, *per se,* but serves both purposes.

Options now exist to enable provision of air breaks for all patient states. In those fully alert and orientated, the referenced oro-nasal mask was the early choice. As it is relatively costly, requires some maintenance and has decontamination needs, an inexpensive disposable non-rebreather oro-nasal mask (Vyaire Medical, Mettawa (IL), USA, ref 001203) evolved as an alternative and is increasingly in use today. This author has confirmed its air break effectiveness via in-chamber transcutaneous PO_2 monitoring. Careful regulation of air delivery to this free flow device is required to avoid overt dilution of the chamber's oxygen atmosphere. Observing the rebreather bag to collapse slightly upon inspiration suggests an appropriate rate of flow. Restrained patients, and others unable to manipulate a face mask (bulky burn dressing covering the hands, for example), are fitted with a face tent (CareFusion, Yorba Linda (CA), USA, Ref: 001220) prior to entry into the chamber. Oxygen flows to the device during active treatment to avoid CO_2 accumulation. To initiate an air break, the chamber operator switches the face tent's oxygen supply to air and reverts to oxygen upon completion of the air break. For patients with a tracheostomy, attachment of a trach collar (CareFusion, Yorba Linda (CA), USA, Ref: 001225) serves this same purpose. Control of oxygen and air to the collar occurs in the same manner as the face tent. For mechanically ventilated patients, adaption of the external control module and in-chamber anaesthesia bag readily permits intermittent air breathing.[24] Switching the chamber compression gas from oxygen to air to attempt provision of air breaks is ineffective and should be avoided.[44]

SUPPORT OF SERIOUSLY ILL PATIENTS

Intravenous fluid and drug administration is commonplace. The infusion pump remains outside the chamber and a through-hull assembly within the chamber door allows as many as six separate infusion lines to connect into the chamber, depending on make and model.

ECG monitoring during monoplace operations is likewise commonplace and can involve either three or five leads. Each connects to a 19-pin through-hull electrical penetrator, so capacity exists to include central arterial and central venous pressure measurements (five lines each) in those so monitored. Manually operated pressure infusers with oxygen-compatible lubricant support the heparinized solution (Ethox Medical, Buffalo (NY), USA). A monoplace-specific non-invasive blood pressure monitor became available in the 1990s (CAS Medical Systems, Branford (CT), USA). It proved particularly useful in that it avoided the need for arterial line placement in patients who require close monitoring otherwise occurring non-invasively. Unfortunately, it is no longer available due to a lack of commercial viability and there may be an occasional need for arterial line placement.

Removal of the vacuum drainage assembly and attachment of a Heimlich chest drain valve (Bard Medical, Franklin Lakes (NJ), USA. Ref 373460) accommodates patients with a chest tube(s). Urinary catheter management involves emptying the drainage bag and rolling it up with the vent open to expel residual air, then resealing, prior to treatment. This helps promote drainage, as the bag will not hang very far below the level of the bladder.

A monoplace-specific ventilator has been available since 1978 (Sechrist Industries, Anaheim (CA), USA) with PEEP and CPAP capabilities. As noted, it is readily adaptable for provision of air breaks.[24] One aspect of ventilator-patient airway management not presently available is suctioning. Attempts to do so by using the internal to external chamber pressure differential have not yet evolved to standard practice because of technical and safety considerations. Suctioning prior to treatment has proven effective enough not to interrupt treatment in the three-decade Prisma Health Richland Hospital experience.

In summary, an appropriately equipped monoplace chamber managed by a knowledgeable team is capable of supporting the full range of patient states.

LIMITED PRESSURISATION CAPABILITY

This was more a shortcoming when treatment pressures greater than 284 kPa were commonplace. Animal studies of cerebral arterial air embolism (CAGE) failed to demonstrate any advantage to preceding 304 kPa (3.0 atm abs) with compression to 608 kPa (6.0 atm abs) in terms of recovery of cortical evoked potentials and cerebral blood flow.[45] These same authors suggested that there might be advantages to confining treatment to 284 kPa. An open-skull animal model of cerebral air embolism using air as the compression and breathing gas reported elimination of arterial bubbles at pressures of 284 kPa (2.8 atm abs) (one animal), 344 kPa (3.4 atm abs) (three animals) and 405 kPa (4.0 atm abs) (two animals).[46] In every instance, there was evidence of change in bubble size and partial restoration of circulation just beyond 203 kPa (2.0 atm abs). Recent authoritative reviews have concluded that there is no conclusive evidence that higher pressures offer any advantage over 284 kPa for both decompression sickness (DCS)[11] and CAGE[47] (these clinical entities being collectively referred to as DCI). US Navy clinical experience comparing CAGE treated on USN TT6A (which includes an initial exposure to 608 kPa) and USN TT6 found no difference in rate of symptom resolution.[48] Recurrence (an ominous prognostic sign[49]) occurred in 19% of those treated on TT6A, and none when using TT6. Onsite monoplace chambers may not always be adequate for the very rare instance of a diver who experiences a rapid uncontrolled ascent after a provocative depth-time exposure.

Such instances have been associated with the use of dry suits during military and civilian diving operations.

Current recommendations centre on the 284 kPa pressure associated with USN TT5 and 6.[11,47] These same recommendations acknowledge the role of monoplace chambers "*under the direction of a diving medicine specialist*".[35] In a 20-year retrospective, Weaver reported encouraging outcomes and tolerance to monoplace chamber use for USN TT6, involving 72 cases of DCI.[33]

HEIGHTENED FIRE RISK

There is no greater threat to hyperbaric operations than fire, where the enclosed pressurised space and use of oxygen serve to compound its effects. Regrettably, monoplace and multiplace chamber fires continue to occur with disturbing frequency. In recent decades, they have largely resulted from the most fundamental of lapses in development and/or execution of a fire safety plan. This allowed, *inter alia*, patients and inside attendants to enter chambers with inadequate screening, resulting in the introduction of otherwise prohibited flame-producing, heat-generating and battery-powered items. Therefore, it is strongly recommended that a key component of any hyperbaric fire safety plan is a strictly enforced 'no pockets' policy for all chamber occupants. As biometric sensors are sufficiently miniaturized to be worn as finger rings and finger jewelry a no-pockets policy would not serve to eliminate these battery powered products. Taping over a traditional finger ring not readily removed prevents damage to the chamber's acrylic tube. This would not be appropriate for biometric sensors, which must be removed.

Oxygen concentration influences burning rates and flame spread, so an oxygen-filled monoplace chamber, indeed, involves greater consequential risk should fire occur than its multiplace counterpart. One might view this somewhat differently than fire risk, which is largely identical regardless of chamber type.

Clinically based multiplace chambers are invariably equipped with one or more fire extinguishing options, the most effective of which is water deluge. When successfully activated it prevented loss of life and serious injury.[50] On two occasions when it failed to operate, 15 occupants succumbed.[51,52] A fire suppression system has not been integral to monoplace design and manufacture. However, a recent standard within Australia and New Zealand requires all monoplace chambers operating within its jurisdiction to be equipped with a fire extinguishing system that "*continuously soaks the patient during depressurization*".[53]

It is critical that comprehensive fire safety precautions exist within every hyperbaric medicine service, regardless of chamber type. They begin with chamber design and construction compliance with authoritative codes and standards, and extend to adherence with manufacturer-recommended operational practice and periodic servicing. Such compliance and adherence renders monoplace and multiplace chambers inherently and intrinsically safe. Failure to follow recognised design codes resulted in one fatal monoplace fire.[54] Shortcomings included installation of an unapproved intercom system, which proved to be the cause of the fire. Failure to follow the most fundamental of manufacturer-recommended servicing expectations was the cause of another fatal monoplace chamber fire.[55]

Complementing manufacturer responsibilities must be an end-user hyperbaric fire safety plan that is strictly enforced. It should centre on preventing prohibited 'No Go' items from entering the chamber secondary to an unwavering screening process. Avoidance of hydrocarbon/oil-based hair and skin grooming products and use of 100% hospital provided cotton clothing (absent pockets) and linen are important additional strategies. Confirmation of patient grounding prior to every monoplace treatment is mandatory. Low relative humidity (RH) promotes static electricity accumulation, the discharge of which could be problematic in the presence of a hydrocarbon-containing atmosphere.

Manipulation of monoplace oxygen flow serves, *inter alia*, to control humidity levels. RH will decrease at high flow rates, as incoming oxygen is dry and there is little accumulation of patient insensible moisture loss. RH will increase with low flow rates as insensible moisture loss more readily accumulates. This desired effect on RH has the added benefit of limiting pulmonary irritation associated with prolonged breathing of dry oxygen. Low flow rates elevate RH from the 20s to greater than 60% in this author's experience. If monoplace patients complain of being cold, it is most likely the result of too high a flow rate. Rather than provision of an extra blanket (representing an additional 'fuel' source in the event of fire), one should slow the flow rate. Except for a high initial flow rate at the beginning of the treatment to hasten conversion of the monoplace chamber's atmosphere from air to oxygen, subsequent lowered rates contribute to patient safety and oxygen conservation.

The 100% oxygen environment restricts use of some specialised critical care equipment that otherwise could be used in the multiplace chamber.

The sum of all of this is that monoplace chambers are inherently and intrinsically safe. The onus is firmly on each programme and its operations personnel to maintain strict compliance with their respective hyperbaric safety plan.

IMPACT OF CHAMBER DECOMPRESSION ON AN EXISTING PNEUMOTHORAX

Another commonly expressed concern relates to the presence of a pneumothorax, either missed prior to compression, developed while at pressure or arising from decompression-induced pulmonary barotrauma. Residual pleural air not eliminated by compression and inherent unsaturation during

oxygen breathing will certainly expand as the chamber ascends, the degree of which is a function of initial volume and degree of pressure reduction. If the volume is significant, it could result in tension pneumothorax.[56] Should observation of the patient during decompression suggest the presence of a pneumothorax, the monoplace operator must immediately halt further ascent. Depending upon the symptomatic state, one might elect to recompress the chamber slightly prior to assembly of appropriate personnel, supplies and portable X-ray. Once they are in place, decompression begins, with the emerging clinical picture serving to dictate rate. Historic multiplace chamber precedent suggests that this process is likely to result in successful management of the patient. On several occasions, a pneumothorax was missed by multiplace IAs and decompression continued unknowingly.[57–59] Each case resulted in tension pneumothorax, one bilateral, and all successfully managed by conventional means, following removal from the chamber. Risk of in-chamber pulmonary barotrauma-induced pneumothorax is low given diver health screening requirements. In the clinical hyperbaric medicine setting, this is an important risk assessment. Patients with underlying pulmonary pathologies for which the risk-benefit analysis favours HBOT require certain precautions. They include provision of an in-chamber bronchodilator assembly, constant ECG monitoring, a reminder to report any change in status, particularly close observation during decompression and slowed ascent rates.

For treatment of CAGE secondary to pulmonary barotrauma, one author suggests a prophylactic chest tube be considered during multiplace operations and recommends it for monoplace practice.[47]

MANAGEMENT OF EXCRETA

Injured divers are encouraged to void and defaecate if possible prior to entering the chamber. For alert and orientated males, a urinal(s) accompanies the patient for use as necessary. Generally, one reserves catheterisation for the more seriously injured. For females, bladder catheterisation is more common given difficulties associated with use of a bedpan, although production of larger diameter monoplace chambers in recent years has made a bedpan somewhat more manageable. During 34 years of monoplace chamber practice at Prisma Health Richland Hospital has there been interruption of recompression for DCI in this regard.

'Short' vs. 'long' DCI treatment tables

An abbreviated approach to DCI treatment presenting at monoplace-based facilities became available in the 1970s.[30] It served to overcome the absence of the intermittent air breathing capability necessary to employ US Navy minimal recompression oxygen breathing treatment tables. Several years later a slight variant was introduced.[60] Reported as effective in acute and delayed DCS and CAGE presentations,[30,31,34,61] these tables compared favorably to standard 'long' USN treatment tables for both minor and serious forms of DCI, based upon review of 2,800 Divers Alert Network (DAN) database patients.[32]

As today's monoplace chamber is likely to be equipped with an air break capability[43] it could be argued that short tables are no longer necessary. However, some are likely to prefer their use. These tables continue to be 'highly effective' in the experience of some and appear to reduce health care costs.[34]

Summary and referral guidance

While there is tacit approval of its on-site role, controversy exists regarding hospital-based monoplace chamber treatment of DCI.[32,36,37] This chamber type's early 'minimalist' configuration and capabilities were suited for use dominated by stable, electively referred outpatients. Design criteria did not account for acutely injured divers, particularly in the era of 'deeper' recompression, alternative breathing gases, extended periods at pressure and lengthy decompressions. It was also uncommon for monoplace supervising physicians to have sought out sufficiently robust training in the diving medical aspects of HBOT. All of this would suggest that early criticism of monoplace recompression was well founded.

Over the ensuing decades, however, biomedical support capabilities have evolved to the extent that hospitalised, critically ill patients routinely undergo monoplace chamber treatment for a number of indications. A more standardised approach to decompression injury management occurred during this same period. These events sufficiently altered the dynamic to a point where today's monoplace chamber can successfully support a majority of DCI cases, when overseen by a knowledgeable physician.

In the USA, only a small minority of the many hospital-based monoplace programmes have adopted these capabilities in order to manage acute severe conditions, including DCI.[62] That few physicians responsible for monoplace delivery of HBOT elect to undergo training specific to injured diver care, and are prepared to remain available beyond normal working hours, is also problematic. Therefore, where to refer injured divers and others for whom immediate hyperbaric oxygenation is imperative is challenging.[62] Given that monoplace chambers dominate the practice of hyperbaric medicine in the USA, and are frequently in closer proximity to a dive site than a multiplace chamber, one would hope that more such programmes will commit to 24/7 availability. This 24/7 shortcoming may exist to some extent elsewhere. While this paper argues for recognition of the monoplace hyperbaric delivery system as a viable option for treatment of DCI, it does so while noting these important caveats.

When an injured diver presents to a medical facility housing a multiplace chamber there is no controversy concerning its advantages over a monoplace chamber. Controversy exists when this same patient presents at a facility equipped with a monoplace chamber. The issue has centred on whether to

Table 1
Diving accident destination planning and prioritising tool

KEY LOGISTICS	CHAMBER 1		CHAMBER 2		CHAMBER 3		CHAMBER 4	
Road distance *(miles)*								
Air distance *(miles)*								
Helicopter pad	☐ Yes	☐ No	☐ Yes	☐ No	☐ Yes	☐ No	☐ Yes	☐ No
Pad altitude *(feet)**								
Chamber 24/7 available	☐ Yes	☐ No	☐ Yes	☐ No	☐ Yes	☐ No	☐ Yes	☐ No
Chamber hospital based	☐ Yes	☐ No	☐ Yes	☐ No	☐ Yes	☐ No	☐ Yes	☐ No
Chamber type	☐ multi	☐ mono	☐multi	☐ mono	☐ multi	☐ mono	☐ multi	☐ mono
Facility type‡	☐A ☐B ☐C ☐D		☐A ☐B ☐C ☐D		☐A ☐B ☐C ☐D		☐A ☐B ☐C ☐D	

ADVANCED CARE	CHAMBER 1		CHAMBER 2		CHAMBER 3		CHAMBER 4	
- IV fluids/drugs	☐ Yes	☐ No	☐ Yes	☐ No	☐ Yes	☐ No	☐ Yes	☐ No
- ECG monitor	☐ Yes	☐ No	☐ Yes	☐ No	☐ Yes	☐ No	☐ Yes	☐ No
- BP monitor	☐ Yes	☐ No	☐ Yes	☐ No	☐ Yes	☐ No	☐ Yes	☐ No
- Invasive pressure	☐ Yes	☐ No	☐ Yes	☐ No	☐ Yes	☐ No	☐ Yes	☐ No
- Ventilator	☐ Yes	☐ No	☐ Yes	☐ No	☐ Yes	☐ No	☐ Yes	☐ No

CONTACT DETAILS	CHAMBER 1	CHAMBER 2	CHAMBER 3	CHAMBER 4
24/7 phone				
Back-up phone				
Landing pad coordinates				
Administrative email				
Administrative website				

HYPERBARIC PHYSICIAN	CHAMBER 1		CHAMBER 2		CHAMBER 3		CHAMBER 4	
i. Dr.								
DMOtrained**	☐ Yes	☐ No	☐ Yes	☐ No	☐ Yes	☐ No	☐ Yes	☐ No
UHM*board certified**	☐ Yes	☐ No	☐ Yes	☐ No	☐ Yes	☐ No	☐ Yes	☐ No
UHM fellowship trained	☐ Yes	☐ No	☐ Yes	☐ No	☐ Yes	☐ No	☐ Yes	☐ No

HYPERBARIC PHYSICIAN	CHAMBER 1		CHAMBER 2		CHAMBER 3		CHAMBER 4	
ii. Dr.								
DMOtrained**	☐ Yes	☐ No	☐ Yes	☐ No	☐ Yes	☐ No	☐ Yes	☐ No
UHM*board certified**	☐ Yes	☐ No	☐ Yes	☐ No	☐ Yes	☐ No	☐ Yes	☐ No
UHM fellowship trained	☐ Yes	☐ No	☐ Yes	☐ No	☐ Yes	☐ No	☐ Yes	☐ No

*** Determine increase or decrease in altitude from scene**
**** Diving Medical Officer**
***** Undersea and Hyperbaric Medicine**

‡ A Wound Center
B Civilian Hospital
C Military Facility
D Commercial Diving

effect patient transfer to a multiplace facility while accepting risks inherent with treatment delay, or to use the monoplace chamber, assuming it is deemed operationally and clinically capable. Kindwall and colleagues in Milwaukee (who felt their recommendations were objective enough as they operated both chamber types) have long held that the monoplace is adequate to treat DCI 'in most cases'.[32] In a related editorial, Moon at Duke agreed, and added that referral of a DCI case to a distant multiplace rather than immediate local treatment in a monoplace "*would be erroneous*".[63] If one accepts that these authoritative authors rendered opinions prior to several technical advancements and treatment table 'streamlining' noted herein, there should be little reason to question their current validity.

If both chamber types are equidistant from an injury site or referring hospital, the question becomes one of appropriate referral guidelines. Intuitively, the multiplace chamber would appear the logical choice and commonly is. However, some issues would need reconciliation. Table 1 represents a sample destination-planning template to guide those responsible for safe conduct of diving activities. It affords

direct comparison of key logistical (including any elevation changes), operational and clinical expertise characteristics, in order to identify which facility would be most appropriate for a given case. For example, one might argue that a severe decompression insult requiring mechanical ventilation might be better served in a capable monoplace chamber within a comprehensive medical centre, rather than a multiplace chamber housed on a military base without clinical facilities and reliant on hand-operated bag mask ventilation.

The medical department of the Divers Alert Network (DAN) classifies referral chambers based upon overall capabilities, regardless of type. In doing so, they place greater emphasis on clinical and operational quality. Comparison is made between a multiplace chamber that has few technical limitations but is 'operationally' challenged and a monoplace programme with technical limitations which are circumvented with operational skill and clinical acumen (DAN America, personal communication, 2019). This decision-making approach appears consistent with the intent of Table 1, as it is with the above example.

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