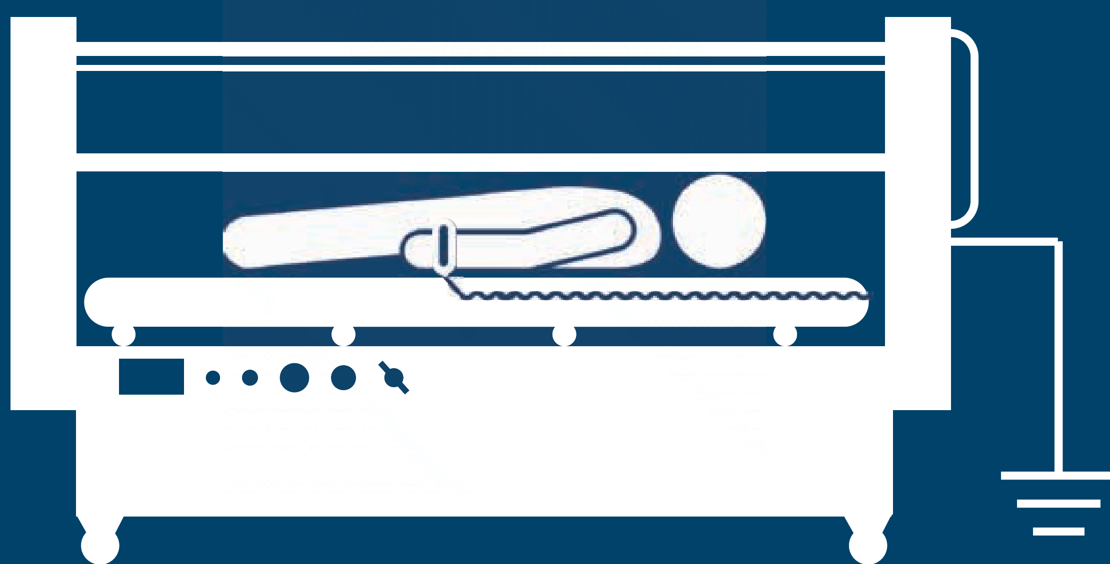


THE RCN BULLETIN

A Newsletter of the DAN Recompression Chamber Network

www.dan.org 10th Edition, July 2025 rcn@dan.org

WHAT'S INSIDE:

THE RCN WELCOME LETTER

We had a tragic start to 2025 with a fatality in a monoplace chamber in Detroit, Michigan (US) on January 31st. There were many versions of what happened printed in the press, discussed online, and released from the court hearings. Immediate attention was paid to the facility staff, and we understand that there will likely be significant legal consequences. While the actual causes and the factors that allowed this to happen will only likely become known by the end of the year, we felt it appropriate to draw your attention to the need for grounding patients in monoplace chambers.

Our FAQ for this edition focuses on this, as since the accident we have had many monoplace facilities asking us to explain why this is necessary, and how to make sure that it is being done correctly.

DAN has a representative on both the NFPA 99 hyperbaric chamber committee, as well as the ASME PVHO committees, and we can inform you that the rules for grounding will be changing shortly.

Please be on the lookout for the next edition of the DAN Risk Assessment Guide for Recompression Facilities, (5th, 2025), which will be published, free online, before the end of this year. You can find the current and future edition here: https://dan.org/safety-prevention/chamber-operation-safety/safety-resources-chamber-operators/

As technology changes, as we learn from accidents, and as we strive to enhance safety, this industry guideline needs to ensure that it contains the latest important information.

This edition provides articles on treating for conditions other than diving injuries, as we know that there are other needs in many locations where hyperbaric facilities are located, a fascinating case report of treatment in a transportable, monoplace chamber, and then a range of technical, operational and medical topics. We also share with you what is available and how things work in Indonesia and Canada.

We have been busy with operational training in places where there is a great need for this. These have been very helpful to local teams and have done much to increase confidence in dealing with complicated cases.

The chambers in our network stretch right around the globe, in all time zones and from the very north to the very south. This helps us to be able to find suitable treatment facilities everywhere where divers are active. Of course, facilities differ greatly in both size and capabilities. However, every one of your facilities is invaluable to DAN, and we are very grateful for your support and making yourselves available to divers in distress.

We try to contact every chamber prepared to treat injured divers, and we try to provide them with technical, operational and medical guidance, advice and education. So, please excuse our calls and emails to update information and ensure that you remain on our chamber map. If you haven't heard from us lately, send us an email at: RCN@dan.org

-Francois Burman, PE, MSC
and the DAN RCN Team

Managing DCS Patients in Indonesia

Bayu Wardoyo

INDONESIA ARCHIPELAGO

Indonesia, with its extensive coastline and dive sites, is a popular destination for divers around the world. However, this popularity also means that cases of decompression sickness (DCS) are not uncommon.

Managing DCS patients in Indonesia involves a network of recompression chamber facilities, each facing unique challenges. One of the most significant obstacles to providing adequate safety services is the country's vast and diverse topography. Many of Indonesia's most popular diving destinations, such as Raja Ampat, Banda, and Wakatobi, are in remote, hard to reach areas. The long travel distances to the nearest medical facilities makes the management of diving accidents even more challenging.

PATIENT ASSESSMENT

Since dive sites in Indonesia are widely dispersed, a significant issue is the limited number of doctors familiar with diving medicine in key diving locations. To address this gap in knowledge, Divers Alert Network (DAN) provided the DAN Academy of Diving Medicine in Bali in 2023. The program invited doctors and nurses from across the country and offered grants to those in remote areas. In total, 50 healthcare professionals completed the program. These doctors and nurses serve as an extension of the DAN medical team and enhance diagnostic and assistance capabilities in the field.

It is evident that these trained doctors and paramedics are instrumental in situations when a dive physician cannot be present to assist the DAN team with diagnosis. As is well-known, early diagnosis significantly influences the necessary course of action in treating DCS.

COORDINATION AND LOGISTICS

Handling diving accidents in Indonesia presents significant challenges. Indonesia's vast territory, with a coastline of 54,700 kilometers, complicates the provision of adequate rescue services and causes lengthy emergency response times.

In November 2019, we received an emergency call alerting us of a diver with Type 2 Decompression Sickness (DCS) in Raja Ampat. When we attempted to refer him to the nearest hyperbaric chamber on Waisai Island, we found it was under repair. Since the medical team advised immediate treatment, we arranged for medical treatment at the nearest operational chamber which was in Bali and nearly 2,000 km away. DAN Travel Assist coordinated an air medivac; however, the air ambulance was based in

Jakarta. The aircraft flew four hours to Sorong to retrieve the patient and an additional three hours to reach Bali, where treatment could finally begin.

TRANSPORTATION AND EVACUATION

Since the country's air evacuation center is located in Jakarta, distance poses a challenge. For example, it takes at minimum two hours to fly nonstop from Jakarta to Bali. Helicopters equipped for air evacuation are available only in a few major cities, and their operational range is limited

In another incident in October 2024, a request was received for a sea evacuation from Nusa Penida Island to Bali. A diver had an accident, and there was no hyperbaric chamber available on the island. While the task itself wasn't particularly difficult under normal conditions, the situation became tense when it had to be completed at night in inclement weather. The assistance service had to ensure that the boat was seaworthy and that the crew was well-acquainted with the local conditions. This heroic effort had everyone holding their breath until confirmation was received that the patient safely arrived at the hospital at 2am.

RECOMPRESSION CHAMBER AVAILABILITY

A hyperbaric chamber may occasionally be unavailable due to equipment malfunctions, staff changes, or maintenance needs. Therefore, all existing chambers must be kept in a state of readiness.

The nearest chamber is often the most suitable option, especially in Indonesia, where evacuation conditions can be difficult. However, this ideal situation may not always be attainable. It is critical for DAN's Recompression Chamber Network to remain current. DAN has identified several newly opened chambers in Indonesia, yet to be registered with the RCN, which are strategically located near popular diving sites.

Over the past two years, DAN has secured nine newly operational chambers located strategically throughout Indonesia as RCN partners. This expansion allows for a more effective dispatch of patients from the nearest incident location.

CHALLENGES AND SOLUTIONS

Another challenge with managing hyperbaric chambers in Indonesia is the language barrier. While "Bahasa Indonesia" is the official language, the country has 718 different regional languages, many of which are not mutually intelligible. Most hyperbaric chamber facilities are in remote areas where the local populations may not fluently speak Bahasa Indonesia.

This is why DAN's support as a liaison is essential. Instructions can be conveyed from the medical team in a manner that local doctors can understand. In some cases, we even seek help from local language translators to facilitate clear communication.

CONCLUSION

Effectively managing DCS patients in Indonesia requires a well-coordinated effort among recompression chamber facilities, medical professionals, and dive operators. Through continuous training, assessment, and the expansion of the RCN, Indonesia is enhancing its capacity to provide effective treatment for divers.

Case Report: Diver with neurological symptoms in a remote location

Manuel Preto CHT, DMT, ECHSM and Eli Silva MD

This case report is published with the authors' permission.

INTRODUCTION

Treatment for decompression sickness was first reported in caisson work during the 19th century, utilizing a multiplace chamber at that time.[1]

National Fire Protection Association (NFPA) code 99 classifies vessels for human occupancy into three categories: Class A (multioccupancy), Class B (monoplace chamber) and Class C (animal or research chamber).[2]

Multilock chambers consist of two or more compartments, allowing access of staff, patients, and equipment while maintaining pressure in the main compartment. They are designed to accommodate two or more individuals, including an attendant.

In contrast, monoplace chambers are single-compartment vessels, designed for one individual, and do not permit direct access to the patient during treatment.

Both Class A and Class B chambers have been used safely in clinical settings.

Given the duration of the US Navy treatment table 6, (USN TT6) the standard treatment table for decompression illness, with a minimum of 285 minutes without extensions, it is no surprise that multiplace chambers offer greater advantages.[3,4] Multiplace chambers can improve the patient comfort besides increasing safety, allowing the presence of an attendant for immediate management of emergencies and continuous assessment. On the other hand, this type of chamber requires a more complex system and technical expertise.

Monoplace chambers have been successfully used to treat divers, with similar complications rates. The rationale for selecting a hyperbaric system depends on its intended use, the available space and conditions for installation and the technical requirements for the setup.

We present a case of a diver safely treated for decompression sickness with neurological® symptoms, using a SOS Hyperlite_1 monoplace chamber, on a remote diving expedition.

CASE REPORT

Written informed consent was obtained from the patient for presentation of the details of his clinical history and de-identified pictures.

We present a case of a 60-year-old male experienced diver, with more than 1000 dives logged, without previous diving-related issues, or other relevant past medical history.

He was part of a scientific diving expedition, on board of a masted schooner originally a codfish fishing ship.

The scientific diving expedition took place on the Gorringe Ridge in the Atlantic Ocean, approximately 110 nautical miles from mainland.

The dive plan consisted of 2 dives per day, adjusted according to previous diving profiles. Sea conditions were moderate in relation to currents and water temperature was in the range of 20–21ºC.

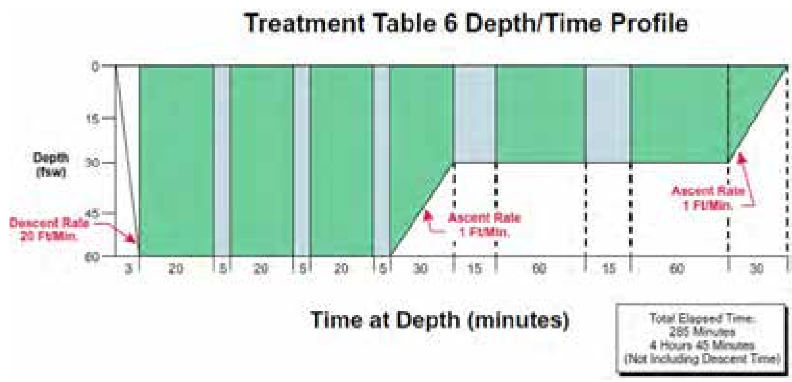
At the time of the accident, patient was diving for 3 consecutive days, with a total number of 6 dives during that period, on open circuit.

On the 3rd day it was recorded a first dive to 53 meters of sea water (msw), for 73 minutes, followed by a second immersion that day, after a 4 hours and 52 minutes of surface interval, to 51 meters of sea water (msw) for 73 minutes.

Upon surfacing, the patient first noticed bilateral shoulder and right elbow pain and decreased muscle strength over his right upper limb, expressing difficulties climbing on to the inflatable raft. No other symptoms were reported.

Immediately after being pulled on to the support vessel, the patient was put on normobaric oxygen through a non-rebreather facemask, reporting improvement of symptoms within 5 minutes. Diver was transferred to the main vessel where he was examined by the diving medical officer on board, approximately 10 minutes after surfacing.

Considering the dive profile and clinical presentation it was decided to provide hyperbaric oxygen treatment, using United States Navy USN TT6, commencing within 1 hour from the onset of symptoms. Patient was advised to increase oral fluids intake, and a 2L water bladder (Camelback®) was provided for inside chamber.



At the second air-break patient reported resolution of symptoms and was asymptomatic for the remaining treatment. Medical examination after completing the treatment was unremarkable.

Patient was advised to refrain from diving for four weeks and to report any recurrence of symptoms.

DISCUSSION

This case report presents a case of decompression sickness that occurred in a remote location during a scientific expedition.

In preparation for the project, considering the diving plan, the characteristics of the dive sites, open sea conditions, and the considerable distance from the mainland, it was decided to install a hyperbaric chamber on board.

The main vessel, originally a codfish fishing ship, was adapted for this purpose but had several limitations, including weight and space restrictions, as a historically preserved deck that needed to be maintained.

After excluding multiplace chambers due to space constraints, the focus shifted to evaluating monoplace chambers based on installation feasibility and technical requirements.

In comparison to multiplace chambers, monoplace chambers offer the advantage of requiring less operational space and enhanced portability.

However, the installation process on the vessel, combined with the rigidity of the structure, posed a challenge for this specific operation.

The market offered several soft chamber options; however, none of them were rated for pressurization above 2 ATA or certified for PVHO-1 use, which is a requirement for clinical use.

The only manufacturer that met the required specifications and characteristics was SOS Hyperlite®.

The Hyperlite_1® model was ultimately chosen due to its unparalleled advantages: Portability (weighing aprox. 50 kg), quieter operation, ease of use, space efficiency, faster setup, and cost-effectiveness.

A crucial consideration was the ability to perform Transfer Under Pressure (TUP) in case of evacuation, ensuring that treatment could continue uninterrupted during transport or while transferring the patient to a clinical chamber.

This capability further solidified the choice of Hyperlite_1® as the optimal solution for this operation.

This patient was clinically stable to be pressurized in a monoplace chamber, with provisions taken to ensure a comfortable environment, regarding anxiety, temperature, hydration and ability to void.

ACKNOWLEDGEMENTS

We would like to thank all the SMM crew, field researchers, scientific departments and divers for their support and data made available.

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Is it feasible and appropriate to use medically remote recompression chambers for provision of clinical hyperbaric oxygen therapy?

Dick Clarke CHT-ADMIN

The hyperbaric chamber enjoys an almost 200-year (1832) history and is arguably the oldest medical technology still operating in essentially unchanged form and function today. Its initial use was speculative and unhelpful but during the late 19th century, decompression sickness (DCS) became its first well-established indication. This afforded bridge caisson and mass transit tunnel workers who labored under compressed air conditions vital access to relief from resulting decompression injury. By the early 20th century, chambers had been incorporated into the care of injured divers. This air breathing 'recompression' form of treatment was based entirely on the inverse pressure-volume relationship characterized by Boyle's Law. During the 1930s, oxygen breathing was employed as it offered several distinctive advantages. All these recompression chambers were located at the worksite and remote from traditional healthcare facilities.

It was this concept of hyperbaric *oxygen* breathing that prompted research into other possible uses of the chamber and by the late 1960s, several additional therapeutic effects had been identified. This represented the dawn of the hyperbaric oxygen therapy era, and chambers were increasingly introduced into the healthcare delivery system.

Can the medically remote diving support chamber be used to treat these other conditions? It can in the right circumstances, and may even be desirable in the absence of a nearby clinically based chamber. There are, however, several factors that need to be considered to ensure that any such use is safe and effective.

First, individuals responsible for medical decision-making (formal diagnosis; risk-benefit analysis; informed consent; hyperbaric dosing orders) should ideally be trained in hyperbaric medicine beyond its diving aspects. Next would be consideration as to which clinical indications would seem appropriate. The practice of hyperbaric medicine includes both inpatient and outpatient settings. Inpatients are generally sicker and frequently require complex biomedical monitoring and concurrent medical support. It is unlikely that these patient needs would be readily transferable to the medically remote chamber. More likely are several of the outpatient indications, where patients are usually ambulatory and not in need of referenced inpatient support.

One prominent example is late radiation tissue injury, which includes Stage 1 oseoradionecrosis (defined as exposed alveolar bone) and essentially all anatomic soft tissue sites (skin, bladder, rectum, colon, cervix, larynx). Late radiation tissue injury is arguably hyperbaric medicine's most common use and has recently evolved as standard of care for soft tissue sites. Diabetic foot ulcers are another common outpatient use. However, hyperbaric oxygen is very much an adjunct to ‘standard care’ and does require transcutaneous oxygen testing if chamber care is to be optimized. This requires confirmation of the presence of locally reversible hypoxia. Not using this screening technology commonly results in failed treatment and massive wasteful healthcare/patient spending. This technology is expensive to acquire if not already available to patients in their regular healthcare setting.

Some other possible outpatient conditions that require no additional in-chamber supportive measures are central retinal artery occlusion, sudden sensorineural hearing loss, chronic bone infections, and less severe forms of carbon monoxide poisoning.

It is, then, feasible to consider the use of medically remote chambers for selected conditions in additions to decompression accidents. Besides introducing potential health benefits to a wider patient population, it would offer valuable hands-on experience/skills maintenance for chamber operations teams. There would be some additional expenses, principally oxygen usage (with care to ensure there remains a ready supply for the sudden arrival of an injured diver).

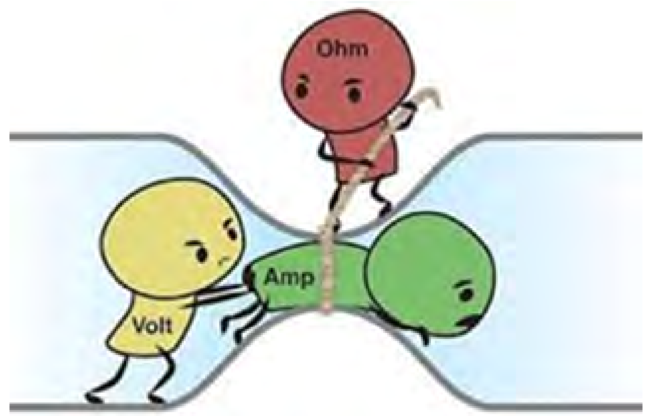
EDITOR’S NOTE

Although the use of transcutaneous oxygen monitoring (TCOM) is ideal to assess tissue oxygenation and therefore the potential for healing in cases of diabetic foot ulcer (DFU), HBO is used as adjunct therapy to treat DFUs in locations where there is no TCOM and where HBO cost is reasonable, in some cases of potential limb loss due to amputation.

Electrical Safety in Hyperbaric Facility

Francois Burman, PE, MSC

All hyperbaric chamber facilities rely on electrical power for their compressors, air conditioning units, lighting, communications systems and a range of other equipment. We cannot do without it, whether it is supplied from outside or using a generator. However, when we hear the word electricity, some get a glassy look in their eyes, some look nervous, and many simply ignore it as something that is just there.



We know that electrical hazards are real, and that electricity can kill, so we do need to have some understanding if we are to use it safely and ensure that our staff and patients are protected from harm.

This article will not attempt to provide a lesson in how or why it works. Instead, it will focus on the basics, explain some of the dangers and important safety aspects, and perhaps answer a few questions that are unique to our environment.

In order to make sense of the terminology we use, let's start with the elements defining electrical energy. Voltage is the driver of current through a circuit. We can use analogies in our chamber environment of pressure (voltage or volts), flow (current or amps) and valve opening (resistance or ohms). The more electrical current (or say air flow) we need, the higher the voltage (pressure) needed, and the lower the resistance to flow (the valve needs to open more). These three terms are all used in determining safety in the chamber.

Another important element to be aware of is where we are in the world. In the Americas and some other countries, the power system is set at 110 – 120 volts (60 Hz) for most of the equipment around or near the chamber. In the rest of the world, it is set at 220 – 240 volts (50 Hz). Hertz (Hz) is another measure of current that may be used with alternating current (AC). Equipment must follow the power supply settings and not be assumed to be compatible everywhere. Most of us have seen travel water heaters and hair dryers burn out when we get it wrong.

The next step is to understand how electrical energy gets distributed to our equipment. We need to know where this is done so we can shut it down in an emergency.

We all know what a switch is, but in electrical systems we have three types. The mains isolator (or main breaker) is usually at the point where the power enters the building or the facility. It is generally on and off only, which needs to be done manually. From there it is broken up into a number of separate lines or circuits to serve each part of the facility, usually done inside or on a distribution board. Each line has its own circuit breaker, a switch that is designed to close if too much current is drawn, which is an essential safety feature. Finally, there are individual switches for things like lights, electrical devices, and, of course, chamber controls. These generally do not have built-in protection unless a fuse is installed - designed to protect circuits from too much current.

Since we are dealing with people, high voltage wiring and equipment, and water and other fluids around or inside chambers (especially diver treatment facilities), we have a safety device known as a ground fault circuit interrupter (GFCI). In other counties this is known as an earth leakage circuit breaker (ELCB). These are designed to protect people from electrocution when exposed to a live conductor or surface.

Since we raise the issue of electrocution – damage caused by electrical system failure -we can consider this in three categories: fire, equipment damage, and injuries.

We can start to sense electrocution at about 0.005 amps (0.5 mA). After this it depends on the amount and the type of current (alternating - AC or direct - DC). The human hazards of electrocution include tetanus (muscular contraction – where you can't let go), breathing arrest (lungs and diaphragm), cardiac arrythmias such as ventricular fibrillation or asystole, and burns. The point at which tetanus commences is surprisingly low: 15 mA for alternating current. A significant thermal burn requires 10 amps where the current flows through the body.

To illustrate the point of wet areas and ground fault protection, if you stand in water, your total resistance to current flow is 1,000 ohms. If where you stand is dry, it's as much as 10 million ohms. Add rubber soles and gloves, 20 million ohms. A GFCI senses any current moving through us to the ground, and switches the mains current off when currents get above 5 mA (that is 0.005 amps) within 100 milliseconds (0.1 seconds). Even with the lowered total resistance to being in water, this is enough to protect you from electrocution.

Apart from not touching any electrical equipment when standing near a wet surface, there are a few rules to follow to ensure electrical safety. Here are some of those Dos and Don'ts:

Always isolate power before opening or touching anything. Note: a switch and a normal circuit breaker are not isolators. Unless you know what type of circuit breaker you have, you need to isolate power at the mains switch – the manual on/off breaker.

If you cannot do this, you must check that the power is off using a multimeter – this ensures you do not get a voltage reading between the live and neutral points on the power outlet.

Do not do any work on a system that is live, regardless of how careful you think you are. 'Live' work requires a special license or permit.

No modifications to electrical circuits are allowed unless the equipment manual indicates they are (like perhaps connecting the device to power).

Always ensure proper warning signs are posted where the possibility of any electrical harm can occur. If you can restrict access to these danger points, so much the better.

If an electrocution emergency occurs, turn off the power before you touch the person, start CPR and use an AED if needed, and call EMS. If you can't disconnect the power, use a dry, non-conductive object like a wooden stick to move the person away from the electrical source.

An essential step in ensuring electrical safety is regular inspection and maintenance. This can be as simple as looking out for damaged wires – pinches or scuffing, and don't forget that rodents have a thing for insulation. Ensure that connections and chamber shell connectors are always tight, keep all electrical equipment away from water (or better yet, keep water away from electrical equipment), and really importantly, test your GFCI (ELCB) monthly by pushing the test button on the breaker. The test button is there for exactly this purpose. Check your chamber grounding – some do it daily and some monthly. Fire and security alarms, and detectors such as those for carbon monoxide, smoke, flame and heat, should be tested at least annually.

Patient grounding will not work if the chamber is not grounded. You need to check patient ground before each and every session in a chamber pressurized with a gas containing more than 23.5% oxygen.

A last word concerns any electrical equipment taken into the chamber. Here our primary concern is fire. The NFPA 99 standard and the DAN Risk Assessment Guide provide information on how to ensure safety where equipment is permitted for use inside the chamber. These include flashlights, otoscopes, and any other battery powered devices.

We cannot be too careful, and we have a duty of care to our fellow staff members, our patients, and the general public. Lack of understanding of chamber electrical systems does not exempt one from the responsibility of ensuring safety. Following the basic guidance in this article will help you make more educated decisions when dealing with any electrically powered systems.

Hyperbaric Chamber Emergencies- Ear and Pulmonary Barotrauma

Sheryl Shea, RN, CHT

In the last newsletter chamber emergencies article, we discussed oxygen toxicity. In this issue, we discuss ear and pulmonary barotrauma.

Ear barotrauma is of concern because it is relatively common, and the inability to equalize the ears can prevent or delay the commencement of the treatment. If not managed, it can cause ear injury including permanent hearing loss. Pulmonary barotrauma in the chamber, while rare, is a life-threatening emergency that must be managed before the patient can return to surface pressure.

Keep in mind that these are just overviews. Your chamber should have emergency action plans (EAPs) in place for managing medical emergencies, individualized by taking into account the specifics of your chamber facility such as proximity to a hospital, medical skill level of staff, availability of emergency and diagnostic equipment and even the type of chamber (mono or multiplace). Chamber medical emergencies include but are not limited to the above, cardiac arrest, omitted decompression of patient or attendant, claustrophobia/anxiety, aggressive or uncooperative patient, and hypoglycemia.

EAR BAROTRAUMA

Ear barotrauma, sometimes called ear block or squeeze, can occur when the patient or attendant are unable to equalize their ears during pressure changes in the chamber. It usually occurs during descent to treatment depth but can also occur during ascent, called reverse block. It most commonly occurs in the first 10 meters of chamber compression.

Since the middle ear is an air-filled cavity, Boyle's Law applies. This law describes how the volume of a gas decreases when pressure increases, and conversely, gas volume increases when pressure decreases. The middle ear is ventilated to surrounding pressure via the eustachian tubes, which are normally closed except during yawning and swallowing. Techniques to open the eustachian tubes must be actively practiced to allow equalization to occur. If not done in time, pressure changes inside the middle ear can result in pain and injury.

Scuba divers are trained in ear equalization techniques during their open water scuba training, so most divers can readily equalize their ears without difficulty. However, some divers tend to have ear equalization difficulties, and indeed any diver, including chamber staff, can have ear equalization difficulties if they have inflammation or congestion of the eustachian tubes, such as with allergies or respiratory infections. A diver could also have an existing ear barotrauma that was sustained during the accident which led to their need for treatment in the chamber, such as an uncontrolled ascent.

Symptoms are the feeling of pressure,

pain which can be severe, tinnitus, feeling of fullness caused by accumulation of blood or fluid in the middle ear, vertigo and hearing loss. Tympanic membrane rupture can occur where pressures between the chamber environment and middle ear are significantly different but is to be avoided due to the risk of infection and the potential impact on future diving.

Preparation of the patient before chamber descent is essential. Ask them about ear equalization ability and any history of ear barotrauma. Explain that ear equalization inside the chamber feels different to underwater equalization. Earlier and more frequent equalization is usually needed. Teach equalization techniques if needed and explain the signal to stop the chamber descent or ascent if unable to equalize.

Once pressurization has begun, the operator and attendant must observe the patient closely. Descend slowly, and stop the descent immediately if the patient or attendant indicate equalization difficulties. If they are unable to equalize with their usual technique, yawning, swallowing, drinking fluids, or a different equalization technique may be helpful. Forceful equalization should be avoided since it may cause injury. The operator may have to decompress the chamber slightly to allow for equalization. Sometimes, much patience is required, including several slight decompressions and time to allow equalization to occur. Failing this, a decongestant nasal spray can be ordered by the physician. In the case of a monoplace chamber or a patient with known ear equalization difficulties, medicating before commencing treatment could be considered.

Worst case scenario, a myringotomy could be performed, however in reality this is rarely required, and would likely entail removing the patient from the chamber to undergo the procedure. In comatose patients, prophylactic myringotomy can be considered prior to treatment. Close attention, coaching, patience by chamber staff, and sometimes medication work in almost all cases of equalization difficulty.

PULMONARY BAROTRAUMA

Pulmonary barotrauma, sometimes called lung overexpansion injury, occurs when air pressure in the lungs expands beyond the lungs' ability to accommodate the increasing volume of gas, such as during a rapid ascent from a dive, or due to air trapping from a bleb or bronchospasm. This can cause alveolar rupture in the lungs, leading to a pneumothorax.

We wouldn't knowingly put someone in the chamber with pulmonary barotrauma, but if the lung rupture is small and asymptomatic at surface pressure, it may go undetected, even by a chest x-ray, until they are well into their treatment table. Less likely with divers is pulmonary barotrauma that originates inside the chamber, since divers are generally healthy and undergo medical screening. However it could occur if there is a sudden rapid decompression, pulmonary structural air trapping, or breath holding during ascent that might occur during an oxygen toxicity seizure.

Pneumothorax is air outside the lung but within the pleural cavity. This accumulated air between the parietal and visceral pleurae inside the chest can apply pressure on the lung and make it collapse.

In the hyperbaric chamber, this situation is complicated by the principles of Boyle's Law: gas volume increases when pressure decreases. This means that the air in the pleural cavity will expand as the chamber is decompressed and can cause a tension pneumothorax that can result in cardiopulmonary collapse. Tension pneumothorax occurs when the air accumulation becomes large enough to compress the mediastinum and push it to the opposite side, along with the trachea. Compression of the great vessels impairs venous return and cardiac output, leading to hypotension and circulatory collapse. This can quickly lead to cardiac arrest if emergency thoracic decompression is not performed. If suspected ascent should be halted until the condition is addressed.

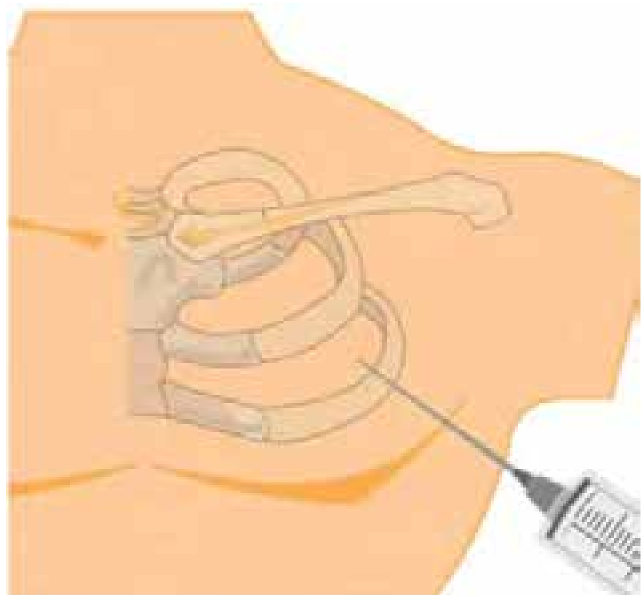
The clinical presentation depends on the degree of collapse of the lung. Signs and symptoms can include:

- Sudden, sharp, stabbing chest pain on the affected side
- Difficult, rapid breathing
- Abnormal chest movement on the affected side
- Diminished, absent, or unequal breath sounds
- Tachycardia
- Cyanosis
- Hypotension

If the patient develops symptoms of a pneumothorax, immediately stop the ascent (decompression) of the chamber, urgently call the treating physician and prepare to lock the physician and emergency medical equipment into the chamber. If the diver is stable, maintain the current pressure while the patient is assessed and the treatment decision can be made.

If a tension pneumothorax is suspected, the chamber can be recompressed back to a deeper depth.

Emergency management can include needle decompression. It requires the placement of an Angio catheter attached to a one-way valve such as a Heimlich valve at the 2nd intercostal space in the midclavicular line above the rib by a trained individual. The intent of needle decompression is to provide a rapid, emergent procedure conducted to relieve a tension pneumothorax, prevent its reoccurrence and allow the collapsed lung to begin re-expanding.



Insertion of a chest tube is a definitive procedure for a pneumothorax. However, in a typical basic remote chamber, the small, confined space, limited assistance, insufficient lighting, requires more time to complete and the increased infection risk may make this an impractical option in most cases until the patient is out of the chamber. It is also placed in patients with a known pneumothorax prior to needed hyperbaric treatment. Knowing its operation and assessing that it is properly functioning before entering a chamber is a skill requirement of the inside tender.

Once the lung has been vented, ascent to the surface can begin. When the chamber reaches the surface, ongoing pneumothorax management should continue, while also monitoring the patient and possibly the tender for DCS symptoms.

In the monoplace chamber, there is no possibility of treating the pneumothorax inside the chamber due to lack of access to the patient. The only option is to stop decompression, remain on oxygen, rapidly assemble emergency personnel and equipment at the chamber, then re-start decompression, adjusting to patient tolerance. If severe respiratory distress occurs, monoplace chambers are capable of rapid decompression, averaging around 60-90 seconds. Once the patient is at the surface, the pneumothorax can be immediately managed emergently.

In any situation where there is a modification of the treatment table due to an emergency in a multiplace chamber, always remember to re-evaluate the inside attendants' oxygen breathing requirement.

There are other types of barotrauma, including dental and gastrointestinal. They will be discussed in a future issue.

References for further education and resources for your EAPs:

The Ears and Diving
https://dan.org/health-medicine/health-resource/dive-medical-reference-books/

Update on Middle Ear Barotrauma after Hyperbaric Oxygen Therapy—Insights on Pathophysiology
https://pmc.ncbi.nlm.nih.gov/articles/PMC4297009/

Medical and surgical management of pneumothorax in diving and hyperbaric chambers. Undersea Hyperb Med. 2024 First Quarter; 51(1):17-28.

Monoplace chamber treatment of decompression illness: Review and commentary
https://pmc.ncbi.nlm.nih.gov/articles/PMC7755460/

Pneumothorax-Stat Pearls – Statpearls Publishing, NIH.gov
https://www.ncbi.nlm.nih.gov/books/NBK441885/

Tension Pneumothorax-Stat Pearls- Statpearls Publishing, NIH.gov
https://www.ncbi.nlm.nih.gov/books/NBK559090/

Sample of emergency equipment for pneumothorax treatment:
https://us.myteleflex.com/en/USD/All-Categories/Interventional-Cardiology-%26-Radiology/Interventional-Radiology-%26-Peripheral-Interventions/Centesis%2C-Drainage%2C-and-Procedure-Trays/Arrow%C2%AE-Pneumothorax/p/AI-01500-E

https://www.sammedical.com/products/sam-thorasite

Hyperbaric Treatment for Divers in Canada

Sherri Ferguson, Msc

Canada has very few hyperbaric chambers to treat divers, in spite of having the longest coastline in the world- 202,080 kilometers. This coastline borders the Atlantic, Pacific, and Arctic Oceans.

Hyperbaric medicine in Canada is not a restricted medical act, which allows for the operation of hyperbaric treatment facilities for alternative health conditions beyond the recognized indications published by the Undersea and Hyperbaric Medical Society (UHMS).

Currently, Canada has 43 hyperbaric facilities, of which only nine are hospital-based and available 24/7 to treat divers. Among the 34 freestanding, non-hospital-based facilities, 21 operate without a physician to oversee or prescribe treatment.

Treatment for decompression sickness (DCS) is covered under the Canadian healthcare system for citizens when prescribed and supervised by a licensed physician.

DISTRIBUTION OF HYPERBARIC FACILITIES

The facilities that provide 24/7 treatment for divers, staffed by experienced licensed physicians, are distributed across the country. The majority (four) are centrally located in the province of Ontario, where 34% of the population resides. These include:

- Hospital-based multiplace chambers in Hamilton, Toronto, and Ottawa
- A clinic-based multiplace chamber in Tobermory, affiliated with a hospital, but not located within one.
- Tobermory is the most popular diving location in Ontario. However, the future of this facility is uncertain as its Medical Director is set to retire. The diving community remains hopeful that a new hyperbaric physician will take up the position.

In the province of Quebec, there are multiplace facilities in both Montreal and Quebec City.

On the East Coast, there are:

- Nova Scotia- hospital-based multiplace chamber in Halifax
- Newfoundland- two monoplace chambers in St, John's, which are scheduled to be replaced by a new multiplace facility in 2026.

St. John's also houses the only hyperbaric receiving facility on the East Coast of North America for offshore saturation divers.

In Western Canada, there are:

- Alberta- three monoplace chambers in Edmonton
- British Columbia- multiplace chamber in Vancouver

The Canadian Navy operates three hyperbaric chambers for emergency use exclusively by its members:

- Fleet Diving Unit Pacific in Esquimalt, British Columbia
- Fleet Diving Unit Atlantic in Halifax, Nova Scotia
- A research facility in Toronto, Ontario

CHALLENGES IN REMOTE AREAS

Several provinces/territories in Canada lack hyperbaric facilities altogether, including Nunavut, the Yukon, and the Northwest Territories. In these areas, flight times to larger cities with hyperbaric chambers can be long, and medevac operations are frequently delayed due to weather conditions.

In the East, New Brunswick and Prince Edward Island must rely on hyperbaric facilities in Halifax and St. John's.

In the West, Saskatchewan and Manitoba often send divers to the United States for treatment, as this is sometimes more accessible than reaching Ontario or Alberta

REGULATIONS AND INNOVATIONS

Canadian regulations require commercial diving operations in remote areas to have on-site hyperbaric chambers, but these regulations vary by province.

The use of hyperbaric evacuation stretchers, which allow treatment to begin enroute to a facility, was first introduced in Quebec and is not being increasingly used across Canada.

Case Study: Pulmonary Barotrauma in a Junior Diver Due to Uncontrolled Ascent

Dr Matias Nochetto

BACKGROUND

A 13-year-old female diver experienced pulmonary barotrauma (PBt) during a recreational open water training dive conducted under professional supervision as part of a junior certification program. She had completed all confined water sessions and one successful open water dive prior to the incident.

DIVE PROFILE AND CONDITIONS

The dive was conducted at a tropical reef site, with a maximum depth of 10 meters. Visibility was moderate, water temperature was 25°C, and current was negligible. The dive group included four participants: two junior divers and two adults. The supervising team consisted of a dive instructor and a divemaster. The minors were paired together and positioned near the instructor throughout the dive.

INCIDENT DESCRIPTION

Approximately 20 minutes into the dive, while the group was stationary on a sandy bottom at 8 meters, one of the junior divers initiated an unplanned and rapid ascent. No distress signal was observed prior to ascent. The instructor attempted to intervene but was unable to reach the diver before she surfaced. On surfacing, the diver reported chest tightness, difficulty breathing, and a crackling sensation in the neck.

Emergency oxygen was administered on the dive boat and the diver was transported to a local emergency department for evaluation.

MEDICAL ASSESSMENT

Upon evaluation, the diver was alert but exhibited mild respiratory distress. Subcutaneous emphysema was present in the supraclavicular area. Imaging confirmed pneumomediastinum and subcutaneous emphysema consistent with pulmonary barotrauma. There was no evidence of pneumothorax or neurological involvement. The patient was managed conservatively with high-flow oxygen and discharged after 48 hours with complete resolution of symptoms.

CONTRIBUTING FACTORS

No equipment failure or medical condition was identified. A review of the incident pointed to behavioral triggers as the likely initiating factor. The diver had been engaged in playful interactions shortly before the ascent, but there were no clear signs of panic or distress. It is believed that a sudden change in perception or an overwhelming sensation underwater may have caused an abrupt decision to surface, bypassing the standard ascent protocol.

This aligns with patterns identified in a recent DAN review of 149 diving injuries in minors, where approximately two-thirds of pulmonary barotrauma cases were associated with rapid ascents, often following a moment of anxiety or emotional dysregulation. SPUMS 2024 guidelines emphasize that minor divers may react unpredictably when faced with real or perceived underwater challenges, due to their developmental stage and limited capacity to regulate behavior under stress.

SUPERVISION AND SAFETY CONSIDERATIONS

Although the diver was under close professional supervision, the case highlights that standard buddy pairing and instructor-led group models may not always provide sufficient margin of safety for new, young divers. SPUMS recommends that minor divers—particularly during early training and the immediate post-certification period—remain within arm's reach of a supervising adult at all times. That adult should ideally be someone who knows the child intimately (e.g., a parent or sibling), capable of detecting subtle behavioral cues and intervening early.

Familiarity not only enhances safety but may also provide a reassuring presence, reducing the likelihood of impulsive or unsafe responses to transient discomfort or confusion underwater. Over time, and only as the young diver's behavior becomes more consistent and predictable, the proximity of supervision can be gradually relaxed.

DISCUSSION

This case underscores the challenges of ensuring safety in pediatric diving. While the diver was medically fit and had successfully completed skills training, her response to a routine situation became unpredictable, resulting in injury. The transition from controlled environments to open water introduces emotional, environmental, and cognitive variables that can easily overwhelm novice divers, particularly minors.

Behavioral unpredictability, even in calm conditions, remains a central risk in this population. Structured dive programs for youth must acknowledge this by enforcing tighter supervision protocols, carefully selecting dive sites, and ensuring that dive buddies or supervisors are prepared to anticipate and manage sudden deviations from planned behavior.

CONCLUSION

Pulmonary barotrauma in minor divers may result from behavioral rather than technical failures. This case supports the need for close, continuous, and familiar supervision during the initial phases of dive training and early certification. Supervision should be proactive, not reactive, with divers kept within arm's reach until they demonstrate consistent, calm, and predictable behavior underwater. A conservative, phased approach to increasing independence is essential in promoting long-term safety in young divers.

INTERESTED IN LEARNING MORE?

Additional readings about this topic can be found at the end of this newsletter.

FAQ

Q: Do patients in multiplace chambers also require grounding?

A: In the light of the chamber fire in Michigan earlier this year, where we read that the facility failed to use grounding straps to discharge static electricity, does this mean all chamber occupants should be grounded? (CBS News article)

This is a very valid question, and one that requires both reference to NFPA 99 as well as some explanation.

NFPA 14.3.1.6.3.2 (2024 edition) states "In Class A and Class B chambers with atmospheres containing more than 23.5 percent oxygen by volume, electrical grounding of the patient shall be ensured by the provision of a high-impedance conductive pathway in contact with the patient's skin."

Let's start by explaining how chambers for human occupancy are classified. It has nothing to do with the gases used for pressurization. A Class A chamber is a multiple occupant chamber, referred to as multiplace; a Class B chamber is a single occupancy chamber, referred to as monoplace.

In any chamber where the intention is for the chamber environment to have an oxygen content of more than 23.5%, all occupants shall be grounded. This requirement does not include chambers with treatment gases that are supplied and dumped through a close-circuit BIBS system.

In practice, we very rarely see any multiplace chambers pressurized with oxygen-rich gases, except for Perry Sigma II, which allows for two patients inside the chamber, which can be pressurized using oxygen. In this case, both patients need to be grounded.

It is essential to note that a static electrical charge on an occupant, especially in an environment with very low humidity, can reach 10,000 to 15,000 volts (10 kV to 15 kV). When discharged, the energy is more than sufficient to ignite materials with low ignition energy characteristics that may be inside a chamber. These could include cotton fluff (lint) and dust. We specifically exclude any flammable vapors inside the chamber, but dust and fluff from clothing and bedding may well be present.

Grounding a patient in a chamber with an internal environment of more than 23.5% (where we pressurize the chamber using oxygen enriched gas) is an essential safety requirement, and grounding of both the occupants and chamber itself must be ensured at all times.

https://panamericahbo.com/products/chamber-accessories/

ABOUT THE AUTHORS

Bayu Wardoyo (Indonesia)

Bayu Wardoyo has been diving since 1993 and became a scuba instructor in 1999. He is the founder of the Indonesia Divers Rescue Team (IDRT), a volunteer group specializing in underwater search and rescue, and has led recovery efforts for incidents including the AirAsia, Lion Air, and Sriwijaya Air crashes. He co-led a national assessment initiative with the Indonesian Ministry of Tourism in 2022, which led to the creation of the DAN Academy of Dive Medicine in Bali. He is the Indonesia Country Manager for DAN and remains active in training, education, and promoting dive safety across Indonesia.

Elisabete Silva, MD (Portugal)

Eli Silva was first introduced to Hyperbaric and Diving Medicine in 2007 during her Anesthesiology residency in Portugal.

Since then, she has been deeply engaged in this field, completing her training in Portugal and later enrolling in the ANZCA Fellowship in Diving and Hyperbaric Medicine.

In recent years, she has served as the Clinical Director of baroOdyssey and has participated in numerous recreational and commercial diving expeditions.

She also works as a training consultant for Diving and Hyperbaric Medicine courses.

Her work has consistently focused on promoting diving safety across diverse environments, particularly conveying knowledge and scientific evidence to the diving community.

Manuel Preto, CHT, DMT, ECHSM (Portugal)

Manuel Preto holds a BSc in Sports Management and is a certified Instructor Trainer in both recreational and technical diving.

Since 2006, he has specialized in hyperbaric medicine, working as an instructor and technical consultant for chamber setup and operations.

Currently based in the UAE, he supports the Dubai Police as a Hyperbaric Project Manager and serves as Vice President of EBAss.

He joined DAN Europe in 2008 and still plays an active role as an Instructor Trainer and Area Manager, contributing regularly to both the Training and Safety Committees.

ABOUT THE AUTHORS

Dick Clarke CHT-ADMIN (United States)

Dick Clarke's accumulated experience within the combined disciplines of undersea and hyperbaric medicine extends over 50 years. Following service in the British Royal Navy throughout the decade of the 1960's he spent two years a program director at the International Underwater Explorers Society on Grand Bahama Island. He subsequently joined the National Oceanographic and Atmospheric Administration undersea living program, operating, living in, and working from seabed habitats in the subtropics and beneath Canadian ice. Dick served as faculty for NOAA's diving medical officer training course for 25 years and from 1976 to 1985 he was employed by Oceaneering International as an oilfield saturation diving superintendent. During this period, he was a member of the team that developed the diver medic training program and its subsequent board certification process.

From 1985 until 2022 Dick centered his hyperbaric and diving medicine operational support, education, and research interests at Richland Hospital/University of South Carolina School of Medicine. Over 8,000 health care professionals trained within this program. He developed the Baromedical Research Foundation, a basic science laboratory that transitioned to become a centerpiece for an international clinical trials consortium. One Foundation study was the first randomized, controlled double-blind trial to demonstrate hyperbaric medicine's treatment efficacy for deficient wound healing. His current research interests address radiation sensitization of hyperbaric oxygen in newly diagnosed squamous cell carcinomas of the head and neck.

Dick was instrumental in the development of the Certification in Hyperbaric Technology (CHT) program and continues to serve as president of its certification body, the National Board of Diving & Hyperbaric Medical Technology. He has written numerous peer-reviewed medical and technical articles, authored chapters in undersea medicine and hyperbaric oxygen therapy textbooks and served as a reviewer for the U.S. Navy Diving Manual and the journals Anesthesiology, Undersea Biomedical Research, Undersea and Hyperbaric Medicine, Diving and Hyperbaric Medicine, Lancet Oncology and the British Medical Journal. Dick continues to serve as a subject matter expert for purchasers of health care, including Medicare and most leading commercial insurers. Since 1996 he has been contracted with the Divers Alert Network to adjudicate diving accident insurance claims and to oversee introduction and operational oversight of an international network of DAN affiliated recompression chambers.

ABOUT THE AUTHORS

Francois Burman, PE, MSC (United States)

Francois is a registered professional engineer and Vice President of Safety Services at Divers Alert Network, based in Durham, NC (USA). He is the author of the Risk Assessment Guide for Recompression Facilities, first published in 2001, and has performed over 150 on-site recompression chamber safety assessments around the world. He has over 35 years of experience in designing, manufacturing, installing, supporting, and providing training in recompression chambers, has been with DAN since 1996, and is very active in supporting recompression chambers, especially through education and training.

Sheryl Shea, RN, CHT (Mexico)

Sheryl is a registered nurse, a Certified Hyperbaric Technologist, and works with the Medicine Department at Divers Alert Network. She has worked as a chamber operator and attendant, trained chamber personnel, worked for many years at a dive shop, has received extensive training in hyperbaric facility safety and technology, performed chamber safety assessments, and serves as both the chamber medical resource and diving medicine information specialist.

Sherri Ferguson, MSC (Canada)

Sherri Ferguson is a Canadian scientist and expert in hyperbaric and diving physiology. She is the president of Shanfe Research & Consulting Ltd., and a research associate with the Divers Alert Network. She was the Director of the Environmental Medicine and Physiology Unit (EMPU) at Simon Fraser University for 18 years, where she oversaw all research into the physiological effects of hyper & hypobaric environments. A professional diver, Ferguson is dedicated to advancing safety standards in the diving community and is the Vice-Chair of the Canadian Standards Association Z275 Occupational Diving and Hyperbaric standards and is the Chair of the sub-committee on Hyperbaric operations and work in compressed air environments. She serves on many diving and hyperbaric committees including UHMS Hyperbaric Safety, the Canadian Association for Underwater Science executive committee, and Scuba Diving International training advisory council and a Director at Large on the Board of the Canadian Undersea and Hyperbaric Medical Associaiton. She is also the first Canadian recipient of the Paul C. Baker Award for excellence in hyperbaric oxygen therapy safety, underscoring her significant contributions to science and public health.

ABOUT THE AUTHORS

Dr. Matias Nochetto (United States)

Dr. Nochetto is DAN's Vice President of Medical Services and Programs. He received his medical degree in 2001 at Universidad de Buenos Aires (UBA) and completed a 3-year clinical and research fellowship in hyperbaric and diving medicine from National Autonomous University of Mexico (UNAM). At DAN, Dr. Nochetto runs the Medical Services Department where a team of paramedics, nurses and doctors handle calls on the DAN Emergency hotline and answer medical inquiries on the DAN Medical Information Line and by email, as well as assisting with development and implementation of DAN medical programs worldwide.

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Chamber Operation Safety website .... chamber-operational-safety

A review of 149 Divers Alert Network emergency call records involving diving minors

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Keywords
Arterial gas embolism; Children; Decompression illness; Pulmonary barotrauma; Scuba diving

Abstract
(Helfrich ET, Saraiva CM, Chimiak JM, Nochetto M. A review of 149 Divers Alert Network emergency call records involving diving minors. Diving and Hyperbaric Medicine. 2023 March 31;53(1):7–15. doi: 10.28920/dhm53.1.7-15. PMID: 36966517.)

Introduction: Minors have been scuba diving for decades, and while the initial concerns about potential long-term complications related to bone development appear to be unfounded, the incidence of scuba diving injuries among them has been poorly studied.

Methods: We reviewed 10,159 cases recorded in the DAN Medical Services call center database from 2014 through 2016 and identified 149 cases of injured divers younger than 18 years. Records were analysed for case categorisation on the most common dive injuries. Information about demographics, level of training, risk factors, and relevant behavioural aspects were collected when available.

Results: While the most common reason for the call was to rule out decompression sickness, the majority of cases pertained to ear and sinus issues. However, 15% of the dive-related injuries involving minors had a final diagnosis of pulmonary barotrauma (PBt). While no reliable data is available on the incidence of PBt in adult divers, the authors' impression based on personal experience suggests that the number of cases of PBt in minors trends higher than in the general diving population. The narratives on some relevant records describe unmanageable levels of anxiety leading to panic.

Conclusions: Based on the results and narratives on these cases, it is reasonable to infer that psychological immaturity, suboptimal management of adverse situations, and inadequate supervision might have led to severe injuries among these minor divers.

Introduction

Minors between 8 and 18 years old have been scuba diving for decades, but data on participation numbers and incidence of injuries are unavailable. When recreational scuba diving began in the 1950s, it was primarily reserved for relatively young, physically fit men. Over the following decades, recreational scuba expanded to include more women with both sexes of varying ages and fitness and, more recently, children. Training agencies have developed programs issuing special certifications for children as young as ten. Once the junior diver turns 15 years old, upgrading to a full certification is an administrative process. Some agencies have gone beyond, developing programs that allow participants as young as eight years old to breathe from a compressed gas source, although these usually involve only surface water activities and close supervision.

Most outdoor recreational activities involve managing inherent risks. Scuba diving requires special equipment and training to survive a hostile environment and physical and mental capacity to manage its risks. Diving can be psychologically stressful for those new to the sport or practicing it in challenging conditions. The most common cause of death in child divers is drowning, whilst the major contributor is panic.[1]

During childhood, dramatic changes happen in the brain. The prefrontal cortex and amygdala mature, giving us tools to perfect decision-making processes, regulate emotions, detect threats, and activate appropriate fear-related behaviours in response to threatening or dangerous stimuli.[2] Psychological immaturity can prevent minors from reacting to emergencies underwater with the same capacity as adults.[3] Panic can lead to uncontrolled rapid ascents, increasing the risk of pulmonary barotrauma.[4] Alternatively, children can lose focus within routine dives and make mistakes such as holding their breath or losing buoyancy control, similarly leading to an increased probability of injury.[5] Scuba diving requires a specific set of skills and physical coordination that may be poorly developed in minors. Demonstration of these skills in a highly controlled environment such as a swimming pool may not readily transfer to the open water environment.[6]

There have been concerns about the potentially harmful effects of compressed gas diving on growth rates. Epiphyseal growth plates have an increased blood supply, and there was concern that under these unique conditions, scuba diving could impose a higher inert gas load and higher decompression stress than on most other body compartments, potentially impairing long-bone development. However, after decades of extensive diving by minors, including long-term follow-ups on cases of the bends, there does not seem to be any evidence to support this theory.[7,8]

Patent foramen ovale (PFO) is more common in children and can be found in up to 36% of individuals.[9] However, the incidence of decompression sickness does not seem to be higher than adults, possibly due to the depth restrictions commonly imposed on young divers.

Asthma with associated bronchoconstriction, air trapping phenomena, and reduced exercise tolerance is frequent in children. Its prevalence diminishes with age, demonstrating that the respiratory system is often still developing until teenagers become young adults. A child breathing from a compressed gas source in a swimming pool only two metres deep may not be at risk of decompression sickness (DCS), but is certainly at risk of pulmonary barotrauma (PBt) and arterial gas embolism (AGE).[10]

The Eustachian tube is not fully developed until approximately 12–13 years of age. The shorter and horizontalised Eustachian tubes, and often hypertrophic adenoids, tend to hinder normal middle ear ventilation, possibly making them prone to middle ear infections. These characteristics expose children to a higher risk of otic barotrauma.[11–13] Adults often experience difficulty with the concept of ear equalisation techniques, and instructors and parents must be convinced the minor comprehends the importance of this skill and is physically capable of performing these techniques effectively and efficiently without hurting themselves.

Temperature loss is higher in children due to the higher body surface area to mass ratio. Poor fit of neoprene wetsuits can increase conductive and convective heat loss, increasing the risk of hypothermia and forcing a high metabolic compensation to mitigate the energy consumption.

The World Recreational Scuba Training Council (WRSTC), a self-governing body with the primary goal of developing minimum standards for training recreational diving worldwide, has determined that a minor may not be deemed fully certified as an autonomous entry-level diver until age 15.[14] The council, however, does not define the minimum criteria to enrol a candidate in training. The council's standards also state that "*students under the minimum age may qualify for a special certification that allows them to dive under the supervision of an adult who has, as a minimum, an entry-level scuba certification*."[14]

While the incidence of diving injuries among recreational divers has been the focus of many studies, very few investigations focus on diving injuries of minors.[15,16] One retrospective study described 22 dive accidents in minors who were treated for AGE (six cases) and DCS (16 cases).[17]

Our study represents a retrospective analysis of diving injuries involving minors assisted through the emergency line of DAN's Medical Services Call Centre (MSCC) and recorded in a database between January 2014 and December 2016. The MSCC is open to all divers in need and professionals managing diving injuries. In general, more than half of users are non-DAN members and thus MSCC data provides a snapshot of injuries in the entire population of active recreational scuba divers.

Methods

The study was approved by the Institutional Review Board at the Divers Alert Network (Approval 020-15020).

This was a retrospective analysis of records stored in MSCC database, in the period from 2014 to 2016 inclusive.

SOURCE OF DATA

MSCC digital records contain case notes of incidents reported to DAN. Some records contain audio files and documents shared by the calling party, like medical notes, diagnostic studies, images, and dive profile logs.

A record usually starts as a transcribed narrative of the first interaction between a caller to the DAN Hotline and the DAN hotline agent (a diver medic, a nurse, or a physician) on call who interviewed the caller. The agent leads the call, gathering the minimally necessary information before recommending the best course of action.

The caller is interrogated about the reason for the call (usually documented as a chief complaint), the events leading to the injury or incident, and the subjective description of symptoms. Recommendations are offered once the hotline agent has enough information to have a reasonably good idea of what might be going on. After the initial contact, DAN Medics remain engaged with the case as it progresses through all phases: during case management while the diver is in the field, offering expert consultation once the injured diver is admitted to a medical facility, and monitoring the patient's progress with frequent follow-up calls after the diver is discharged. The result is usually a reasonably good recollection of events and outcomes.

IDENTIFIYNG CASES INVOLVING MINORS

In the observed period, there were 10,159 emergency case records involving divers of all ages. The injured diver's age or date of birth was not being explicitly recorded or provided by callers. Thus, we used a query written in Transact Structured Query Language (T-SQL) SQL Server Management Studio (SSMS) to search through four text fields (chief complaint, history of present illness, initial assessment, recommendations) for the keywords suggesting the victim was a minor (e.g., identifiers for ages < 18 years old, child, daughter, son, boy, girl, etc.).

After identifying 2,269 cases, further review rejected 2,020 false-positive cases not involving minors. Out of the remaining 249 cases, 35 were not diving-related. Of the remaining 214 cases, only 106 cases had explicitly stated the diver's age; these cases were confirmed to fit the study criteria. One hundred and eight cases were ambiguous and required further investigation.

For an ambiguous case to be included, there had to be an abundance of indicators that the case referred to involved a minor. Some of the indicators of a minor were a parent calling on behalf of their child, the injured diver being a member of Boy Scouts, or enrolment in high school. Exclusion information for potential adults included enrolment in college or university, completing a divemaster course, or being in military service. With further review, 65 records were excluded as the divers were positively identified as older than 18 years of age at the time of the incident. From the remaining 43 records, 34 divers were positively identified as minors with a confirmed age, and nine divers were confirmed minors at the time of the incident but did not have confirmed ages. All 43 cases, in addition to the previous 106 cases, were included in the 149 cases in this study.

CASE CATEGORISATION

The included cases were classified using a protocol with inclusion criteria for each category. The categories, based on the most common dive injuries, were as follows: arterial gas embolism (AGE); anxiety; decompression sickness (DCS); ear, nose and throat injuries (ENT); hazardous marine life injury (HMLI); immersion pulmonary oedema (IPO); musculoskeletal; other; pulmonary barotrauma (PBt); caller 'uncertain'; unrelated; and unrelated infectious gastroenteritis. Each case was categorised twice, once for 'reason for call' and once for 'final diagnosis category'. The reason for call was determined from the caller's concerns or chief complaint (see Table 1). The final diagnosis category used for this study was determined by a senior physician at DAN after reviewing all case notes (see Table 2). When available, a treating physician diagnosis (TMD) was cross-matched with DAN's final diagnosis category.

SUBSAMPLE VALIDATION

The final sample of cases was validated with subsample validation. Three hundred and fifty cases were randomly selected from the original 2,269 cases and independently verified by a second reviewer with 100% match for both confirmed and suspected minors.

The categorisation of 'reason for call' and 'final diagnosis category' was also confirmed via subsample validation

Table 1
Reason for call classification descriptions; AGE – arterial gas embolism; DCS – decompression sickness; HMLI – hazardous marine life injury

Reason for call	Description
Arterial gas embolism	Caller suspected AGE. Chief complaint was acute onset of focal neurological deficit, severe headaches associated with vomiting and seeking hyperbaric treatment options.
Anxiety	Caller's chief complaint was minor's anxiety
Decompression sickness	Caller suspected DCS. Chief complaint related to joint pains, fatigue, decompression injuries.
Ear nose and throat	Complaints related to ears and sinuses including problems equalising and headaches.
HMLI	Injury from hazardous marine life.
Other dive related	Non-emergent dive-related injury including 'fin foot', trauma, and eye irritation.
Respiratory	Complaints related to respiratory system including shortness of breath, difficulty breathing, non-cardiac chest pain, dyspnoea, coughing, suspected pulmonary barotrauma including pneumothorax, immersion pulmonary oedema.
Uncertain	Caller suspected something was wrong with child but was 'uncertain' regarding cause. Caller was seeking any connection between child's complaints and diving.

Table 2

Final diagnosis classification descriptions; DCS – decompression sickness; HMLI – hazardous marine life injury

Final diagnosis category	Description
Arterial gas embolism	Confirmed focal neurological deficit in direct association with a dive exposure. Unlikely if onset greater than 15 minutes after surfacing.
Anxiety	Treating physician diagnosed minor with anxiety or anxiety-related issue; no other injuries.
Decompression sickness	Signs and symptoms highly compatible with DCS in association with a moderate to significant dive exposure. No other compelling explanation for symptoms. Recompression therapy, normobaric oxygen, or simply time (mild/marginal cases) resolved the case. Unlikely if symptom onset more than 6 hours after surfacing. Very unlikely if symptom onset more than 24 hours after surfacing.
Ear nose and throat	Signs and symptoms compatible with ear or sinus barotrauma, and/or ear infection (troubles equalising, dizziness, nausea, vomiting, headaches, pain in sinus regions, or as diagnosed by a physician).
HMLI	Injury reported as being caused by direct or indirect contact with hazardous marine life species.
Musculoskeletal	Musculoskeletal ailments not compatible with DCS. Symptoms can often be explained by recent, normal movements associated with diving such as carrying a tank.
Other, dive related	Non-emergent dive-related injuries. Included fin foot, dehydration, trauma, exhaustion, suit squeeze, contact dermatitis, unknown rash (non-HMLI and non-DCS), eye irritation, and swallowed water.
Pulmonary barotrauma	Signs and symptoms compatible with a form of extra-alveolar air (pneumothorax, pneumomediastinum, subcutaneous emphysema).
Non-diving related	Signs and symptoms, or symptom latency is incompatible with a diving injury; or examining physician ruled out a diving injury. Patient had unrelated illness or infectious gastroenteritis that is not a result of diving.

with a second independent reviewer, with 100% match of categorisation following criteria in Tables 1 and 2.

Results

Among 10,152 cases in the database for the observed period, we positively identified 149 records (1.5%) involving minors with a suspected diving injury, 100 of which were finally diagnosed with dive-related injuries.

A concern about DCS was the primary reason for calls involving minors, accounting for 38% of all calls, followed by ENT-related complaints (26%). Pulmonary barotrauma was suspected in 12 cases (8%), and AGE was suspected in six cases (4%). However, the final diagnosis was more often ENT-related with 32% of all injuries, 15% musculoskeletal issues, 12% gastrointestinal issues, 9% PBt without AGE, 1% PBt with AGE, and 6% DCS, with other diving and non-dive related cases accounting for 25% of all calls (see Table 3).

DECOMPRESSION SICKNESS

Decompression sickness was indicated as a reason for a call in 56 cases. However, the diagnosis was confirmed in only nine, representing 16% of suspected DCS cases, 6% of all calls, and 9% of all diving injuries. Based on manifestations, four cases were neurological DCS, four were mild DCS (three with musculoskeletal pain and one with rash), and one case was inner ear decompression sickness (IEDCS). Only one minor diagnosed with DCS reported having decompression obligations during the dive.

Of the remaining 47 cases initially suspected to be DCS, the final diagnosis was musculoskeletal issues in 22 cases; gastrointestinal issues in 12 cases; four cases of ENT barotrauma; one case of PBt, one anxiety, and one HMLI. Five cases were classified as 'other, dive related', two being dehydration, one physical exhaustion, one case of contact dermatitis, one fin-foot, and one suit squeeze.

EAR AND SINUS BAROTRAUMA

Similarly to adults, ENT issues were minors' most common diving-related injuries (*n* = 47, 32%). Ear nose and throat injuries were suspected early on 39 calls, and in all those cases, ENT injuries were confirmed, validating the general assumption that ENT barotraumas can usually be self-diagnosed by laypeople. Of the remaining eight cases, ENT issues were not initially suspected. Four called for concerns

Table 3

Reason for call vs final diagnosis category; AGE – arterial gas embolism; DCS – decompression sickness; ENT – ear, nose and throat; GI – gastrointestinal issues; HMLI – hazardous marine life injury; IPO – immersion pulmonary oedema; PBt – pulmonary barotrauma

Condition	**Reason for call**		**Final diagnosis**		
	Cases (*n*)	**% of all calls**	**Cases (*n*)**	**% of all calls**	**% of diving diagnoses**
DCS	56	38%	9	6%	9%
Respiratory (unspecified)	12	8%	–	–	–
PBt (without AGE)	–	–	13	9%	13%
PBt and AGE	6	4%	2	1%	2%
Anxiety	1	1%	3	2%	3%
ENT	39	26%	47	32%	47%
HMLI	12	8%	12	8%	12%
IPO	1	1%	0	0%	0%
Other dive related	5	3%	14	9%	14%
Caller uncertain	17	11%	–	–	–
Sub-total diving	149	100%	100	68%	100%
GI issues	–		18	12%	–
Musculoskeletal	–		23	15%	–
Other non-diving	–		8	5%	–
Sub-total non-diving	**–**		**49**	**32%**	**–**
Total:	**–**		**149**	**100%**	**–**

about DCS, two called suspecting AGE, one called for PBt, and one caller was 'uncertain' about what was going on with the minor but knew there was something wrong. Eleven minors with ENT injuries were relatively inexperienced divers, 10 being entry-level students.

PULMONARY BAROTRAUMA AND ARTERIAL GAS EMBOLISM

Fifteen minors were diagnosed with PBt, 13 without neurological findings, and two exhibited signs compatible with AGE. Concerns about PBt was a reason for the call on 12 occasions, and among those the diagnosis was confirmed in eight instances. Of the remaining four, two were diagnosed with non-dive-related issues, one with an ENT barotrauma and one with a musculoskeletal ailment. Of those finally diagnosed with PBt, only one caller was initially concerned about AGE with PBt being the culprit. Three callers did not seem to have any red flags about the type of injury possibly sustained, and one called for concerns about DCS.

Possibly contributing factors associated with PBT were identified in 11 cases (73%); there was insufficient evidence to determine a cause of PBt in the remaining four cases (27%). In seven cases (64%), there were confirmed reports of rapid ascents; of these seven cases, six (86%) had rapid ascents due to confirmed or highly suspected anxiety. One child became anxious after practicing a controlled emergency swimming ascent (CESA) during training; another reported an anxiety attack underwater that led to breath-hold and a rapid ascent. A child freediver planned a dive to 15 feet (4.6 m), then extended to 35 feet (10.7 m) for unknown reasons. This child then had 'seizure-like' activity underwater, right leg weakness upon surfacing, and a final diagnosis of AGE from the treating physician. It is unreported if the child breathed from compressed air at depth, although likely given the symptomology and treating physician diagnosis. Three more minors likely became anxious at depth, leading to rapid, unplanned ascents and consequent PBt. The final case with rapid ascent did not confirm or deny any anxiety from the child, although both the child and their dive buddy were diagnosed with PBt by their physician.

Of the remaining four instances of PBt (36%), an event happened at depth that likely led to accidental breath-hold and PBt. Two of these cases (50%) were caused by issues with equipment; one child reported a free-flowing regulator, while another reported being overweighted. It is likely this diver attempted to assist ascent by increasing lung volumes with deep inspiration and breath-holding. Of the other two cases, one diver had an 'enormous belch' during ascent, which suggested considerable aerophagia. In the final case, the minor stated they simply laughed 'uncontrollably' underwater. Also of interest is two young divers in this cohort (13%) who noticed chest pain after the first dive but continued to dive for the day. It is unclear whether that might have contributed to the severity of the initial injury.

Concerns have been raised about weight belts slipping off and causing uncontrolled ascents,[2] but incidents of this nature were not seen in this group. Regarding their level of training, five of the injured children were students completing a junior open water diver or open water diver program. Level of training was not available in the remaining cases.

ANXIETY

Anxiety seems to have played a significant role as the trigger in at least one third of the cases of PBt, but anxiety was also the final diagnosis in three minors (2%) with post-dive symptoms. Only one caller considered anxiety as the potential culprit for the child's manifestations. In this case, the treating physician considered anxiety the most likely cause of symptoms. Still, there was a discrepancy between treating physicians and DAN regarding whether recompression and hyperbaric oxygen treatment (HBOT) would be recommended as a precautionary approach. In another case, the Coast Guard evacuated a minor for suspected DCS, but the final diagnosis was 'hyperventilation syndrome'. In the third case, the initial working diagnosis was 'possible IPO' due to an unprovoked sudden onset of coughing while at depth. However, a timely medical evaluation did not reveal any objective findings or abnormalities to substantiate this suspicion and diagnosed the case as being due to a panic attack. Later, the novice diver admitted to feeling too anxious underwater due to limited visibility and wanting to end the dive.

Discussion

The number of injured minors recorded in the MSCC represents only 1.5% of all reports. The most remarkable finding of this study is that despite having significantly more calls for suspicion of DCS, pulmonary barotrauma was more common. The low number of DCS cases is possibly the result of less provocative dives being done by minors.

Although anxiety was rarely the reason for a call or a final diagnosis, different levels of anxiety are woven throughout various case narratives. Panic is a known trigger leading to dangerous scenarios in diving.[18] A recent study suggests a major difference between minor and adult divers is developmental difference in executive function, leading to issues with response inhibition, sustained attention and cognitive flexibility.[19] This conclusion is in line with our observations; in one third of the cases of PBt, narratives describe high levels of anxiety and even panic. These minors were accompanied by an adult diver, which might have prevented an even more severe outcome.

Physiological, psychological, and behavioural differences between minors and adults support the notion that their challenges also differ. A difference in diving injuries, especially between instances of DCS and PBt, is also consistent with DAN's observations with adult callers on the DAN Hotline – a future extension on this study would compare injury incidence between adults and minors.

ASSESSMENT OF MEDICAL, PHYSICAL, AND PSYCHOLOGICAL FITNESS TO DIVE

Minor diver candidates are often referred to physicians for assessments for fitness to dive. Medical fitness to dive is well-covered on dedicated forms available online on the World Recreational Scuba Training Council's (WRSTC) website, on the Undersea and Hyperbaric Medical Society's (UHMS) Recreational Diving Medical Screening System, and by the South Pacific Underwater Medicine Society's (SPUMS) Diving Medical.[14,20,21] Physical and psychological fitness can be challenging to assess and are often left to the discretion of a clinician who may not have training in diving medicine or any diving experience. However, such assessments have limitations even when conducted by appropriately trained physicians. Provided there are no medical or physical contraindications, psychological fitness might be better gauged as a candid discussion between the physician, the candidate's legal guardians, and the scuba instructor,[22] with the candidate present if deemed appropriate.

Assuming the minor has the body mass and strength to cope with and overcome potentially adverse situations (currents, drifting, or rescue of an adult-sized diver) and has no medical contraindications, perhaps the most critical aspect of diving fitness is reviewing the candidate's psychological maturity, as this is the most important factor in accepting and managing unseen risks, and predicting behaviour in adverse circumstances. Children often have a well-developed sense of adventure and a poorly developed sense of mortality.[5] Chronological age is a poor predictor of maturity in minors. Albeit more cryptic and admittedly rather impractical, perhaps reflection on the intersection between biological, psychological, and social age could more accurately predict the physiological and psychological response of a person making use of life-support equipment to survive a hostile environment.

Remarks for clinicians

A physician assessing fitness to dive should only do so if being fully cognisant of the nature of the activity, the type of equipment to be used, the environment in which it is to take place, and the physiological and psychological effects of the underwater environment on the diver.

When assessing a minor's fitness to dive, clinicians must remember that the candidate's guardians and dive instructor might offer a valuable perspective on the candidate's psychological maturity.

Diving can impose a wide variety of challenges on those practicing it. As an aquatic recreational activity, diving can lead to musculoskeletal strain, which can be, and often is, misdiagnosed as DCS. While some risks are inherent to diving physiology, others might be related to psychological stress, practicing physical activity, or traveling (for example, fatigue, gastrointestinal issues, dehydration, among others). Divers often experience non-diving injuries during or around the diving activity and are misdiagnosed due to a recent history of diving. Conversely, dive-related injuries can often be missed by a clinician without knowledge of diving medicine. If a physician is unsure of the proper course of action, the DAN hotline is available 24/7 for consultations in diving medicine.

Remarks for the industry

Minor divers are a special population. These individuals face different challenges than adult divers and pose different challenges for dive professionals.

When training individuals in vulnerable populations, no other group generates more polarisation than young divers. Those with a favourable view are often seduced by the child's joy, lack of fear, and the rewarding feeling of witnessing the development of aquaticity in a short time. Those sceptical often base their position on mental maturity, rudimentary understanding of physics, anatomy, and physiology necessary to understand mechanisms of injury and accept risks, or simply question the physical strength of a young diver to rescue an adult in an adverse situation. Solid arguments can be made both against and in favour.

Perhaps dive professionals should have specialised training to teach young divers and lead them during open water dives. Such training should focus on their individual needs and unique behavioural aspects that seem to make them more prone to incidents and injuries. Minor divers should always be at an arms-length distance from an adult diver who needs to monitor them closely, especially with regards to comfort and air consumption. As the diver matures emotionally and their response to stress becomes more predictable, this distance could be gradually relaxed.

Safety enhancements can also be made regarding the standard operating procedures in open water dives. Recreational scuba divers are encouraged to adopt the 'buddy system' for mutual support and monitoring stress reactions in adverse circumstances. Under this arrangement, two individuals are paired and operate together as a single unit throughout the dive. They are encouraged to stay close and communicate regularly. The more they dive together, the more they know each other, and the more efficient they become. The concept has proven to work well in many disciplines, including diving. However, minor divers may not be reliable dive buddies due to their smaller body size, reduced strength, lesser maturity, and often unpredictable response to threats. WRSTC standards state that "*students under the minimum age may qualify for a special certification that allows them to dive under the supervision of an adult who has, as a minimum, an entry-level scuba certification*".[14] An argument could be made that when the team involves pairing an adult and minor where there is a significant body size or strength dissymmetry, the safety of both could be unacceptably compromised if the adult is depending on the minor for assistance in an emergency. In these cases, a team of three seems to be a more prudent minimum.

Modifying the dive plan and standard safety protocols is logical when leading dive groups containing young divers with inherent limitations. In the same way that a dive professional must hold certifications in wreck diving to teach wreck diving or to lead a group on a wreck, specific dive training should be available for dive professionals to teach and guide minor divers before working with them. This training should include an extensive explanation of minors' different challenges and how to manage them.

Instructors should be knowledgeable about the signs of anxiety and be confident in recommending to the candidate and their parents that the candidate might not be yet mentally mature enough to be a safe diver without fear of being accused of discrimination. Each minor is physically and psychologically different, and pre-existing physical, behavioural, and emotional limitations can compound the anxiety minors are more likely to experience.[23]

LIMITATIONS

This study has limitations worth emphasising. As with most epidemiological studies in diving medicine, the primary limitation to the generalisation of results is the lack of a denominator. This limitation, and a relatively small sample size, prevents us from inferring the possible prevalence of diving injuries among minors and making sensible comparisons with adult diving populations. A future study design would be to look at adult diver injury incidence from the DAN Hotline and compare to minor divers.

Another limitation concerns the methodology used. As this retrospective study was waived from consent, we did not contact any party to gather more information about these incidents. Instead, we worked with the documentation available: written narratives, call recordings, medical records shared by calling parties, and any public domain records when available. Re-interviewing the parties involved in these cases could provide much more data than we could gather by retrospectively reviewing existing records.

The role of anxiety as a trigger and root cause of an injury is likely underrepresented. This could be partly due to the subjective nature of anxiety, a possible behavioural bias from minors not always accepting and verbalising their fears, and inherent defects in the quality of the data captured and its completeness.

Due to inherent limitations in telecommunications, the final diagnosis category of 'anxiety' as the explanation of all manifestations was at the discretion of the evaluating physician and could be underestimated as well. We have since updated our standard operating procedures and tools to better capture anxiety as a differential diagnosis and risk factor.

Conclusions

Dive-related emergencies involving minor divers are rare. Our data suggest that lung over-expansion injuries seem more common than DCS. During the three years we analysed, 10% of the calls involving a minor with a suspected diving injury had a final diagnosis of PBt, making up to 15 percent of the diving injuries in minors during that period.

Factors contributing to PBt in minors might be associated with fitness and immaturity. Qualified fitness to dive evaluation, improved training, and closer adult supervision might help mitigate the risks of injuries in minor divers.

Dealing with diving accidents is extremely stressful at the best of times, but it is far more so if the victim is a minor, due to the additional emotional pressures, which should not be underestimated.

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Guidelines

South Pacific Underwater Medicine Society (SPUMS) position statement regarding paediatric and adolescent diving

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Adolescents; Children; Fitness to dive; Medicals – diving; Recreational divers; Risk assessment; Scuba diving

Abstract

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This paediatric diving position statement was developed from a targeted workshop at the 51st Annual Scientific Meeting of the South Pacific Underwater Medicine Society (SPUMS) on 8 June 2023. It highlights the factors that SPUMS regards as important when undertaking health risk assessments for diving by children and adolescents (defined as aged 10 to 15 years). Health risk assessments for diving should be performed by doctors who are trained in diving medicine and who are familiar with the specific risks which result from breathing compressed gas in the aquatic environment. Undertaking a diver health risk assessment of children and adolescents requires a detailed history (including medical, mental health, psychological maturity), a comprehensive diver medical physical examination and evaluation of all relevant investigations to exclude unacceptable risks. In addition, assessment of the individual's motivation to dive and reported in-water capability should occur, whilst engaging with their parent /guardian and instructor, where appropriate, to ensure that safety for the child is optimised. The guideline applies to all compressed air diving including scuba and surface supply diving provided in open and contained bodies of water.

Introduction

This paediatric and adolescent diving position statement was formulated through expert consensus from a targeted workshop at the 51st Annual Scientific Meeting (ASM) of the South Pacific Underwater Medicine Society (SPUMS) on 8 June 2023. Ten statements were developed and accepted in principle by workshop participants. Final editing and referencing were by the SPUMS Paediatric Diving Working Group. During this process, the age range was reclassified as paediatric and adolescent, and an additional statement was added (11 statements in total) that enhanced certain salient points to consider when assessing and consenting these prospective divers.

The society published its first guidelines for paediatric divers in 1990, setting a minimum age of 16 years before medical health risk assessments would be undertaken on prospective open water divers. This was revised in 1992 to a minimum age of 14 years, taking into consideration the level of psychological maturity, physical capability, and confidence for the candidate in managing the underwater environment.[1] It was also consistent with the now retired Australian Standards: Training and certification of recreational divers. Part 1: Minimum entry-level SCUBA diving. 4005.1(2000).[2]

The June 2003 edition of SPUMS Journal (Volume 33, Issue 2) was dedicated to children in diving. Many experts in the field weighed in and continued the discussion in that and subsequent journal issues that year.[1–7] The two decades since the 2003 publication have seen substantial increases in diving course options for children by training organisations. Children as young as 10 years have been completing diving courses allowing open water diving with well-established training organisations around the world, albeit with defined restrictions and limits. Some of these commenced prior to 2000, with even younger participants.[7] It is noted also, that children aged 8–10 years can access introductory experiences using scuba equipment, directly supervised by instructors and confined to a pool environment.[8]

Evidence-based medical practice should be focused on the health and wellbeing of the prospective candidate and not the commercial interests of industry. It is widely acknowledged that a child's chronological age doesn't necessarily correspond to their physical, psychological, emotional, or intellectual level of development.[3,9]

The latest version of the SPUMS Recreational Dive Medical was published in 2020, with updated cardiovascular health guidelines.[10,11] At that time, SPUMS did not update the guidelines on medical health risk assessment of prospective child and adolescent divers.

Other medical societies, such as the Dutch Society for Diving and Hyperbaric Medicine and German Society for Diving and Hyperbaric Medicine recently revised their recommendations for this unique subset of the population.[12–14] There is a paucity of quality evidence regarding current best practice for assessment of children and adolescents seeking to undertake compressed gas diving, and the advice provided to them and their parents or guardians. Most information consists of case reports, retrospective event analysis, prospective cohort studies, and expert opinion. The South Pacific Underwater Medicine Society acknowledged that its existing guidelines required updating to support health risk assessment of children and adolescent prospective divers.

Definitions

In developing this current position statement, SPUMS has adopted the following definitions:

Paediatric (adjective) – refers to describing children from birth to 17 years of age.

Child or Children (nouns) – refers to individuals or groups including infancy through to puberty (puberty is achieved when the child reaches reproductive maturity: this includes a range of ages and is different according to the sex of the individual).

Adolescent (noun or adjective) – defined by the World Health Organisation as 10–19 years of age.[15]

It is also recognised that there may be individuals from the above descriptor groups for whom this SPUMS position statement is not relevant. The terms will be used in the text to refer to a narrower range of age groups defined in Statement 1.

Whilst acknowledging limited data in this field, it appears that diving amongst children and adolescents is relatively safe. This is likely due to experienced medical assessment, consent alongside their legal guardian, and engagement with a supportive and skilled instructor through a training organisation with appropriate, established procedures. Vandenhoven's retrospective study demonstrated that children had a high rate of medical issues incompatible with diving when medically assessed prior to diving.[7] One in eight children were excluded from diving on medical grounds.[7] Available evidence also suggests that even after medical clearance, children still have a high rate of ear, nose and throat (ENT) issues, specifically middle ear barotrauma.[4,7,9,12,16] Training organisations which vet their paediatric and adolescent divers by establishing pool skills and optimising ear equalisation techniques before proceeding to open water environments, appear to have a high degree of success with safe diving practices in their young trainees.[7]

Fatalities are infrequent in children and adolescents compared to adult recreational divers, although participant rates are far lower.[9] The Australasian Diving Safety Foundation data from 1966 to 2020 revealed five out of 531 scuba deaths (1%) were in children and adolescents (aged 8–15 years).[17] One series from DAN North America reported that children (defined as aged 12–17 years) made up 1.9% of all deaths reported between 2012–2015.[18] These data did not permit incidence to be calculated. Although infrequent, any child or adolescent diver death is unacceptable.[19–23] The cause of most paediatric deaths was arterial gas embolism from pulmonary barotrauma.[18] Anxiety and/or panic was a common precedent to rapid ascent in children and adolescent divers, which in turn resulted in pulmonary barotrauma.[9,22] Pulmonary barotrauma and subsequent arterial gas embolism can occur in water depths as shallow as one metre.[24] Asthma may also result in pulmonary barotrauma.[12,25] Decompression sickness was a less commonly confirmed diagnosis in one paediatric population.[9] Depth restrictions and less provocative diving may have reduced incidence of decompression sickness in this series. Fortunately, recompressing children with hyperbaric oxygen for decompression sickness under the current adult guidelines appears safe.[22]

Disclaimer

The advice contained in this SPUMS Position Statement is applicable to medical health risk assessment of children and adolescents aged 10–15 years who are seeking to undertake compressed air diving including scuba diving and surface supplied compressed air (e.g., 'hookah' diving).

The statements do not constitute a 'Standard'. The statements are based on analysis of available published evidence and expert opinion. They are expected to provide guidance to medical practitioners when undertaking health risk assessments on children and adolescent prospective divers.

The document should be used on a case-by-case basis utilising information on individual circumstances and as broad guidance for doctors. The society recommends engagement with the child or adolescent, their parent(s) / legal guardians, and the dive instructor when assessing 'fitness to dive' of the applicant. From the age of 15 years, adult guidelines apply.

Statement 1

The definition of a paediatric/adolescent diver for SPUMS diving medical assessment is from attaining the age of 10 years to less than 15 years of age.*[4]

* The society recognises that there is considerable individual variability of physical and emotional maturity in this age range, which needs to be taken into account by the assessing doctor. See Statement 11 for additional recommendations. The society also recognises that there are other definitions and published age ranges for this population.[12,18,22]

Statement 2

It is the society's position that all prospective children and adolescent divers should be medically assessed for health risks that may be incompatible with diving before commencing scuba diving training. It is recommended that doctors who perform diving medical assessments on children and adolescents have undertaken additional professional development in diving medicine and are up to date with specific risks for this population. Where there is doubt or the child has complex health issues, additional specialist (or specialist centre) advice should be sought.

For children (and those who are legally minors), such a medical assessment would also include consent from the parent(s) / legal guardian to confirm appropriate education regarding risk has been covered, understood and accepted by both parties.[1,4,23] The doctor should determine the reason why the child wishes to dive and their motivation and should be mindful of any excessive coercion from care givers.[4,6,12,16,23,25]

Statement 3

Dive medical assessments should be performed:

- prior to initial training for any compressed air diving, including scuba and surface supply diving, provided in open and contained bodies of water (from 10 years of age), and
- following any significant health event.

Statement 4

In addition to adult contraindications which preclude diving, children or adolescents <u>should not dive</u> if they have any of the following medical conditions:

- Epilepsy (any type including absence seizures);[10]
- Combined anxiety disorder and panic disorder;[7,9,12,22,23]
- Attention deficit hyperactivity disorder;[12,16,26,27]
- Asthma (including well controlled and exercise induced), cystic fibrosis, and other chronic respiratory tract illness;[6,7,10,12,16,22,23,27,28]
- Congenital heart disease despite correction;[10,12,27]
- Insulin dependent diabetes mellitus;[10]
- Migraine with aura;[10]
- Tympanostomy tubes present in either or both ears;
- Hereditary or acquired bleeding disorders;
- Any medical condition that could cause sudden incapacity.[10]

This list is not exhaustive and detailed specialist advice should be sought regarding any specific medical conditions which are identified in children and adolescents who seek to dive.

Statement 5

There is evidence of increased potential risk from diving in children / adolescents compared with adults, particularly relating to:

- cognitive and emotional maturity, attention and focus, and antecedent risk for panic underwater;[5,7,9,12,22,28]
- attention deficit and hyperactivity disorder and associated potential risks;[26]
- risk of ear nose and throat and respiratory tract infections;[7,16,28–30]
- immaturity of the paediatric airway;[6,7,12,22,27,28,31]
- risk of persistent (patent) foramen ovale (PFO);[6,7,9,12,16,27,28]
- risk of hypothermia;[5,6,12,16,25,27,28]
- limited physical capabilities.[3–5,9,12,25,32]

Statement 6

The assessing diving doctor needs to pay careful attention to the child or adolescent's:

- past medical history;
- psychological maturity and executive function*;[3–5,7,9,12,16,22,25,32]
- physical maturity;[3–5,9,12,25,32]
- ear nose and throat assessment;[5–7,9,12,16,23,25,27,28,32]
- asthma risk;[9,12,23,27]
- risk of PFO;[6,9,12,16,27]
- hypothermia risk;[5–7,9,12,16,23,25,27,28]
- reported in-water and swimming capability**;[6,7,8,33]
- motivation for diving including whether the child perceives they are under pressure to dive.[4,6,12,16,23,25]

Physical examination should include a comprehensive medical assessment as performed for an adult diving medical examination, including pulmonary function testing and audiogram.[10]

* Where this is unable to be assessed accurately at interview, the assessing physician should seek further information from reliable third-party sources (e.g., other clinicians, allied health personnel, teachers).

**If a child is unable to swim, then they should not dive.

Statement 7

The society considers that for a diving doctor to form an opinion about medical risk for children and adolescents intending to scuba dive, the discussion with the candidate, legal guardian/s, and diving instructor must include:

- the child's / adolescent's swimming ability / in-water capability;[7]
- assessment of their level of maturity and understanding of the risks involved with diving;[22]
- assessment of their physical capabilities;[3–5,9,12,25,32]
- additional acceptance of risk by the legal guardian/s;[7]
- consideration of Gillick competency (determining whether a child / adolescent diver is functionally competent to provide informed consent).[34]

Statement 8

Recommendations for child / adolescent diver safety during subaquatic activities should include:

- emphasis of the need for physical and psychological fitness during their training;[1,4,5,23]
- emphasis of the need for accessory diving skills, including snorkelling and buoyancy control;[4,23]
- counselling regarding the risk of pulmonary barotrauma and resultant arterial gas embolism and the avoidance of panic;
- ensuring that the child / adolescent and their parents / guardians are complicit in this understanding and sign the acceptance of risk on the SPUMS Statement of Health for Recreational Diving;[1,4,5,10,23]
- determining that the child / adolescent is complicit in the decision to dive and not being coerced;[4,6,12,16,23,25]
- where possible, include the dive instructor in the decision making;[1,7,27]
- when diving, ensure:
  - » that a minimum of two adult certified, competent divers accompany the child or adolescent when diving; one of whom knows them well (e.g., parent or sibling);[9]
  - » the focus of the adults is as supervisors to the child or adolescent only;[3–5]
  - » the child or adolescent should be within arms-length distance from the adult and in direct view at all times;[9]
  - » that the child or adolescent diver is not expected to rescue their adult supervisor(s).[3–5,9,12,25,32]
- encouragement for training agencies to develop specialised training modules (including on-line) to teach young divers and lead them on open water dives;[9]
- in addition to limitations in Statement 6, child or adolescent divers should not dive in hazardous marine environments as defined in AS/NZS 2815.6 (2013) Section 1.1.4 (a)–(g), listed in Appendix 1.[35]

These recommendations are best managed by training agencies who have a special interest in child and adolescent divers and can provide individualised support for the specific needs and unique behavioural aspects of this population.

Statement 9

Regarding garments and equipment for the child / adolescent diver, these should:

- be appropriately sized and fit;[7,16]
- be appropriate thickness of wetsuit for thermal protection in the planned water temperatures*;[33]
- be of a weight that the child can carry when walking;
- preferably have integrated weights in the buoyancy compensator device**.[12]

* Hypothermia is a greater risk in children due to higher surface area to volume ratio.

** This avoids the need for a weight belt which could more easily slip off a child, leading to a rapid ascent with subsequent pulmonary barotrauma / arterial gas embolism.

Statement 10

The society recognises that there is limited evidence of harm to children and adolescents who have undergone medical risk assessment by a doctor who has training in diving medicine, and who undertake compressed air diving in a controlled, supervised environment within current training systems.[7,9,18,20–22,27] However, available studies also provide limited evidence of safety and do not permit accurate assessment of risk or incidence of harm in the child / adolescent population of divers. The negative impact of fatalities and episodes of significant injury in children is of such magnitude that a conservative approach is warranted when providing health risk advice.

Statement 11

The society supports, in-principle, the position of other medical societies and experts to stratify children or adolescents by age, when considering the diving activity,

*** Footnote:** Appendix 1 can be found on the DHM Journal website: https://www.dhmjournal.com/index.php/journals?id=346 environment, water temperature and limitations on depth of diving, and number of supporting certified diving adults (minimum of 2), when the child / adolescent is diving.[4–7,12,16,28,33,36]

Recommendations

This guideline was based on expert opinion from SPUMS clinician members present at the 51st SPUMS Annual Scientific Meeting, Cairns, Australia, June 2023. Their expert opinion is based on lived experience and currently available literature, which is limited to expert consensus, case studies, prospective cohort studies, and retrospective analyses.

Conclusions

Children and adolescents are an important group within the diving population who have development-specific considerations. Close attention needs to be placed on the medical history and assessment of the ear, nose and throat, and respiratory systems, in-water capabilities, and neurodevelopmental evaluation due to antecedent risks in the subaquatic environment.

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