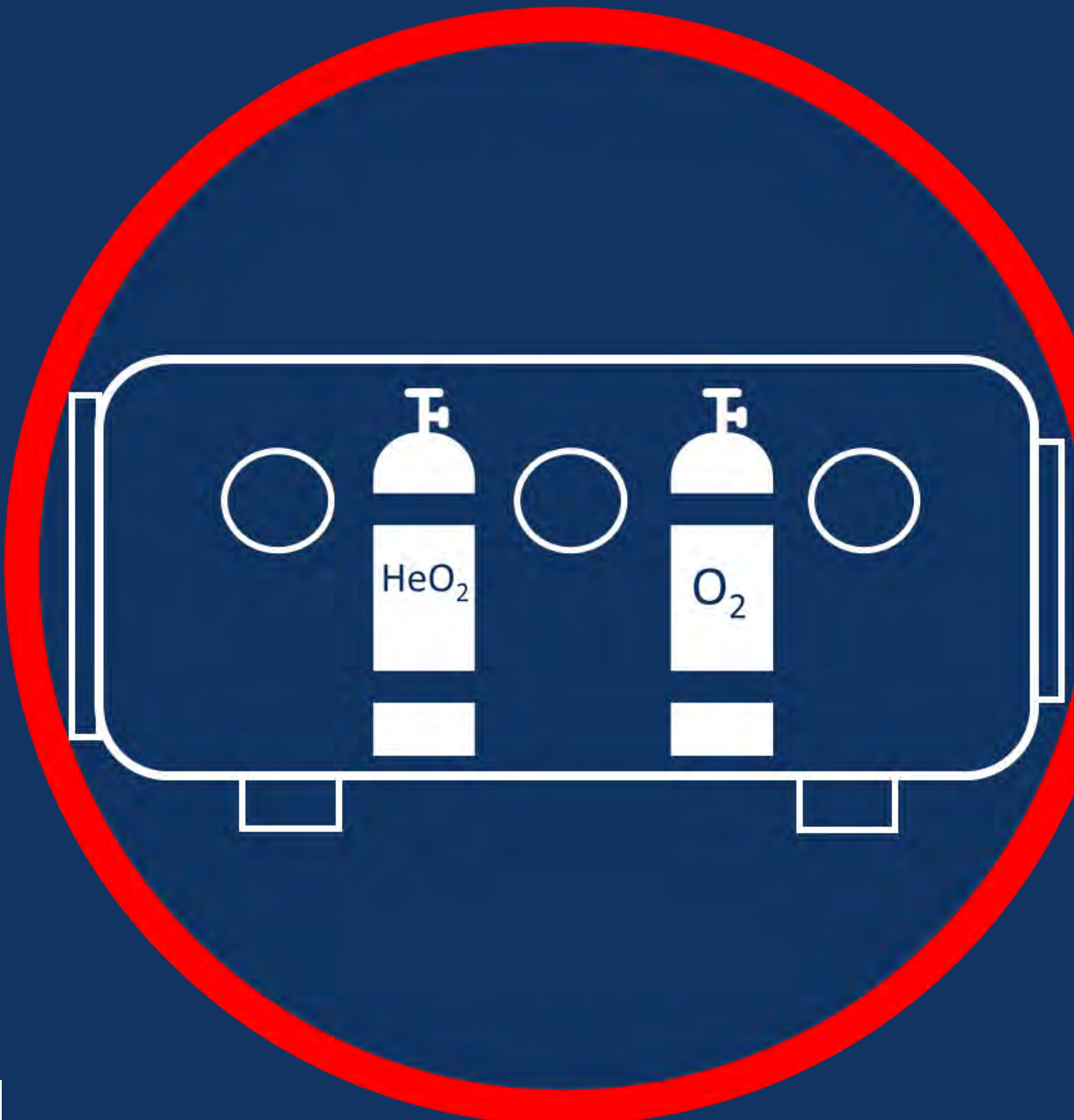
DAN
RECOMPRESSION CHAMBER NETWORK



THE RCN BULLETIN

A Newsletter of the DAN Recompression Chamber Network

www.dan.org 7th Edition March 2022 rcn@dan.org

WHAT'S INSIDE:

THE RCN WELCOME LETTER

The DAN team is pleased to share our 7th newsletter with you. In this edition, we bring you contributions from 7 different countries around the diving globe.

We are now into COVID year 3, diving tourism remains a challenge, and our network of chambers is still dealing with a greatly reduced number of diving injuries. In fact, there are several remote chambers out there that have remained closed for this entire period.

The challenges some of you now face are staff shortages, skills degradation, and maintenance issues due to a lack of cashflow. It is our hope that once the restrictions are lifted, divers around the world will be very eager to get back out to their favorite dive destinations.

This edition presents the second article in the treatment table series, this time written specifically for us by a Polish colleague who has excellent experience in utilizing these modalities.

We have two rather unique dive regions to spotlight, namely Iceland and the Brazilian island of Fernando de Noronha. This is part of our goal to highlight different and often unique diving locations.

In recent years, we have seen a flood of hyperbaric chambers being introduced for health conditions and in some cases, advertising treatment for diving injuries. Please be aware that all diving treatment tables that are currently followed in our industry have been thoroughly researched in the treatment of diving injuries over many years and are tested and proven to be effective. Pressure and suitable dosage units of oxygen are key in ensuring good outcomes. Treatment at pressures less than 1.8 ATA have not been shown to be effective in managing cases of decompression illness.

Finally, for those of you who are interested in useful and relevant publications, the Workman Hyperbaric Safety, A Practical Guide (2nd Edition) is now available through Best Publishing, in both hard copy as well as electronic format. There are interesting articles, guidelines, and advice presented by hyperbaric experts from all around the world.

As some of you commence with preparation for the likely post-pandemic phase, please remember that we are here to help. Reach out to us with your questions and needs for guidance, advice, and support. You can email us directly at rcn@dan.org.

- Francois Burman and the DAN RCN Team

The Use of Heliox in the Treatment of Injured Divers

DR. JACEK KOT

Recompression treatment is used routinely for any gas-bubble disorders. In the diving world, this means decompression illness (DCI), which describes both decompression sickness (DCI) and arterial gas embolism (AGE), usually due to pulmonary barotrauma (PBT) of ascent. Outside diving operations, similar treatment is used for iatrogenic AGE created unintentionally during invasive medical procedures (coronarography, cardiac surgery or neurosurgery, lung biopsy, etc.).

Recompression treatments rely on several factors. The most important is pressure, as it decreases the size of gas bubbles. At the same time, it allows the increasing of partial pressure of treatment gases, oxygen, and helium. Shrinking of bubble radius diminishes symptoms in case of extravascular bubbles (e.g., in joints or skin), or moves intravascular bubbles toward smaller vessels. Moreover, decreasing the radius decreases the bubble surface as well. This is of great importance, as induction of inflammatory reactions and intravascular coagulation depends on the contact area, both with blood cells (e.g., platelets) and endothelium – the inner membrane of the blood vessels. Mathematically, the relation between gas bubble volume and its radius is not linear, i.e.
$V = 4/3 \cdot \pi \cdot r^3$, which means that doubling the pressure ($2 \cdot P$) decreases volume by half ($1/2 \cdot V$). Still, the radius is reduced only by 1/5 (to 80% of its initial value). So, to get radius halved, one must increase pressure six times ($6 \cdot P$). Based on those calculations, high-pressure treatment tables were used in the past, mainly with compressed air and long subsequent decompression.

Indeed time, the second factor of the recompression treatment, is needed to diffuse gases from inside of gas bubbles into surrounding tissues and the lungs (as the minimum therapeutic effect) and resolution of symptoms (as the maximum therapeutic effect). Nowadays, the shortest time of recompression treatment is 2 hours 15 minutes (e.g., US Navy Table 5), up to 36 hours for compressed air saturation treatment at 2.8 ATA (e.g., US Navy Table 7), or even longer for heliox saturation treatment at 225 fsw (e.g., US Navy Table 8).

It is little doubt nowadays that the most essential factor of the recompression treatment is oxygen. Breathing hyperbaric oxygen (HBO2) at partial pressures greater than 1.0 ATA, usually from 1.9 ATA to 3.0 ATA, during recompression treatment enhances elimination of inert gas(es) from tissues and gas bubbles. Moreover, HBO2 exerts an anti-inflammatory effect by decreasing cellular and endothelial reactions induced by gas bubbles. Therefore, HBO2 is used for initial recompression therapy and subsequent treatments if DCS symptoms persist after the first session. During extensive experiments conducted after World War II, it was found that the optimal partial pressure of oxygen for DCS treatment is 2.8 ATA (18 msw). Since then, such partial pressures of oxygen have been used in many recompression schedules, including US Navy T5, US Navy T6, Comex Cx18, Royal Navy 61, Royal Navy 62, or 'Catalina' Table.

The colour for oxygen was blue in Poland

On the other hand, using high partial pressures of oxygen or breathing too long with an increased partial pressure of oxygen may induce oxygen toxicity, either cerebral, pulmonary, or both, at the worst, or strong oxidative stress at best. The latter can aggravate so-called ischaemia/reperfusion injury, which occurs when ischemic tissues open suddenly for high blood and/or oxygen influx. Moreover, as the regular gas, oxygen per se also plays a role in gas bubble volume. Indeed, there were some reports of initial deteriorations which can occur just after compression during the first hyperbaric treatment of DCI, with one of the plausible explanations of oxygen entering the gas bubbles temporarily increasing its size.

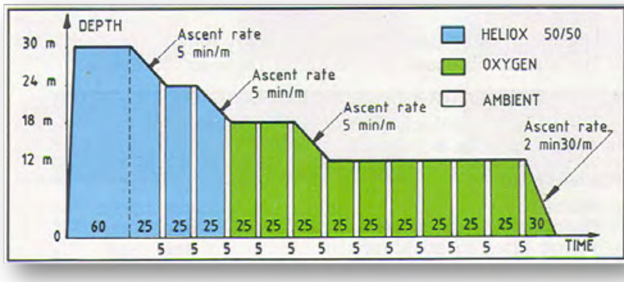
The connection of higher ambient pressures and relatively lower oxygen partial pressures is also sometimes used in recompression therapy; for example, USN T6A could be used either with air, nitrox (50% oxygen / 50% nitrogen) or heliox (50% oxygen / 50% helium) at the highest therapeutical pressure of 6 ATA, with subsequent breathing of oxygen at both 2.8 ATA and 1.8 ATA stages.

The positive effects of helium-based breathing mixtures for recompression therapy after air dives had been reported already in the 1980-1990s. Since then, there was only one prospective, randomized, double-blind study comparing 50/50 heliox with 100% oxygen at 2.8 ATA. This study reported that in the heliox group, 36% of cases required multiple recompressions (more than 2). At the same time, in the control group, multiple recompressions were used in 64% of cases. A series of animal experiments showed that isobaric breathing gas shifts from air (21% oxygen / 79% nitrogen) to heliox (21% oxygen / 79% helium) at 2.8 ATA and 5.0 ATA enhances bubble shrinking rate.

Some hyperbaric centers use heliox in recompression therapy routinely, but most do not due to the high cost of gases, separated gas storage, and personnel training. The most current international guidelines allow using heliox recompression schedules, but not with a strong recommendation. For example, the Hyperbaric Technicians and Nurses Association (HTNA) says that "the use of deep recompressions using heliox is relatively weak. It cannot and should not be considered a 'standard of care', "It may be indicated for significant neuro DCI when oxygen use was unsuccessful OR initial presentation is serious OR rapidly progressive". Also, the European Committee for Hyperbaric Medicine (ECHM) leaves the final decision to the treating medical facility recommending "HBOT/ recompression therapy tables (USN T6 or Heliox Cx30 or equivalent) for the initial treatment of DCI (strong recommendation, low level evidence)". Moreover, they "suggest the use of lidocaine and Heliox recompression tables for serious neurological DCI (standard recommendation, low level evidence)".

If a hyperbaric medical facility decides to use heliox for recompression, an additional risk assessment must be conducted. This concerns amount and purity of mixed gas supply to BIBS for the entire recompression schedule, calibration of flowmeters, and use of helium-ready mechanical ventilators for intensive care treatment.

Since the 1990s, we have been using a recompression schedule of Comex Cx30 with heliox 50% oxygen / 50% helium for treatment of the most severe spinal cord decompression sickness and iatrogenic cerebral or cardiac arterial gas embolism. The decision whether to use US Navy Table 6, with oxygen extensions when necessary, or Comex Cx30 with heliox is left to the admitting physician. In some cases, this is the primary hyperbaric treatment, but sometimes this is the second option to be used after unsatisfactory results of the first recompression.



Comex Cx30 Table

Among some other cases, we treated a 40-year-old recreational Ukrainian technical diver who dove to 75 msw using trimix 15% O2, 40% He, and N2 balance. After 15 minutes of bottom time, he started an ascent to the first decompression stop at 59 msw. He continued decompression as scheduled up to 22 msw, where he should have switched to nitrox 50% O2 / 50% N2. Due to the failure of one breathing regulator and overwhelming panic, he surfaced with more than 30 minutes of omitted decompression. On the surface, neurological symptoms of spinal DCS occurred after 30 minutes with bilateral weakness of both legs and upper extremities. During the next 2.5 hours, he was transported to Kyiv, where he lost consciousness during urination and convulsed. After regaining consciousness, he was placed in a local hyperbaric chamber (non-medical one) and compressed to 8 ATA (70 MSW) on air; after 3-5 min, decompression started to 4 ATA (30 MSW), but spinal DCS symptoms got worse (progressing weaknesses of both legs into full paraplegia with paralysis of the urinary bladder). While still in the chamber, he was (re)compressed again to 8 ATA (70 MSW) with subsequent long-lasting air decompression; details of decompression are unknown, but most probably, it was one of the old Russian recompression air tables. In the meantime, the diver's buddy, who was a Polish technical diver, directly contacted DAN Europe Polska which was operated by our National Centre for Hyperbaric Medicine in Gdynia, Poland. The advice was to stop decompression at 2.8 ATA (18 MSW) and continue 'treatment' according to US Navy Table 6 with oxygen. After the session, the diver remained conscious, but complete paraplegia persisted. Based on an international agreement between Polish and Ukrainian consulates, the patient was transferred by road ambulance to our Centre. We started Comex Cx30 with heliox 50% O_2 / 50% He.

Additionally, the patient was monitored and re-hydrated accordingly; he also received drugs as adjunctive treatment of spinal DCS (methyl-prednisolone [Solu-Medrol], lignocaine, low molecular weight heparin enoxaparin natricum [Clexane], antioxidant Acidum ascorbicum [Vitaminum C], and pantoprazole [Controloc] as prevention of gastroduodenal ulcers induced by steroids). After the Comex Cx30, there was a significant improvement of clinical status with the partial regaining of muscle strength of both legs.

Later, he received 13 standard HBO sessions (70 min at 2.5 ATA) once daily with gradual improvement. In further rehabilitation, he participated in the additional 18 standard HBO sessions (as above) and completed treatment with independent walking. His physiological functions of urination and defecation were partially restored in the following months, but sexual functions had not recovered even after follow-up years.

The Institute's recompression chamber

Recompression Chambers and Diving Emergencies in Iceland

DR. LEONARDO GIAMPAOLI

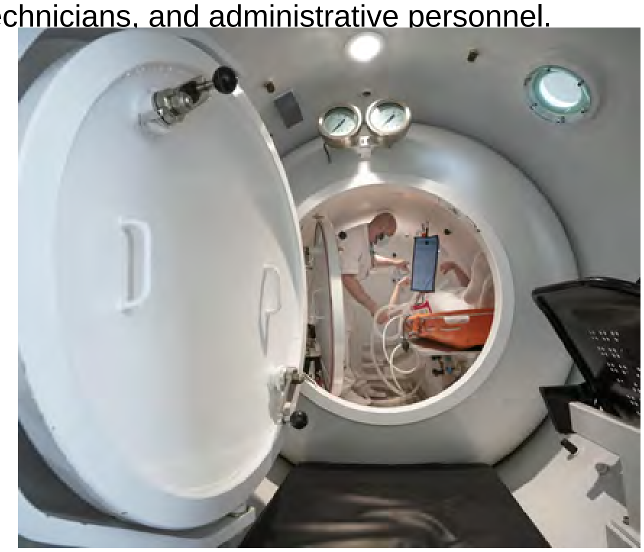
Within the Arctic Circle in the North Atlantic Ocean between the American and Eurasian continental plates, Iceland, well known as "The Land of Fire and Ice", is a dream playground for divers wishing to experience anything from subaquatic geothermal areas to ice diving. With a land area of approximately 103,000 km2, 14% of its surface is covered by glaciers and lakes, subpolar oceanic landmass, and tundra.

Iceland
(*Photo By: Laura López; Diver: Thomas Gov)*

29 recreational dive sites are located around the country that include boat, shore, and inland diving. They are registered with the Icelandic Sport Diving Association (Sportkafarafélags Ísland), and there are plenty of other popular dive sites used by local divers and the tourism industry. The most popular dive site is Silfra, with crystal clear glacier water running between the continental plates, which is visited on a daily basis by dozens of divers. Technical, SCR/CCR (Semi-Closed and Closed-Circuit Rebreathers) divers make up a small part of "recreational" diving. There is some commercial diving activity within the private sector. Important professional diving activities include tactical, rescue, and public safety diving operations undertaken by the Icelandic Coast Guard (Landhelgisgæsla Íslands), the Fire Department (Slökkvilið), and the Police (Lögreglan) diving teams.

Iceland has a multiplace hyperbaric chamber available 24/7 for diving emergencies and it is located at the Hyperbaric and Dive Medicine Department of the National University Hospital of Iceland (Landspítali) in Reykjavík. The hospital has advanced care facilities, including a trauma and emergency room, intensive care unit, surgery and radiology with CT scan, and MRI, which are in the same building as the hyperbaric chamber. This allows for integrated care to the patient along with other medical specialties, such as intensive care, pediatrics, anesthesiology, etc. The hospital takes care of 110,000 patients annually with approximately 700 beds, supported by 6,000 employees and 2,000 students.

The Hyperbaric and Dive Medicine Department has operated 24 hours a day, 365 days a year uninterrupted since 1993, with a highly qualified and specialized staff in hyperbaric and dive medicine, including physicians, nurses, technicians, and administrative personnel.



Hyperbaric Chamber, Landspítali

The equipment includes a multiplace recompression chamber, modified for clinical HBOT (Hyperbaric Oxygen Therapy), capable of recompression up to an operating depth of 55 MSW* (180 feet*). It has the capacity for 7 seated, non-critical patients or 1 critical patient on a bed together with 2 non-critical patients at one time. This can be configured for a maximum of 2 critical patients on beds if necessary. It has the capability for intensive care and emergency surgical or medical procedures when required.

The special gas system with supply of Nitrox and Heliox in different concentrations allows it to perform diverse treatment tables, such as the full range of the Norwegian, US Navy, and Comex tables together with standard air tables. These are increasingly falling out of use. However, staff and the department are prepared together with the required logistics to perform such complex treatments under extreme circumstances when other tables are not an option. In-water recompression is not practiced nor recommended in Iceland.

Icelandic Fire Department
(Diver: Atli Fannar Jonsson)

Redundant is the word that describes this chamber and in general the department. Everything is thought out and designed to have multiple backup plans to ensure uninterrupted quality operation with a high level of safety. Being the referral (and in fact only) center for diving emergencies in the country and surrounding locations, preparedness to operate in even the most extreme scenarios is essential. This includes for example, operational procedures under volcanic gas and ash storms, CBRNE (chemical, biological, radiological, nuclear, and explosive) scenarios, and mass diving casualties in need of recompression.

Language is not a concern in the treatment of cases, as within the hyperbaric unit, staff can cover more than 8 languages and a competent, immediate translation service provided by the hospital can be accessed if needed.

National University Hospital of Iceland with Coastguard Rescue Helicopter. (Photo By: Mbl.is)

In the case of a diving emergency, the first step is to activate the National Emergency Line by calling 112, where a special protocol for this scenario will be activated, involving competent authorities. Depending on the type and location of the accident, pre-hospital care is provided by Red Cross Ambulance paramedics and Fire Department EMTs. In remote areas that require a rescue, the Coast Guard helicopter has ambulance capabilities and a flight physician will be called. If the accident is near a hospital, the diver will be taken by ambulance to the nearest ER for primary assessment while transport to the hyperbaric chamber by aircraft ambulance is being coordinated.

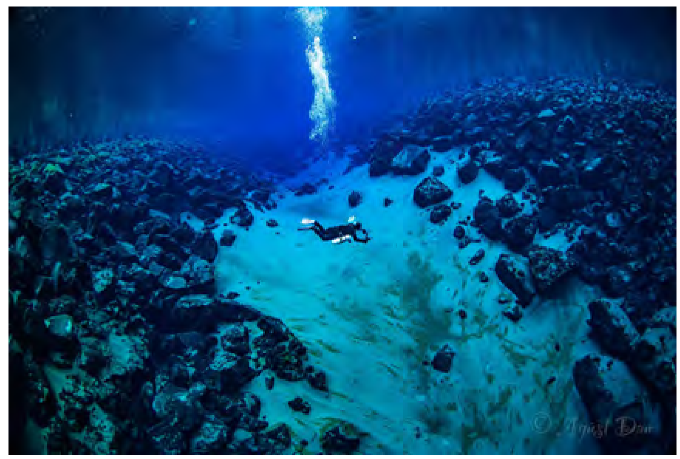
The hyperbaric chamber building has a helipad and it is 5 minutes away from the national airport in the case of fixed wing ambulance transportation. In all cases, the patient will be assessed firstly in the ER where the dive physician will evaluate the patient and establish the required recompression treatment. The department is also linked 24 hours a day directly to the national emergency system by radio, which allows remote assessment between the Dive Physician on-call and the ERs from other towns around the country, the Coast Guard, and ambulance crews nationwide.

The department engages in daily out-patient treatments following indications from the American and European guidelines, as issued by the UHMS and ECHM, together with recommendations from other countries such as Norway, Australia, Canada, and UK. Other services such as Fitness to Dive examinations, dive tests in the chamber, tours of the facility, dry dives, workshops with conferences, and investigation advisory are all part of the daily activities of the department.

Patient on hyperbaric ventilator

The statistics of fatalities and diving accidents are confidential, nevertheless prevention and safety practices are very solid in this industry.

In the past, buoyancy control accidents were the most frequent ones, related to dry suit diving by inexperienced divers. However, strong safety policies by the diving industry and National Parks were successfully established, leading to the immediate cessation of incidents of this nature. Implementation of these policies is a good demonstration of cooperation and risk mitigation.



Diver in Iceland

***Abbreviations**

- MSW: Meters of Salt Water.
- FSW: Feet of Salt Water.
- CBRNE: Chemical Biological Radiological Nuclear Explosives.
- EMT: Emergency Medical Technician.
- UHMS: Undersea Hyperbaric Medical Society.
- EUBS: European Undersea Baromedical Society.
- UK: United Kingdom.
- ER: Emergency Room.
- CT Scan: Computerized Tomography Scan.
- MRI: Magnetic Resonance Imaging. Numbers are rounded for better representation.

AGE in the Galapagos

DR. GABRIEL IDROVO

It was the last of many busy days with surges and currents in the open waters around the Galapagos archipelago in the eastern Pacific Ocean. At the bridge of a huge Ecuadorian tuna fishing boat, the captain was urgently called from the lower deck. One of the divers in charge of removing dolphins and sea turtles, accidentally caught in the giant fishing nets, was paralyzed after a dive. In fact, the 34-year-old diver's hookah air supply was cut off during a maneuver, so, after a 90-minute dive, he had to make an emergency ascent from 25 msw. Six minutes after surfacing, he lost muscle power and sensitivity in the lower limbs. The captain immediately contacted us in an effort to organize a sea-level evacuation by air to our hyperbaric medical facility in Puerto Ayora, Santa Cruz Island, using the ship's helicopter.

Six hours later, the victim arrived to our unit. He was conscious but complaining of great pain in his trunk and four limbs, inability to move from the neck down, and without sensory function from the nipple-level down.

Containerized recompression chamber

He showed painless urinary retention, not urinating since before the accident. With the initial diagnosis of DCS with probable AGE, IV saline was started and a urinary catheter was inserted. After an initial extended USNTT6, the pain improved, and the patient was able to move his right arm and leg. Following daily hyperbaric treatments (USNTTs 5 and 9) and physical therapy, the patient progressively recovered his limb movement and coordination, and was able to stand up alone after the 5th treatment. The following day, the urinary catheter was removed. The patient continued to improve, walking longer distances with total sphincter control until his release from the unit ten days later. He walked out without assistance.

After a period of observation, he flew back to the mainland, where he continued physical therapy. A brain MRI showed multiple areas of diffuse hypoxic-ischemic injuries (encephalomalacia) in the subcortical frontal, parietal, periventricular, and occipital lobes. Last time we heard from him, he was in great physical shape doing jump rope and running, but stated that the weakness of his left leg would come back if he remained 48 hours without muscle training.

This patient will likely need to maintain a lifetime exercise program or risk a relapse in left leg symptoms.

Remote Chambers: Fernando de Noronha

DR. EDUARDO VINHAES

Located 550 km (340 miles) off the northeast coast of Brazil, the Fernando de Noronha Archipelago is one of the most popular places for recreational diving in the South Atlantic. Discovered in 1503 by Portuguese explorers, the archipelago is composed of 21 islands and rocks of different sizes, the homonym main island represents 65% of its total area. Nornonha has since been a strategic location for navigation between South America and Africa. Rich in history, the archipelago suffered constant invasions from English, French, and Dutch seamen between the 16th and 18th centuries. In 1942, it became a Brazilian federal territory and during World War II, an airport was built by the United States Army Air Forces for the Natal-Dakar air route. This provided a transoceanic link between Brazil and West Africa, transporting personnel and cargo during the Allied campaign in Africa.

Created in 1988, the Fernando de Noronha National Maritime Park encompasses 70% of the archipelago's area. It was fundamental in preserving a good part of its primitive natural heritage, creating the conditions for the development of tourism which is currently the main local economic source. With water temperatures of around 26°C (78.8°F) and visibility of up to 50 meters (164 ft), one of the main tourist attractions in Fernando de Noronha, without a doubt, is recreational diving.

Since the installation of the first recreational diving operation in the mid-1980s, several scuba diving sites have been explored. There are currently 19 sites open to divers, at depths ranging from 12 to 60 meters (40 to 196 ft). Dives are mostly carried out from dedicated dive boats provided by local dive operators. Almost all dives are made with compressed air, but some local operators have facilities for diving with other breathing mixtures, including trimix. Although there is no official data, it is estimated that between 2,000 to 3,000 dives are carried out per month (data up to 2019), and among the main local diving points, we have a wreck, the V 17 – Ipiranga, a Brazilian Navy corvette that sank in 1983 and is almost 60 meters (196 ft) deep.

Dedicated chamber building on the left

With intense diving activity, the possibility that a decompression accident could occur involving divers in Fernando de Noronha has logically been considered by local diving operators for a long time. Small local hospitals typically have limited resources. In the eventual case of a more serious patient, the only definitive treatment option is usually the transport by air to the continent, a 1h and 40 minute flight. It should be noted that the local airport receives few commercial flights only during daytime.

What would be the best course for an injured diver with severe decompression illness and significant neurological impairment? Flying untreated DCI cases is not an ideal course of action. Exposing these patients to altitude before an initial recompression treatment could cause additional decompression stress, potentially worsening the patient's condition.

The initial response came through the Noronhense Association of Scuba Diving Companies (ANEMA), an association formed by the first and main local recreational diving operators and which acquired a used hyperbaric chamber in the mid-2000s. After several years of effort to renovate and install the equipment, ANEMA officially opened the hyperbaric unit in 2016. Located next to the small local hospital, the hyperbaric unit could treat injured divers with indication for recompression, minimizing the need for an AirEvac that could be riskier and expensive.

This laudable effort by ANEMA has been accompanied and applauded by DAN. In 2016, DAN sent two volunteer instructors to Fernando de Noronha to train the staff designated by ANEMA on the operation of the hyperbaric unit. On this occasion, a protocol was also presented to some of the local doctors to assist with the evaluation of injured divers by making it easier and more efficient, while at the same time securing the record of important data from each case, and the subsequent communication with the DAN Emergency Line. This ultimately helps in the diagnosis and decision on the best course of action for each case. The goal was to install an operational hyperbaric chamber on the island while ensuring the local medical resources could count on the medical and logistical support necessary to treat injured divers.

However, six years after the equipment had been successfully installed, the local hyperbaric unit has yet to be fully operational due to financial constraints with ANEMA and logistical challenges with securing oxygen and other essential components from mainland.

The correct and safe installation and maintenance of chambers and hyperbaric systems intended for the treatment of patients, including injured divers, is a process that requires special attention, skilled labor, and solid administration. The need to install such equipment in a remote location with very limited resources and access can prove to be a great challenge and make the process slow and unpredictable. In addition to the logistical and operational difficulties from the point of view of the equipment, there is still a need to guarantee information support and guidance to local health professionals on how to proceed in the event of therapeutic recompression being necessary.

Therefore, it is important to emphasize that that the existence of a hyperbaric chamber successfully installed in a remote location is not a guarantee of adequate care to an injured diver. Seeking information in advance about local medical support and a prior conscious judgment about the risks divers face in these places is the individual responsibility of each diver. But remember that whenever you need it, whether you have a question or seek support in the event of a diving accident, DAN will be there to help.

Chamber still in pristine condition

Is this Decompression Sickness? Case Studies on Cozumel

DR. DARIO GOMEZ

I remember during the early years of my training in hyperbaric medicine, a professor said: “anyone can diagnose decompression sickness (DCS), but not everyone can or wants to do a differential diagnosis.” These words have stayed with me for the length of my career.

Some examples of differential diagnosis, like vertigo, can indicate inner ear or vestibular decompression sickness where bubbles form in the perilymph fluid of the cochlea. Other diving-related causes should be considered, as recompression treatment can cause some of these conditions to worsen. In particular, inner ear barotrauma would be a contraindication to recompression as more gas may be forced into the cochlea causing further trauma. Alternobaric vertigo and Benign Paroxysmal Positional Vertigo should be differentiated from decompression sickness by history. Cerebral arterial gas embolism affecting the midbrain or cerebellum can also present as inner ear decompression sickness, but receives similar treatment.

We should also consider differential diagnosis for divers due to the stress of diving, which can exacerbate chronic medical problems like cardiac disease. Other common pathologies include pain from a previous musculoskeletal injury and stroke, and hypoglycemia for altered mental status. Other concerns include drowning or near-drowning, and thermal stress.

In many cases, when we find the typical presentation of DCS, it is diagnosed and treated with good results, however, in some instances this is not the case. Even with typical presentations, there are some with little to no response from treatment. We know DCS presents in various ways. Below are some atypical case summaries.

Dr Gomez supervising a treatment

Case One

44-year-old, otherwise healthy, male, certified scuba diver. Patient was diving one day, two uneventful dives. First dive 85ft for 35 min, surface interval 50 min, second dive 68ft for 50 min. Two hours after his last dive, he presents paresthesia and pain in lower limbs, which lead him to seek evaluation at a local hyperbaric chamber. There, he was diagnosed with mild dehydration and DCS. He received a USNTT6 and two USNTT9 in the following days with little improvement. Patient continued with pain in lower limbs, increased paresthesia, and the addition of difficulty walking. Patient contacted us for a second opinion on the third day of treatment as he was not improving. After talking to him and the treating physician, we suggested looking for another diagnosis as the patient was deteriorating. Laboratory studies and MRI were ordered with no findings. By the fifth day, the patient’s numbness, pain, and tingling were worsening. The patient decided to self-discharge and go to another facility where we recommended a lumbar puncture, where high protein was found. After that result, a specific blood test to detect Guillain-Barré syndrome was ordered, and that confirmed the diagnosis. Patient is still recuperating.

Case Two

18-year-old, otherwise healthy female, certified scuba diver. Brought to our ER for sudden behavioral changes. Patient was at her hotel and started having acute psychoses. After evaluation from psychiatrist and neurologist, a relative over the phone mentioned she was scuba diving that morning. After our evaluation, other than fatigue, we found no symptoms related to DCS. We treated her with a USNTT6 and after the second period of oxygen at 60 ft, symptoms subsided. Patient stayed two days for observation and was discharged asymptomatic, with only some residual amnesia. Patient completely recuperated and hasn't had another episode in the last 5 years. She continued scuba diving.

Case Three

29-year-old, otherwise-healthy female, certified scuba diver. Patient presented numbness and discomfort in lower limbs during her ascent from an uneventful 42 ft, 35 min single dive. On arrival, she had minimal strength in lower limbs and although the dive profile looked unprovocative, she received a USNTT6 with two extensions at 60 ft and two extensions at 30 ft. Later that day, a second standard USNTT6 was prescribed. Patient condition continued to deteriorate as she realized she could not move her legs and became paraplegic. Hyperbaric treatment continued twice a day until completing 10 treatments with marginal improvement daily. She was treated for ten more days for a total of 20 treatments. We tried to rule out any other neurological pathology as the dive profile didn't match the severity of symptoms. CT Scan, MRI, Spinal tap, Echocardiogram with no findings. Control MRI at Day 15 showed diffuse injury in spinal cord from T5 to T8. Patient was transferred to her home country via air ambulance with partial mobility of lower limbs and sphincter control, and has continued to improve to date.

These cases are good examples. One with symptoms which presented as DCS but weren't, one which didn't present as DCS but was, and one which was difficult to understand the severity. The optimal way of undertaking diagnoses improves the use of our tools (basic or advanced), improves communication with our patients, provides a plan of treatment, improves prognosis, and may be useful for preventative interventions. To reach these goals, we must understand the relation of the clinical utility of tests and possible diagnosis, and how to best implement findings in clinical practice. All of these are important to fulfill our ultimate goal, which is to help our patients to have the best possible outcome.

Remote Learning and Education Opportunities for Chamber Operators, Technicians, and Physicians

SHERYL SHEA RN, CHT

The importance of training and education to maintain safe hyperbaric chamber operations cannot be overstated. Simply having a hyperbaric chamber that is operational, with all the proper maintenance completed, is not enough. It is imperative to have well-trained and practiced chamber operators, inside tenders, and physicians who understand not just the basics of decompression illness, but how to operate the chamber in order to treat it. Compliance with rules and standards does not mean one is ready to deal with patient and chamber emergencies – comprehension is the key!

Operators must understand why and how various chamber systems work, and be practiced not only in their operation, but in the ways that things can go wrong and how to react. This can only be accomplished through hands-on training coupled with education. That safety manual that is someplace near the console, with a list of emergency action plans inside, does not help when things go wrong if the operator, tender, or physician facing the emergency has never put an EAP into action. Having all systems maintained and in-date does not mean you can be sure the EAP will be successful when needed, or that all staff can recognize an impending emergency and react promptly and effectively.

For many accidents, there is no clear "smoking gun" and these usually happen unexpectedly. However, the two key failings in responding to an accident are a lack of emergency drills, and inadequate training.

All chambers should have regular emergency drills, initial training for all new staff, and refresher training for regular staff and after periods of inactivity, for example, pandemic shutdowns.

RCAP hyperbaric safety class

Opportunities for further education should be emphasized to increase the level of comprehension – not just the "how" but also the "why". Avoiding chamber accidents is not the only important reason for an emphasis on education. Avoiding misdiagnosis of DCI, recognizing weaknesses in the system, enabling staff to educate patients and adequately answer their questions, and encouraging staff interest and pride in their work are just a few reasons why education is crucial.

However, accessing outside educational opportunities can be difficult. Lack of time, remote chamber locations, lack of funds, and pandemics are just some of the barriers to education. This is one of the few ways the pandemic has helped – many educational sources that were once only available "live" were converted to remote learning during the pandemic. There are courses both formal and informal, short and long, plus articles and webinars. Some have a cost, but many do not. We have attempted to provide a sample of remote educational offerings here below, but there are more out there if you search.

Here are some useful links to organizations offering hyperbaric staff training and publications.

Baromedical Nurses Association (BNA)

- 1-hour courses with a CEU credit.
  USD 15 for non-members; free for members.

Divers Alert Network (DAN)

- Essentials of Dive Medicine e-learning course: a primer for medical doctors with an interest in diving medicine. Please send an email to rcn@dan.org and we will send you the invitation. The course is free.
- Pathophysiology of DCS, free.
- Decompression Theory & Gas Exchange, free.

DAN Southern Africa (DAN SA)

- Chamber attendant and operator e-learning training course. This course has a cost but may be available through the RCAP to chambers as part of ongoing subsidized training programs. You can contact us directly at rcap@dan.org.

European Undersea and Baromedical Society (EUBS)

- Good Clinical Practices in HBO Therapy, free.

International ATMO online CME articles

- Free if you do not request education credits.
- Full-length courses at a cost.

National Board of Diving and Hyperbaric Medical Technology, USA (NBDHMT)

- Hyperbaric Technologists (CHT)
- Hyperbaric Registered Nurse (CHRN)
- Continuing Education: DMT Recertification

Southern African Undersea and Hyperbaric Medicine Association (SAUHMA)

- Chamber Attendant Course
- Chamber Operator Course
- Hyperbaric Training for Nurses

Publications

- DAN Risk Assessment Guide for Recompression Chamber Facilities, free.
- Hyperbaric Facility Safety: A Practical Guide, 2nd Ed Wilbur T. Workman, Best Publishing.

Gas Analyzer Calibration for the Treatment of Injured Divers

FRANCOIS BURMAN, PE

A question often raised during any form of safety or compliance assessment is whether the gas analyzers have been calibrated or not. Do these instruments actually need to be calibrated or do they just need to be checked? There are a range of opinions as to the right way to do this, depending on the background of the chamber operators. Commercial diving life support technicians need to control very low levels of oxygen at a high degree of accuracy and ensure that carbon dioxide (CO_2) levels are kept below safe surface equivalent levels. Equipment must be robust and redundancy is usually needed to ensure that the environment is kept at exact levels.

- Surface decompression chamber operators may only need to be concerned about fire-safe oxygen levels and ensuring that the decompression gas is actually oxygen.
- Military operators may need extremely robust equipment, depending on where their systems are deployed.
- Recompression facilities for injured divers and hyperbaric oxygen therapy chambers have a different set of criteria as these are medical treatments. We will be focusing on this set.
- Finally, scientists may need very high levels of accuracy for their research, but usually where the equipment will be housed in stable and well-protected environments.

Before we discuss the appropriate way to set up gas analyzers for the **recompression treatment of injured scuba divers**, we should accept that our equipment may be different to what others may use and some of the practices will differ. There is no one size must fit all approach here. Analyzers using high technology sensors may only require annual calibration, but then only using accurate calibration gases. It all comes down to the risk of exposure to the gas and the effect that an incorrect result may have on the patient.

We will be discussing the two main types of gas analyzers used for air-filled recompression chambers: oxygen and CO_2 analyzers.

Oxygen analysis is performed to achieve two goals. The first of these is to ensure that masks are tight-fitting so that the patient gets the best dose possible and that there is no excessive leakage into the chamber, which poses a very real fire risk. The second is to ensure that the treatment gas is what it is meant to be - either "100%" oxygen or the correct amount in the therapeutic gas mixture being used – say 50% for a 100 fsw mixed gas treatment table.

Oxygen analyzing cells are usually not accurate over the full range from zero to 100%. As a general rule, you should expect the analyzer to be accurate within ±20% of the desired value.

This means you would set up the analyzer (we often refer to this as spanning) using air at 21% and it would be accurate to within ±1% of the read-out in the range between 16.8 – 25.2%. Remember that we must keep the chamber environment to below 23.5%. The tricky part here is what gas to use – any air cylinder perhaps, the environment perhaps, some gas flow from the chamber prior to treatment commencing? Our go-to is to simply read the atmospheric environment and assume that it is 21%. You will read later than this is not necessarily the best way to do this.

Then for the treatment gas, we simply need to know that it is or is not what we expect it to be. It is a pass or fail test and the actual percentage is less important.

Some analyzers do allow for dual range spanning: low meaning around 21% and high meaning 50 – 100%.

Modern oxygen analyzer with dual-range calibration capabilities

An additional and potentially important consideration here is the actual flow rate used to span the analyzer. The way to ensure consistency, accuracy, and the highest degree of confidence is to span the analyzer at the same flow rate that will be used throughout the treatment. This implies that we need to have a flow through the sensor unit when we span it. This can be a challenge if the chamber is not set up with this ability.

Remember that you will need to keep an eye on the flow meter at all times so that you can keep the flow rate constant as pressure changes.

So, to summarize:

- Span the analyzer each day before use on air to provide a baseline for any leakage into the chamber – we want to keep the environment under 23.5% during treatment, and
- Check that the treatment gas is what it is meant to be. You can certainly span the high range if the analyzer has this dual range capability.

We do not need to zero a typical recompression chamber oxygen analyzer. Please remember to set your high and low alarms once you have spanned your instrument.

And no, you do not need to adjust your reading for altitude. 21% remains the proportion of oxygen to nitrogen regardless of altitude (or depth).

The **calibration of a CO_2 analyzer** is a little more complex.

The correct calibration practice here is to firstly zero the analyzer using any gas that has no carbon dioxide (such as oxygen, helium, or nitrogen). Next, we set the analyzer to a known value of carbon dioxide, using a calibration gas that contains a measured quantity of CO_2 around where you expect it (say 500 – 1000 ppmv) with the balance of the calibration gas being the gas that you will be analyzing (so this would be air in our case).

As before, we need to use the same flow rate for calibration that will be used while monitoring the chamber atmosphere and keep it the same throughout the treatment.

Multigas analyzer

Depending on the equipment manual, this calibration process would be done each day prior to treatment. However, calibration gases are not easy to come by and for recompression on air, we are more concerned about keeping the surface equivalent value of CO_2 to below the safe limit rather than any great accuracy in the reading. The generally accepted accuracy of these instruments is ±2% of the read-out.

The maximum safe limit for CO_2 levels is 5,000 ppmv surface equivalent. This means that for a 2.8 ATA treatment, the maximum level of the CO_2 in the chamber gas as it leaves the sensor to the atmosphere outside the chamber is 5,000 ÷ 2.8 or 1,785 ppmv. Unlike the oxygen analyzer, depth does play a role in determining the amount of CO_2 that patients and tenders may inhale. Here it is not the concentration, but the amount that plays a role.

The generally accepted way is to span the analyzer on ambient air – take care to avoid any proximity with people or typical sources of CO_2 and use the generally accepted standard atmospheric level of 400 ppmv, unless you have reason to suspect it to be higher.

Leave any zeroing of the analyzer to either the factory default reset, or when the analyzer is serviced by a professional technician.

Remember that all CO_2 analyzers have a warm-up period, which can be between 30 seconds and several minutes. It differs between models.

The workhorse of many recompression chambers

A final word on CO_2 analyzers. It is very important to ensure that the sensor vents to atmosphere with no resistance (back-pressure). So, if you have one sensing line and two instruments, place the oxygen analyzer cell closer to the chamber and the CO_2 sensor just before the line exhausts to the atmosphere.

In conclusion, we do not need absolute values in ensuring safe and effective recompression treatments. Some basic steps using generally available and economical instruments will ensure that the readings are accurate enough to achieve these purposes. If a research project is being done, of if assessing the exhaled CO_2 from a diver, the calibration process might need to be more precise.
The easy way to distinguish between calibration and spanning or setting-up processes is that we calibrate against a known (measured) amount while we span using an expected amount.

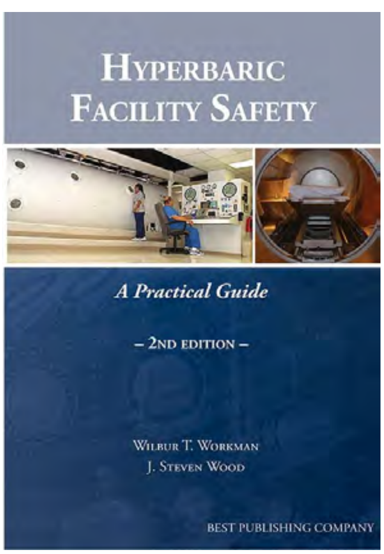
FREQUENTLY ASKED QUESTIONS

Q: Our unit is new and we have so many things to think about. Could you please share with us the 10 most important things that we should focus on from a safety perspective? Our hospital has asked to demonstrate that we are a safe facility.

A: This is a very valid question and has been asked on several occasions.

While there are perhaps 100 things if not more that even the most basic facility will need to consider, we can prioritize these based on a score obtained from a simple risk assessment tool. It is all about frequency of exposure, probability that an incident could lead to an accident, and what the likely consequences could be.

Using actual on-site assessments of 150 facilities around the world, here are the 10 primary risks based on their risk score. You may be surprised by some of these findings.



Second edition of the Workman seminal publication

1) Safety drills not practiced - an emergency action plan may fail if it is not carried out promptly and correctly. We try to avoid accidents from happening, but they do happen.

2) Alternative breathing gas for operator not provided – remember that in the event of a fire or contaminated chamber environment, it will take time to get the chamber to the surface. The operator must have a safe and non-oxygen enriched gas throughout the process.

3) Emergency operating and medical procedures undocumented - if it is not recorded, then it does not exist! Even if they are perhaps not entirely correct, at least you will be following something.

4) Maintenance system absent, inadequate, or inappropriate – you cannot expect to have no equipment failures, which usually occur at a critical time if you do not take care of your facilities.

5) Leak testing not done – oxygen leaks introduce a fire risk; sensing lines may lead to under-reading of the depth gauge or inaccurate chamber environment oxygen level measurements.

6) Air supply analysis or quality control lacking – you cannot see, smell, feel, or taste most contaminants in breathing gas. It is only through a carefully considered air quality and analysis control system that you can be more assured of safety.

7) Particle filters before regulators absent – most high-pressure regulator failures are caused by dirt and particulates lodging on the sensing surface of the regulator valve. The downstream pressure will not remain constant and either the breathing device will fail, or the regulator safety valve will pop and likely cause the operator to panic.

8) Standard operating procedures not documented – how can you demonstrate effective and safe practice if everyone relies on what they think is best? If it is not recorded…...it does not exist.

9) Oxygen cleaning procedures not in place – while oxygen cleaning is not required on a regular basis - except in the event of contamination, suspected contamination, or a lack of confidence in how maintenance was done - when it is required, you will need to have at least a basic oxygen cleaning procedure in place. This might be as simple as a procedure for selecting and then monitoring an external cleaning service provider.

10) Operator checklists inadequate or lacking – many operators become complacent as the awareness of risk diminishes with time and when start-up and shut-down procedures become too familiar. Remember that that the risk does not change – it is as dangerous on the first day as it is years later. Documented and recorded checklists, followed consistency and with full attention, will prevent most system-related accidents from happening.

While some of these may come as a surprise, all of these have a significant impact on the safety status of your facility. None of these are difficult to put in place, demonstrate when requested to do so, or present in the event of an incident.

About The Authors

Dr. Jacek Kot (Poland)

Jacek was educated at the Medical University of Gdansk and works as a diving and hyperbaric medicine specialist, as well as a professor at the Hyperbaric Centre of the Institute of Maritime and Tropical Medicine in Gdynia, Poland. While still a medical student, he qualified as an advanced recreational diver. He then joined a newly created research group looking at saturation decompression on nitrox, heliox, and trimix, and shortly thereafter completed his training in technical diving. Believe it or not, his professional interests include saturation decompression, long decompression after deep bounce dives, HBOT in critically ill patients, and HBOT for necrotizing soft tissue infections!

Dr. Leonardo Giampaoli (Iceland)

Leonardo is a doctor specialized in hyperbaric and undersea medicine. His diving experience began 24 years ago and merged with his medical career over the years. His passion for knowledge has led to complement his experience in the fields of high pressure breathing gas systems and as an hyperbaric chamber technician certified as an inspector of high pressure cylinders, oxygen service, safety officer, among others.

He currently works as a Hyperbaric & Dive Physician, Training Coordinator, and Safety Officer at the Hyperbaric & Dive Medicine Department of the National University Hospital of Iceland (Reykjavík). He has been an active member of the UHMS and EUBS since 2016, and is the actual vice-president of the Colombian Hyperbaric and Dive Medicine Association. He is also an ad honorem advisor of the Colombian Navy and diverse commercial diving companies in subjects of special environment diving, including deep diving in high altitude locations. When off-duty he spends time diving and teaching his favorite diving specialties: altitude and solo diver, currently with a trimix Instruction level, full cave, and Rebreather Diver.

Dr. Gabriel Idrovo (Galapagos, Ecuador)

Gabriel is an Ecuadorian medical doctor and completed his hyperbaric medicine training in Paris in 1993. This was followed by the UHMS course in diving medicine in Seattle, Washington-USA. Gabriel is a very experienced diving medicine educator and has been a PADI OWS Instructor for 30 years. He is also a DAN first aid instructor. He has been the medical director of the only recompression chamber in the Galapagos, in Puerto Ayora, since 2001.

Dr. Eduardo Vinhaes (Brasil)

Eduardo Vinhaes is a diving and hyperbaric medicine specialist. Certified diver since 1982 with training in technical diving, has been participating as physician and diver in many diving expeditions in remote areas including high altitude diving (Lake Titicaca, Bolivia) and cave diving. After finishing medical residences in General and Thoracic surgery, he received his training in Hyperbaric Medicine the University of Campinas Hyperbaric facility and actually is the coordinator of the Post Graduate Course in Hyperbaric Medicine in another traditional medical school (Santa Casa de São Paulo) in Brazil.

About The Authors

Dr. Dario Gomez (Mexico)

Dario Gomez is a physician that has focused all his professional life around diving and hyperbaric medicine, with a special interest in prevention, understanding, and mitigation of dive accidents. His efforts have been focused not only on treatment of DCS and clinical hyperbaric medicine, but also in education of divers and medical personnel. He frequently participates as speaker or faculty in hyperbaric and diving medicine courses, symposiums, and post-graduate courses. Based in Cozumel, Mexico, he is the DAN medical liaison for the region.

Francois Burman, PE (South Africa)

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 Clinical 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.

Contact Information

- Divers Alert Network .... +1-919-684-2948
- Recompression Chamber Network technical and operational assistance .... rcn@dan.org
- DAN Recompression Chamber Assistance Program .... rcap@dan.org
- Recompression chamber and medicine enquiries .... medic@dan.org
- General diving safety enquiries .... riskmitigation@dan.org
- Chamber Operation Safety website .... chamber-operational-safety