DAN DIVERS ALERT NETWORK

HEALTH & DIVING REFERENCE SERIES

DECOMPRESSION SICKNESS

FOREWARD

DAN's Health & Diving Resource Series is a comprehensive collection of online and printed resources developed from years of DAN-supported research and insights gained from assisting thousands of members through dive and medical emergencies. These materials provide valuable information on topics critical to diver health and safety, as well as common issues encountered by new and experienced divers. As your dive safety association, it is our duty to provide the diving community with these vital education and reference tools. The series offers greater insight into topics such as ears and equalization, cardiovascular health, decompression sickness, hazardous marine injuries, and much more. Through information and education, we hope to enhance diver safety and incident prevention.

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INTRODUCTION TO DECOMPRESSION SICKNESS

> "One of the hazards associated with underwater diving is decompression sickness (DCS) caused by uncontrolled release of gas from tissues during or after surfacing."

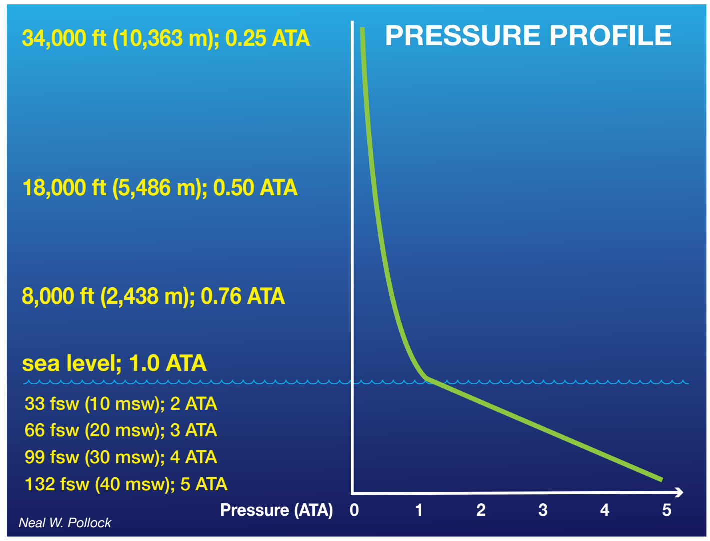
Diving is a popular recreational pastime, as well as an activity with numerous practical applications in the scientific, commercial, military and exploration realms. While diving can be done safely, it is essential for all divers — no matter what their reason for diving is — to appreciate that the underwater environment is unforgiving. Problems may arise during a dive due to insufficient medical or physical fitness, improper use of equipment, or inadequate management of the high-pressure environment.

One of the hazards associated with the pressurized underwater setting is decompression sickness (DCS), a condition also known as "the bends." This chapter explains the basics of DCS, while subsequent chapters provide details regarding its manifestation and management, as well as risk factors that may predispose you to the condition and preventive steps that you can take to minimize your chance of developing it.

THE PHYSIOLOGICAL MECHANISMS OF DECOMPRESSION SICKNESS

TISSUE TENSION

When a diver is exposed to an environment of elevated pressure, inert gases, for example, nitrogen, accumulate in tissues. The deeper a dive is, the faster the body's absorption, or "uptake," of such gases. When the diver ascends, the drive is reversed and gas leaves tissues. A diver's ascent must be controlled to allow for an orderly elimination, or "washout," of the accumulated gas. A slow ascent, conducted either continuously or in stages, usually allows for safe decompression, whereas a too rapid ascent following gas accumulation can sometimes result in DCS.



Air pressure increases slowly from zero at the boundary of space to one atmosphere (14.7 psi) at sea level; water pressure increases much more dramatically, adding one atmosphere of pressure for every 33 ft of seawater.

The concentration, or "tension," of dissolved inert gas within your body's tissues is a function of ambient pressure — that is, the pressure of the environment surrounding you at any given time. The inert gases that are not used in your body's metabolic reactions normally exist in equilibrium with your ambient environment — in the same concentration as in the air around you. Tissues under such conditions are described as "saturated." Minor pressure changes, such as those created by shifting weather conditions, produce minor pressure variations in atmospheric gases that are then matched by pressure changes in the gases in the body's tissues. When a pressure difference, or "gradient," is created, molecules from the area of higher concentration flow toward the area of lower concentration until balance is re-established. Since all of us constantly experience minor changes and corrections of this nature, the gas tension in our bodies is in a state of dynamic rather than static equilibrium — even before diving is added to the equation.

PRESSURE

The diving environment puts a significant additional burden on this adaptive mechanism. Here's why: pressure is measured using a unit known as an "atmosphere." There is no actual physical boundary between the Earth's atmosphere and space, but the atmosphere is often considered to extend 62 miles (100 kilometers) from sea level to the edge of outer space. The pressure produced by this entire column of gas acting at sea level is one atmosphere, equal to 14.7 pounds per square inch (psi) or 101.3 kilopascals (kPa). By comparison, the change in pressure underwater increases by one atmosphere for every 33 feet of saltwater and every 34 feet of freshwater. As a result, any variation you experience in surface atmospheric pressure is extremely modest compared to the variation in pressure you can undergo when you travel vertically underwater; this can create huge gradients in the uptake of gases during your descent and in their elimination during your ascent.

GAS EXCHANGE

Your lungs serve as the primary connection between your body and the environment in which you are situated at any given time. When you expose yourself to increased pressure underwater, the gas in your lungs is compressed. This creates a gradient from your lungs to your bloodstream and, subsequently, from your bloodstream into your tissues as they are perfused, or supplied, with oxygenated blood. Your tissues will take up inert gas until the gradient is eliminated, an effective state of equilibrium, or saturation, with the surrounding environmental pressure. It takes a long exposure for complete saturation to be reached, but once reached, staying longer does not further increase gas uptake or the required decompression.

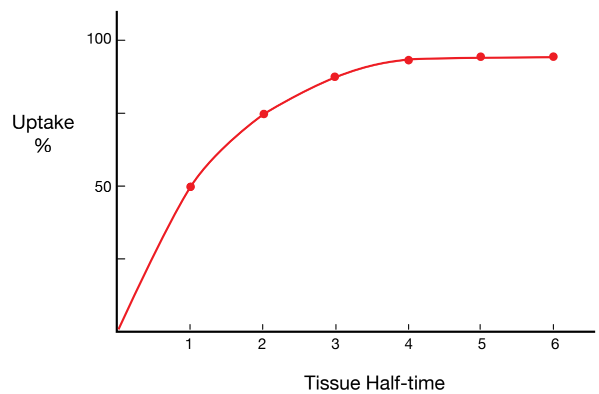
PREDICTING GAS UPTAKE AND ELIMINATION

TISSUE COMPARTMENTS

This natural physiological mechanism can be predicted by a series of mathematical algorithms based on "half-time compartments," which approximate the exponential uptake and elimination patterns expected in various types of perfused tissues. The key to these algorithms is that different parts of the body take up and eliminate inert gases at differing rates — for example, blood is considered a "fast compartment" and bone a "slow compartment." (The term "compartment" is not meant as an exact referent for these tissues but, rather, as a mathematical construct to estimate what happens in various parts of the body.)

The fastest tissues are the lungs, which achieve equilibrium almost instantly. Blood follows in speed, then the brain. The slowest tissues are those that are relatively poorly perfused, such as ligaments and cartilage, or those that have a high capacity for inert gas uptake, such as fat in poorly perfused areas. The reason for using a mathematical algorithm to estimate tissue status is that it is not yet practical to directly measure uptake or elimination in specific tissues.

An example may demonstrate how the algorithms work. Let us imagine a diver who has been instantly displaced from the surface to a fixed depth — effectively, a fixed pressure — and let us say that in this particular dive scenario, a fast compartment has a half-time of five minutes. In such a case, the first five minutes of exposure to the higher pressure would result in sufficient inert gas uptake to eliminate half of the difference produced by the pressure gradient (50 percent, in other words); this is the steepest portion of the uptake curve. The second five-minute period would eliminate half of the remaining difference (another 25 percent). The third five-minute period would eliminate half of the remaining difference (12.5 percent); the fourth, 6.25 percent; the fifth, 3.125 percent; and so on. This exponential pattern means that the rate of change becomes progressively slower as the magnitude of the difference decreases. The example described a fast compartment; half-times for slow compartments have been computed in some algorithms out to almost 500 minutes. In decompression theory, the absolute difference in pressure is immaterial — the same half-time construct applies to any gradient. With no additional influences on the process, equilibration, or saturation, would be achieved in a period equal to about six half-times. As gas dissolves in the tissue, the difference between the external pressure and internal pressure decreases, reducing the driving force.



The half-time concept describes how an undersaturated tissue takes up inert gas. When held at a fixed pressure, enough gas is taken up to eliminate half of the difference in gas pressures in each half-time period. For a theoretical tissue with a half-time of 10 min, 50 percent of the difference is eliminated in the first 10 min, then 25 percent in the next 10 min (half of the remaining 50 percent), then 12.5 percent in the next 10, and so on.

Most dives do not last long enough for the diver to reach saturation — these are known as "bounce dives." During such exposures, the inflow gradient exists throughout the descent and bottom phase of the dive, which causes continued uptake of inert gases, certainly in the body's slow compartments and probably in intermediate compartments. When the diver starts to ascend, and the ambient pressure starts to drop, the gradient begins to reverse — first in fast compartments and then in progressively slower compartments.

DEGREE OF SUPERSATURATION

Effectively, during and after surfacing, most of a diver's tissues will be supersaturated in comparison with the ambient pressure. If the degree of supersaturation is modest, inert gases can travel in an orderly manner from the body's peripheral tissues into the blood and then to the lungs, from where they can be exhaled to the atmosphere. But if the degree of supersaturation is too great, the elimination of inert gases becomes disorderly. In this case, gas bubbles can form in the tissues of the diver's body.

Bubble formation does not always cause problems, but the higher the gradient, or degree of supersaturation, the greater the likelihood that signs and symptoms of DCS can occur. It is a dangerous misconception that measurable bubbles form after all dives and are of no importance. But at the same time, it is a misconception that bubbles visualized in the blood stream in and of themselves signal DCS. The formation of gas bubbles during decompression represents a stress greater than is optimal and may lead to DCS. It is best to follow conservative dive profiles to minimize the likelihood of bubble formation. The greatest difficulty is in knowing what counts as "conservative," since most divers have never been monitored for bubbles, and uptake and elimination is altered by a number of factors in addition to the pressure-time profile.

The half-time compartment calculations are used to generate exposure-limit predictions for a range of hypothetical compartments. In paper or plastic form these are known as "dive tables." Modern dive computers allow for much more flexible guidance since they are able to continuously monitor the pressure-time profile and simultaneously compute the status of a variety of theoretical tissue compartments. But in reality, the picture is much more complex. Gas exchange is influenced by more than just the pressure-time profile. So while it is important for divers to understand the concepts behind calculating half-time compartments, divers must also keep in mind that a wide range of factors can influence gas uptake and elimination and effectively alter decompression risk. Thus the onus is on the diver not to rely too heavily on a table or device for safety.

2

EFFECTIVE USE OF YOUR DIVE COMPUTER

> "Divers are surprised when symptoms of DCS develop after dives that appeared safe according to their dive computers. Remember, models reflect an average diver, not you."

In recent years, dive computers have supplanted dive tables as the primary means of regulating dive profiles. Dive computers offer an advantage in that they enable the diver to dynamically establish different compartments as the controlling compartment, as conditions change during a dive. In reality, the compartments in a dive computer's modeling software do not have to represent any particular tissue, as long as the guidance provided by the model results in an acceptable outcome — specifically, very little DCS.

IMPORTANT CAUTIONS

While the guidance provided by decompression models can be very useful, it is important for divers to keep in mind that dive schedules — whether they are presented in printed tables or on the screen of a dive computer — are limited in what they measure and in the assumptions upon which the model was constructed. Tissue compartment parameters can be adjusted, or new compartments can be added to an algorithm, if experience shows deficiencies in a given model — but in real time, the calculations are limited by the variables that are being processed. Algorithms can estimate limits based on time and pressure (depth) profiles for a given breathing gas, but they are not able to compute the impact of myriad real-time factors, including thermal status, exercise intensity, joint forces and a host of individual predispositions that are currently not well understood, let alone quantifiable in their impact on decompression stress.

Divers are often surprised when symptoms of DCS develop after dives that were conducted within the limits of their dive computers. It is important to remember, though, that while mathematical models predict outcomes, they do not guarantee them. The fact that a dive was conducted within the limits suggested by a dive computer (or a dive table) does not make a DCS hit “undeserved.” The mathematical algorithms provide guidance that must be evaluated and tempered by a thoughtful diver.

Many divers are also unaware of the fact that dive computers make use of many different mathematical models, or versions of different models; there is no universal standard. A single manufacturer may even use more than one model, possibly in a single type of computer. This makes it extremely difficult to assess the nuances of every system.

BASIC GUIDELINES

There are some basic guidelines that can help to ensure the safe and effective use of a dive computer. The following considerations are intended to offer a somewhat light-hearted insight into what your dive computer can — and cannot — do.

It is helpful to think of your dive computer in these ways:

- As a business competitor: Master it by learning its strengths and weaknesses.
- As a date: It must be turned on for the relationship to work.
- As a buddy: It should descend and ascend whenever, but only when, you do.
- As a personal assistant: It reminds you of rules and schedules you might otherwise forget.
- As an actor: It recites the lines without having to understand their implications.
- As a politician: Do not believe everything it tells you.
- As a hotel concierge: It will help you do what you want — but at a price.
- As a stranger: It knows virtually nothing about your personal reality.
- As a mate: Is it compatible with your friends?
- As a news reporter: It will air your dirty laundry.
- As a tool: Use it appropriately.

SPECIFIC TIPS AND TRICKS

PUSH THE RIGHT BUTTONS

You should know not only which buttons to push to make your computer work, but also which mathematical model or model derivation it employs in making its decompression computations. There is a surprising range in models, from conservative to liberal, and these differences may not be evident at first glance. For example, a computer may establish conservative limits for an initial dive but liberal limits for repetitive diving. It is best to learn enough about the various available models and derivations before you select a dive computer, so you are sure to choose one that is compatible with your own level of risk tolerance. Choosing one purely based on familiarity may not be the best strategy. Even if you have had good outcomes on previous dives with a computer, it does not guarantee that it will be the best one for your future diving. Accumulating knowledge takes commitment, but informed planning for decompression safety should be a top concern.

TUNE IN AND TURN ON

Failing to turn on your dive computer (or to take it with you on a dive) may sound like a joke, but it does happen and can create real problems. No computer can factor in the exposure profile of a previous dive if it was not there. And any decompression model is invalid unless you start using it when you are "clean" — fully off-gassed from any previous dives. If you forget to take your computer with you on a dive early in a repetitive series, you are then restricted to using tables for the duration of that series (assuming that you are able to manually compute the exposure of the unmonitored dive). And do not even think about hanging your computer on a downline during a surface interval in an effort to compensate for having forgotten it on an earlier dive; there may be stories about that happening, but it is not a responsible practice.

USE IT APPROPRIATELY

The only person who does not have to worry about taking a dive computer on every dive is the one who uses it solely as a datalogger — that is, only to record time and depth information instead of to calculate decompression profiles. Remember, however, that using your computer simply to log your time and depth data means that you must still plan all your dives using dive tables and must recompute your repetitive group status afterward, as appropriate. You cannot move in and out of relying on your computer's decompression computations unless it has recorded all of your exposure profiles.

REMEMBER ITS LIMITATIONS

Dive computers are wonderful at carrying out programmed mathematical computations, but they are blind to the many insights you may have before, during and between your dives. For example, your dive computer knows nothing about your personal health status, your level of physical fitness or your individual susceptibility to decompression stress. It also knows nothing about your thermal stress or physical efforts during or between dives. The fact that many dive computers display water temperature might suggest that thermal stress is factored into the device's algorithms. A water temperature reading, however, provides no useful information regarding thermal stress, since the diver carrying the device could be wearing anything from a bathing suit to a wetsuit without a hood to a cold-water drysuit with a hood, gloves and cold water undergarments. More importantly, it is not yet possible to directly compute the impact of differences in thermal status during different parts of a dive, even if the computer was able to measure the diver's core temperature and skin temperature in key spots. We do know that being warm (rather than cool or cold) during the compression and bottom phase of a dive promotes inert gas uptake (not optimal), and that being warm during the decompression phase promotes elimination (optimal). While impractical for the comfort-loving diver, decompression safety is optimized by being neutral or cool during the inert gas uptake phase of descent and bottom time and warm during the inert gas elimination phase of ascent. While the concept of thermal changes on decompression stress is clear, we are still years away from being able to quantify the realworld effects of these factors for dive-planning purposes. Similarly, while some computers are able to track gas consumption, we have much to learn before this information can be meaningfully incorporated into decompression models. Variations in air consumption can reflect differences in the depth of a dive or in the diver's experience, level of anxiety or degree of physical exertion. The bottom line is that interpreting the precise physiological impact of the interactions among these diverse factors is exceedingly difficult, requiring thoughtful practice by divers.

HEED YOUR COMPUTER'S READINGS

Divers need to pay attention to their dive computers if the information provided is to be of any use. Be aware that confirmation bias can promote risky behavior. "Getting away with" a risky exposure once, twice or even many times may eventually catch up with you. It may not truly be safe for you or for a partner who might have a higher degree of susceptibility to decompression stress. Those who wish to worry less about their exposure will have greater peace of mind if they choose a computer that employs an extremely conservative decompression model. It is also important to pay attention to your dive computer. If you are diving with a group, do not forget that there can be considerable variability in the guidance provided by different computers or computers with different user-selected settings. That means there is considerable benefit in diving with others who use a computer with a similar decompression model and settings, because if modest discrepancies arise, following the most conservative directive will likely not be terribly burdensome for the group. But if members of a group are using dive computers with substantially different models, and each diver wishes to follow his or her own device, it can lead to a breakdown in the buddy system.

DO NOT RELY BLINDLY ON YOUR COMPUTER

Although heeding your computer is important, do not take its advice unthinkingly. The same profile can sometimes be conducted without problem again and again, right up to the dive where it does not prove safe. Divers often try to blame a specific factor, such as dehydration, for the development of symptoms following one dive but not another. This approach is not productive. The range of variables in play during a dive are rarely identical, and there is a probabilistic element to decompression risk — that is, chance can play a role in the manifestation of DCS. The best approach is to avoid the extremes of either fatalistic resignation or smug focus on a single supposed magic bullet. There are many, many small steps you can take to make any dive safer. The most important one is to stay within a reasonably conservative time-depth profile and to add safety stops to every dive. Other important steps are to minimize your exercise intensity and avoid overheating during the gas-uptake phase of your dive, to choose the right breathing gas, to practice enough that you are able to perfectly control your buoyancy, to remain well-rested and well-hydrated, choose more conservative user-adjustable settings on the computer, and to dive with a partner who has similar goals and follows similar practices. Adding small safety margins to each step can help to provide a comfortable security cushion. Dive computers are powerful tools, but sound knowledge of diving physiology, good physical conditioning and adherence to thoughtful practices offer the best protection for divers.

KEEP IT WITH YOU

If you do develop DCS symptoms, you should keep your computer with you when you go for medical evaluation. Some facilities may have the ability to download or review your profile to aid in the evaluation of your case. The medical staff will surely appreciate seeing confirmation of your description of the events that precipitated your symptoms.

3

DIAGNOSING DECOMPRESSION SICKNESS

> “While DCS is commonly thought of as a bubble disease, bubbles are probably only the gateway to a complex array of consequences and effects.”

DCS may develop when a diver’s degree of supersaturation is so high (or, stated another way, if the elimination gradient is so steep) that a controlled transfer of inert gases from the body’s tissues to the bloodstream — and then from the bloodstream to the lungs and the lungs to the environment — is not possible. If that removal process is inadequate, inert gases will come out of solution and form bubbles that can distort tissues, obstruct blood flow, cause mechanical damage (to the joints, for example) and/or trigger a cascade of biochemical responses.

Although much is known about DCS, its mechanisms of insult are still being investigated. And while DCS is commonly thought of as a bubble disease, bubbles are probably only the gateway to a complex array of consequences and effects.

SIGNS AND SYMPTOMS OF DECOMPRESSION SICKNESS

The collective insult to the body's systems can produce symptomatic DCS. The condition's primary effects may be evident in the tissues that are directly insulted. Its secondary effects can compromise the function of a broad range of tissues, further jeopardizing the diver's health.

The ability to recognize the signs, or objective evidence, and the symptoms, or subjective perceptions, of DCS — and to differentiate them from signs and symptoms less likely to be associated with DCS — is important. A variety of classification systems have been established for DCS. One common approach is to describe cases as Type 1 or Type 2.

Skin mottling like this is characteristic of cutis marmorata, a condition that can warn of likely development of more serious Type 2 symptoms.

TYPE 1 DCS

Type 1 DCS is usually characterized by musculoskeletal pain and mild cutaneous, or skin, symptoms. Common Type 1 skin manifestations include itching and mild rashes (as distinct from a clear mottled or marbled and sometimes raised discoloration of the skin — a condition that is known as cutis marmorata that may presage the development of the more serious symptoms of Type 2 DCS). Less common but still associated with Type 1 DCS is obstruction of the lymphatic system, which can result in swelling and localized pain in the tissues surrounding the lymph nodes — such as in the armpits, groin or behind the ears.

The symptoms of Type 1 DCS can build in intensity. For example, pain may originate as a mild ache in the vicinity of a joint or muscle and then increase in magnitude. However, the pain associated with DCS does not typically increase upon movement of the affected joint, although holding the limb in one position rather than another may reduce discomfort. Such pain can ultimately be quite severe.

Common sites of musculoskeletal pain associated with type 1 DCS.

TYPE 2 DCS

Type 2 symptoms are considered more serious. They typically fall into three categories: neurological, inner ear and cardiopulmonary. Neurological symptoms may include numbness; paresthesia, or an altered sensation, such as tingling; muscle weakness; an impaired gait, or difficulty walking; problems with physical coordination or bladder control; paralysis; or a change in mental status, such as confusion or lack of alertness. Inner ear symptoms may include ringing in the ears, known as “tinnitus”; hearing loss; vertigo or dizziness; nausea; vomiting; and impaired balance. Cardiopulmonary symptoms, known commonly as “the chokes,” include a dry cough; chest pain behind the sternum, or breastbone; and breathing difficulty, also known as “dyspnea.” The respiratory complaints, which are typically due to high bubble loads in the lungs, can compromise the lungs’ ability to function — threatening the affected diver’s health, and even life, if treatment is not sought promptly.

Type 2 symptoms can develop either quickly or slowly. A slow build can actually obscure the seriousness of the situation, by allowing denial to persist. For example, fatigue and weakness are common enough concerns, especially if their onset is protracted, that they can be very easy to ignore. Less common symptoms, such as difficulty walking, urinating, hearing or seeing — especially if their onset is quick — can sometimes prompt faster recognition of the existence of a problem. It is fair to say that divers can initially be reluctant to report symptoms, though they usually will do so if their symptoms do not go away. This is a shortcoming divers should be aware of, lest they fall prey to it.

The Romberg test evaluates postural control. The sharpened Romberg, which includes crossing the arms and putting one foot in front of the other, is more sensitive to changes in static balance. The sharpened Romberg is commonly used as part of the neurological assessment of injured divers.

PRESENTATION OF DCS

The presentation of DCS is frequently idiosyncratic — that is, its "typical" pattern can be atypicality. In some cases, an affected diver's chief complaint may draw attention away from more subtle but potentially more important symptoms. The following list ranks the initial manifestations of DCS, from those most commonly to least commonly reported (Vann et al. 2011):

Monoplace hyperbaric chambers hold only the patient being treated. The chamber walls are frequently made of acrylic to reduce any sense of claustrophobia.

- Pain, particularly near the joints.
- Numbness or paresthesia.
- Constitutional concerns — such as headache, lightheadedness, unexplained fatigue, malaise, nausea and/or vomiting, or anorexia.
- Dizziness or vertigo.
- Motor weakness.
- Cutaneous, or skin, problems — such as an itch, rash, or mottling ("cutis marmorata").
- Muscle discomfort.
- Impaired mental status.
- Pulmonary problems — such as breathing difficulties ("the chokes").
- Impaired coordination.
- Reduced level of consciousness.
- Auditory symptoms — such as hearing sounds that are not there or having a hard time hearing.
- Lymphatic concerns — such as regional swelling.
- Bladder or bowel dysfunction — such as retention of urine.
- Compromised cardiovascular function.

According to this recent review, pain and numbness, also known as paresthesia, were reported initially in nearly two-thirds of cases of DCS, constitutional symptoms in approximately 40 percent of cases, dizziness/vertigo and motor weakness in approximately 20 percent, and cutaneous symptoms in approximately 10 percent (Vann et al. 2011).

DIFFERENTIAL DIAGNOSIS OF DECOMPRESSION SICKNESS

DCS is a high-profile diving injury because of its potential severity. But divers need to remember that not all diving-related problems turn out to be DCS. When two or more conditions have overlapping symptoms, as is the case with many diving-related injuries, differential diagnosis is the process by which medical personnel figure out which of the potential conditions is most likely responsible for the symptoms.

The term decompression illness (DCI) was coined to encompass both DCS and the related condition known as arterial gas embolism (AGE), the latter arising from barotrauma of the lungs that introduces gas into the systemic bloodstream. Some of the other conditions and circumstances that involve similar symptoms include inner-ear barotrauma; middle-ear or maxillary sinus overinflation; contaminated breathing gas; oxygen toxicity; musculoskeletal strains or trauma sustained before, during or after a dive; marine life envenomation; immersion pulmonary edema; water aspiration; and coincidental neurological disorders, such as stroke (Vann et al. 2011). Thermal stress — sometimes due to excessive heat, but usually due to cold exposure — can also be responsible for similar symptoms. In some cases, a careful medical history can easily rule out one diagnosis or another. For example, symptoms of immersion pulmonary edema often develop at depth. In such a case, a good history would rule out DCS, which only develops after significant decompression stress during ascent.

It is essential for divers with any of these symptoms to seek medical evaluation and support. While first responders are able to perform initial analysis of an injured individual, such as administering a field neurological assessment, the capabilities of nonphysicians do not come close to the clinical skills and insights held by experienced clinical specialists.

4

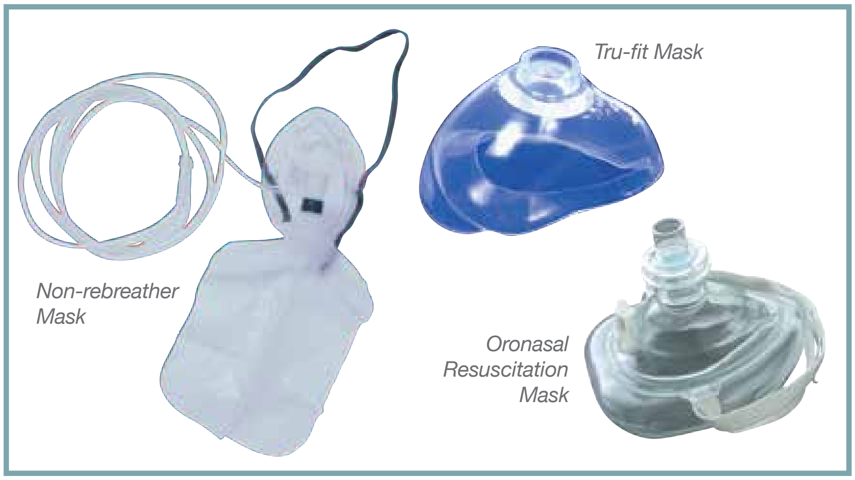
TREATING DECOMPRESSION SICKNESS

"If signs or symptoms consistent with DCS develop, initiate appropriate first aid and contact the nearest emergency medical services. For additional emergency assistance contact DAN +1-919-684-9111."

There are several elements to the effective management of DCS, specifically on-the-scene evaluation and first aid, transport and definitive medical evaluation and treatment. Anyone who has suffered DCS should seek appropriate evaluation, and possibly ongoing care, from a physician well informed about diving-related medical issues.

ON-THE-SCENE FIRST AID

The foundation of first aid is basic life support. The primary first aid measure for DCS is delivery of supplemental oxygen in the highest concentration, or fraction, that is practical (Longphre et al. 2007). High oxygen fractions, if provided rapidly and over a sustained period, can reduce or even eliminate symptoms of DCS, albeit often only temporarily if definitive treatment is not secured. Continuous-flow oxygen systems, using non-rebreather or pocket masks, are frequently available in diving environs; however, such equipment delivers modest oxygen fractions. Much higher fractions can be achieved with demand masks, though they are appropriate only for conscious individuals able to breathe on their own.



A variety of different masks can be used with oxygen systems.

Rebreather systems are another on-the-scene option; such systems permit the unused oxygen in the diver's exhalations to be recycled, or rebreathed. A rebreather apparatus can thus provide high fractions with minimal gas use and may prove especially helpful in settings where the supply of oxygen is limited (Pollock 2004; Pollock and Natoli 2007).

Chemical oxygen generating systems — devices with a long shelf life that deliver oxygen via a chemical reaction — may in some situations be the only option available. However, if emergency medical services are not readily accessible, such devices are unlikely to provide a sufficient oxygen supply (Pollock and Natoli 2010).

DAN experts developed this remote emergency oxygen ($REMO_2$) surface oxygen rebreather for first-aid use (Pollock and Natoli 2007).

SUBSEQUENT EVALUATION

First aid is just the first step in treating an affected diver. Anyone who has experienced symptoms associated with DCS is advised to seek subsequent medical evaluation. This should occur even if the diver's symptoms improved or disappeared upon the administration of oxygen, since subtle issues can be missed or symptoms can return once oxygen delivery is stopped. For the same reason, it is advisable to seek input from an experienced dive-medicine specialist — someone aware of all the nuances in the presentation, course and treatment of DCS.

HYPERBARIC OXYGEN THERAPY

The definitive treatment for DCS is hyperbaric oxygen (HBO) therapy, or the delivery of pure oxygen at a pressure substantially higher than that of atmospheric pressure. HBO therapy reduces the size of any bubbles and improves gradients which promote oxygen delivery and inert gas elimination. HBO therapy is typically delivered in recompression chambers.

This is a monoplace hyperbaric chamber — able to hold a single patient, without any inside support personnel, or "tenders."

This is a small multiplace and multilock hyperbaric chamber; it can hold multiple patients plus inside tenders. Personnel or equipment can be transferred into or out of the chamber while treatment is ongoing.

A common HBO regimen is the US Navy Treatment Table 6 (USN 2008). According to this regimen, the hyperbaric chamber is initially pressurized to 2.8 atmospheres absolute (ATA), equivalent to the pressure found at 60 feet (18 meters) of seawater. The patient breathes pure oxygen, interspersed with scheduled periods of breathing regular air to reduce the risk of oxygen toxicity. The usual duration of the USN TT6 treatment is just under five hours, but extensions can be added as required, based on the patient's response.

HBO treatment can be conducted in a monoplace chamber, often an acrylic tube sized to hold just one patient, or in a multiplace chamber, sized to accommodate one or more patients plus one or more "tenders" — that is, technicians or other medical personnel. Multilock chambers are designed to allow patients, tenders or equipment to be transferred into and out of the chamber while treatment is ongoing.

The course of HBO therapy will vary according to the particulars of each case; both the presentation of DCS and its response to treatment can be idiosyncratic. A full resolution of DCS symptoms can often be achieved with one or sometimes multiple HBO treatments. In some cases, however, resolution will be incomplete, even after many treatments. The normal clinical approach is to continue the treatments until no further improvement is seen in the patient's symptoms. Modest residual symptoms will then often resolve slowly, after the treatment series is ended. Full resolution of symptoms can sometimes take months to achieve and in some instances may never be realized.

This is a large multiplace and multilock hyperbaric chamber, in which multiple pressure exposures can be conducted simultaneously.

IN-WATER RECOMPRESSION

In-water recompression may be an alternative to chamber recompression in remote locations, if there is neither a nearby chamber nor the means to quickly transport the patient to a chamber elsewhere. The technique involves bringing the diver underwater again, to drive gas bubbles back into solution to reduce symptoms and then slowly decompress in a way that maintains an orderly elimination of the excess gas.

While in-water recompression is simple in concept, it is practical only with a substantial amount of planning, support, equipment and personnel; appropriate water conditions; and suitable patient status. Critical challenges can arise due to changes in the patient's consciousness, oxygen toxicity, gas supply, and even thermal stress. An unsuccessful in-water recompression may leave the patient in worse shape than had the attempt not been made. The medical and research communities are divided on the utility of in-water recompression. It is beyond the scope of this publication to consider all of the relevant factors, but it is fair to say that there are probably more situations when in-water recompression should not be undertaken than situations when it would be a reasonable choice.

As a general rule, a diver who develops symptoms consistent with DCS should be removed from the water, and first aid should be delivered on the surface, even if there is likely to be a delay before definitive medical care can be sought.

EMERGENCY RESOURCES

The best course of action, if signs or symptoms consistent with DCS (or any other serious injury) develop, is to initiate appropriate first aid and then immediately contact the nearest emergency medical services (EMS). The next step should be to contact DAN to seek advice regarding the proper progression of care. The organization's emergency hotline number is +1-919-684-9111.

It is generally not appropriate to show up unannounced at the nearest hyperbaric chamber. This could mean bypassing a facility where the victim might be able to receive a more thorough and appropriate evaluation. Remember that not all injuries associated with diving are DCS, even if it seems so in the heat of the moment. In addition, the chambers at some facilities are not available to treat divers at all times or ever. One of the challenges within North America is the shrinking number of hyperbaric chambers that accept diving casualties, particularly outside normal business hours.

The key point to remember is that establishing contact with emergency medical services and DAN can ensure timely and appropriate case management. When in doubt, call.

WHEN YOU CALL THE DAN EMERGENCY HOTLINE

1. Tell the operator you have a dive emergency. The operator will confirm your name, location and phone number, and either connect you directly with DAN medical staff or have someone call you back at the earliest possible moment.
2. The medical staff member may make an immediate recommendation or call you back after making arrangements with a local physician.
3. The medical staff member may ask you to wait by the phone while arrangements are being made. These plans may take 30 minutes or longer, as complex coordination is often required. If the situation is life-threatening, arrange safe transport for the diver to the nearest medical facility for immediate stabilization and assessment first. Then call the DAN Emergency Hotline for consultation with the local medical provider.

Even if symptoms were not severe and they resolved completely, a diver who has had multiple bouts of DCS must take special considerations. Especially if DCS is recurring following otherwise safe dive profiles, a dive medical specialist must be consulted to determine if diving can be resumed safely.

DAN EMERGENCY HOTLINE +1-919-684-9111

5

FACTORS CONTRIBUTIONG TO DECOMPRESSION STRESS

> “A number of factors contribute to your individual susceptibility to DCS and can even alter your susceptibility from day to day.”

The most significant risk factor is your exposure profile — that is, the time, depth and ascent rate of your dives. Some degree of exposure intensity is required to initiate a decompression insult, regardless of the presence of other predisposing factors.

There are a host of factors, however, that can play a role in your outcome if you experience an exposure sufficient to make DCS a possibility. Several common risk factors are outlined in this chapter.

WORKLOAD

DURING THE DIVE

The timing and intensity of exercise during a dive can substantially affect your risk of DCS. A high workload during the descent and bottom phase of a dive will increase your inert gas uptake, effectively increasing the subsequent decompression stress. And exertion near the end of or immediately after a dive, particularly if it involves high joint forces, can stimulate bubble formation and increase the likelihood of bubbles passing through the lungs without being filtered out of the circulation.

You should keep your exercise intensity as low as possible during the bottom phase of a dive. Mild exercise — on the order of no more than two to three times resting effort, and with very low joint forces — is appropriate during the upper ascent and stop phases of a dive. However, any exercise, particularly exercise involving high joint forces, should be avoided as long as possible after a dive. If you are unable to avoid postdive exercise, you should keep your dive profiles very conservative to minimize your overall risk.

ESTIMATED METABOLIC ENERGY REQUIREMENTS FOR SELECTED PHYSICAL ACTIVITIES

PHYSICAL ACTIVITY	MET
LIGHT-INTENSITY ACTIVITIES	**< 3.0**
SLEEPING	0.9
WATCHING TELEVISION	1.0
WRITING, DESKWORK, TYPING	1.8
WALKING AT 2.5 MILES PER HOUR (4.0 KILOMETERS PER HOUR)	2.9
MODERATE-INTENSITY ACTIVITIES	**3.0 TO 6.0**
WALKING AT 3.4 MILES PER HOUR (5.5 KILOMETERS PER HOUR)	3.6
UNDERWATER SCUBA SWIMMING AT 20 YARDS PER MINUTE (0.6 KNOTS)	5.0
SURFACE SWIMMING AT A LEISURELY PACE	6.0
VIGOROUS-INTENSITY ACTIVITIES	**> 6.0**
JOGGING, GENERAL	7.0
UNDERWATER SCUBA SWIMMING AT 34 YARDS PER MINUTE (1 KNOT)	7.5
SURFACE SWIMMING, CRAWL, AT 50 YARDS PER MINUTE	8.0
WALKING AT 5.0 MILES PER HOUR (8.0 KILOMETERS PER HOUR)	8.3
SURFACE SWIMMING, CRAWL, AT 75 YARDS PER MINUTE	11.0
UNDERWATER SCUBA SWIMMING AT 40 YARDS PER MINUTE (1.2 KNOTS)	11.0

Modified from Ainsworth et al. (2011)

THERMAL STRESS

A diver's thermal status has long been known to influence decompression risk. The impact is best appreciated by considering the two fundamental phases of every dive: the descent and bottom phase, when gas uptake occurs, and the ascent and stop phase, when gas elimination occurs.

TWO PHASES

During the descent and bottom phase of a dive, a relatively warm state results in increased inert gas uptake; this is equivalent to conducting a deeper and/or longer dive. On the other hand, if you can maintain a cool or thermoneutral state during your descent and bottom phase, you will effectively reduce your inert gas uptake. This beneficial effect will be further magnified if you exert yourself as little as possible during this phase.

During the ascent and stop phase of your dive, a relatively warm state will promote inert gas elimination, thus reducing overall decompression stress. On the other hand, a cool or cold state during this phase will reduce inert gas elimination, effectively prolonging and possibly increasing decompression stress.

The decompression hazard associated with hot water suits — which effectively establish a warm condition in both phases of a dive — was established in a study of North Sea divers conducted 30 years ago (Shields and Lee 1986). The impact of thermal status on decompression stress was even more elegantly demonstrated in a recent study conducted by the U.S. Navy (Gerth et al. 2007). The controlled conditions of a research study cannot be directly correlated with everyday diving practices, but the key message from these studies is the importance of thoughtful thermal status. Keeping neutral on your way down — certainly avoiding unnecessary overheating — and warm on your way up (approaching a cool-warm pattern) will reduce the risk of DCS in comparison to being warmer on your way down and cool on your way up (a warm-cool pattern).

OPTIMAL PRACTICES

The difficulty comes in reconciling optimal practices for decompression safety with divers' desires and normal practices. It is understandable for divers to want to warm themselves before the start of a dive, in anticipation of getting colder as the dive proceeds. Historically, divers did this by pouring warm water into their wetsuits or gloves before a dive. Then some divers began to place chemical hot packs in their suits. Modern divers have even more choices available to them, due to today's array of active heating garments suitable for use with either wetsuits or drysuits. The problem, though, remains the same: warming the body's peripheral tissues enhances circulation and increases the delivery of inert gases, particularly if the heating is applied early in a dive, when inert gas uptake is typically at its highest level. Furthermore, both warm water and chemical hot packs lose their effectiveness over time, potentially creating the warm-cool pattern shown to generate the greatest risk of DCS. Even active heating garments — which are able to keep the diver warm throughout a dive — involve a somewhat elevated risk. As shown with hot water suits, a warm-warm pattern, while associated with less DCS than a warm-cool pattern, remains more hazardous than a cool-warm pattern. Practically, divers should maintain adequate thermal protection to ensure clear thinking and physical capability. Excessive warming during dives should be avoided.

Divers must also keep in mind that postdive warming can also influence decompression risk. Indulging in rapid postdive warming, such as by taking a hot shower or getting into a hot tub, decreases the solubility of inert gas in tissues. This will promote the formation of bubbles in local tissues, often before perfusion increases sufficiently to remove the gas. Skin symptoms, fortunately often mild and transient — not cutis marmorata — can develop with rapid warming of the skin postdive. The challenge is to get divers to prioritize safe decompression over pure comfort. If an active heating system is to be used, this means leaving it off or on its lowest setting during your descent and bottom phase, and then turning it up a modest amount during your ascent and stop phase. It also means delaying the postdive pleasure of jumping into a hot shower or hot tub. If delayed gratification is not your style, then you should use more conservative dive profiles to reduce your overall risk.

POSTDIVE AIR TRAVEL

Modern air travel has made distant dive locations easily accessible. Flying to a destination near sea level before diving engenders virtually no risk (outside the possibility of mild dehydration or impairment due to long periods of relative immobility). Since flights end with compression, the tissues of plane passengers will be undersaturated upon landing and subsequently accumulate inert gases to re-establish equilibrium with the ambient pressure.

Flying after diving, however, increases decompression stress, since the pressure in an aircraft cabin is lower than that of ground-level atmospheric pressure. Commercial aircraft must have the capability of maintaining cabin pressure at an equivalent of 8,000 feet (2,438 meters), approximately 0.76 ATA. This does not mean that cabin pressure is always maintained at higher pressures. A recent study found that 10 percent of the commercial flights tested had cabin pressures exceeding 8,000 ft (Hampson et al. 2013). Now imagine that you have just completed a dive to 66 feet (20 meters), where you experienced an underwater pressure of 3.0 ATA. Your return to the surface, and the 1.0 ATA pressure of sea level, has already subjected your body to a threefold reduction in pressure (3.0:1.0). If you then get on a plane that has a cabin altitude of 8,000 feet, you would be subjecting yourself to a fourfold reduction (3.0:0.76) and thus to even greater decompression stress. Furthermore, should your plane suffer an unlikely but not impossible cabin depressurization, you would be subjected to a much greater decompression stress.

DAN and the Undersea and Hyperbaric Medical Society (UHMS) held a workshop in 2002 to review the available data regarding the decompression stress of flying after diving and develop consensus guidelines (Sheffield and Vann 2004). There were two important stipulations regarding the guidelines: first, adhering to them will reduce your risk but offers no guarantee that you will avoid DCS, and second, observing even longer surface intervals than the recommended minimums will reduce your DCS risk further still. Keeping in mind these caveats, these are the guidelines:

- After a single no-decompression dive, a minimum preflight surface interval of 12 hours is suggested.
- After multiple dives per day or multiple days of diving, a minimum preflight surface interval of 18 hours is suggested.
- After dives requiring decompression stops, there was little evidence on which to base a recommendation, but a preflight surface interval substantially longer than 18 hours is considered to be prudent.

There are two further factors of note regarding the DAN-UHMS flying after diving guidelines:

- They apply to flights at altitudes of between 2,000 and 8,000 feet (610 and 2,438 meters). The effect of a flight at an altitude below 2,000 feet was considered mild enough not to warrant special consideration — giving divers the flexibility to engage in modest postdive air travel, such as a short, low-altitude, inter-island flight.
- They apply only to divers who have experienced no DCS symptoms. It is essential that a diver who is experiencing any symptoms consistent with DCS seek treatment prior to flying.

It is important to remember that any postdive ascent to a higher altitude — even using ground transportation — increases your decompression stress. Taking a cautious approach in such a case, by keeping your final dive profiles more conservative and/or delaying your travel to the higher altitude, is always advisable. The US Navy has generated detailed tables and procedures that allow computation of exposure limits to a greater range of altitudes and with more time flexibility than the DAN-UHMS guidelines (USN 2008). It is important to appreciate, though, that these are simply mathematical constructs based on the same data used in developing the DAN-UHMS guidelines. Furthermore, they require the computation of repetitive groups for planning, something that is done with dive tables but not dive computers. Despite these limitations, they can be useful, particularly for a regular pattern of altitude diving.

MEDICAL AND PHYSICAL FITNESS

Poor medical and physical fitness can compromise your safety in general and may increase your risk of DCS. Definitive data are limited, but there is no question that it is prudent to maintain a high level of physical fitness and to dive progressively more conservatively as your fitness level declines. Safe diving is possible throughout much of a normal life span, but it is important for all divers to seek regular, objective evaluation of their capabilities and to adapt their diving practices accordingly. But even for divers who have transitioned from independent to more dependent forms of diving, in which they increasingly rely on the support of others, there will ultimately be a point at which they should hang up their fins.

PHYSICAL ACTIVITY RECOMMENDATIONS

Adults need two types of regular activity to maintain or improve their health—aerobics and strength training. The Centers for Disease Control and Prevention's 2008 Physical Activity Guidelines for Americans recommends at least two and a half hours a week of moderate-intensity aerobic exercise to achieve health benefits, and five hours a week to achieve additional fitness benefits. And just as important as engaging in aerobic exercise is doing muscle-strengthening activities at least two days a week.

While good health and physical fitness will not solve all problems, the foundation is an important one. An adequate physical reserve can allow a quick response to keep a small problem from becoming a serious one. Relevant scenarios can be easily imagined for almost any dive.

Regular aerobic exercise has many positive benefits. Cardiac reserve is the difference between the rate at which the heart pumps blood at rest and its maximum capacity. An increase in this reserve may make it easier to meet the physical demands of diving activity and stress. Blood values of cholesterol can improve, reducing susceptibility to heart disease. Insulin sensitivity can improve, reducing the risk of developing diabetes. While the data specific to diving are much more preliminary, there is also some evidence that higher levels of aerobic fitness may contribute to a reduced decompression stress.

Most individuals are aware that being fit can improve quality of life. A major problem, however, is that time takes a toll on us. The ease with which we maintain our fitness level in our 20s can be very different from the reality as decades pass. Aerobic fitness typically declines on an average of one percent per year after age 30. The important point is that while some decline may be unavoidable due to a gradual loss of muscle mass and a reduction in the metabolic activity of aging muscle, the rate can be slowed and the reserve range broadened by adopting healthy lifestyles as early as possible.

The physical fitness needed for diving will vary with the demands of the environment, the equipment, and the nature of the dive. The best strategy is to incorporate regular physical activity into your life to improve or preserve your capabilities, and to prolong your diving life. Do not count on diving to keep you physically fit. If done properly, it should be your relaxing time in the water. To maintain or build aerobic capacity and strength, swim, cycle, run, or do whatever other physical activities you can enjoy. The more fit you are, the longer you get to play.

Detailed physical activity recommendations can be found at cdc.gov/physicalactivity/everyone/guidelines.

STATE OF HYDRATION

Dehydration gets a substantial amount of attention in the lay diving community as a risk factor for DCS, but probably more than is warranted. Sound hydration is important for good health, both for general and for diving health, but for your dive profile, thermal stress and exertion level are far more important risk factors for DCS. The undue focus on dehydration is probably a result of two issues. The first is that substantial fluid shifts can result from DCS, often creating a need for substantial fluid therapy and creating an impression that this was a cause, rather than a consequence, of the disease. The second issue is human nature — the understandable desire to assign blame for a condition that is capricious. DCS is fickle. A diver may adhere to a similar dive profile many times without incident but then develop DCS while following the very same profile. It is comforting to try and identify a single causal agent, even if this is more wishful than factual. It is important for divers to realize that a multitude of factors can subtly affect the risk on any one dive and that there is a probabilistic nature to the disease. Focusing on a range of strategies to reduce risk is more effective than trying to put all the blame on one.

BREATHING GAS MIXTURE

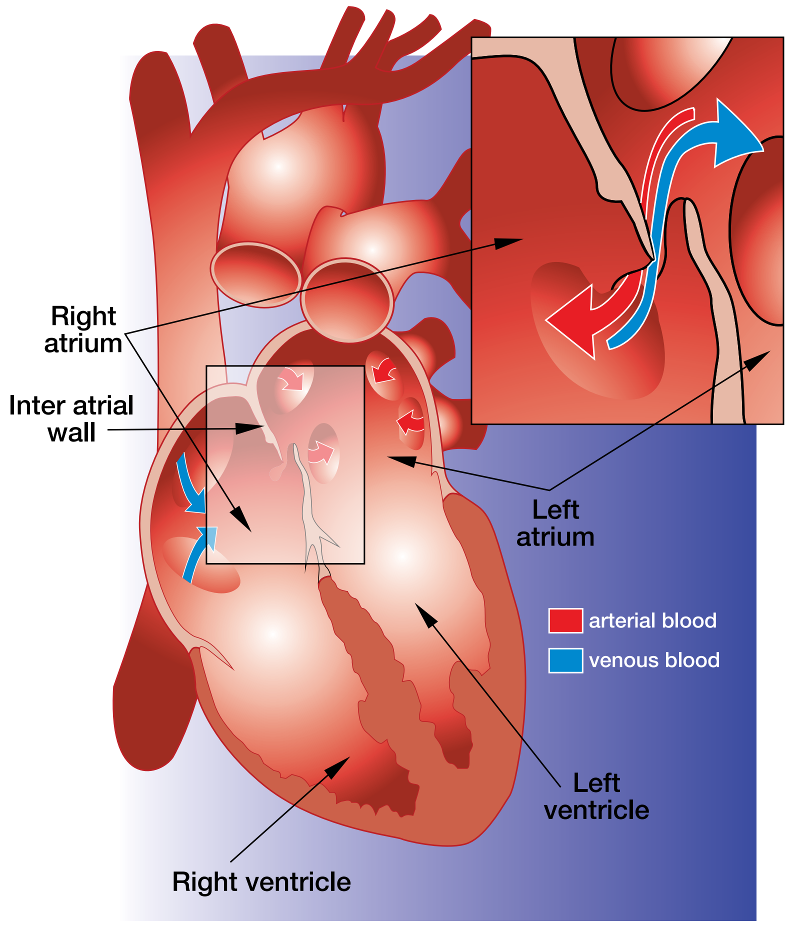
The particular breathing gas mixture you use, and how you use it, can play a role in the development of DCS. A mixture known as enriched air nitrox, or simply nitrox, is increasingly popular for recreational diving. The percentage of oxygen in the mix is increased, reducing the nitrogen fraction. This means that there is less nitrogen uptake at a given depth. The decompression effect of nitrox, compared to that of air, can be calculated by computing what is known as equivalent air depth (EAD). The risk of DCS when diving with nitrox to the EAD table limits is not appreciably different than diving with air to the air table limits. It is possible to achieve a decompression safety buffer by using nitrox with air table limits, since this will reduce your inert gas uptake compared to using air.

The critical caveat with nitrox is that its higher oxygen content means that a diver breathing nitrox is at risk of developing oxygen toxicity at a shallower depth than a diver breathing air. The recommended maximum partial pressure of oxygen — partial pressure being the portion of the total gas pressure represented by a single gas — is 1.4 ATA for recreational diving. When diving with air (21 percent oxygen), this level is reached at a seawater depth of 187 feet (57 meters) — beyond the usual recreational diving limit (187 feet of seawater = 6.6 ATA * 0.21 ATA oxygen in air = 1.4 ATA). When diving with a 32 percent nitrox mixture, this level is reached at a seawater depth of 111 feet (34 meters), and with 36-percent nitrox at just 95 feet (29 meters) — depths commonly reached by recreational divers.

CARBON DIOXIDE LEVEL

Elevated levels of carbon dioxide can increase the risk of DCS and lower the threshold for oxygen toxicity. Carbon dioxide is a potent vasodilator, meaning it causes the blood vessels to widen, increasing blood flow and the delivery of gases to tissues. Factors that can raise divers' carbon dioxide levels include the increased dead space of breathing equipment (gas volume that must be moved but does not take part in gas exchange), the additional work of breathing dense gas underwater, and exercise. Using a well-designed and well-maintained breathing system, minimizing physical effort and remaining relaxed while underwater can minimize carbon dioxide increase.

PATENT FORAMEN OVALE



Patent foramen ovale (PFO), literally, open ovale window, is a persistent opening between the left and right atria of the heart. In fetal circulation, a major opening between the atria allows blood to largely bypass the lungs that are not yet being used for gas exchange. A flap normally closes over the opening after birth and is sealed by tissue. In approximately 25 percent of the population, a partial opening remains, the PFO. The opening can range in size from functionally irrelevant to physiologically significant, the latter allowing a substantial portion of blood to be shunting from the right heart to the left heart, bypassing gas exchange and filtration in the lungs. PFOs typically produce no symptoms and individuals are unaware of their status unless they are incidentally discovered through medical tests. However, the presence of a large PFO may increase the risk of DCS in divers who develop significant bubble loads. The correlation between PFO and DCS risk is not a clear one, since the frequency of PFO in the population is fairly high while DCS is relatively rare. The safest strategy — even if you have not been diagnosed with a PFO, but most certainly if you have — is to dive in a manner calculated to keep your bubble load low; this effectively eliminates any concern that bubbles might pass through a PFO and bypass the lungs, where they would normally be filtered out.

The most commonly held consensus is that screening all divers for PFO is probably not warranted. And even in divers who have been diagnosed with a PFO, deciding whether it warrants surgical closure is a choice that each individual should consider carefully with a well-informed medical team.

ADDITIONAL FACTORS

A host of other factors may also contribute to any given individual's risk of DCS. Some probably play minor roles, and some potentially play important roles that have not yet been fully defined. Nutritional status, for example, plays a major role in one's general health and often in one's physical fitness, too. While research on the subject of nutrition and diving is limited, it is possible that it also affects decompression safety. For example, one study assessed the relationship between cholesterol levels and decompression-induced bubbles. Doppler ultrasound was used to classify the 30 subjects as either "bubble-prone" or "bubble-resistant." Among the study's findings was that, on average, bubble-prone subjects had higher total blood cholesterol levels than the bubble-resistant subjects (Webb et al. 1988). Additional research into this and many other areas is needed.

SEX

There is little evidence in the diving medicine literature that sex plays a role in the development of DCS. Even if women do have a slightly elevated risk, as is suggested in the aviation medicine literature, it is possible that making safer choices with regard to your diving practices can compensate for any slightly elevated physiological susceptibility.

AGE

Advancing age is sometimes suggested to increase DCS risk, but it may simply reflect typical patterns of compromised physical and medical fitness.

6

SUMMARY AND CLOSING THOUGHTS

"Prolonging shallow stops — either safety or obligatory — is cheap insurance. Stay long, breathe easy."

The best way to avoid DCS is to be well informed and to dive conservatively, with good control. Acknowledging and accommodating any factors that may predispose you to DCS, setting reasonable limits for yourself, and then following those limits can confer a reasonable expectation of safety.

ENSURE YOUR SAFETY

Most diving is now guided by dive computers. It is important to understand, however, that simply diving within the limits of your computer's algorithm will not ensure your safety. Dive computers provide guidance based on your time-depth profile. They are unable to consider additional conditions or individual factors that can dramatically influence your risk — and thus they must be used thoughtfully. Many dive computers allow users to make adjustments in the algorithm's computations, with the aim of adding safety buffers. It is important that divers know the conservative measures that are available, know how to employ them and are encouraged to employ them — and still dive with caution in mind. As a general rule, multilevel dives progressing from deep to shallow, with increasingly longer steps in the shallowest stages, will likely reduce your decompression risk.

DCS is a major concern for divers because of the potential severity of the condition. But without dismissing that concern, divers must also remember that DCS is a relatively rare disease and just one of many diving-related health concerns.

Fortunately, all the measures you can take to diminish your likelihood of suffering DCS will enhance your overall diving safety as well. These are the key measures:

- Take small steps that favor conservatism in a variety of areas, to substantially improve your overall likelihood of a safe outcome while diving.
- Acquire enough knowledge to permit you to appreciate both the hazards of diving and likely solutions.
- Attain sufficient skill, particularly with regard to buoyancy control, to ensure that all your dives can be conducted as planned.
- Practice good buddy selection, so your plans and actions are compatible with those of your diving companions and with safe diving practices.
- Maintain good communication with your buddies, to address problems quickly, when they are likely to be most manageable. Informed and thoughtful collective action on the part of all divers in a group is critical to ensuring a good outcome.

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DAN HEALTH & DIVING RESOURCES

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Generated from more than 30 years of research and medical data analysis, each reference booklet provides extensive insight into a single topic critical to diver health and safety.

For more information about DAN's Health & Diving initiative, visit DAN.org/Health.

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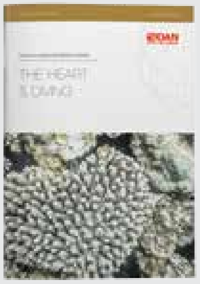
Ear injuries are the leading cause of injury among scuba divers. Many of these injuries can be easily prevented. The Ears & Diving reference book examines the complex anatomy of the ear, proper equalization techniques, symptoms of injury, medical conditions and the importance of good aural hygiene in the preventative care and management of this vital organ.

HAZARDOUS MARINE LIFE

While exciting, observing marine life in their environment comes with a risk. Injuries, though rare, may occur as a result of an uninformed swimmer or diver's actions. The Hazardous Marine Life reference book examines the most common hazardous marine life that water enthusiasts may encounter and introduces the mechanisms of injury, techniques for injury prevention and application of first aid.



THE HEART & DIVING

Cardiovascular health is an essential component of scuba diving safety. However, heart health may deteriorate gradually as divers age and can put divers at risk. This book covers the basic concepts of normal heart functions in physical activities, physical fitness requirements of diving, how heart diseases may affect dive fitness and how divers can maintain their fitness capacity.

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