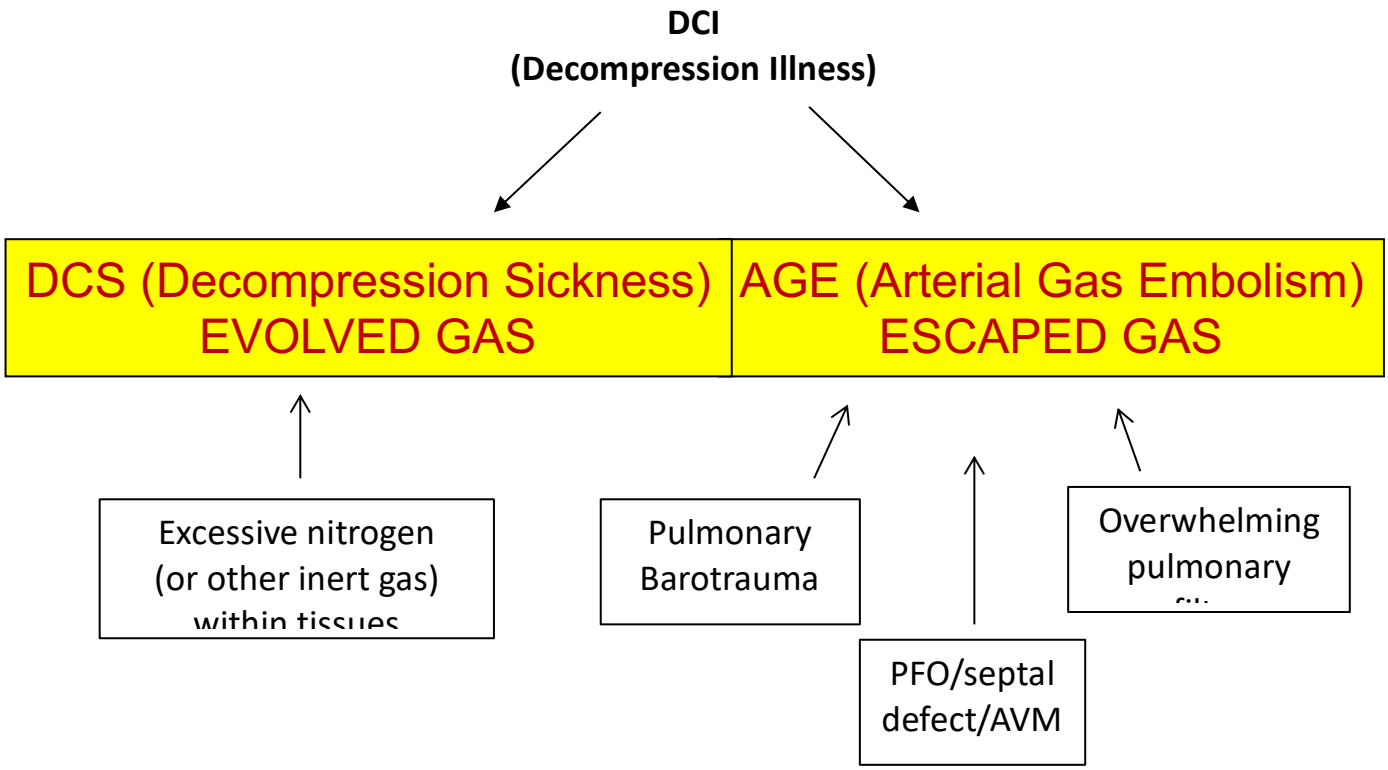
Decompression illness: further reading

WHAT IS THE PATHOPHYSIOLOGY OF DCI?

There are two main mechanisms by which DCI occurs.



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Decompression Sickness (DCS) - Evolved gas

When an individual is at depth there is a slow movement of inert gases from the blood stream into tissues. This inert gas is usually nitrogen in air or mixed gases breathed by divers. This will occur on all dives with all divers to a greater or lesser degree depending on the diver and the dive profile.

If an individual dives very deep or for very long then more nitrogen will become dissolved in the blood. This will then cross into muscle, fat and other tissues over time.

Normally, as the individual ascends the nitrogen will be expelled back along the same pathway often forming bubbles within the veins. The lungs act as a filter and take these bubbles and excess nitrogen out of circulation.

If there is excessive nitrogen that does not make it out of the tissues then this can form bubbles in the tissue at surface. This creates symptoms wherever the bubbles are e.g. joint pains. See "How does DCI manifest?" below for more information on how DCI can present.

Arterial Gas Embolism (AGE) - Escaped gas

In this type of DCI the bubbles in the veins as described above "escape" into the arterial circulation. These bubbles form emboli in small blood vessels and can cause symptoms ranging from minor tingling, dizziness and skin rashes to loss of consciousness and death. They commonly block cerebral vessels. The degree of damage and symptoms depend on where the bubbles have gone, how big they are and how much damage they have done. See "How does DCI manifest?" below for more information on how DCI can present.

There are 3 main mechanisms for this.

1. *Pulmonary Barotrauma/Pneumothorax/Burst Lung*

For this to occur an individual for some reason holds the air within their lungs. This may be inadvertent breath-holding during an emergency or because they are unconscious. As they ascend the lung expands beyond its normal capacity and thus bursts. This is in keeping with Boyle's Law. A rapid ascent is commonly linked with pulmonary barotrauma.

Air from the lungs passes directly into the arterial circulation, through the pulmonary veins as bubbles.

2. *PFOs, Heart Septum defects and Arteriovenous malformations*

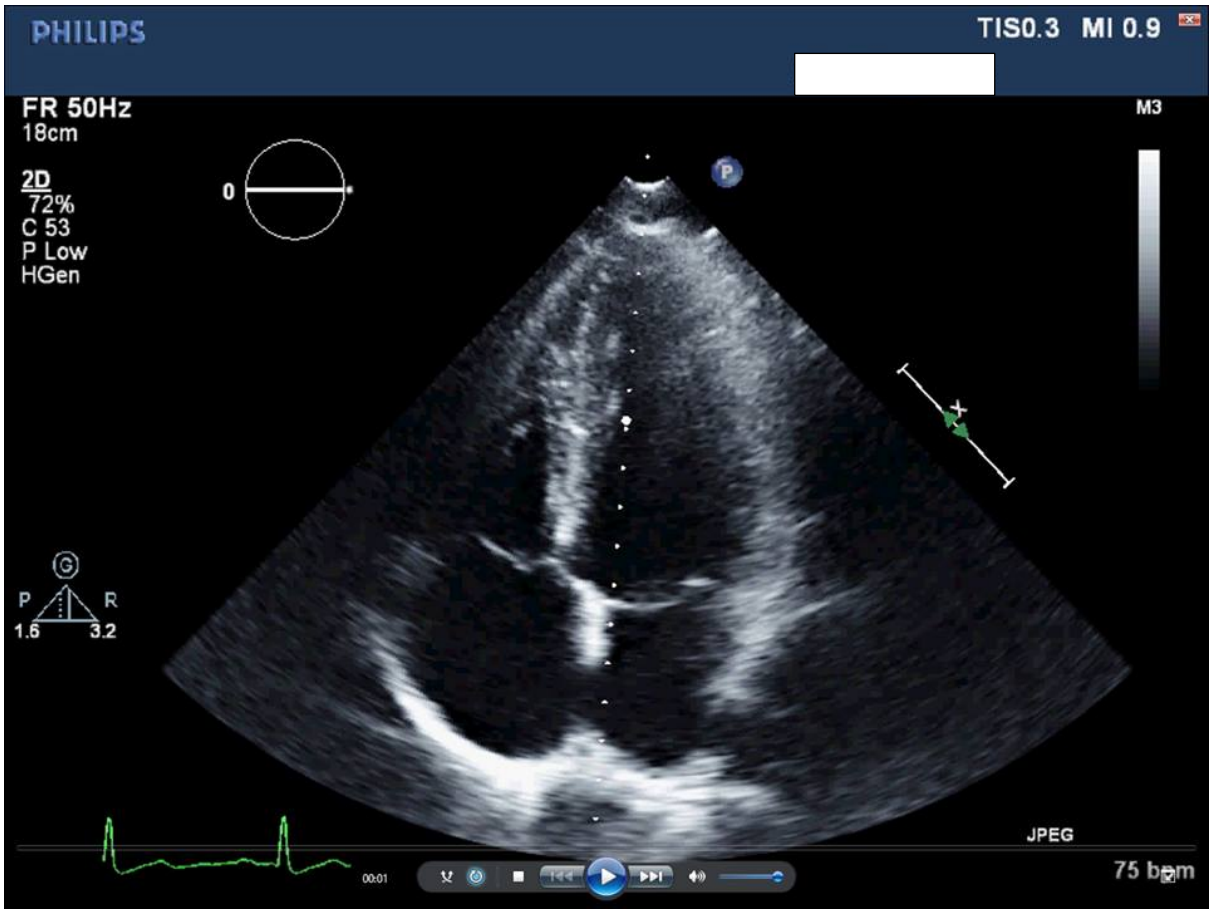


Figure 1 – A large PFO seen on TTE

Approximately 1/3 – ¼ of the population have a Patent Foramen Ovale (PFO). For more information see below.

Also, congenital cardiac or pulmonary abnormalities (ASD/VSD/AVM) provide a direct connection between the bubbling right side and the arterial circulation.

However, in order for the bubbles to pass into the arterial circulation there needs to be an increase in thoracic pressure. This is brought about by straining, which can happen when an individual lifts a heavy tank, blows their nose or has difficulty opening their bowels. This then forces bubbles across from the veins to the arteries as described above.

3. *Overwhelming of the Pulmonary Filter*

In everyone there is the capacity to shunt bubbles through the pulmonary circulation if there are enough bubbles and enough strain. So, if an individual really exerts themselves after a dive with a high nitrogen load then this can cause bubbles to shunt into the arterial circulation as shown above.

HOW DOES DCI MANIFEST?

Decompression illness can give a variety of symptoms and essentially if a diver is unwell within the first few minutes to days after a dive it is worth speaking to a diving doctor.

AGE usually presents within 10-20 minutes of surfacing from a dive, and the diver may be unconscious or obviously very unwell with breathing difficulties, paralysis and seizures whereas DCS may develop over a longer time period. However, neurological DCS can appear very similar to the symptoms of AGE, but the first aid treatment for both is the same. 90% of cases of DCS appear within 30 minutes – 6 hours and will occur during or after ascent. 50% of these cases will present within the first hour. Divers often deny the reality of their symptoms, hence delaying definitive treatment. Very rarely there may be a longer latent period from 24 to 36 hours. Earlier onset of symptoms usually indicates more severe disease. Ascent to altitude after diving, (driving over mountains, flying), exercising or breathing gases apart from air (Entonox) may enhance the onset of symptoms.

Also, it is an evolving disease. The symptoms can change over a few hours as the bubbles move or damage to the tissues from a bubble manifest.

These are some of the commonest symptoms and mechanisms

1. Limb pain – Vague pain in a joint or limb that is typically described as like a tooth ache. The gas is trapped within the tissues of the arm/leg. This is usually a type of DCS.
2. Back pain/pain across the abdomen – In medical terminology we call this girdle pain. It is a pain coming from the middle of the back and spreading into the abdomen. This is often gas trapped in the spinal cord either DCS or AGE depending on the dive profile.
3. Nerve symptoms – Tingling in skin, weakness in the muscles, difficulty expressing oneself or not behaving normally, poor co-ordination, loss of bowel or bladder control, changes in hearing or eyesight, memory loss, unconsciousness. Again depending on the dive profile this can be due to escaped or evolved gas within tissues.
4. Ear problems (Staggers) – Sense of spinning and inability to stand up due to dizziness. Hearing loss. Ringing in the ears, nausea and vomiting. Can be due to DCS or AGE. Sometimes this is actually due to barotrauma (damage to the eardrum or inner ear) from over equalisation or rapid ascent.
5. Chest Pain or breathing difficulties (Chokes) – this would tend to occur very shortly after a dive and suggest an individual has burst a lung or possibly immersion pulmonary oedema (water on the lungs due to exposure to pressure). However, it could represent gas within the heart vessels.
6. Rash – rashes can be very difficult to interpret but can be a manifestation of gas trapped in skin vessels. Taking a picture of the rash and sending it to a hyperbaric centre is a good idea as very often the rash will have disappeared by the time the diver reaches a chamber. It is not until they are examined properly by a diving doctor that other signs are apparent. Divers tend to think the skin rash is of no consequence but this is mistaken thinking and could lead to significant disease if not treated correctly.
7. Glands enlarged – lymph nodes and lymphatic drainage can be blocked by bubbles within the system blocking drainage or damaging the vessels.

8. "Not quite right" – constitutional DCI is difficult to diagnose as the individual just has a variety of symptoms such as headache, apathy, inappropriate fatigue, malaise, loss of appetite, difficulty in carrying out simple arithmetic and word blindness

HOW IS DCI DIAGNOSED?

Currently, there are no specific diagnostic tests, investigations or imaging techniques which would confirm or deny a diagnosis of DCI. It is therefore up to a qualified diving doctor to take a history, examine the diver and then decide clinically whether it is DCI or not. The history will give many clues as to the likelihood of the presentation being DCI, particularly in cases which are non-specific. Treatment would not be delayed in order to get a full history and examination if the presentation was very obvious. Our doctor would accompany the diver into the chamber to continue the assessment in order to get the diver under pressure as soon as practically and safely possible.

We will ask questions about the dive profile (depth and time), type of breathing apparatus, gas mix, type of dive, ascent rate, problems during the dive, duration of surface interval between dives and any decompression or safety stops missed.

We would also ask questions about previous medical history, (including previous DCI), current medications, and then specifically about the symptoms. If the doctor is worried about the progression of DCI or there are concerns about pulmonary damage, we would arrange for a chest X ray and other investigations to be done in the local Emergency Department prior to compression in a chamber.

HOW IS DCI TREATED?

FIRST AID

First principles in any first aid situation are to assess for a safe approach to the casualty, look for and treat in order or concurrently: catastrophic haemorrhage (bleeding), airway, breathing, circulation, disability and exposure. The well-known mnemonic is cABCDE which all divers should be familiar with. We offer training to keep skills up in this area – please follow this link.

Oxygen is the primary treatment for suspected DCI. Do not be put off by people suggesting that oxygen only makes it worse, the saturation levels are over 94% or there is too much admin involved if the oxygen cylinder is used – these are all stories we have been told in the past. Divers often feel better after being on oxygen and think the problem has gone away. When they stop breathing oxygen, symptoms can return. All UK MCA approved dive boats should have at least one oxygen cylinder and equipment on board.

The bottom line is high flow oxygen via a reservoir mask. The diver should have free flow oxygen if possible, although some makes of oxygen equipment have a demand valve, similar to a diver's regulator. The diver may not get enough oxygen this way however so free flow is better. Document the time oxygen was started and the number of litres per minute given as this will be relevant to the treating doctor.

Other first aid treatment is fluids if the diver is conscious and able to swallow. Give water or cold drinks. Do not give Entonox (50% nitrous oxide/50% oxygen) under any circumstances to anyone who has recently dived as the nitrous oxide is highly soluble and will increase the inert gas load, making the symptoms of DCI worse. It can also expand within the air filled spaces of the body and cause barotrauma to the lungs, ears, sinuses or gut. Do not give pain killers unless you have a very long transfer to a chamber, and only after discussion with a diving doctor.

CHAMBER TREATMENT

If the diver has a rapidly progressing neurological DCI or AGE, with shortness of breath, possible lung damage, history of loss of consciousness, seizures or other serious symptoms then they would be taken to the nearest Emergency Department for assessment. In Plymouth, the diving doctor will also attend the department to work with the ED team and to offer expert advice as to fitness for the diver to go in the chamber.

If the diver is brought to DDRC, the duty doctor will see and examine immediately. At DDRC Healthcare we arrange for the chamber attendant to be present so any changes during treatment can be assessed by them. The diver will be measured for a latex neck seal (if allergic to latex we have alternatives), and shown the hood system we use here (see picture). This allows the diver to speak, read, watch a film or sleep without the hindrance of a heavy face mask. If the diver feels claustrophobic however, we do have face masks.

The first treatment is the longest one and depends on the gas mix the diver was using, depth and symptoms. Very often we will use a Comex 30 table which uses a 50:50 oxygen/helium mix at 30m, with decreasing depths over time (and lasts for over 7 hours) initially for spinal DCI, AGE and those divers using trimix or mixed gas during deep technical dives. Alternatively we will use the US Navy long oxygen table (USN TT6) which goes to 18m and uses oxygen for various lengths of time. This can last from 4.45 hours to over 7.5 hours.

WHAT CAN I DO TO STOP MYSELF GETTING DCI?

There is only one way to not get DCI. Don't get in the water. Unfortunately, there is an inherent risk of decompression illness with every dive an individual does, no matter how experienced or inexperienced you are. Unfortunately, even if an individual completes a perfect profile they can still suffer DCI.

However, there are some things you can do to lower your risk. This list is not exhaustive but does cover some of the main ways you can reduce risks.

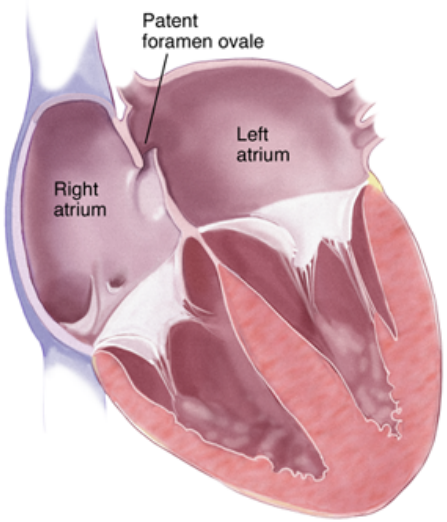
1. Dive well within your computer and/or table limits – don't miss deco.
2. If you are using a computer add on extra conservative settings to limit yourself.
3. Dive with Nitrox (if trained to do so)
4. Dive shallow
5. Keep hydrated
6. Keep warm
7. Dive in a buddy pair
8. Don't drink alcohol. Don't use recreational drugs.
9. Look after your health generally. Eat a healthy balanced diet and do regular exercise and keep your weight within normal limits.
10. If you have a health problem then please declare it on your medical form and seek a dive medical professionals opinion well before you dive.
11. Dive safe. "Plan your dive and dive your plan". Add in levels of safety along the way and establish good signals so you can communicate underwater.
12. Dive within your limits of safety and what you feel comfortable with. If you don't feel comfortable at a dive site then don't get in the water. Panic due to anxiety can be a major cause of DCI.
13. Keep your kit serviced and in full working order. Kit failures are often a reason for rapid ascents.
14. Diving with the same buddy who knows you well is always better if at all possible. If you don't know your buddy make sure you establish good communication and again dive the plan you make.
15. Consider if you are diving on a holiday the possibility of day to off gas. There is no hard and fast rule about this, but certainly 4 dives a day for 6 days in a row will put a serious amount of nitrogen into the system.
16. If you are diving at altitude be wary and follow your training organisations guidelines strictly.
17. Adhere to safety stops on top of decompression stops strictly.

A NOTE ABOUT INSURANCE

Treatment for DCI in the UK is free but if you are diving abroad you must ensure you have adequate insurance cover. Companies specialising in dive trip insurance are widely available via the internet or dive magazines. Many divers use their bank travel insurance to cover them for trips abroad but read the small print as there is often a depth limit. They will not cover you if it can be shown you have exceeded the depth limit agreed, by even a tiny amount.

WHAT IS A PFO?

A persistent foramen ovale or patent foramen ovale (PFO) is the term used to describe a flap opening between the 2 upper chambers of the heart. These are called the atria. The opening is a remnant of foetal circulation when the growing baby in the uterus received all its' nutrients via the umbilical cord and did not require oxygen from the air. When a baby is born it takes the first gasp of air which inflates the lungs and increases the pressure in the left side of the heart. In 2/3 of the population this permanently closes the PFO that is present. However, in approximately 1/3 of people, the PFO remains and in general this does not cause any problems. In divers, venous gas bubbles returning to the right side of the heart and lungs can overwhelm the lung filtering system and the bubble pressure can increase that of the left atrium and thus cause bubble to cross the PFO into the left side. This causes the bubbles to then be distributed to any part of the body in the arterial system. Very often this can cause immediate problems in the heart and brain as the arteries supplying these organs are the first ones branching off from the aorta. Symptoms of damage to the heart are similar to that of a heart attack, with chest pain, shortness of breath, sweating and nausea or vomiting, and if bubbles go to the brain, the symptoms can mimic a stroke. As these are gas bubbles, treatment is recompression in a hyperbaric chamber.



However, damage from bubbles is not just caused by the bubbles themselves. Bubbles can lodge in any of the body tissues and where they touch the lining of those tissues, (eg: blood vessels) an inflammatory response can also occur. Even when the bubbles have been squashed by recompression, the inflamed area can continue to cause problems and this is why quite often divers will require more than one treatment in a recompression chamber.

If you are treated for DCI at DDRC Healthcare we will discuss the potential mechanism of injury, particularly if there is a possibility of a PFO. Some people have migraine with aura which is now known to be a risk factor for DCI in divers with a PFO. In many cases the cause of your DCI is simply related to basic physics: you were down too deep and too long. In some cases, the so-called "no fault" dive where the diver has maintained safe diving practices but still had DCI, we may ask your own GP to refer you to a diving cardiologist who specialises in screening for a PFO if we think this may be a possible cause of your injury. Screening is not done prior to diving as it is neither cost effective nor evidence based.

Repair of the PFO for recreational divers is not available on the NHS at present. The diving cardiologist may recommend alternative methods of diving to reduce your risk of DCI. These include breathing nitrox (if trained), avoiding decompression dives, always dive with a buddy and dive no deeper than 15m (air depth).