# The Risks of Scuba Diving: A Focus on Decompression Illness

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## Abstract

*Decompression Illness includes both Decompression Sickness (DCS) and Pulmonary Overinflation Syndrome (POIS), subsets of diving-related injury related to scuba diving. DCS is a condition in which gas bubbles that form while diving do not have adequate time to be resorbed or "off-gassed," resulting in entrapment in specific regions of the body. POIS is due to an overly rapid ascent to the surface resulting in the rupture of alveoli and subsequent extravasation of air bubbles into tissue planes or even the cerebral circulation. Divers must always be cognizant of dive time and depth, and be trained in the management of decompression. A slow and controlled ascent, plus proper control of buoyancy can reduce the dangerous consequences of pulmonary barotrauma. The incidence of adverse effects can be diminished with safe practices, allowing for the full enjoyment of this adventurous aquatic sport.*

## Introduction

Scuba diving is a sport with exhilaration, beauty, and fascination; however, the risks involved are often not advertised. Two specific conditions can turn a fantastic dive into trouble, with occasional fatal outcomes: Decompression Sickness and Pulmonary Overinflation Syndrome. After spending six years as a US Navy Diving Medical Officer, I will share some case reports and discuss the physiology, clinical presentation, and treatments for these diving-related injuries.

Decompression Illness includes both Decompression Sickness (DCS) and Pulmonary Overinflation Syndrome (POIS), subsets of diving-related injury related to scuba diving. Divers should understand their limitations and how to prevent adverse outcomes. DCS is a condition in which gas bubbles that form while diving do not have adequate time to be resorbed or "off-gassed." This results in bubble entrapment in specific regions of the body, most commonly in joints such as the shoulder. If adequate decompression time is omitted, the trapped bubbles may lead to DCS.[1] POIS is due to an overly rapid ascent to the surface resulting in the rupture of alveoli and subsequent extravasation of air bubbles into tissue planes.[2] On rare occasions, the bubbles may traverse the cerebral circulation, causing a potentially fatal condition.[2] Divers must always be cognizant of dive time and depth, and be trained in the management of decompression. A slow and controlled ascent, plus proper control of buoyancy can reduce the dangerous consequences of pulmonary barotrauma. Overall, the incidence of adverse effects can be diminished with safe practices, allowing for the full enjoyment of this adventurous aquatic sport.

## Relevance to Hawai'i and Asia Pacific

The Hawaiian Islands and islands throughout Asia Pacific are popular scuba diving venues with an abundance of marine life and warm, comfortable weather conditions year-round. The incidence of diving-related DCS ranges from 1 to 35 events per 10,000 dives, depending on region of the world and specific class of diving (ie, recreational, commercial, military, or scientific).[3,4] Assuming an average of fifteen diving-related injuries per 10,000 dives, and approximately 200 daily dives across the Hawaiian Islands, we would predict one DCS or POIS event every week.[3,4]

## Example Cases

### Case 1

A 28-year-old US Navy SEAL performed a working dive using scuba to secure an apparatus on the bottom to buoy lines at the water surface. This entailed multiple descents and ascents. The seas had been choppy with swells of two to four feet and currents at roughly one to two knots, thus creating a challenging environment. The diver descended to 60 feet and ascended to the surface, intermittently holding his breath while bobbing up and down on the surface. After obtaining the next piece of work equipment from the zodiac boat, he made another descent to 60 ft, followed by ascent to the surface. This time, he noted blurry vision in his right eye, thinking he had merely gotten seawater under his mask. The diver proceeded to the bottom again to finish his job. Upon ascent, he experienced mild paresthesias to the right side of his face. The diver was brought into the zodiac boat and described his symptoms to the diving supervisor. His symptoms quickly progressed to involve numbness and tingling in his left upper extremity, at which time the duty diving bends team (a specialized and trained group of divers and medical personnel who respond to diving casualties) was activated. The diver was promptly transported to the support team and diving chamber. When the diver arrived approximately five minutes later, the entire right side of his body was numb. He also had difficulty ambulating. The diver was urgently brought to the hyperbaric chamber where he immediately descended to 60 feet of seawater (fsw) and was placed on 100% oxygen. Within minutes, the diver had full resolution of his symptoms. A full treatment per the US Navy standard diving guidelines was completed for the diagnosis of arterial gas embolism (AGE).

This scenario describes pulmonary barotrauma resulting in arterial gas embolism. The diver's rapid ascent to the surface after repeated dives placed the diver at increased risk for POIS. His symptoms were of quick onset and rapid progression, ultimately requiring emergent treatment with hyperbaric oxygen therapy (HBO). Fortunately, he was in close proximity to a diving chamber and had expeditious treatment.

Following HBO treatment, the resolution occurred quickly after he reached 60 fsw, which supports the diagnosis of arterial gas embolism. In AGE, air bubbles enter into the cerebral circulation and become lodged in the arterial vasculature, resulting in symptoms mimicking a stroke. HBO therapy essentially follows Boyle's Law, wherein the increase in atmospheric pressure causes the volume of the bubble to decrease, allowing for circulation to be restored.

### Case 2

A 35-year-old man was in the process of becoming certified as an advanced scuba diver with a dive company from O'ahu. He was to complete multiple dives, including wreck and night dives. The first day, he completed a dive for thirty-five minutes to 65 feet, followed by another dive that night for thirty minutes to 45 feet. The diver felt well and the following morning joined his dive crew for his third dive of the weekend. He made a dive to sixty feet for 45 minutes. The fourth dive, two hours later, had been planned to a maximum depth of fifty feet. The diver was feeling very tired with pain in his right shoulder. Despite his symptoms, he continued with his final dive. Surprising to him, when he reached depth, his shoulder pain resolved. However, when he reached the surface after this final dive, his shoulder pain recurred. This diver did not state any complaints after his dive course and went home. His wife noted that her husband was acting more fatigued than usual and perhaps had some element of confusion and memory loss. Furthermore, he began to complain of worsening shoulder pain. The following day, the diver presented for medical advice, examination and possible treatment. His symptoms raised the suspicion for DCS, even though his dive computer did not show any "omitted decompressions" during his dives. Omitted decompression occurs when a diver fails to make a needed decompression stop. Dive computers are programmed to indicate when decompression stops are required and the duration of these stops. Since DCS was suspected, he was treated in the hyperbaric chamber, and his symptoms resolved after two days of HBO therapy.

This diver likely suffered from decompression sickness, which may be seen in divers who adhere to their dive time and depth and do not omit decompression. Interestingly, this diver had an echocardiogram with agitated saline which revealed a Patent Foramen Ovale (PFO). It is unclear whether the PFO contributed to his DSC.

## Discussion

Diving compressed gases (ie, scuba diving) can lead to two very serious medical conditions: Decompression Sickness (DCS), otherwise known as "the Bends," and Pulmonary Over-Inflation Syndrome (POIS). DCS most often is not lethal, but is associated with morbidity, whereas POIS can result in a spectrum of disorders from minor complaints to potentially lethal sequelae unless emergent treatment with hyperbaric oxygen therapy is performed.

There are four distinct disorders as a part of POIS: Arterial gas embolism (AGE), pneumothorax, mediastinal emphysema and subcutaneous emphysema. They all result from overdistention and rupture of the lungs by expanding gases during ascent.[1,2] The expanding gases cannot escape, leading to one of the myriad of symptoms of POIS. Boyle's law states that if the temperature of a fixed mass of gas is kept constant, the relationship between the volume and pressure will vary in such a way that the product of the pressure and volume will remain constant.[2] In other words, on ascent, when the atmospheric pressure is decreasing, the volume of gas bubbles will increase ($P1V1 = P2V2$). This explains why pulmonary barotrauma occurs. Inexperienced divers who panic may ascend rapidly and develop POIS.

Air embolism is the most serious manifestation of POIS, resulting from gas passing from the ruptured lung into the pulmonary veins and then into systemic circulation. Here, it can cause vascular damage or obstruction, hypoxia, infarction, and activation of an inflammatory cascade. Initial presentation includes loss of consciousness or symptoms similar to acute stroke. The symptoms upon ascent are often immediate, but may present up to ten minutes after surfacing. Serious effects may result from blockage of cerebral or coronary vessels by bubbles merely 25 to 50 microns in diameter, or by interrupting flow. Treatment must be immediate, consisting of urgent recompression in a hyperbaric chamber.[1]

The three types of pulmonary barotrauma are typically less serious, but may warrant treatment. The mechanism is similar to the pathophysiology of pulmonary barotrauma. After alveolar rupture, gas escapes into the interstitial pulmonary tissues. This gas may track along the loose tissue planes surrounding the airways and blood vessels, into the hilar regions, and then into the mediastinum, neck and the pleural space. This results in mediastinal emphysema, subcutaneous emphysema or pneumothorax. Symptoms include voice changes, feeling of fullness in the throat, dyspnea, dysphagia, retrosternal discomfort, chest pain, or in extreme cases, syncope and collapse. As in the case of emphysema, crepitus is often palpated on the surface of the skin. Usually these syndromes are self-limited and treated with observation, allowing time for resorption of the gas bubbles. Mild symptoms may be treated with 100% oxygen administered by face mask for approximately 4-6 hours. In severe, albeit rare cases, a shallow decompression treatment may be started, which is usually adequate for resolution. Pneumothorax may require chest tube placement, depending on the size and symptoms present.[1,2]

Decompression sickness is much more common. Present-day diving often follows dive tables, initially adopted by the US Navy. Modern technology allows for most divers to use dive computers which can track their dive and decompression time accurately, without having to calculate diving time based on depth and the dive tables. Despite advances with dive computers, divers still develop DCS, either from human error or from disobeying their decompression guidelines. Even if a diver is adherent to appropriate dive time and depth, the dive tables are not infallible and DCS may still occur.

During DCS, there is liberation of gas bubbles from solution into the tissue or blood. Symptoms often resolve, but, these bubbles may lead to death or permanent neurological impairment. Bubbles may cause direct mechanical effects such as tissue distortion or disruption, or ischemia by blocking blood vessels or increasing tissue pressure sufficient to impair perfusion. They are also known to precipitate an inflammatory cascade via neutrophilic activation as a consequence of endothelial or cellular damage.[1,2] Basically, when diving, the deeper the depth, the greater the partial pressures of gases, which leads to an increase in bubble formation/extraction into the tissues. The longer one remains at that depth, the more bubbles will "on-gas." The ability of these bubbles to become resorbed into solution, or "off-gas" will depend on how many gas bubbles have accumulated, which depends on time and depth. Thus, one is required to undergo decompression stops in order to allow time for this "off-gassing" to occur. If decompression is omitted, the result may be decompression sickness.

Furthermore, the severity of DCS will also be determined by the amount of omitted decompression. There are many theories as to how DCS develops, but one unifying mechanism has not been established. It is a multifactorial and multiorgan process.

There are established risk factors that may predispose a diver to developing decompression sickness. Lack of physical fitness, increased age, obesity, dehydration, physical injury, alcohol use during diving, repetitive dives, and traveling to altitude to dive are some of the risk factors that may lead to higher incidences of DCS.[1] The best outcomes after diving are in physically fit individuals who are well-hydrated and who follow their dive tables or dive computers without pushing the limits.

Clinical manifestations are classified into two categories: Type I "pain only," and Type II "serious." Type I is more common, often with limb or joint pain, and usually affecting the shoulder.[1,2] Classically, this pain is unaffected by range of motion testing, which differentiates it from musculoskeletal trauma or injury. However, one must be cautious because old injuries are predisposed to developing DCS, acting as a nidus for bubble formation and trapping.[1] In Type II, symptoms are more serious and usually occur with a significant amount of omitted decompression or extreme deep and long dives. Cerebral, cerebellar, spinal, and inner ear DCS comprise the Type II sub-categories, with emergent decompression being necessary to avoid death or long-term neurological defects.[1]

Whether one is treating decompression sickness or pulmonary overinflation, the mainstay of treatment is to recompress the affected diver in a hyperbaric chamber with 100% oxygen at high partial pressures. This immediately reduces bubble size, and produces an increased diffusion gradient of inert gas (usually nitrogen) out of the bubbles.[2] This leads to relief of ischemia and hypoxia, and restores normal tissue function. As long as the chambers are operated by well-trained staff and measures are taken to mitigate any adverse effects from decompression therapy, HBO treatment has the potential to reduce mortality and morbidity in most cases of DCS.

## Treatment in Resource Constrained Environments

In environments which are remote or where resources are limited, divers who succumb to decompression sickness may undergo in-water decompression, as long as the following parameters are met: (1) additional divers can assist the stricken diver and accompany them under water; (2) the sea state does not pose an increased risk to any of the divers or crew; (3) the diver with DCS is stable, without any altered state and has ability to use his or her extremities without additional risk; and (4) enough air and tanks are available for in-water decompression. One may try to use 100% oxygen underwater, if available, but there MUST be another diver closely monitoring for oxygen toxicity, and the diver should not be at a depth greater than 30 feet of salt water ($O_2$ toxicity risk is greatly increased when submerged to depths greater than this). Another treatment for austere environments includes 100% oxygen on the surface, which may be beneficial as a bridge to more definitive therapy. A final option is air evacuation to the closest treatment facility.

Whenever diving operations are underway there always needs to be a plan for potential emergency situations, and the boat operator needs to have radio and phone numbers available.

## Treatment in Non-austere Environments

In diving areas where resources are available, treatment for DCS predominantly entails HBO therapy. However, if symptoms are mild, observation only is required. The stricken diver should still have expert consultation either by a diving medical specialist or by the nearest emergency room.

If a diver should surface with symptoms suggestive of severe barotrauma, severe DCS, or arterial gas embolism, all efforts should be undertaken to transport the patient emergently to the nearest hyperbaric chamber.

## Conclusion

Scuba diving is an extremely popular sport, especially in the Hawai'i. Many experienced divers as well as newly trained divers flock to the region to experience the marine environment. A moderate climate makes the sport popular throughout the year. With the incidence of decompression illness approximating one DCS case per 1000 dives, we would expect at least one event every week. These diving related disorders need to be recognized, and supervisors and the divers should be cognizant of the risks and dangers that can accompany any dive. Divers need to be well-trained, know their limits, follow their planned dive, and always have an emergency plan.

## Disclosures

The author reported no conflicts of interest.

## Disclaimer

The views expressed in this manuscript are those of the author and do not reflect the official policy or position of the Department of the Army, Department of Defense, or the US Government.

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*Alternobaric Vertigo (Photo: Russell Gilbert MD)*