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ARAŞTIRMA MAKALESİ / ORIGINAL ARTICLE
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# The common effect of dysbarism-related diffuse arterial air embolism and rare CO toxicity during SCUBA diving

## SCUBA dalışı sırasında disbarizme bağlı yaygın arteriyel hava embolisi ve nadir CO toksisitesinin ortak etkisi

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## ABSTRACT

Due to the pressure changes during a dive, various traumatic effects can range from mild paresis to death, affecting organs and tissues containing air, especially the middle ear, lung, and sinuses. In this case, the autopsy of a male experienced diver, who was found floating prone on the sea surface and was unresponsive when transported to the hospital, was conducted. After evaluating all the findings, it was concluded that the cause of death was the combined effect of rare carbon monoxide (CO) toxicity and diffuse arterial air embolism due to dysbarism.

**Keywords:** *Diving fatalities, gas embolism autopsy, decompression sickness*

## ÖZET

Dalış sırasında basınç değişimine bağlı olarak orta kulak, akciğer ve sinüsler başta olmak üzere hava içeren organ ve dokularda hafif pareziden ölüme kadar değişen çeşitli travmatik etkiler ortaya çıkmaktadır. Olgumuzda, deniz yüzeyinde yüzüstü pozisyonda bulunan ve hastaneye nakledildiğinde yaşam bulgusu olmayan deneyimli erkek dalgıcın otopsisi tarafımızdan yapılmıştır. Tüm bulgular birlikte değerlendirildiğinde; ölüm nedeninin nadir görülen karbonmonoksit toksisitesinin ortak etkisi ve disbarizme bağlı diffüz arteriyel hava embolisi olduğu sonucuna varılmıştır.

**Anahtar Kelimeler:** *Dalış ölümleri, gaz embolisi otopsi, dekompresyon hastalığı*

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## INTRODUCTION

Self-Contained Underwater Breathing Apparatus (SCUBA) diving is increasingly popular in Turkey. This activity, performed under various physical conditions, carries inherent risks that can result in illness, disability, or death. As the number of SCUBA divers increases, so do dive-related deaths (1). Loss of consciousness underwater can lead to drowning, and underwater scenarios that cause unconsciousness carry a high mortality risk (2). Factors such as hypoxia, fluid aspiration, vomiting and aspiration of vomitus, hypothermia, dangerous marine creatures, decompression sickness, arterial gas embolism (AGE), nitrogen narcosis, CO toxicity, $O_2$ toxicity, $CO_2$ retention, and pre-existing conditions like diabetes, ischemic heart disease, and epilepsy can alter consciousness during a dive (3).

Dysbarism, a general term for pressure changes, can cause barotrauma, which refers to trauma from the mechanical effects of these changes. Pressure changes can lead to various traumatic effects, from mild bleeding and paresis to death, particularly affecting air-containing organs like the middle ear, lung, and sinuses (4).

SCUBA diving involves using portable breathing equipment that allows air/gas breathing at pressure appropriate to the ambient pressure at the current depth, enabling longer underwater stays. High-pressure gas in the breathing apparatus can be atmospheric air or gas mixtures like Trimix (Nitrogen + Helium + Oxygen), Heliox (Helium + Oxygen), and Nitrox (Nitrogen + Oxygen) to mitigate pathological effects of increased partial pressure. SCUBA systems can be open-circuit (where expired air is released) or closed-circuit (where expired air is reused after $CO_2$ removal and $O_2$ replenishment) (1).

CO is a toxic, colorless, odorless, and tasteless gas, produced in small amounts by hemoglobin metabolism in the body and from the incomplete combustion of carbon-containing substances. If the exhaust of the compressor used for compressed air is too close to the air inlet, CO can contaminate the breathing air (1). CO binds to hemoglobin with 200 times the affinity of oxygen, causing hypoxia by shifting the oxyhemoglobin dissociation curve to the left (5). COHb levels below 10% may show no symptoms, while higher levels can cause headaches (in 20-30 %), weakness, nausea, vomiting, drowsiness, sweating, blurred vision (in 30-40 %), and severe symptoms like Cheyne-Stokes respiration, loss of consciousness, convulsions, coma, and death (in over 40%) (1).

SCUBA diving deaths are rare in routine autopsies, and not all forensic specialists have sufficient experience with such cases. This study aims to discuss the death examination and autopsy findings of a patient who died from the combined effects of dysbarism-related diffuse arterial air embolism and rare CO toxicity during SCUBA diving.

## CASE

The autopsy of the body who found floating prone position on water surface after SCUBA diving and reported as forensic case was performed by us. His relatives and SCUBA group members who diving together testified that went to the sea for diving, they made diving, last seen when the person swimmed to the surface of the water, the group members did not see the person after the diving, they started to search him and informed to 158(Coast Guard) and 112(Emergency medical Services). They explained that the body was located 30-40 meters far from the diving route, the mask was on his face, but the regulator that allows him to breathe was not in his mouth, didn’t move, was bruised and there was vomit contamination in his mouth and equipment. It was stated that he had made cardiopulmonary resuscitation by his teammates after he had been taken to the boat and he was disembarked and was transferred to the hospital by ambulance within half an hour but the person could not be saved.

External examination of the body by the physician on duty revealed that there was no compression on the back of the body and livor mortis was detected in light red color.

The initial external examination showed livor mortis on the back and no signs of trauma, assault, or fractures. Blood contamination was present in the mouth and nose, with a bitten tongue and slight discoloration in the head and neck area.

X-ray examination of the whole body was performed before the autopsy. However, due to artifacts and problems with the position of the body, the image associated with air embolism could not be evaluated.

During the autopsy, we carefully opened the skull, taking great care to avoid damaging the vascular system, in light of the possibility of arterial air embolism. Upon dissecting the dura mater, air was observed in the cerebral vessels of the parietal and frontal lobes. To prevent iatrogenic air leakage into the intracranial vessels before the brain was removed, the vertebral artery and carotid internas were clamped and then severed at the clamped points. The intracranial organs and tissues were then removed from the skull. A detailed examination of the circle of Willis revealed air movement within the cerebral arteries, basilar arteries, and communicating arteries. Hemorrhage was noted in the mastoid cells when the cranial base bones were examined.

Upon opening the chest, we removed the sternum and made a small, smooth incision in the pericardium, which we filled with water to create a small pool. A second incision was made in the right heart with a long scalpel, causing air bubbles to emerge from the water-filled pericardium. The lungs appeared swollen, bright, stretched, and showed bleeding on their anterior surfaces. Foamy fluid was released from the lung sections without any pressure being applied. This foamy fluid was also observed in the trachea, bronchi, and bronchioles. Fractures were detected at the third intercostal level on the sternum and bilateral ribs two to five along the midclavicular line, likely caused by cardiopulmonary resuscitation (CPR) efforts, as there was no accompanying ecchymosis. No macroscopic pathological findings were detected in other tissues and organs examined.

Histopathological examination of tissues collected during the autopsy did not reveal any microscopic findings that could have influenced the cause of death. However, analysis of a blood sample taken from the body revealed a carboxyhemoglobin (COHb) level of 33.9%. Based on the autopsy results, it was concluded that the individual's death was due to the combined effects of carbon monoxide poisoning, decompression sickness, and arterial gas embolism.

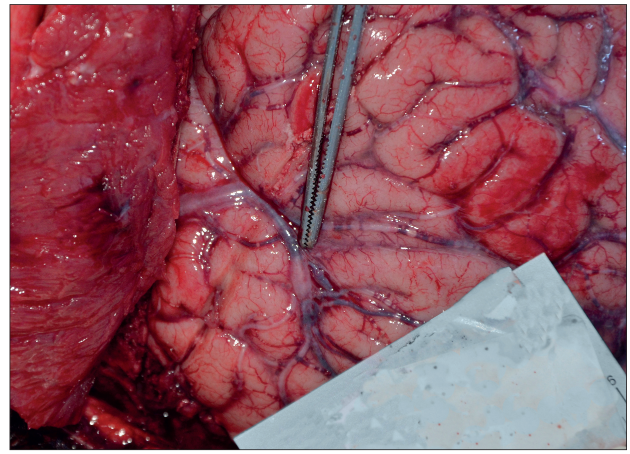

**Figure 1.**

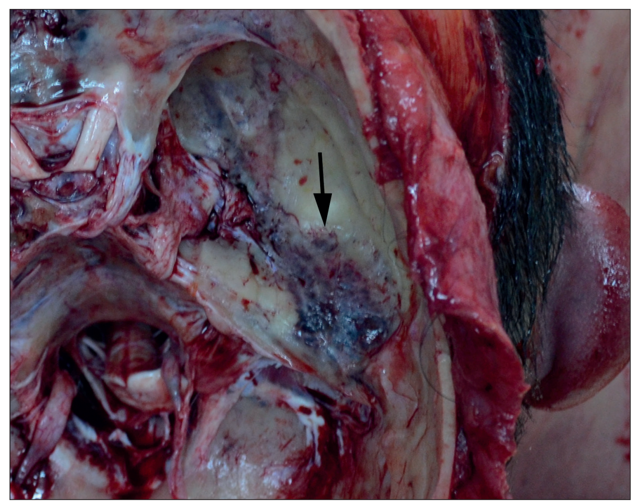

**Figure 2.**

## DISCUSSION

Under normal conditions, there is a balance between outdoor pressure and the pressure within air-filled organs and tissues. Changes in outdoor pressure produce corresponding effects based on the rate of pressure change in the body. Air-containing organs and tissues, such as the middle ear, lungs, sinuses, and gastrointestinal tract, are particularly affected in individuals frequently and intensely exposed to pressure changes, such as SCUBA divers. Severe manifestations and fatal outcomes can occur when blood circulation to vital organs is compromised due to pathologies in the circulatory system (6). The Decompression sickness, a form of dysbarism, is common among divers. It occurs when divers ascend too quickly from deep water to the surface, failing to allow adequate breaks for the body to acclimate to the pressure changes. Rapid ascent prevents the effective removal of non-reactive gases, like helium, used during diving. The gases dissolved in the blood form bubbles as the pressure decreases, obstructing tissue perfusion by transitioning from a liquid to a gaseous state. The condition can manifest in a range of symptoms from fatigue and dyspnea to paraplegia and even death (7). Arterial gas embolism occurs when bubbles form in the arterial system due to decompression. These bubbles can block blood vessels, causing infarction in the organs and tissues they supply (7). Additionally, air embolism may occur when air enters the blood vessels through ruptured alveolar walls due to lung expansion and contraction. This can lead to symptoms such as chest pain, loss of consciousness, vision and hearing loss, and dyspnea if vital organs like the brain, heart, and lungs are affected. If the vessels supplying the extremities are blocked, symptoms such as numbness, weak pulse, paleness, coldness, and pain can occur.

Carbon monoxide (CO) and carbon dioxide ($CO_2$) gases, which can be present in the compressed air used by divers, may enter the breathing air due to a compressor malfunction or a failure in the filtration system, leading to poisoning (8). In our case, the toxicology report indicated a carboxyhemoglobin (COHb) level of 33.9% in the blood. COHb levels between 30-40% can cause symptoms such as weakness, nausea, vomiting, drowsiness, sweating, and blurred vision. When the forensic investigation file related to the incident was examined, it was seen that it was reported that the co rate was high in the oxygen cylinder examined in the case. When evaluating the crime scene, medical history, autopsy findings, histopathology, and toxicology results, it was considered that the diver likely experienced impaired consciousness due to CO poisoning. This impaired state could have led to the diver's rapid ascent to the water surface, resulting in decompression sickness. The presence of vomit in the mouth and on the equipment further supports the occurrence of CO poisoning, as vomiting is a common symptom of CO exposure.

The mortality rate associated with SCUBA diving activity is reported to be 163 deaths per 1,000,000 divers per year, or approximately 1 in 6,000 divers (9). According to data from the Professional Association of Diving Instructors (PADI) in 2009, an organization that regulates 60-70% of SCUBA diver certifications worldwide, the number of certified divers has exceeded 18.4 million since 1967, with more than 500,000 new divers being certified annually (10). The Divers Alert Network (DAN) publishes an annual report on diving accidents. The 2006 report investigated the causes of death in 88 American and Canadian divers who died in diving accidents. The most common cause of death was drowning, accounting for 56 cases, followed by acute cardiac problems and arterial gas embolism. The study also noted that trauma and CO intoxication were less common causes of death during diving. In 10% of cases, the cause of death could not be determined due to the inability to recover the body or make a definitive diagnosis (11).

Lippmann's report on DAN Asia-Pacific data indicates that SCUBA-related mortality in Australian divers is 0.7 per 100,000 dives and 8.5 per 100,000 divers. This report, which examined 351 fatalities between 1972 and 2005, identified several factors that triggered accidents: equipment problems (15%), issues with air/respiratory gas (15%), poor water conditions (13%), anxiety/stress (9%), excessive effort (9%), collision with a boat, vomiting, fluid aspiration, attempted suicide (22%), and unidentified factors (17%). The primary cause of death was drowning, accounting for 50% of cases, followed by arterial gas embolism (AGE) at 19% and cardiac problems at 14% (1,12).

A study conducted by the Department of Underwater and Hyperbaric Medicine at Istanbul University analyzed fatal diving accidents between 2007 and 2013 at forensic medicine units in Istanbul, Adana, Izmir, Bursa, Mersin, Çanakkale, Aydın, Muğla, and the Turkish Underwater Sports Federation. The study reported 20 deaths due to SCUBA diving accidents. Of these, 12 (60%) were due to drowning in water. Two cases (10%) were attributed to "asphyxia caused by air embolism and drowning in water." One case (5%) involved "complications from oxygen-free underwater environments." Another two cases (10%) were due to "air embolism." There was one case (5%) of "blunt force trauma, including left arm amputation, right brachial artery/vein injury, rib fractures with right lung contusion, and external bleeding." One case (5%) was due to "pulmonary edema caused by decompression and AGE." Finally, one case (5%) was due to "CO intoxication caused by problems in the SCUBA tube." (1). In our case, it was concluded that the individual, who lost consciousness due to carbon monoxide poisoning, swam uncontrollably and rapidly to the surface of the water. This rapid ascent led to decompression and arterial gas embolism (AGE). The death was determined to be the result of the combined effects of carbon monoxide poisoning, decompression, and AGE.

## CONCLUSION

In all of the deaths caused by the SCUBA diving accident, the components of the SCUBA tank gas mixture need to be evaluated, especially in terms of CO (13). When evaluating CO amount, increase in the partial pressure of CO with the increase of outdoor pressure in the underwater environment aggravate CO's toxic effects in body and accordingly the measured value in tube air may not be parallel with the clinical results (1). The forensic doctor should know that autopsy findings alone are not sufficient to determine the cause of death in dive-related deaths and should be aware that incorrect results may arise due to common postmortem changes that may be misinterpreted (14). Postmortem examination should not be initiated until the conditions in which the death occurs are fully examined, but an autopsy should be performed as soon as possible to prevent postmortem changes that may mask the findings or lead to false evaluations (13,14).

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