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Black box of diving accidents: Contribution of forensic underwater experts to three fatal cases

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ABSTRACT

Diving is a popular activity, largely practiced worldwide. Diving fatalities are not rare events, with drowning being the most common cause of death, followed by cardiac-related natural causes, immersion pulmonary edema and arterial gas embolism. In such cases, positive signs of drowning are not specific, depending also on the time of submersion of corpses. Moreover, drowning can be the terminal event. Over the years, measures to perform appropriate post-mortem examination in cases of diving fatalities were suggested, including the execution of post-mortem CT-scan, the use of a decompression chamber and the adoption of specific autoptic techniques. Although a multidisciplinary approach in forensic investigations concerning diving fatalities is discussed, poor cases focus on how the analysis of diving computer records and equipment can contribute to determining the cause of death. The present study shows how the cooperation between a forensic underwater expert and a forensic pathologist played a crucial role in interpreting radiological findings, guiding the autopsy and confirming/denying circumstantial data emerging from the investigations. Technical analysis of dive computer records and diving equipment is a fundamental step in the definition of the cause of death in diving fatalities. All diving computer data, not only those related to maximum depth and ascent's profile, should be considered in detail, and the immersion graph carefully studied by both the forensic pathologist and the forensic underwater experts. The diving technical data can often play a crucial role in explaining any legal issue related to the circumstances of death, possibly leading the prosecutor to further investigation.

1. Introduction

Diving is one of the most popular underwater activities as it is largely practiced worldwide in freshwater or saltwater for both recreational and occupational purposes [1,2]. Recreational diving in particular is a fast-growing type of marine wildlife tourism activity that usually encourages visitors to access marine protected areas [3].

Over the years, diving techniques and technologies have gradually advanced in order to increase divers' safety and bottom time at depth [4]. Modern equipment include conventional SCUBA (Self-Contained Underwater Breathing Apparatus) and closed-circuit rebreathers [4,5]. SCUBA usually consists of a single gas storage cylinder and a two-stage pressure regulator: the first stage reduces the pressure of the air into the cylinder (200–300 bar) to a value around 9–11 bar; through second-stage diaphragm the intermediate pressure is reduced to ambient pressure into the mouthpiece so the diver can inhale with minimal resistance and exhale releasing air into the water [2,6]. In a rebreather, the exhaust breath is recirculated through a loop into a flexible bag and inhaled by the diver again; a classic rebreather is made up of a mouthpiece with a shut off dive/

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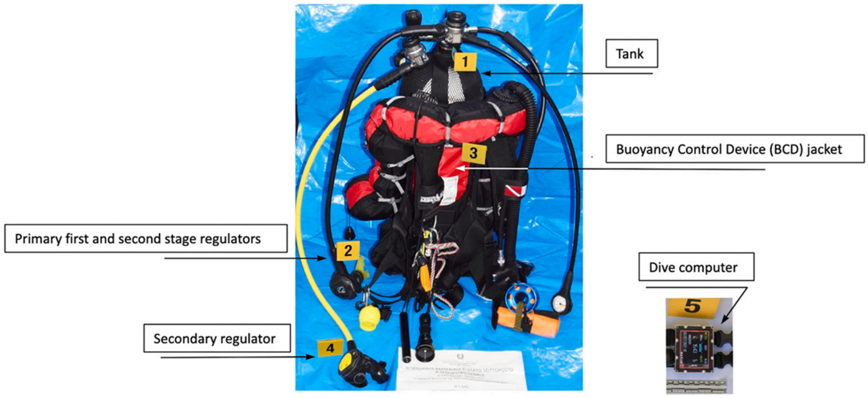

Fig. 1. Equipment in case#1 (SCUBA).

surface valve, breathing bags for inspiratory and expiratory gas, a scrubber containing absorbent material to retain the CO_2 exhaled by the diver, electronic monitoring system of PO_2 through a solenoid, and lastly manual valves for diluent gas and oxygen supply [5,6]. Typically cited advantages of close-circuit rebreathers compared to open-circuit SCUBA include reduction of gas consumption, improved decompression efficiency and silent operation due to the absence of exhaled bubbles [7]. Despite being relatively safer than it used to be in the past, recreational diving can lead to serious incidents, and even death [8]. According to the 2020 DAN (Divers Alert Network) Annual Diving Report, 189 recreational diving fatalities occurred in 2018, with drowning representing the most common cause of death, followed by cardiac-related natural causes, immersion pulmonary edema, arterial gas embolism (AGE) and intoxication [7]. Since positive signs of drowning are not specific and not largely evident if the corpse remains a few days in the water depending on temperature, diagnosis is one of exclusion [8]. Moreover, in many cases drowning only represents the terminal event of a sequence starting with a cardiovascular disease, loss of consciousness because of pulmonary barotrauma and cerebral arterial gas embolism (PBT/CAGE), gas toxicity, decompression sickness or physical injuries. Therefore identifying the underlying cause of death can be particularly difficult in forensic practice [9]. Over the years it has been largely recommended to adopt specific although not always easily applicable measures to perform post-mortem examination in cases of diving fatalities, including the execution of post-mortem computer tomography (PMCT) imaging before the autopsy [10–14], the use of a decompression chamber in order to prevent the dissipation of gas [8] and the adoption of specific autoptic techniques [10,11,15].

Although the relevance of a multidisciplinary approach in investigations concerning diving fatalities is widely discussed among forensic pathologists [16–18], poor cases described in forensic literature are clearly focusing on how the analysis of diving computer records and equipment can contribute to properly determining the cause of death. Such a topic however, should be carefully explored because of the numerous and various legal implications that a diving accident potentially entails.

In this respect, the present study on diving fatalities shows how the cooperation between a forensic underwater expert and a forensic pathologist played a crucial role to interpret radiological findings, guide the autopsy and confirm/deny circumstantial data emerging from investigations. In the following three emblematic cases there were legal issues that the diving technical data were asked to resolve: unsuitability of the equipment (case#1), hit-and-run (case#2), failure to respect diving certification limits and delayed medical assistance (case#3).

2. Case-reports

Three seventy-year-old recreational divers - two males and a female - went diving with friends to the same stretch of sea between June and July. A male was an experienced SCUBA diver with previous myocardial infarction undergoing angioplasty and stent implantation (case #1), while the other one had a history of percutaneous closure of patent *foramen ovale* and numerous previous dives beyond 40 mt limit of his recreational rebreather diving certification (case #2). Both went diving in open water. The female suffered from aortic insufficiency with hypertension and underwent previous upper left pulmonary lobectomy for malignancy (case #3). She went SCUBA diving in a cave. In all three cases, after irregular dives, the victims emerged unconscious and unresponsive to the surface. In case #1 the man presented red-tinged foam exuding from the mouth. In case #2 there was white foam exuding from the diver's mouth. In case #3 the victim was in a face down position with no mouthpiece and white foam exuding from the mouth and nostrils. Despite cardiopulmonary resuscitation (CPR) maneuvers being performed on respective boats, all divers died on the spot.

For all cases the following ascertainments were performed: testing of the equipment, analysis of the dive computer records, PMCT scans and autopsy with histologic and toxicological examinations.

2.1. Testing of the equipment

The equipment was tested by a forensic dive expert in a highly-specialized diving technical center.

Case #1.

SCUBA diving equipment was made up of a 15 liters tank containing air, a buoyancy control device (BCD) jacket, primary first-stage and second-stage regulators, a secondary regulator and a dive computer. (Fig. 1).

Pressure in the tank was 100 bar. Carbon Monoxide (CO) was absent. There were salt crystals in the sintered filter of the first-stage regulator and the second-stage regulator was set to "pre-dive" position, with consequent blockade of Venturi effect despite a diver's inspiratory effort.

The equipment was not the victim's personal property, but a rental.

Case #2.

The equipment included a 12 liters tank containing air, a BCD jacket, a first-stage regulator, two second-stage regulators (primary and emergency) and a dive computer. (Fig. 2).

Pressure in the tank was 170 bar. CO was absent. Primary second-stage regulator was set to "dive" position but balanced in such a way

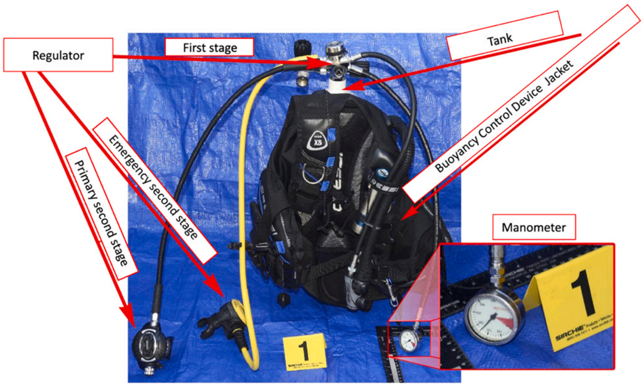

Fig. 2. Equipment in case#2 (SCUBA).

to determine an inhalation effort above the maximum limit required by law.

Case #3.

The rebreather diving equipment consisted of a 3 liters tank containing gas mixture with 19% O_2, 40% He, 41% N (PO_2 1.3 bar), a 3 liters tank containing diluent gas mixture with 18.6% O_2, 41.6% He, a BCD jacket, a solenoid for electronic monitoring system of PO_2, an Automatic Demand Valve for diluent gas supply, a filter and a dive computer.

Alongside the basal structure, the diving equipment included a second dive computer, a secondary oxygen tank with a valve in close contact with the frame, an argon cylinder for the supply of the dry suit, and three bailout cylinders. These last respectively contained oxygen, gas mixture Tx 18.8/37.6 and gas mixture Tx 48/22.9. (Fig. 3).

The main tank had a pressure of 0 bar while the one containing the diluent gas mixture had a pressure of 100 bar. Automatic Demand Valve was closed. The filter was flooded. Following pressures were also measured: 100 bar in the secondary oxygen tank, 130 bar in the bailout tank containing oxygen, 0 bar in the bailout tank cointaining gas mixture Tx 18.8/37.6 and 195 bar in the bailout tank containing gas mixture Tx 48/22.9.

2.2. Dive computer records

Data from the dive computer were downloaded using Subsurface 4.8.5 software and analyzed by a forensic dive expert.

Case#1.

The dive computer registered a maximum depth of 37 mt, total diving time of 27 min and a thermocline of 6.1 °C (from 21.9 °C to 15.8 °C) in 12 min from the beginning to 37 mt of depth. (Fig. 4).

Case#2.

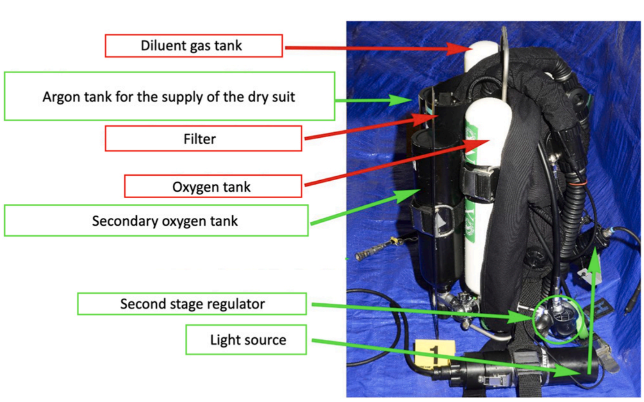

Fig. 3. Equipment in case#3 (rebreather).

The dive computer registered a maximum depth of 31,9 mt and a total diving time of 15 min. (Fig. 5).

Case#3.

The dive computer registered a maximum depth of 58 mt and a total diving time of 110 min. (Fig. 6).

2.3. Radiology

PMCT (Post Mortem Computer Tomography) was performed before autopsy with equipment MSCT (Multi Slice Computed Tomography). 64B Light Speed VCT (GEMS: General Electric Medical Systems). The images were elaborated with AW (Advantage Windows) 4.4 GEMS post-processing workstation to obtain MPR (multi-planar reconstruction), MIP (maximum intensity projection), MinIP (minimum intensity projection) and 3D-VR (3D-volume rendering) reconstructions.

Case#1.

PMCT performed five days later showed air-equivalent attenuation values in the cardiocirculatory system of head and neck, thorax including the lumen of the anterior descending artery's stent (Fig. 7a,b), abdomen and lower limbs. In the maxillary sinus there were hydro-air levels with water sedimentation. Ground-glass opacification and pleural effusion were found in both lungs (Fig. 7c).

Case#2.

PMCT performed three days later revealed hydro-air levels in the maxillary sinus and in the ethmoidal cells (Fig. 8a), moderate air-equivalent attenuation values in the head-neck district, low-density liquid material in the nasopharynx, trachea (Fig. 8b) and main bronchi, ground-glass opacification and pleural effusion in both lungs and liquid material in the stomach.

Case#3.

PMCT performed a day later revealed diffuse subcutaneous emphysema (Fig. 9a) and air-equivalent attenuation values in the cardiocirculatory system of head (Fig. 9b), neck, thorax (Fig. 9c), abdomen and lower limbs. In the maxillary sinus there were hydro-air levels with water sedimentation. Ground-glass opacification and pleural effusion were present in both lungs.

2.4. Autopsy

Post-mortem examination was conducted using specific techniques. In order to detect the presence of air in the circle of Willis, the middle cerebral, basilar and vertebral arteries were isolated and tied before removing the brain, which was then placed under water and the clamps removed to observe the presence of air bubbles escaping from the cut ends of the vessels [15]. The pericardial sac was filled with water, then an incision was made on the left ventricle and according to Richter's technique, on the right ventricle [19]. Histological examination was performed using hematoxylin-eosin stain. Toxicological analyses' results were negative for alcohol and drugs in all cases.

Case#1.

No significant pathological findings were detected during the external examination performed the first day after death. Autopsy performed twelve days later revealed green discoloration of abdomen, scarce air bubbles in the circle of Willis and in the heart cavities. Pleural cavity contained 400 ml of transparent fluid. The heart weighed 370 g and air bubbles were detected in the ventricles. There was a metallic stent in the anterior descending artery. Stenosis of the circumflex artery by atheromatous lesion was present. Patent *foramen ovale* was absent. The lungs weighed 430 g (left) and 520 g (right). No water was detected in the digestive tract. Histology revealed atheromatous plaque in the circumflex artery with loss of 60% of the lumen, fibrosis, stretching and *fragmentatio* of left heart's myofibrils. Acute emphysema, intra-alveolar hemorrhages and some phytoplankton specimens were detected in the histological samples

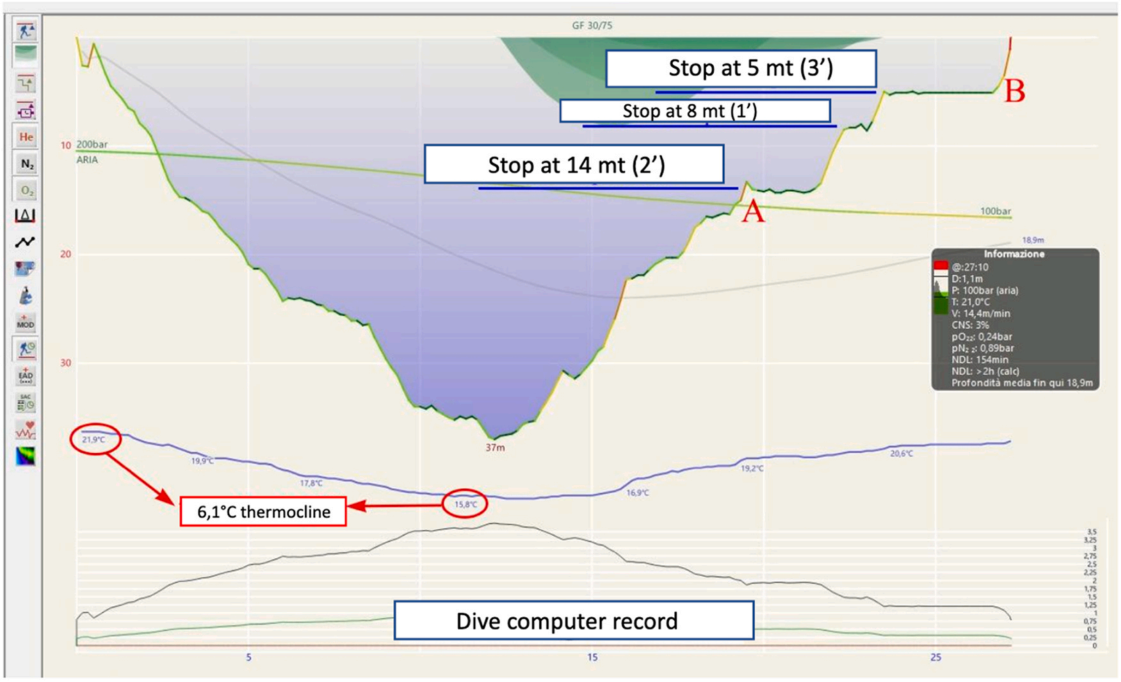

Fig. 4. Dive computer record in case#1.

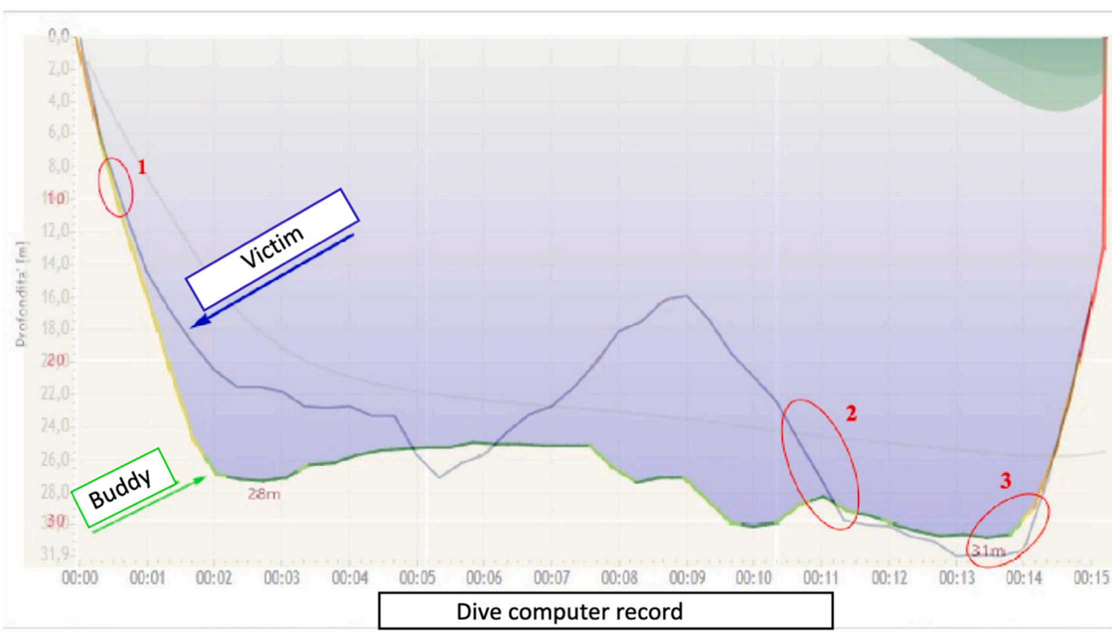

Fig. 5. Dive computer record in case#2.

from the lungs. The cause of death was determined to be an acute cardiac event.

Case#2.

External examination performed the first day after death showed reddish hypostasis in the anterior surface of the neck and shoulders with white frothy fluid exuding through the mouth. Autopsy performed seven days later showed multiple petechial hemorrhages in the inner aspect of the scalp, a few air bubbles in the circle of Willis and frothy fluid in the trachea and main bronchi. The heart weighed 300 g; no air bubbles were detected in the cavities. Patent *foramen ovale* was absent. No evidence of relevant age-related changes or other cardiac diseases consistent with a clear cause of cardiac death was observed [20]. Lungs were 260 g (left) and 500 g (right) of weight. In the left lung there was no upper lobe. The right lung was markedly overinflated and crepitant with frothy fluid exuding from the cut surfaces when squeezed. Water was detected in the small and large intestine. Histological examination showed massive acute pulmonary emphysema, oedema and eosinophilic amorphous material in the alveoli, diffuse myocardial sclerosis. The cause of death was determined to be acute mechanical asphyxia by drowning.

Case#3.

Autopsy performed four days after death showed subcutaneous emphysema in the upper chest and bilateral subpleural emphysema. Mass air bubbles were found in the circle of Willis and in the left side of the heart. The heart weighed 390 g and presented a regularly located-well functioning device closing *foramen ovale*. No evidence

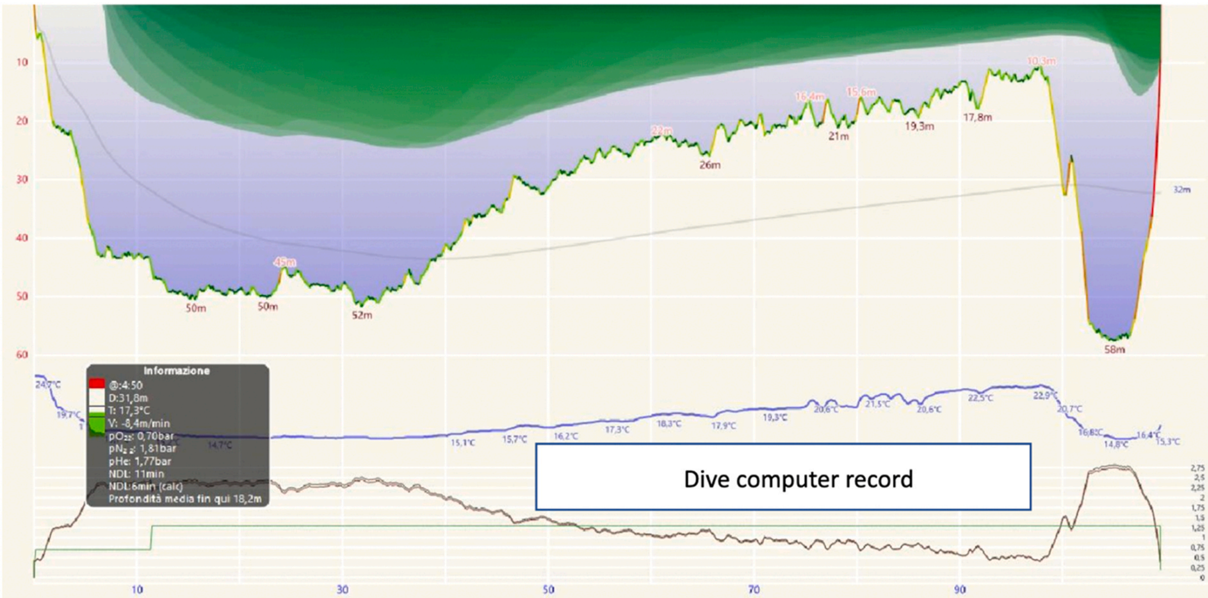

Fig. 6. Dive computer record in case#3.

Fig. 7. PMCT findings in case#1: a) Lumen stent of anterior descending artery (green arrow) with b) air-equivalent attenuation at MinIp reconstruction (orange arrow). c) Pulmonary ground glass opacification.

of relevant age-related changes or other cardiac diseases consistent with a clear cause of cardiac death was observed [20].

Lungs were 720 g (left) and 735 g (right) of weight. No water was detected in the digestive tract. Histological examination showed massive acute pulmonary emphysema, alveolar hematic congestion and diffuse myocardial sclerosis. Toxicological analyses were negative for alcohol and all drug tests The cause of death was determined to be pulmonary barotrauma/massive cerebral age embolism.

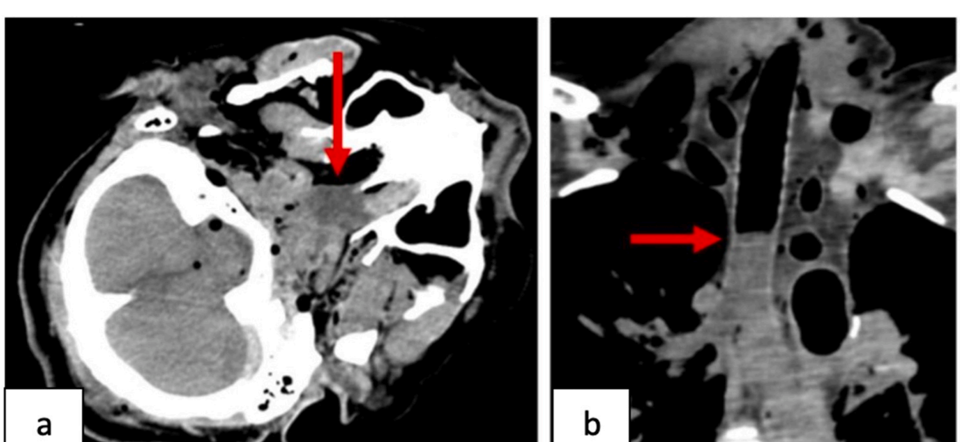

Fig. 8. PMCT findings in case#2: a) Hydro-air levels in the ethmoidal cells (red arrow). b) Moderate air-attenuation values in the trachea (red arrow).

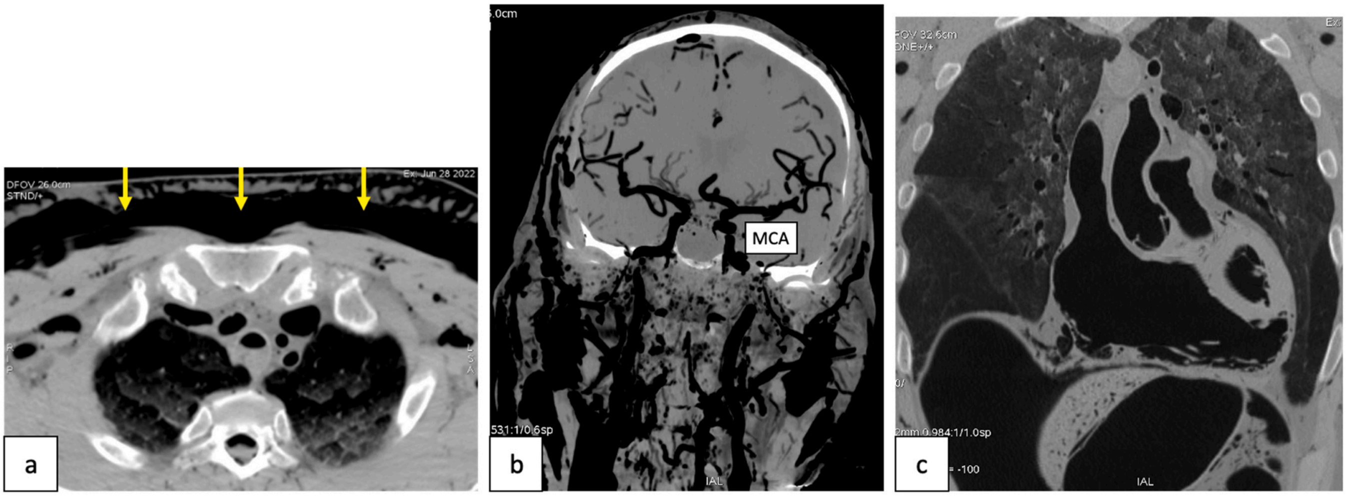

Fig. 9. PMCT findings in case#3: a) Subcutaneous emphysema (yellow arrows). b) Air-equivalent attenuation values in the intracranial circle (MCA: middle cerebral artery). c) Air-equivalent attenuation values in the heart and mediastinal vessels.

Table 1 resumes the main technical, radiological and autoptical findings.

3. Discussion

Nowadays diving accidents represent an increasingly relevant topic in scientific literature. Because of its growing epidemiological impact among recreational practitioners, in fact such an issue is often debated among clinicians focusing on challenging differential diagnosis of pathological disorders that most frequently affect divers and their appropriate treatment [9,21]. International data about diving-related fatalities however, have also led forensic research to pay greater attention to the definition of the cause of death when the victim is a diver. Moreover, in many cases it is on the forensic pathologists and forensic underwater experts' explanation of some legal issues that the prosecution of the investigations depends.

Most literature defines particular autopsy techniques that must be adopted as well as post-mortem imaging's contribution to guide through the dissection [10,11,16]. Edmonds et al. (2014) emphasized logistical and technological problems related to conducting the autopsy at depth in a hyperbaric environment, which has been frequently indicated as the gold standard for detecting gas in the body and avoiding postmortem decompression artifacts [8,11]. Consequent modifications in autopsy techniques include the underwater dissection of brain and heart [10,11]. Casadesús et al. (2018) proposed a strategy to observe the presence of air in the circle of Willis and in the left side of the heart based on the identification and ligation, respectively, of the internal carotid arteries, the superior cerebellar arteries and the basilar artery in the cranial base and of the internal thoracic artery and veins in the second intercostal space lateral to the sternum [15]. Extensive literature also focuses on the diagnostic relevance of radiology in diving accidents [12–14,21,22]. Considering the most frequent causes of death among divers, performing PMCT or at least a chest radiograph before the autopsy has proven to be particularly important in order to further investigate the drowning aspect and the possibility of barotrauma/fatal air embolism [12,14]. Laurent et al. (2014) emphasized the importance of performing PMCT as early as possible, to facilitate the interpretation of intra-arterial gas, which is reasonably excluding putrefaction origin if the CT is conducted within 24 h postmortem and off-gassing with a cut-off time of 3 h postmortem [12]. Relating to postmortem diagnosis of vital gas, Egger et al. (2012) developed the Radiological Alteration Index (RAI), a score (0–100) which is based on the quantification of the grade of gas (0, I, II, III) present in seven sites (heart cavities, liver parenchyma and vessels, left innominate vena, abdominal aorta, kidney parenchyma, vertebra L3, subcutaneous pectoral tissues) as it appears at PMCT. Despite being able to detect gas grade III due to cadaveric alteration in the heart cavities and in the cranial cavity based on cut-off points of > 50 and > 60 respectively, its practical use can be difficult since a RAI over 50 does not exclude that a vital air embolism occurred before the development of postmortem gas [23]. Recent research connects the problem of radiological interpretation of intra-cadaveric gas to difficulties with performing PMCT soon after death and determining the etiopathogenetic role in air production played by post-mortem decompression, resuscitation procedures and decomposition, suggesting to analyze intracardiac CO_2 concentrations to make correct differential diagnosis [24]. Giaconi et al. (2022) proposed to consider the presence of gas within the portal system and the subcutaneous tissues in a medium-high quantity as possible indicators of corpse decomposition, meaning that any presence of intra-arterial gas ultimately cannot be interpreted as of putrefactive or embolic origin [14].

Although the importance of a multidisciplinary approach involving dive experts has been often claimed to be an essential part of the post-mortem diagnostic process, most diving-related fatalities were documented based on witness statements, radiological data and autoptical findings [10,16]. Only in a few cases the technical underwater analysis was properly taken into account [17,25]. Indeed, dive experts do play a crucial role in the determination of the cause of death, especially when PMCT and autopsy results are difficult to interpret. Therefore, not only maximum dive depth and ascent's profile [15,16] but also full dive computer record and technical underwater ascertainments should be reported in detail when discussing diving-related deaths.

For all three cases of diving-related fatalities, the technical analyses of dive profile and diving equipment were carefully discussed by the forensic pathologist and the underwater expert, giving a fundamental contribution to the definition of the circumstances and the cause of the deaths.

Case#2 was about a 70-year-old woman who died after a cave diving with a friend. Technical ascertainments on the dive equipment revealed that the victim's primary second-stage regulator was correctly set on "dive" position but it was calibrated in such a way to actually require an excessive inhalation effort. Analysis of dive computer records for both divers confirmed the buddy's witness reported to have made a regular descent up to 30 mt while the victim slowed down shortly after immersion because she was feeling cold (Fig. 5, number 1). At minute eleven the buddy realized that the

Table 1
Summary of the main technical, radiological and autoptical findings for the three cases (M: male; F: female; MD: maximum depth; TDT: total diving time; CS: cardiocirculatory system; N: negative).

CASE		*#1*	*#2*	*#3*
SEX		M	F	M
AGE (y.o.)		70	70	70
EQUIPMENT		SCUBA	SCUBA	REBREATHER
DIVING TESTING		Salt crystals in the sintered filter. Second-stage regulator in pr-dive position.	Second-stage regulator in dive position requiring excessive inspiratory effort.	Flooded filter Empty main O_2 tank with secondary O_2 tank difficult to reach.
DIVE COMPUTER DATA	MD (mt.)	37	31,9	50
	TDT (min.)	27	15	110
	OTHER	Descent with thermocline of 6.1 °C	First attempt of ascent at 27 mt followed by uncontrolled descent. Relatively rapid ascent to the surface	Extremely rapid ascent to the surface.
PM-CT	AIR IN THE CS	Yes	Yes	Yes
	HYDROAIR LEVELS IN THE SINUSES	Yes	Yes	Yes
	GROUND GLASS OPACITIES	Yes	Yes	Yes
	OTHER	-	Liquid in the airways and in the stomach.	-
EXTERNAL EXAMINATION		Green discoloration of abdomen	Reddish hypostasis in the anterior surface of the neck and shoulders. White frothy fluid exuding through the mouth.	Subcutaneous emphysema in the upper chest and subpleural emphysema.
MACROSCOPIC FINDINGS AT THE AUTOPSY		Air bubbles in the circle of Willis. Overinflation of lungs. Metallic stent and atherosclerosis in the coronary circle, no patent *foramen ovale*.	Petechial hemorrhages in the scalp. Air bubbles in the circle of Willis. Overinflation of the lungs. No patent *foramen ovale*.	Air bubbles in the circle of Willis. Regularly located-well functioning device closing *foramen ovale*.
HISTOLOGY		Atheromatous plaque in the circumflex artery (60%), fibrosis, stretching and fragmentatio of myofibrils.	Acute pulmonary emphysema, oedema, and eosinophilic amorphous material in the alveoli, diffuse myocardial sclerosis.	Massive acute pulmonary emphysema, alveolar hematic congestion, and diffuse myocardial sclerosis.
TOXICOLOGY		Negative	Negative	Negative
CAUSE OF DEATH		Acute cardiac event	Drowning	Pulmonary barotrauma/massive cerebral air embolism

victim was in trouble so she started ascending and at the depth of 28 m to reach for her friend, who panicked and rejected her regulator after two respiratory acts; further attempts to give the victim her regulator back failed because the victim's mouth was shut. After a brief unintentional sinking, the two women started a rapid ascent to the surface. When emerged, the victim was unconscious and unresponsive. The graph (Fig. 5) shows the victim's first solitary attempt to ascend from 27 mt to 16 mt of depth, where she arrived at minute nine, most likely increasingly breathless, considering the respiratory effort required by the equipment. She then proceeded to descend up to 28 mt (Fig. 5, number 2), in the attempt to get her buddy's attention. The final ascent took place after fourteen minutes of immersion from the depth of 31,5 mt (Fig. 5, number 3) and occurred simultaneously for both divers. Despite being relatively limited, the presence of gas in the circle of Willis and the final relatively rapid ascent to the surface suggest the hypothesis of CAGE. However, PMCT detection of hydro-air levels in the sinuses, liquid in the upper airways, bronchi and stomach, as well as the autoptic findings of white frothy fluid in the air passages and emphysema *aquosum* made the diagnosis of drowning the most probable. Petechial hemorrhages in the scalp, absence of air bubbles in the left side of the heart and histological evidence of acute pulmonary emphysema with eosinophilic amorphous material in the alveoli were confirmatory. Moreover, since the ascent of both divers was faster than expected, the conclusion was that the buddy put herself in danger in the effort of saving the victim's life and no hit-and-run occurred. Technical report's contribution was crucial to the determination of circumstantial data and to elaborate an accurate reconstruction of the diving accident with focus on the victim's last moments before death.

In case#3 the data of an extremely rapid ascent of the victim to the surface was reported by all witnesses and confirmed by the dive computer record, which registered a maximum speed of 60 mt/min (Fig. 6). Both radiology and autopsy contributed to determine pulmonary barotrauma/massive cerebral air embolism to be the cause of death, as the presence of gas bubbles in the cardiocirculatory system of brain and left heart detected by the PMCT was confirmed at post-mortem examination and emphysema was both a macroscopic (subcutaneous) and microscopic (subpleural, pulmonary) finding. Furthermore, the victim's diving history included numerous dives beyond the depth limit of his certification, therefore a proper reconstruction of the accident was particularly important to determine if careless circumstances lead to his death The presence of a secondary oxygen tank (Fig. 3) confirmed the victim's purpose to dive beyond the limit of 40 mt of depth even that day. According to the witnesses and the dive computer record (Fig. 6), in particular, after ninety-eight minutes of regular descent, bottom time and ascent, the victim told his buddy that he would have extended by a few minutes the safety decompression stop at the depth of 12 mt and made an "OK" sign. Left alone, he realized that the main oxygen cylinder was empty - technical analysis detected a pressure of 0 bar - and tried to access the additional one with no success because this was extremely close to the equipment's frame. As a result, he rapidly sank up to 33 mt of depth with rupture of the Automatic Demand Valve's membrane and consequent flooding of the filter, ultimately reaching a maximum depth of 58 mt. Afterwards, using the BCD jacket, the diver made an excessively rapid ascent to the surface, as shown by the last part of the graph (Fig. 6). Because of the high mortality rate of massive cerebral air embolism and the prompt start of CPR maneuvers, the conclusion was that no medical negligence occurred in this case. While being fundamental to support radiological and autoptic findings as well as circumstantial data in case#2 and case#3, the study of dive computer record and equipment proved to be crucial for the determination of the cause of death in case#1. According to the dive's history, during the ascent at the depth of 14 mt, the victim reported discomfort by pointing to his chest. In response to this act the team immediately stopped to allow him some time for recovery before proceeding in response to his "OK" sign. After the regular safety stop at 5 mt depth, the ascent was completed and the man emerged unconscious and unresponsive to the surface. PMCT performed five days after death for judicial matters showed high amounts of air bubbles in the cardiovascular system, including that of brain and heart. As the presence of intravascular gas is common in diving fatalities, hypotheses of barotrauma/CAGE, post-mortem off-gassing and decomposition were taken into account. At first, dive computer records (Fig. 6) excluded an uncontrolled ascent to the surface, confirming that the victim made a regular ascent and three stops before reaching the surface: one of 3 min at 14 mt, where the witnesses said that he reported discomfort; another of 1 min at 8 mt and the last one of 3 min at 5 mt. Moreover, considering that each 10 mt depth of water increases the pressure by one atmosphere [8], in an ascent from 37 mt (corresponding to 4,7 ata) to 14 mt (corresponding 2,4 ata) the ratio is less than 2:1 so the pressure change is not sufficient to determine a pulmonary barotrauma. A dive up to 37 mt lasting 27 min however, is deep and long enough for a significant amount of nitrogen to get dissolved in the vessels. As the presence of gas in muscles and joints is not easily detectable when gas is present in large volumes with wide distribution as in this case, it may not be possible to exclude that off-gassing phenomenon occurred. In addition, a post-mortem interval of five days was long enough for the gas to come out of solution and reach both arteries and veins. Finally, since the body was refrigerated soon after death and the corpse did not present external signs of decomposition when PMCT was performed, the conclusion was that the presence of gas was mainly due to post-mortem decompression artifacts and had not played any contributory role to the victim's death. The autopsy showed transparent pleural effusion, normal-weighing heart and lungs and a 60% atherosclerotic stenosis of the circumflex artery. No frothy fluid in the air passages and emphysema *aquosum* were found. As already discussed by Sadler et al. (2013), sudden death from natural causes is often inappropriately attributed to drowning simply due to its occurrence in the water [18]. A major contribution to differential diagnosis comes from circumstantial data which must be confirmed by dive computer records. In this case, no apparent struggle was reported by the buddies and the graph (Fig. 4) excluded an involuntary sinking as opposed to case#2 (Fig. 5) and case#3 (Fig. 6), suggesting that the diver did not panic. Moreover, no additional factors that could have interfered with normal diving in such an expert swimmer were identified. Technical ascertainments on the equipment assured that it was functioning well except for salt crystals in the sintered filter of the first-stage regulator and the "pre-dive" position of the second-stage regulator. While considered to not be sufficient to cause loss of consciousness, in fact those anomalies could have contributed to increase the victim's respiratory effort. Considering the history of myocardial infarction and microscopic heart findings, the cause of death was determined to be an acute cardiac disease. Thermocline-induced vasospasm could have been a contributing factor. The witnesses' report of red-tinged froth exuded from the victim's mouth when he reached the surface was consistent with a profuse pulmonary oedema of cardiac origin. As the equipment was not the victim's personal property, further investigations were ordered by the prosecutor to determine if the rental company was responsible for poor maintenance.

4. Conclusions

In conclusion, technical analysis of dive computer records and diving equipment is a fundamental step in the definition of the cause of death in diving fatalities. All diving computer data, and not only those related to maximum depth and ascent's profile, should be taken into account in detail, and the immersion graph carefully studied by both the forensic pathologist and the underwater expert. Moreover, as SCUBA and rebreather are based on different mechanisms of functioning, the underwater expert should be called upon to explain to the pathologists how the equipment normally works even if testing has excluded the presence of irregularities.

In cases where PMCT and autopsy give revealing results, diving technical analyses contribute to confirm and explain the forensic pathologis's conclusions. In presence of uncertain or poorly specific radiological and autoptical findings, a proper reconstruction of the diving accident is requested, in order to detect artifacts and make a correct differential diagnosis among the multiple possible causes of death in divers. Finally, the diving technical data often play a crucial role to explain any legal issue related to the circumstances of death, leading the prosecutor to further investigations.

Conflict of interests

Authors declared no conflict of interests.

Ethics approval

Data were acquired as part of a forensic judicial investigation and in accordance to Italian Police Mortuary Regulation.

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CRediT authorship contribution statement

Ilaria Tarozzi: Conceptualization, Data curation, Writing – original draft preparation, Writing – review & editing. **Lorenzo Franceschetti:** Corresponding author, Methodology, Data curation, Writing – review & editing. **Gianfranco Simonini:** Validation, Methodology, Data curation. **Silvia Raddi:** Writing – original draft preparation, Data curation. **Davide Machado:** Validation, Methodology, Data curation. **Valentina Bugelli:** Writing – original draft preparation, Writing – review & editing, Conceptualization, Data curation, Supervision.

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