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CASE REPORT

The use of dive computers in forensic investigations of fatal breath-hold diving accidents: a case study

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Abstract
Freediving is a type of diving in which divers rely solely on how long they can hold their breath underwater during their dive, which is why it can also be referred to as 'breath-hold diving'. Unlike scuba (self-contained underwater breathing apparatus) diving, individuals do not require training or licencing to perform freediving and may not be aware of the risks of this activity. This paper presents a case in which coastguards retrieved a free diver's lifeless body from the seafloor. In most cases such as this, the deceased individual's cause of death would be ruled as drowning. With the deceased diver's dive computer, we concluded that a shallow water blackout caused him to drown. Data from the dive computer were extracted, graphed, and analysed to explain how a skilled swimmer and diver drowned on one of his seemingly ordinary diving trips. The dive computer can be the sole witness to a fatal dive event and provide invaluable information to forensic scientists since the diver is almost always alone. To our knowledge of the available literature, dive computers have been used in scuba diving fatality investigations; however, we believe that they have not been used in death investigations of breath-hold divers. Deficient or hasty conclusions are often based solely on autopsy findings without data collected by diving technicians and investigators. It is crucial to wait to draw conclusions until all possible dive information has been gathered and studied. This study discusses the deficiency in presenting a reasonable idea to the grieving family and friends of how their beloved relative could have drowned even though he was known to be a fit and skilled diver and avid swimmer.

Keywords Breath-hold diving · Freediving · Diving investigations · Shallow water blackout · Dive computers

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Breath-hold diving

Freediving, known as 'breath-hold diving' or 'freediving', includes diving without using a breathing apparatus or an external air source. It is an increasingly popular recreational and competitive sport, with several disciplines for the maximum duration, distance, or depth performed on a single breath [1]. It involves diving for food or shell collection, spearfishing, snorkelling, underwater photography, or mere competition to reach greater depths or stay underwater longer [2].

In breath-hold diving, physiological and psychological stress can develop rapidly by unexpected environmental changes such as currents, temperature, waves, aquatic fauna, and other activities with higher consumption of oxygen reserves [3].

Freediving and spearfishing require no licensure. Free divers are usually less educated than scuba (self-contained

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underwater breathing apparatus) divers regarding dangers and precautions during their dives [2].

Investigators and medical examiners must have a basic knowledge of diving physiology and the techniques used to draw correct conclusions about causes and manners of death [4]. In most diving-related fatalities, the cause of death is labelled ‘drowning’ as a standard practise. Even though this statement is true, it is often disappointing and inconvenient for the family and friends of the deceased and for the diving and licencing agencies, investigators, and dive researchers who wish to prevent such problems in the future [5].

Diving computers

Diving computers are now considered standard equipment, especially for scuba divers, that accurately show and store the details of a dive (depth, time, rate, number of descents, decompression states and stress, anticipated profiles, temperature, gas pressure, and oxygen consumption). Using appropriate software, retrieval is performed of the diver’s history, level of expertise, inexperience, heart rate, and difficult or prolonged diving situations. A qualified technician can download these data, and this is performed for the deceased diver, fellow divers, and the rescue team [6].

Freediving with additional tasks or stress can push the diver’s limit to go down deeper than planned or stay longer [7, 8]. The human body’s response to freediving undeniably impacts its performance and well-being [9]. In freediving, the most significant physiological changes in the human body are caused by dive time and depth [10].

In 1983, Karl Huggins developed the first underwater dive computer for commercial use [11]. Almost all scuba divers now wear dive computers on their wrists [12], in addition to the growing numbers of skin divers. Dive computers convert ambient pressure variations to depth estimates in terms of water density [13]. Dive computers determine factors that may have affected the deceased individual’s cause of death, such as shallow water blackout, pulmonary barotrauma, aspiration, pulmonary oedema, and decompression sickness [14]. In addition, data from previous dives can give an idea of the diver’s experience, fitness, attained depths, and capacity for breath holding [15].

Breath-hold diving physiology

A person can hold his breath for 30 to 90 s. A trained free diver can stay underwater for over 6 min (world records: 11:35 for males, 9:02 for females). The main factors that affect the period of breath holding are lung volume, oxygen consumption rate, and tolerance to carbon dioxide gas [16].

Even without hyperventilation before diving, hypoxemia and fainting may occur, usually during the last metres of ascent, a condition that is referred to as ‘hypoxic shallow water blackout’, ‘ascending blackout’, ‘hypoxia of ascent’ or misleadingly ‘deep water blackout’. *Shallow water blackout* is the loss of consciousness in the diver usually preceded by hyperventilation during a breath-hold dive after excluding other aetiologies of unconsciousness. It can affect even well-trained and experienced individuals [17].

Hyperventilation before diving lowers arterial partial carbon dioxide (CO_2) pressure. It increases the alveolar and arterial oxygen concentration and delays the urge to breathe, which increases when the partial pressure of CO_2 is between 45 and 60 mm Hg [18].

When the diver descends, the high pressure results in increased alveolar and arterial pressures of O_2 (PAO_2 and PaO_2, respectively) sufficient to maintain consciousness, with the progression of dive hypoxemia developing with depletion of O_2 reserves without a considerable rise in the arterial pressure of carbon dioxide ($PaCO_2$) to trigger inspiration. When starting to ascend, PAO_2 drops rapidly, exacerbating the hypoxemia already present and creating a hazard for hypoxic loss of consciousness a few metres near the water’s surface. Consequently, the diver starts to drown and cannot keep his airways clear, aspiration and swallowing of water takes place, leading to cardiac arrest within a few seconds to minutes [17, 19].

Slight variations in depth may lead to substantial changes in pressure. For every 10 m of depth, the atmospheric pressure increases by 1 bar (750 mmHg). Boyle’s Law (pressure × volume = constant) implies that the air volume in a breath-hold diver’s lungs is halved if the diver reaches 10 m of water depth [20, 21].

Case study

Circumstances of death

A 24-year-old healthy young man went spearfishing on a private boat with a group of friends; all were experienced divers, whilst his wife stayed on board. The incident took place in February 2011, when they dove around Moon Island in Dubai. It was a windy day with 1–2-m waves, the water temperature was 25 °C, and the underwater visibility was approximately 10 m, dropping to 2–3 m near the seafloor. The divers dove in couples in a series of breath-hold dives; the deceased diver was accompanied by his lifelong friend, who reported that he ascended before him and waited for him to follow, but he did not. They searched for him, recorded the coordinates, and called for help. His body was retrieved hours later, was unable to be resuscitated, and his belt was removed and then transferred to Dubai Mortuary.

Post-mortem examination

On external examination, the body was dressed in a 3-mm neoprene diving suit that the paramedics cut during the resuscitation

Fig. 1 The dead diver wearing his dive suit after it was cut during resuscitation

process with some seafloor gravel and sand attached to it; his hair, mouth, and nostrils were also soiled with seafloor debris. The diving wrist computer was retained for further examination.

Pre-autopsy radiographs showed no signs of fractures or pathologic changes; fingerprints were sent to the crime lab for identification. Body fluids were collected for toxicological screening.

Fig. 2 Froth from mouth and nostrils; the identification cards and eyes were obliterated for ethical and confidentiality considerations

Table 1 Summary of the three consecutive dive dates reported on the dive computer

Dive History

Free dive history

	Longest dive		Deepest dive					
Date	Max. depth	Dive time	Max. depth	Dive time	Total dive time	Total dives	Avg. depth	Cumulative divetime
28/01/2011	9.4 m	12:01:32 ص	9.7 m	12:01:27 ص	12:31:59 ص	26	7.5 m	12:31:59 ص
18/02/2011	7.4 m	12:01:17 ص	8.9 m	12:01:10 ص	12:33:14 ص	38	5.8 m	01:05:13 ص
25/02/2011	15.7 m	12:01:29 ص	16.4 m	12:01:19 ص	12:23:21 ص	22	9.1 m	01:28:34 ص

External examination showed signs of submersion and profuse bloody froth from the mouth and nostrils. No palpable crepitus was felt in the upper torso, and the gross morphology of the skin was void of any signs of injuries from poisonous marine fauna. The body was in a well-established rigour mortis status, and livor mortis was unobservable by the compressing neoprene wetsuit (Figs. 1 and 2).

The autopsy showed congestion of most internal organs and moderately bulky lungs (1570-gm weight) with slight pleural effusion. Pink froth and exudate were noticed within the larynx, trachea, bronchial lumens, and cut lung tissue sections. Eight millilitres of red-coloured serous fluid were collected from the sphenoid sinuses. No signs of internal trauma were recorded.

Toxicological results were negative for alcohol, illicit drugs, commonly prescribed medications, and an array of poisonous substances.

Analysis of dive computer recordings

The deceased individual's dive computer was taken to the head of the technical department of the brand dealer (Suunto), where all the data were extracted, graphed, analysed, and compared with previous data on the same computer.

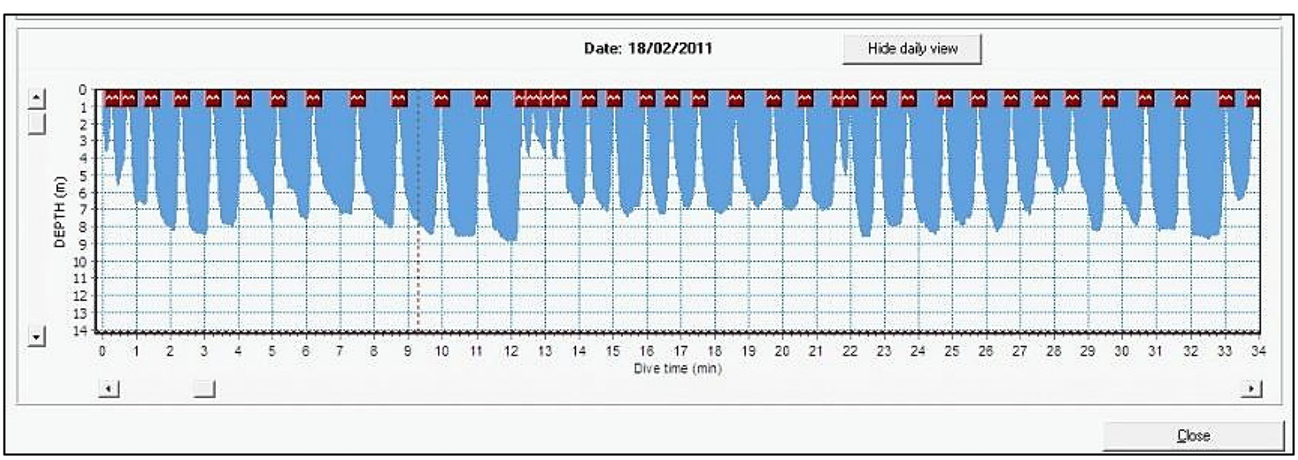
In the current study, the downloaded dive portrait was built up from the actual diving accident recorded by the deceased individual's wrist diving computer, a 2010 Suunto D4i model. This model of computer is a temperature-compensated pressure sensor, calibrated according to EN 13319 (functional and safety standards for depth gauges); when set on gauge mode for freediving, it shows profile data of the most profound estimated depth ever recorded in 1-, 2-, and 5-s intervals, with an accuracy of ± 1% of the full scale at 0 to 100 m/328 ft and 20 °C/68 °F (per EN 13319) [22].

The deceased individual's dive computer was set to gauge mode with a free dive recording rate of 1 s (the highest sampling rate). In this record format, it is doubtful that the depicted descent and ascent profiles differed from his actual descent and ascent rates.

Data on the dive history extracted from the computer (Table 1) showed that the total number of dives of the deceased individual on 28/01/2011 [1 month before] was 26. The deepest dive he performed that day was 9.7 m, and the average depth was 7.5 m.

The graph representation of the same dive (Graph 1) shows the pattern, depth, and duration of each dive during the day. Note that the diver starts the dive at zero depth on the graph, descends, and an amount of time elapses, after which he ascends, as represented by the blue troughs on the chart.

Another graph extracted from the computer (Graph 2) shows the details of dive number 21 on that day and number



Graph 1 The pattern of the dives on a particular day

Suunto Dive Manager 3.0.0 ٢٨/٠٢/٢٠١١

85. 25/02/2011 10:32:23 Õ

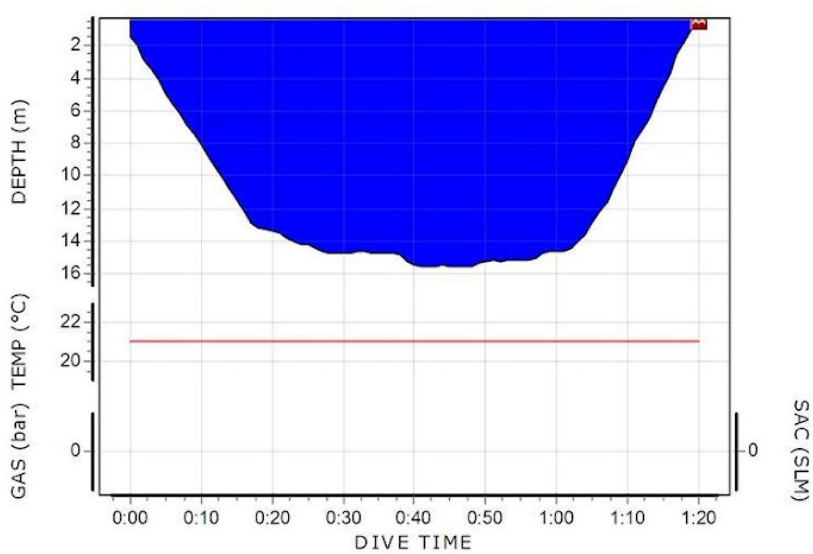
Information from dive computer

Dive no.	**85**	DC Dive no.	**21**	Sampling Rate	**1 sec**
Start time	**25/02/2011 10:32:23 Õ**	Surface Interval	**00:02:00**		
End time	**25/02/2011 10:33:43 Õ**	ID no.	**94505010**		
Dive time	**00:01:20**	Model	**D4**	Dive type	**Free**
Max depth	**15.6 m**	Personal info	**Suunto Diver**	Alarms Recorded	**1**
Oxygen Percent	**21%**			OLF	

Weather		Temperatures		Buddy
Visibility		Start of dive	**21 °C**	Boat name
Weight used	**0 kg**	Max depth	**21 °C**	Dive Master
Dive gear		End of dive	**21 °C**	Custom 1
				Custom 2
				Custom 3
				Custom 4
				Custom 5

Cylinders

Cylinder size	Oxygen Percent	Start	End	Average depth	SAC Rate	Gas used Pressure used	Gas used Rate used	Gas used Volume gas used
12 liters	**21%**	**0 bar**	**0 bar**	**11.7 m**	**0 SLM**	**0 bar**	**0 bar/min**	**0 liters**



Tissue saturation on start

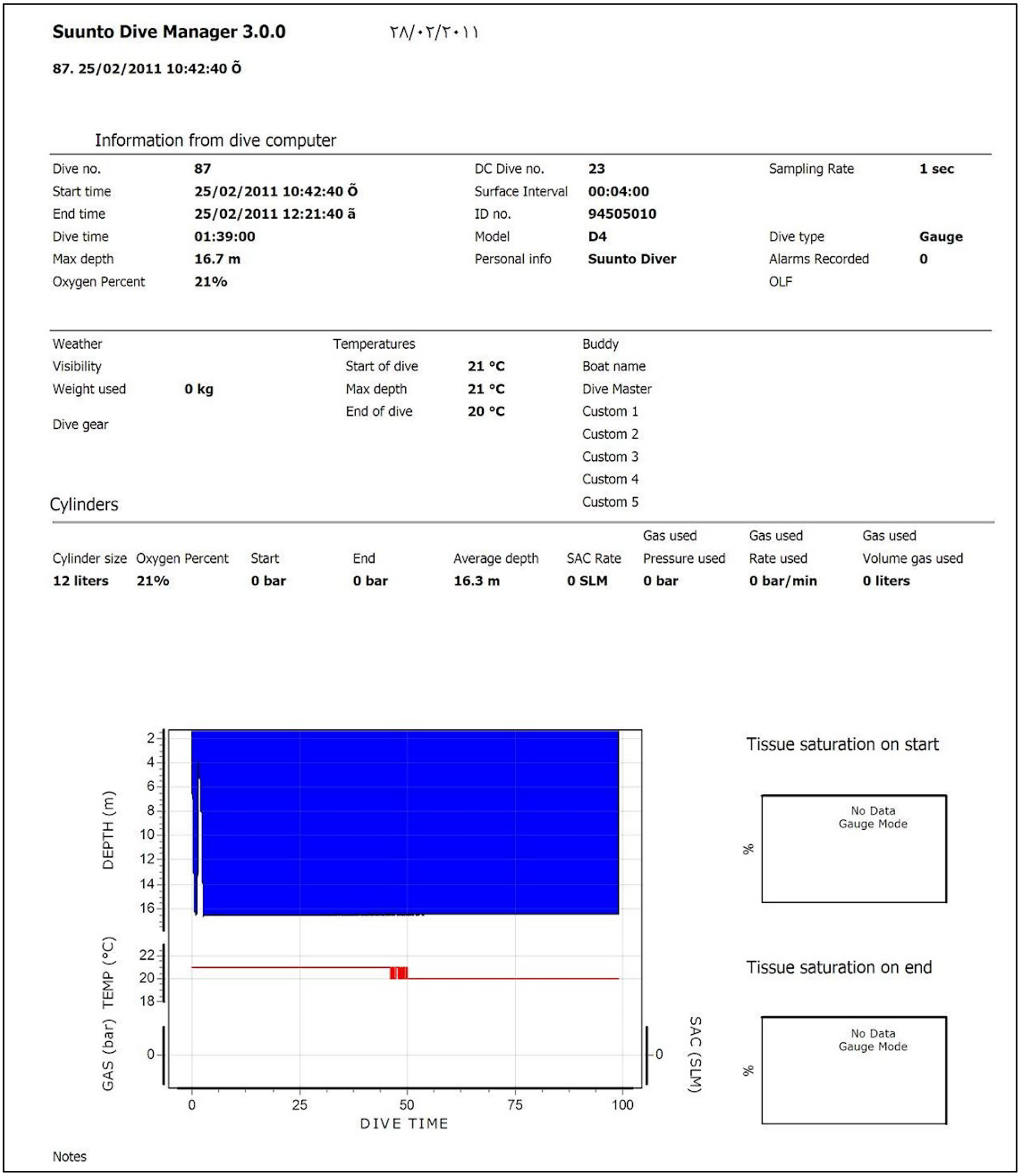
% No Data Gauge Mode

Tissue saturation on end

% No Data Gauge Mode

Notes

Graph 2 The details of a regular dive that preceded his demise



Suunto Dive Manager 3.0.0 ٢٨/٠٢/٢٠١١

87. 25/02/2011 10:42:40 Õ

Information from dive computer

Dive no.	**87**	DC Dive no.	**23**	Sampling Rate	**1 sec**
Start time	**25/02/2011 10:42:40 Õ**	Surface Interval	**00:04:00**		
End time	**25/02/2011 12:21:40 ã**	ID no.	**94505010**		
Dive time	**01:39:00**	Model	**D4**	Dive type	**Gauge**
Max depth	**16.7 m**	Personal info	**Suunto Diver**	Alarms Recorded	**0**
Oxygen Percent	**21%**			OLF	

Weather		Temperatures		Buddy
Visibility		Start of dive	**21 °C**	Boat name
Weight used	**0 kg**	Max depth	**21 °C**	Dive Master
		End of dive	**20 °C**	Custom 1
Dive gear				Custom 2
				Custom 3
				Custom 4
Cylinders				Custom 5

Cylinder size	Oxygen Percent	Start	End	Average depth	SAC Rate	Gas used Pressure used	Gas used Rate used	Gas used Volume gas used
12 liters	**21%**	**0 bar**	**0 bar**	**16.3 m**	**0 SLM**	**0 bar**	**0 bar/min**	**0 liters**

Notes

Graph 3 The final dive of the deceased

85 recorded on the watch with a sampling rate of 1 s. It shows the type of dive (free) with the exact time (start and finish), the dive duration, the surface interval between this dive and the preceding dive, and the maximum depth attained for that dive. Note that here, there was one single dive that lasted for 120 s and reached a maximum depth of 15.6 m.

Graph 3 shows the deceased diver's final dive (dive number 87 recorded on the computer and dive number

23 on 25/02/2011); he started descending from the surface of the water at 10:42:40 AM to reach a maximum depth of 16.7 m. The dive portrait extracted from the computer draws the first thin blue trough representing the first descent; as per the following crest of the picture (his ascent), he did not reach the surface of the water and started to descend once more to the seafloor where he stayed until his body was retrieved by the coastguard. The graph postulates that an incident occurred just below the surface, preventing the diver from reaching the surface. The watch's memory became full after 2 h of recording all the parameters every second, so there were no records of ascent during body retrieval.

It should also be noted that the diver was wearing a diving belt with 8 kg of lead metal set as a weight to counteract his positive buoyancy caused by his lungs, body fat, and neoprene dive suit. If not retrieved by the coastguard, his body would have stayed pinned down on the seafloor for an extended period until putrefaction began.

We believe that a shallow water blackout can explain the death of the breath-hold diver; this is supported by the data extracted from the deceased diver's dive computer. As mentioned above, the diver descended from the surface of the water, reaching a topmost depth of 16.7 m (Graph 3), which was much higher than his average dives, as shown in the history of previous dives. Unconsciousness ensued just below the surface of the water with maximum expansion of the lungs. The unconscious diver started inhaling water to replace the air in his lungs with loss of protective body reflexes.

The value of the dive computer is also supported by a previous study by Sayer and Azzopardi, who mentioned that downloaded data could be of great value in accidents, especially when the diver is alone during the last moments of his dive or when there are conflicting reports from witnesses or the diving organisations [23].

Conclusion and recommendations

Investigating a diving-related fatality is always a challenge for any medicolegal examiner or forensic pathologist. Insufficient or erroneous conclusions are built on autopsy findings without the advice of a dive technician, researchers, or treating medical practitioners. The deficient conclusion that a diver died due to drowning provides noncompetent clarification of the cause of death and is generally not accepted by all concerned parties. Getting to the root cause of why he drowned is very important, and in this case, the dive computer provided critical information to achieve that goal.

Investigating diving accidents is an interdisciplinary task. A conventional autopsy is essential to rule out other possible causes of death. Additionally, an essential understanding of the physiology of diving is required to properly understand the circumstances before issuing an accurate death certificate. A professional examination of diving gear and the diving computer, if it was worn by the free diver, can give appropriate data to aid a forensic pathologist in reaching a conclusion regarding fatal diving accident causes of death. Conclusions must be delayed until all available dive information has been collected, explored, and studied.

Key points

1. Investigating diving accidents is an interdisciplinary task.
2. Dive computers, when available, should be used in all diving fatality investigations.
3. Understanding each dive's detailed description and circumstances is crucial before issuing an accurate death certificate.
4. Breath-hold diving death can be caused by a hypoxic shallow water blackout.

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Data availability All data generated or analysed during this study are included in this published article.

Declarations

Informed consent and ethical approval The study was approved by the Dubai Police's research and ethics committee (Forensic Laboratory).

Conflict of interest The authors declare no competing interests.

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