Diving Accident Evacuations by Helicopter and Immersion Pulmonary Edema

Laëtitia Corgie; Nicolas Huiban; Jean-Michel Pontier; François-Xavier Brocq; Jean-François Boulard; Marc Monteil

BACKGROUND: Scuba diving activities expose divers to serious accidents, which can require early hospitalization. Helicopters are used for early evacuation. On the French Mediterranean coast, rescue is made offshore mainly by a French Navy "Dauphin" or at a landing zone by an emergency unit EC 135 helicopter.

METHODS: We retrospectively analyzed diving accidents evacuated by helicopter on the French Mediterranean coast from 1 September 2014 to 31 August 2016. We gathered data at the Center for Hyperbaric Medicine and Diving Expertise (SMHEP) of the Sainte-Anne Military Hospital (Toulon, France), the 35 F squadron at Hyères (France) Naval Air Station, and the "SAMU 83" emergency unit (Toulon, France).

RESULTS: A total of 23 diving accidents were evacuated offshore by "Dauphin" helicopter and 23 at a landing zone on the coast by EC 135 helicopter without hoist. Immersion pulmonary edema (IPE) accounted for one-third of the total diving accidents evacuated by helicopter with identified causes. It was responsible for at least half of the deaths at the dive place. A quarter of the rescued IPE victims died because of early cardiac arrest.

DISCUSSION: Helicopter evacuation is indicated when vital prognosis (IPE and pulmonary overpressure in particular) or neurological functional prognosis (decompression sickness) is of concern. IPE is the primary etiology in patients with serious dive injuries that are life-threatening and who will benefit from helicopter evacuation. A non-invasive ventilation device with inspiratory support and positive expiratory pressure must be used, in particular for IPE.

KEYWORDS: immersion, pulmonary edema, diving accident, helicopter rescue, medical evacuation.

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Scuba diving activities expose professional, military, and sport divers to serious accident, which can require early hospitalization without delaying access to a hyperbaric center and an emergency unit. In this context, helicopter is the way of choice for diving accident early evacuation. It is indicated when the vital prognosis, immersion pulmonary edema (IPE), and pulmonary overpressure in particular, or the neurological functional prognosis in decompression sickness (DCS) is of concern. On the French Mediterranean coast, rescue can be made mainly offshore by a French Navy (FN) 365 N "Dauphin" helicopter of the 35 F squadron at Hyères (France) Naval Air Station or at a landing zone by an emergency unit EC 135 helicopter not equipped with a hoist. These patients evacuated by helicopter are mostly admitted in the very large referral hyperbaric center (SMHEP) at Sainte-Anne Military Hospital (Toulon, France). This is the first hyperbaric center in France and in Europe for diving accidents, covering about 110 diving accidents per year.

METHODS

The objective of this work was a retrospective epidemiological study concerning patient observations of diving accidents evacuated by helicopter from 1 September 2014 to 31 August 2016, gathering data at the Center for Hyperbaric Medicine and Diving Expertise (SMHEP) of the Sainte-Anne Military Hospital (Toulon, France), the 35 F squadron at Hyères (France) Naval Air Station, and the "SAMU 83" emergency unit (Toulon,

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France). We studied patient observations in order to specify the type and the gravity of these diving accidents, on the one hand for those taken care of offshore by the FN "Dauphin" helicopter and secondly for those evacuated to a landing zone at the coast by the EC 135 helicopter of the "SAMU 83" emergency unit. The study was approved by our Institutional Review Board and complied with the review board regulations.

RESULTS

We characterized diving accidents evacuated offshore by the "Dauphin" helicopter and compared them over the same period with those evacuated to a landing zone for the EC135 helicopter without a hoist. From 1 September 2014 to 31 August 2016, diving accidents offshore evacuated by an FN "Dauphin" helicopter ($N = 23$) accounted for 17% of the rescue missions ($N = 138$). Among the 138 offshore rescue missions, in 63% of cases rescued persons were safe and sound ($N = 87$); rescue missions with injured people ($N = 51$) were mainly triggered by diving accidents (41%) (**Table I**).

There were 23 diving accidents handled offshore with the FN "Dauphin" helicopter (**Table II**). All types of diving were made with air gas, except one with a rebreather with Trimix mixture (oxygen, nitrogen, and helium).

IPE was the most common cause of diving accidents picked up offshore ($N = 8$). Five were evacuated to the hospital: four men and one woman. Four had a significant rise in troponin and one had troponin at the limit of normal. Between these four with increased troponin, two had normal echocardiography and two had myocardial dysfunction. In particular, one 39-yr-old woman presented with a left ventricular ejection fraction of 20%. Two patients had normal coronary angiography. Finally, three men died of early cardiac arrest caused by IPE, whose diagnosis was confirmed by autopsy. The age of subjects who suffered from IPE ranged from 39 to 74 yr, with an average of 59 yr.

Five evacuated victims suffered from a biochemical diving accident. Four of them presented with benign hypercapnia, but with the initial symptomatology of headache and vomiting. One was taken care of after an oxygen toxicity seizure during a dive with rebreather and Trimix gas. This one was complicated by a pulmonary overpressure with cerebral and generalized aeroembolism, then drowning, and finally asystolic cardiac arrest and death. The age of subjects suffering from biochemical diving accidents ranged from 30 to 65 yr, with an average of 46 yr.

There was also one DCS with capillary leak syndrome and hypotension, one drowning after epileptic seizure in a patient with an epileptic medical past, and one asthenia. Five etiologies could not be specified, among which were three deaths at the dive, including two autopsy reports not found and an autopsy not realized due to an altered body, and two medical records could not be studied (unspecified destination).

About the seven dead patients, six died immediately at the dive place by early cardiac arrest, including three IPE confirmed by autopsy and three with unspecified etiologies. One other died in hospital after an oxygen toxicity seizure complicated by cerebral and generalized aeroembolism, pulmonary overpressure and drowning, followed by asystolic cardiac arrest.

There were 23 diving accidents handled on a coast landing zone by emergency service "EC 135" not equipped with a hoist (Table II). All dives were with air gas. Among them, 15 patients had DCS: 13 men and 2 women. Those included nine medullary neurological patients, four vestibular complaints (inner ear), one pulmonary patient, and one cutaneous and articular bend case associated with discomfort. The search for right-left shunt in these patients was positive nine times, probable once, negative three times, and unspecified twice. The age of patients suffering from DCS ranged from 37 to 73 yr, with an average age of 53 yr.

There were five IPE victims: three men and two women. One had an electrocardiographically demonstrated myocardial ischemia, one had a troponin elevation with altered left ventricular ejection fraction and mild hypokinesia, and two had normal troponin. The age of these subjects ranged from 40 to 66 yr, with an average age of 52 yr.

Table I. Breakdown (%) by Type of Pathology of Offshore Rescue Missions ($N = 51$; FN "Dauphin" Helicopter), September 2014–August 2016.

TYPE OF PATHOLOGY	PERCENTAGE (%)
Diving accident	41.2
Traumatic	13.7
Digestive	11.8
Cardiovascular	11.8
Environmental	11.8
Neurological	5.9
Pulmonary	2.0
Psychiatric	2.0

Table II. Comparison of Type of Diving Accident Evacuated by Helicopter ($N = 46$) According to the Aircraft Used, September 2014–August 2016.

	OFFSHORE FN DAUPHIN ($N = 23$)	LANDING ON THE COAST SAMU 83 EC 135 ($N = 23$)
IPE	8	5
Biochemical	5	0
DCS	1	15
Drowning	1	0
Asthenia	1	0
Panic attack	0	1
Isolated procedure error	2	2
Unspecified	5	0

IPE: immersion pulmonary edema; DCS: decompression sickness.

DISCUSSION

The French Sportive Federation of Scuba Diving (FFESSM) recorded about 400 diving accidents each year along with 10 to 20 deaths.[12] The Mediterranean French coast is the premier national diving area with 300,000 dives per year. It includes much sought after high-quality dive sites, with deep wrecks beyond 40 m (131 ft), near the coast. Between 1998 and 2002, the average age of divers increased. During this period, the group of divers over 41 yr of age increased by 20.8%.[9] The group from 31 to 60 yr of age represented 59% of divers in 2002.

The majority of the most severe IPE evacuated by helicopter, especially those associated with cardiac arrest or increase in troponin and myocardial dysfunction, are managed offshore. It involves the need to helicopter directly over the dive place by the FN "Dauphin" helicopter. In those cases, the initial symptomatology is, of course, more severe than those managed on the coast and evacuated by EC 135 helicopter. These cases include cardiac arrest, chest pain, and respiratory distress. The patients evacuated from a landing zone with EC 135 helicopter were not as sick as those who needed to be retrieved from the sea. There was no difference in the medical team configuration and qualification. IPE accounts for one-third of the identified causes of diving accidents evacuated by helicopter. This value is three times greater than the IPE share (13%) in all diving accidents handled by the SMHEP (Toulon, France) over the period 2010–2013.[21] In our series IPE is responsible for at least half of the identified etiologies of death that occurred directly at the dive place. These patients were already in cardiac arrest before the arrival of the emergency medical team. A quarter of the rescued IPE victims died because of cardiac arrest before the rescue arrival (**Fig. 1**). Faced with these results, we will review IPE pathophysiology and its management (**Fig. 2**).[17]

IPE is a cause of diving accident that should not be underestimated any more in terms of frequency and severity.[12] It should be included in the differential diagnosis of acute hypoxemia in diving accidents.[26] Its occurrence can be promoted by physical effort or exposure to cold and stress. Another risk factor is arterial hypertension. IPE pathophysiology involves several mechanisms including immersion with hydrostatic compression and redistribution of blood volume to the thorax called "blood shift", cold or stress with peripheral vasoconstriction, and physical exercise. These factors can lead to increased blood pressure and cardiac output, all of which can induce pulmonary capillary hyperpressure with passage of bloody serosities through the alveolar-capillary membrane, resulting in alveolar flooding.[14,20,28] In addition, breathing cold and dense air can induce mechanical damage to the alveolar-capillary membrane. When the environmental demands are too intense or if the diver has an underlying cardiovascular pathology such as poorly controlled arterial hypertension or heart failure, the adaptive mechanisms are insufficient to avoid pulmonary edema.[10] A study concluded that the altered right/left heart stroke volume balance could play an essential role in the development of immersion pulmonary edema.[7] The development of immersion pulmonary edema is closely related to hemodynamic changes in the right but not the left ventricle.[8] A diver using negative pressure breathing while exercising is at greatest risk of developing interstitial pulmonary edema. Otherwise, differences in pulmonary lymphatics, as a smaller pulmonary lymphatic network, could represent a predisposing factor.[6]

Clinical signs such as cough, dyspnea, hemoptoid or foamy sputum, or lipothymia appear during immersion, possibly on the bottom with sometimes an aggravation during the ascent. Clinical examination may reveal fine crackles to look for, including in the anterior position, cyanosis, oxygen desaturation, or massive pulmonary edema with major hypoxemia. There may be chest pain due to hypoxic and/or catecholenergic myocardial injury. Extravascular lung water can be assessed by using the detection of ultrasound lung comets by chest ultrasonography.[4] At the hospital, early thoracic computed tomography may reveal an interstitial syndrome with frosted-glass opacity and thin thickening of interlobular septa compatible with a venous engorgement mechanism. The lesions predominate in the anterior position and in the lingula (**Fig. 3**).

The outcome is most often quickly favorable after stopping the environmental stress and treatment with normobaric oxygen for 24 to 48 h.[14,20] However, this type of accident can be very serious and can cause myocardial dysfunction and sometimes cardiac arrest.[18]

Pulmonary overpressure is a differential diagnosis but is a rare medical emergency. In any diving accident there should be suspicion of barotrauma.[1] During ascent, the diver must exhale freely in order to balance the intrapulmonary pressure with the ambient hydrostatic pressure. When diving, the change of pulmonary gas volume obeys the Boyle-Mariotte

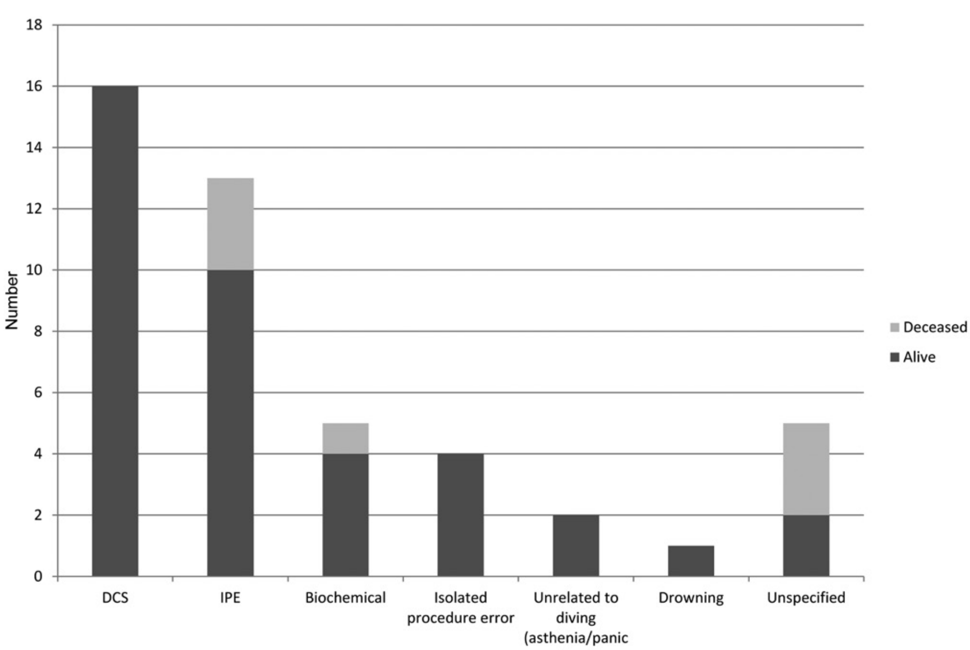

Fig. 1. Distribution by type of all diving accidents evacuated by helicopter ($N = 46$) September 2014–August 2016.

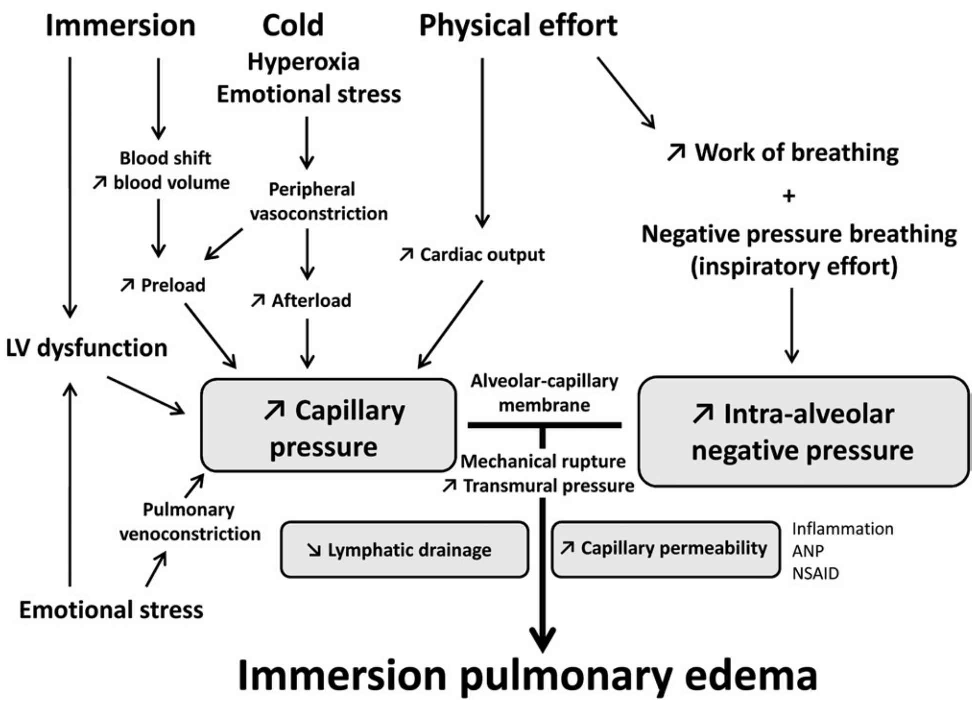

Fig. 2. Main pathophysiological mechanisms of IPE in scuba diving accidents. Translated from Gempp et al.[17]

law (pressure × volume = constant). The vast majority of these accidents occur in novice divers and generally in shallow water, with the lung volume doubling between 10 m (33 ft) and the surface (at −10 m, the pressure is multiplied by 2).[2] The contributing factors are insufficient expiration during the ascent, a fragility of the pulmonary parenchyma, and a very rapid ascent. Pulmonary overpressure may result in mediastinal emphysema, pneumothorax, and/or arterial gas embolism. Mediastinal emphysema can induce vocal changes, neck pain, dyspnea, dysphagia, retrosternal discomfort, syncope, or loss of consciousness. The clinical signs to look for are cervical and upper thorax subcutaneous emphysema, muffled heart sounds, cyanosis, tachycardia, hypotension, and signs of tamponade in cases of pneumopericardium.[27] Symptoms of pneumothorax usually appear quickly during ascent, with abrupt chest pain and dyspnea. Clinical signs, such as decreased hemithorax movement or a vesicular murmur decrease, are difficult to perceive if the pneumothorax is minimal. If the pneumothorax occurs at the bottom in hyperbaric conditions, it will worsen and become a tension pneumothorax during the ascent with signs of shock and sometimes a state of apparent death on the surface.[19] Arterial air embolism is a serious complication that results from the passage of lung gas into pulmonary veins and into systemic circulation, with activation of inflammation cascade. The early symptom onset, within 5–10 min after returning to the surface, is an absolute criterion for the diagnosis of arterial air embolism, but not exclusive because it is possible to observe it in some cases of cerebral DCS.[16] Clinical signs appear suddenly and are mainly neurological, such as confusion, aphasia, visual acuity decrease, paresthesia, vertigo, convulsions, or various forms of paralysis. A complete neurological examination should always be performed in the face of symptoms suggestive of pulmonary overpressure. Signs of myocardial infarction by air embolism of the coronary arteries should be sought.[27]

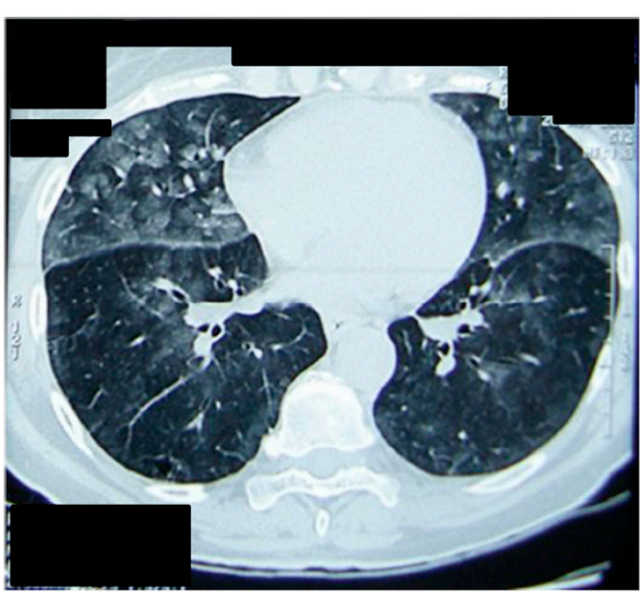

Fig. 3. Thoracic computed tomography characteristic of IPE.

The treatment at the dive place conditions the prognosis. The evacuation must not be delayed. The circumstances of the diving accident should be investigated in order to guide the diagnosis.[15] The start of normobaric oxygen therapy with the mask at high concentration (15 L · min^{-1}) should be immediate.[5] A moderate hydration by a peripheral venous access is started to treat dehydration relative to immersion. The specific treatment according to the type of diving accident is started, without forgetting the treatment of hypothermia. For IPE and after exclusion of a pneumothorax, if there are decompensation signs, the use of a continuous positive airway pressure device is justified or, better, the use of non-invasive ventilation with inspiratory pressure support and positive expiratory pressure after exclusion or exsufflation of a pneumothorax.[3,22] Administration of aerosolized beta-2 agonists could be considered.[23,25] Serious DCS is a medical emergency that requires a rapid transfer to the nearest specialized medical unit without interruption of normobaric oxygen therapy and a recompression to limit morbidity.[11] In cases of cardiac arrest, which is most often induced by hypoxia (drowning, IPE…), cardiopulmonary resuscitation is started with five breaths initially. If cardiac activity is not restored, a bilateral exsufflation needle is recommended by the French Military Health Service to quickly treat a tension pneumothorax. Finally, in case of failure, a rescue recompression is considered in the event of a massive aeroembolism of the heart and large vessels.[3] The choice of the vector for evacuation depends on the symptomatology and the proximity of a hyperbaric center and a health care emergency unit.[24]

Concerning diving accidents, helicopter evacuation is indicated when the vital prognosis, IPE and pulmonary overpressure in particular, or the neurological functional prognosis in cases of DCS, is of concern. The helicopter is the method of choice for evacuation due to its speed of intervention at sea. A medical team composed of an emergency doctor and a nurse completes the crew. During the transport, the flight altitude must remain below 300 m (984 ft) to avoid additional depressurization. The hoist is discussed if the boat is nonmaneuvering more than 25 min away from a port and if there are concerns for the vital or neurofunctional prognosis.[13] Intervention times are according to the distance, then once on site, depending on the severity of the patient and the time spent for management. The noisy atmosphere and vibrations onboard a helicopter are common constraints, however other problems also occur, as described in the following. The difficulties of these rescue interventions are increased by aeromaritime conditions (meteorology, sea state, helicopter hoist, limitation of the time spent in the area ...), as well as the smallness of the cabin. The FN "Dauphin" helicopter has a range in a nonmedicalized version of 160 nmi, which is 296 km, and in a medicalized version of 120 nmi, which is 222 km. The winch has a lifting capacity of 272 kg and a maximum of two people simultaneously hoisted. Response to offshore with hoist is unrestricted during the day, but at night only with a clear night. This aircraft is not equipped with Doppler but only with a three-axis autopilot which does not ensure the capture, holding, and stationary departure in automatic mode. The small volume of the cabin does not allow easy medical care of the patient on board. The EC 135 helicopter of the "SAMU 83" emergency unit participates in the operations and assumes charge of a diving accident when the patient is evacuated first by boat from the dive and then toward the nearest landing zone, which makes landing possible. Its range is about 140 nmi (260 km), with an autonomy of about 3 h. It is not equipped with a hoist and it can only use lighted or an already recognized landing zone. The volume of the cabin, however, is relatively large.

Helicopter rescue missions on the French Mediterranean coast are mainly carried out offshore by the FN "Dauphin" helicopter. Diving accidents have a prominent role in those missions, in terms of frequency and severity of patients. The complementarity of the available aircraft in this area makes it possible to take care of and evacuate patients who suffer from a diving accident. Diving accident management is optimized by admission of these patients to the very large referral hyperbaric center (SMHEP) at Sainte-Anne Military Hospital (Toulon, France). In our series, IPE is currently by far the most common etiology found in patients with serious diving injuries that are life-threatening and who benefit from helicopter evacuation. IPE is responsible for at least half of the deaths at the dive place and represents a third of diving accidents evacuated by helicopter. A non-invasive ventilation device with inspiratory support and positive expiratory pressure should be carried out for the most serious diving accident medical care, in particular for IPE.

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