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Original Communication

Post-mortems in recreational scuba diver deaths: The utility of radiology

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ABSTRACT

Post-mortem radiology and autopsy findings in a series of six diving-related deaths are presented. The cases had different causes of death but essentially similar radiological findings. We propose that the so-called classical radiological features of cerebral arterial gas embolism more likely represent "off-gassing" (gas coming out of solution into intra-vascular spaces due to pressure changes). As such, we suggest that post-mortem radiology, when accompanying a competent autopsy examination, be limited to the chest, whereby it may be useful in the demonstration of pneumothoraces which might not be demonstrated at autopsy, thereby providing supporting evidence for barotrauma in the context of appropriate clinical and autopsy findings.

1. Introduction

Numerous publications have reported the use of plain radiography and more recently, computerised tomography (CT) and magnetic resonance imaging (MRI) as an adjunct to post-mortem in diving fatalities.[1–6] The consensus of these papers is that post-mortem radiology is a useful technique because it can show large volumes of intra-vascular gas, usually in the heart and cerebral vessels, which is claimed to be indicative of arterial gas embolus. Indeed, most protocols for autopsy in diving accidents recommend the use of some form of post-mortem radiology.[1,7]

This study presents six cases of diving-related deaths studied independently by both a pathologist experienced in diving fatalities and by an experienced radiologist. The cases had different causes of death but essentially similar radiological findings.

2. Methods

All diving fatalities in the Coronial jurisdiction of Plymouth and South West Devon between January 2005 and November 2007 were autopsied at Derriford Hospital, Plymouth. In all cases radiological investigations comprising only a series of plain X-rays including lateral skull, supine and decubitus chest, and supine abdomen and pelvis were performed prior to the autopsy. All radiology was performed within 24 h of death and the autopsies commenced as soon as possible after this.

The autopsies were performed following a published protocol,[1] with primary opening of the elevated chest, clamping of the carotid arteries and aspiration of the four chambers of the heart, followed by opening the head and clamping of the basilar and vertebral arteries prior to removal of the brain. Tissues from the major organs were retained for subsequent histological examination and specimens were sent for toxicology in all cases. Only the positive findings from these investigations are presented herein.

Cerebral arterial gas embolism (CAGE) was given as the pathological cause of death if the following three criteria were met: a suitable history (rapid ascent followed by loss of consciousness); gas in the left side of the heart and the circle of Willis and mediastinal or thoracic subcutaneous emphysema or pneumothorax.

3. Results

3.1. Case 1

This was a 40 year-old male with no significant medical history who was a recreational diver. The dive was onto an offshore shipwreck, to a depth of 22 m. At 15 min into the dive, he was found floating face down in one of the chambers of the wreck by his dive companions, who took him to the surface in a controlled ascent. Despite intensive resuscitation attempts, he did not revive. Examination of his equipment showed his air cylinder was empty.

Post-mortem radiology showed diffuse bilateral alveolar shadowing throughout almost the whole of both lungs. There was gas in the aorta and in both ventricles, with a gas "angiogram" in both brachial arteries and in the left common carotid artery. A gas "angiogram" of the basilar artery and posterior cerebral arteries

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was seen. There was gas in a hepatic vessel and gaseous distension of small and large bowel.

Autopsy showed frothy fluid within the larynx, trachea and main bronchi. The lungs were very heavy and markedly oedematous. Histologic examination of lungs showed intra-alveolar fluid. The pathologic cause of death was given as drowning.

3.2. Case 2

This was a 65 year-old male with a history of hypertension, left ventricular hypertrophy and peripheral vascular disease. He was a novice recreational diver, on an offshore dive, planned to be the first of the day. He had struggled on the surface swim to the descent line buoy, but was happy to proceed with the dive. Following an uneventful 21-min dive to 20 m, he started a controlled ascent, shortly into which he ran out of air and started sharing his companion's air. The remainder of the ascent was said to be rapid but controlled. Immediately after surfacing he was conscious, however within 2 min he became unconscious and despite resuscitation attempts, he did not revive.

Post-mortem radiology showed a coarse granular pattern throughout both lungs with a shallow right-sided pneumothorax. Gas was noted within the cardiac contour and in the ascending aorta. There were air fluid levels within both ventricles and a gas angiogram was seen outlining both brachial arteries, both carotid arteries, both common iliac arteries and both profunda femoral arteries. There was moderate gaseous distension of the stomach and small bowel with pneumatosis of the large bowel.

Autopsy showed subcutaneous emphysema over the chest, extensive bubbles of gas within the circle of Willis and communicating arteries (Fig. 1) and approximately 20 ml of gas in the left atrium and 5 ml of gas in the left ventricle. There was mild coronary artery disease, the heart showed fine myocardial scarring and the lungs mild emphysema. Histologic examination showed patchy panmyocarditis, myocyte hypertrophy and myocardial scarring. The kidneys showed age-related glomerulosclerosis and the liver moderate centrilobular macrovesicular steatosis. Intravascular spaces consistent with gas bubbles were seen in the subpleural alveolar vessels and also within cerebral vessels. The pathologic cause of death was given as CAGE. The myocarditis was considered contributory but not causative to the death.

3.3. Case 3

This was a 57 year-old male with no known significant medical history on a recreational dive onto an offshore shipwreck, to a depth of 18 m. After 27 min he started a controlled ascent and approximately 1 min into a planned 3-min safety stop at 6 m, he lost consciousness. He was taken to the surface by his companion, but despite attempted resuscitation, he did not revive.

Post-mortem X-rays showed bilateral airspace shadowing in the lungs and intra-vascular gas was seen within the ascending aorta and aortic arch, both axillary arteries, both brachial arteries, both external iliac arteries and both profunda and superficial femoral arteries. There was gas within the cardiac ventricles. Intra-vascular gas was also present within the venous plexus around the prostate and bladder and in the femoral veins.

Autopsy showed mild subcutaneous emphysema of the soft tissues of the chest and neck and a few small bubbles in the arteries of the circle of Willis. The lungs were mildly oedematous; there was severe single-vessel coronary artery atherosclerosis and the heart showed moderate four chamber dilation and mild left ventricular hypertrophy. Histologic examination showed moderately marked myocyte hypertrophy and intra-alveolar pigmented macrophages. The pathologic cause of death was given as coronary artery disease.

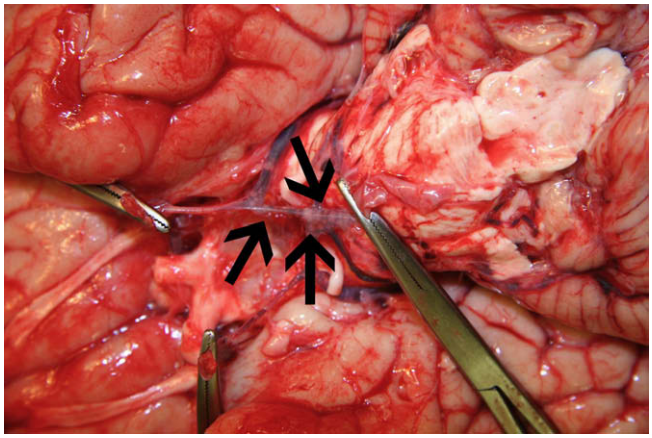

Fig. 1. Base of brain once removed from skull demonstrating gas bubbles in the vessels of the circle of Willis (arrows).

3.4. Case 4

This was a 47 year-old male with no significant medical history. He was an experienced dive instructor who was on a recreational dive into an inland quarry. The dive was technical, to a depth of 90 m using a tri-mix breathing system. The dive profile showed a very rapid ascent after 21 min. He was alive on surfacing; following which he shouted something and then collapsed face down in the water. He never regained consciousness despite intensive resuscitation efforts.

Post-mortem plain X-rays showed extensive gas within the carotid arteries and intra-cerebral arteries and veins. There was a small right-sided pneumothorax and extensive gas present within both atria and ventricles. There was extensive gas in the intra-hepatic veins, both iliac arteries, the left common iliac vein and both common femoral veins.

At autopsy there were extensive gas bubbles within the cerebral arteries and the brain showed moderate generalised swelling, with bilateral uncal grooving. The lungs were mildly heavy and oedematous, there was mild coronary artery disease and the heart was distended, with large volumes of gas in all four chambers. There was a 5 mm diameter probe-patent foramen ovale. Histologic examination showed intra-vascular spaces consistent with gas bubbles within cerebral arteries, alveolar capillaries and larger arteries and veins within the lungs. The heart showed mild myocyte hypertrophy and the kidneys age-related glomerulosclerosis. The pathologic cause of death was given as CAGE.

3.5. Case 5

This was a 42 year-old male with no significant medical history. He was a recreational diver and this was a dive onto an offshore shipwreck, to a depth of 26 m. He failed to surface and his body was found in the wreck three and a half hours after the start of the dive. The body was brought to the surface in a controlled ascent. Examination of equipment showed an empty tank.

Post-mortem radiology showed bilateral alveolar pulmonary shadowing throughout the whole of both lungs. Gas was seen in the right atrium, pulmonary outflow tract and in the aortic knuckle with a gas "angiogram" in both arteries and veins. There was intrahepatic gas with gas outlining the portal venous system in the right lobe of the liver. Intra-muscular gas was seen in the right side of the abdominal wall and there was an extensive gas venogram outlining the common femoral veins bilaterally with a smaller quantity of gas within the superficial femoral arteries bilaterally.

Table 1
Radiological findings and pathological conclusions following autopsy examination.

Case	Radiological findings								Pathological cause of death
	Alveolar pulmonary shadowing	Pneumothorax	Intra-cardiac gas	Intra-cranial gas	Intra-arterial gas	Intra-venous gas	Portal vein gas	Gas in muscle tissues	
1	✓		✓	✓	✓		✓		Drowned
2	✓	✓	✓		✓	✓	✓	✓	CAGE
3	✓		✓		✓	✓		✓	Coronary artery disease
4	✓	✓	✓	✓	✓	✓	✓		CAGE
5	✓		✓	✓	✓	✓	✓		Drowned
6	✓		✓	✓	✓	✓	✓	✓	Drowned

Further intra-muscular gas was noted in the muscles of the legs and gas was seen in the venous plexus around the base of the bladder. The lateral skull film demonstrated gas in the carotid arteries and possibly in the circle of Willis.

Autopsy showed a moderate amount of air within the intra-cerebral veins and arteries and the brain was mildly swollen. The lungs were heavy and markedly oedematous. There was a moderate amount of air in the right ventricle, but other cardiac chambers were free of air. Histologic examination showed early acute hypoxic/ischaemic changes in the brain, mild myocyte hypertrophy and mild centrilobular macrovesicular steatosis. The pathologic cause of death was given as drowning.

3.6. Case 6

This was a 43 year-old female with no significant medical history who was a recreational diver. This was a dive onto an offshore shipwreck, to a depth of 26 m. She failed to surface and her body was found in the wreck four and three-quarter hours after the start of the dive. The body was brought to the surface in a controlled ascent. Examination of equipment showed an empty tank.

Post-mortem X-rays showed bilateral alveolar pulmonary shadowing. Extensive gas was noted in both ventricles, right atrium and aorta with a gas "arteriogram" and "venogram" around both shoulders. There was extensive intra-hepatic gas and gas was seen throughout the whole of the inferior vena cava, both common iliac and common femoral veins and both femoral arteries. Gas was seen in both vertebral arteries, the basilar artery and in the circle of Willis.

Autopsy showed extensive gas within all visible cerebral veins and arteries and the brain was mildly swollen. The lungs were distended, heavy and oedematous. The right side of the heart contained significant amounts of gas and there was a small amount of gas within the left side of the heart. There was mild coronary artery atherosclerosis. Histologic examination showed air spaces within intra-cerebral vessels. The heart showed mild myocyte hypertrophy. The pathologic cause of death was given as drowning.

Table 1 summarises the radiological findings and the pathological conclusions of the six cases presented.

4. Discussion

In order to discuss this topic it is necessary to clarify the terms being used. Intra-vascular gas simply means gas within blood vessels and can occur as a result of several mechanisms which may be encountered in a diving-related post-mortem. Gas formation can be seen as a result of decomposition of a body. This type of gas is usually seen many hours to days after death and if seen at all within the first 24 h is usually of small volumes.[8,9] Attempted resuscitation with intra-venous cannulation, cardiopulmonary resuscitation and endotracheal intubation with positive pressure ventilation may all result in intra-vascular gas.[9,10] Gas may also be manifest in the vascular spaces due to decompression "off-gassing". This is simply where a liquid at high pressure can dissolve more gas than at lower pressure and moving either a live body quickly or a dead body at all from high to low pressure will result in gas coming out of solution into the intra-vascular space.[9,10]

Pulmonary barotrauma of ascent (PBT) can occur in situations where a pressure gradient that is sufficient to cause damage to pulmonary tissues results. The effect of this gradient depends both on the compliance of the pulmonary tissues and the pressure differential itself. It is thought that high pressure intra-alveolar gas can dissect into intra-pulmonary vascular spaces and thence into the pulmonary veins and the systemic circulation. In this way, it is postulated, death could result as a consequence of gas embolism in the coronary or cerebral circulations or of ventricular "air lock" with subsequent cardiac pump failure.[11,12]

Death could also occur due to CAGE, rather than coronary arterial gas embolism and CAGE is intuitively more likely to occur in a diving situation due to the vertical position of the body and the buoyancy of gas bubbles in the circulation. Death resulting from CAGE follows a typical clinical scenario where a diver, after rapid ascent, suffers within minutes, unconsciousness and cardiac arrest which is unresponsive to resuscitation.[11,12]

In this paper a series of diving fatalities are reported with a combination of well documented ante mortem situations, a uniform series of radiographs obtained within hours of death all interpreted by a single experienced radiologist and an autopsy performed by one experienced pathologist.

There can be clinically no doubt that Cases 5 and 6 died of drowning. The bodies were found within a wreck, there was no possibility of rapid ascent and the bodies, once found, were brought to the surface in a controlled ascent by the rescue diver. Decomposition is ruled out as both were examined radiologically within 24 h of death. However radiologically, both bodies show findings classically ascribed to CAGE, with large volumes of gas in both sides of the heart, gas angiograms in the thorax around the shoulders and in the neck (Fig. 2) and gas in the intra-cerebral vessels. The findings in these bodies argue strongly that the radiological appearances are simply the effect of "off-gassing". Excellent experimental evidence for this explanation is provided by Cole et al. who sacrificed sheep under hyperbaric conditions and used CT to show large volumes of gas in the intra-vascular space including within the cardiac chambers.[13] They conclude, as do we, that imaging techniques demonstrating intra-vascular gas are not helpful in determining whether arterial gas embolism has occurred.

It is also difficult to adequately explain on the basis of barotrauma the finding of portal vein gas in our patients. To suggest that arterial gas embolus has occurred and is secondary to pulmonary barotrauma requires that bubbles of gas have passed from the alveoli to the pulmonary veins, through the left heart and then through the visceral capillary network before coming together

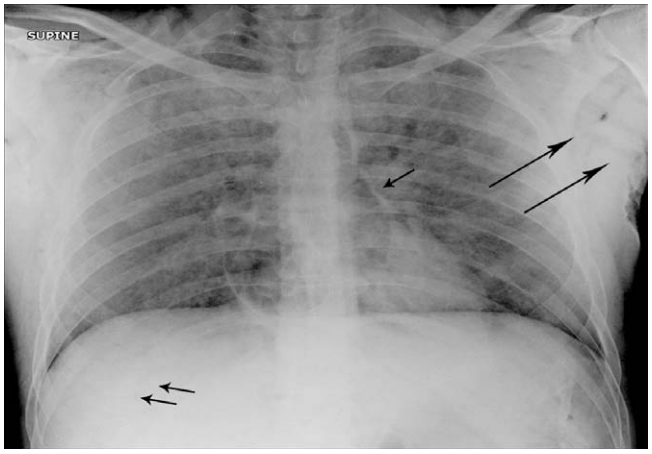

Fig. 2. (Case 5) The chest X-ray shows bilateral alveolar pulmonary shadowing with extensive intra-cardiac gas (single short arrow), a gas "angiogram" around the shoulders (two long arrows) and portal venous gas (two short arrows).

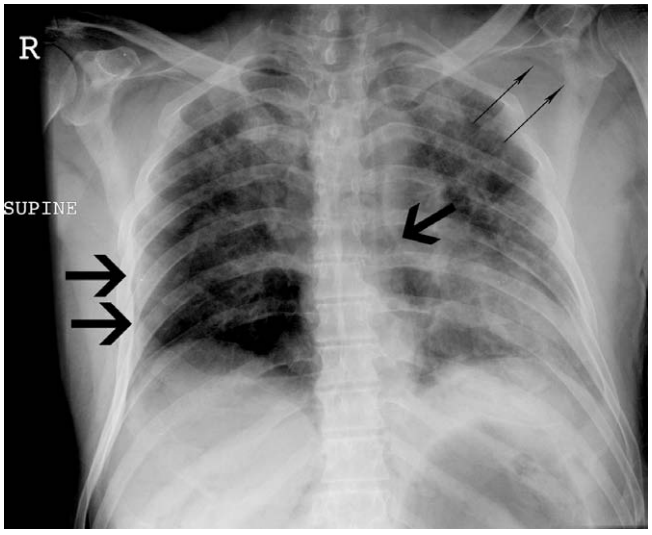

Fig. 3. (Case 2) The chest X-ray shows bilateral pulmonary shadowing with a shallow right-sided pneumothorax (two short arrows). Gas is seen in the cardiac chambers and in the ascending aorta (one short arrow). A gas angiogram is seen outlining both brachial arteries (two long arrows).

again as larger bubbles in the portal veins. This seems intuitively unlikely. On the other hand, simple "off-gassing" would lead to gas within arterial, venous and portal circulations.

Cases 1, 5 and 6 are undoubtedly due to drowning, two with controlled ascents of the body; however all showed extensive intra-arterial gas. Case 3 clinically and pathologically died from coronary artery disease but also had extensive intra-vascular gas. Cases 2 and 4 fit well with the clinical syndrome of CAGE and are radiologically as classically described for that syndrome (Fig. 3).[2,3] The only potentially significant difference radiologically between those whose deaths were due to CAGE and those that were not was the radiological presence of a small pneumothorax in Cases 2 and 4 which were subsequently found to be the two patients who had a clinical diagnosis of arterial gas embolus. The presence of a pneumothorax is convincing radiological evidence that the patients had suffered pulmonary barotrauma. However, at post-mortem, a pneumothorax was not convincingly demonstrated in either of these two patients using the conventional pneumothorax test (puncturing the chest under water).

In conclusion, we present a series of diving fatalities with close correlation of dive histories, post-mortem radiology and pathological findings which show that the so-called classical radiological features of CAGE are in fact more likely represent "off-gassing". Post-mortem radiology in the form of chest X-ray may be useful in the demonstration of pneumothoraces which may not be demonstrated at autopsy thus providing supporting evidence for barotrauma in the context of appropriate clinical and autopsy findings.

Conflict of interest

None

Funding

None declared.

Ethical approval

None declared.

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