

Case reports

Serial chest computed tomography imaging in a freediver with a case of pulmonary barotrauma of descent (lung squeeze) showing the time course of resolution

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Abstract

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Freedivers can suffer respiratory symptoms indicative of freediving induced pulmonary syndrome (FIPS). Aetiology includes immersion pulmonary oedema and barotrauma of descent in the tracheobronchial or pulmonary parenchyma, also colloquially called ‘squeeze’. The pathophysiology and natural history are still largely unknown. This case report describes a freediver who developed haemoptysis following a 49 m personal best constant weight bi-fin dive, presenting with two episodes of haemoptysis within 24 hours post-dive. This style of diving entails finning down to the desired depth, turning with a single pull on the rope, and then finning up to the surface without use of the arms. The diver exhibited no other symptoms and remained haemodynamically stable. Computed tomography (CT) imaging performed two days post-dive showed ground-glass opacities in the right upper and middle lobes. Treatment involved hospitalisation, high-dose corticosteroids, and antibiotics. Follow-up CT scans post-dive revealed almost complete resolution (six days) followed by complete resolution of pulmonary abnormalities (21 days). This case is unique for its documentation of changes in lung findings over three sequential CT scans, providing a timeline of anatomical recovery. Serial CT scanning would not be routinely recommended from a radiation safety perspective but yielded interesting data into the time course of this trauma. The findings raise questions about the underdiagnosis of squeeze injuries, as this diver displayed minimal symptoms despite radiographic evidence of ground-glass opacities. This case highlights the need for standardised imaging and management protocols, as well as further research into the natural history and clinical significance of FIPS.

Introduction

Freediving induced pulmonary syndrome (FIPS) encompasses signs and symptoms freedivers can experience after diving from immersion pulmonary oedema, barotrauma of descent, or airway barotrauma.^{1,2} Squeeze is the colloquial term often used to describe FIPS, with a poorly understood time course of resolution. Squeeze is caused by a changing pressure differential between a gas containing space in the body and the surrounding ambient pressure, causing a relative negative pressure inside the lungs. It can manifest as regional lung collapse/atelectasis, fluid shift from the alveolar capillary beds causing pulmonary oedema, or rupture of the bronchial and/or alveolocapillary beds producing alveolar haemorrhage leading to haemoptysis.³

There are few cases with computed tomography imaging (CT) after a squeeze, and none with serial follow-up imaging to track radiographic resolution of the injury.

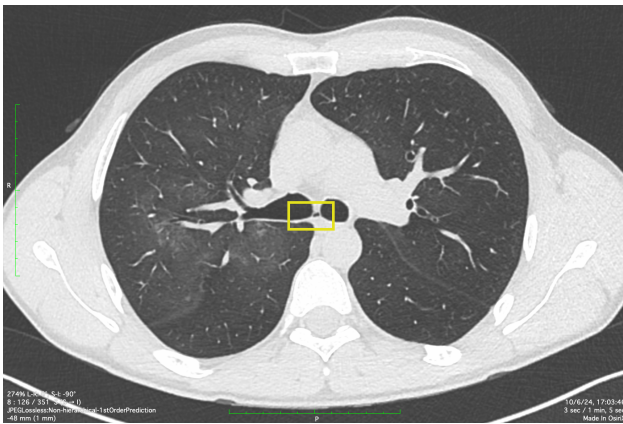
Case report

The diver described here provided written consent for publication of his case history and images.

We report a freediver who experienced haemoptysis manifesting as two isolated events of blood clots cleared from the throat at two and 24 hours post-dive respectively. He was hospitalised for further workup and found to have ground-glass opacities in the right upper and middle lobes on a non-contrast CT scan at two days post-dive, along

Figure 1

Initial CT chest on day two post-dive showing the 2 mm bronchial diverticulum as indicated by the box



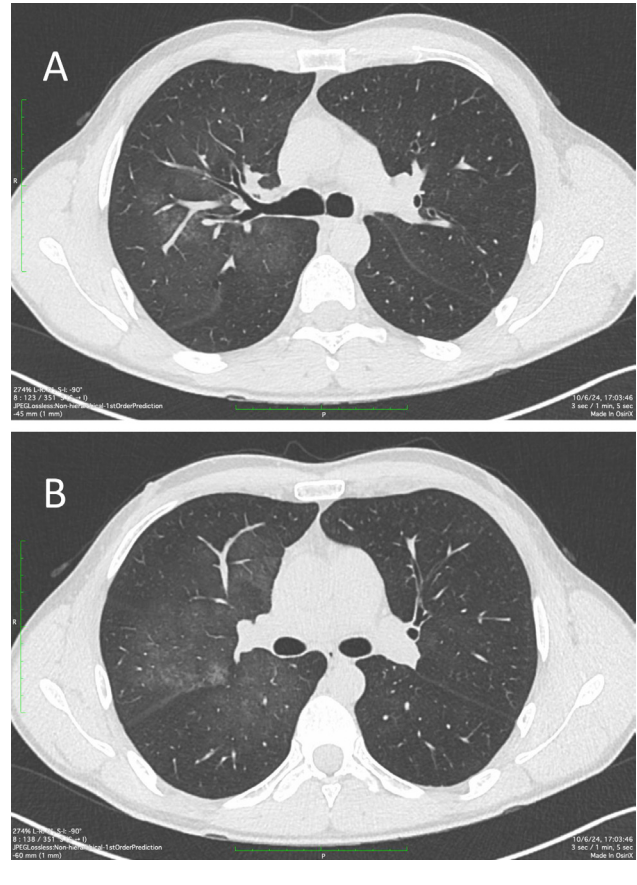
with an incidental finding of bronchial diverticula, and was discharged six days post-dive after ground-glass opacities were found to be resolving upon repeat chest CT. This case is unique as this diver underwent three CTs following the resolution of lung squeeze.

On the morning of the incident, the diver reported a training dive session in which he performed three constant weight bi-fin dives to 20 m, 40 m and 49 m (a personal best). He was practicing ear equalising with mouth-fill only when feeling slight ear pressure rather than in anticipation of ear pressure, which resulted in fewer equalisations. He denied any exertion or physical discomfort during any of the dives. On the last dive to 49 m he reported extending his neck to look up at the surface on the initial ascent. He also tugged on the rope three times rather than one time. He surfaced from all dives feeling well. In the evening, he cleared his throat as he would normally clear mucus and expelled an approximately 2 x 2 cm thick, dark red blood clot. He denied coughing, shortness of breath, congestion, throat soreness, or any discomfort anywhere in his body prior to or after expelling the blood. After 10 hours of sleep, he tried to clear his throat gently and a similar amount and quality of blood clot was expelled again.

On day two post-dive he was seen by a pulmonologist group who performed a bilateral ultrasound of his anterior lung fields and reported right-sided pulmonary oedema. A nasopharyngolaryngoscopy was clear, and a CT chest showed “mild ill-defined central peri-bronchovascular ground glass opacities in the right upper and middle lobe. A tiny diverticulum measuring up to 2 mm diameter projects from the medial inferior aspect of the left main bronchus and appears to make a connection with a similar sized outpouching projecting from the inferior medial aspect of the right main bronchus, reflecting tiny diverticula/trace fissures connection between the 2 bronchi” (Figure 1 and Figures 2A–2B). The patient was offered a bronchoscopy

Figure 2

A – CT chest at level of the carina on day two post-dive showing central peri-bronchovascular ground glass opacities in the right upper and middle lobe; B – CT chest at level below the carina on day two post-dive showing central peri-bronchovascular ground glass opacities in the right upper and middle lobe



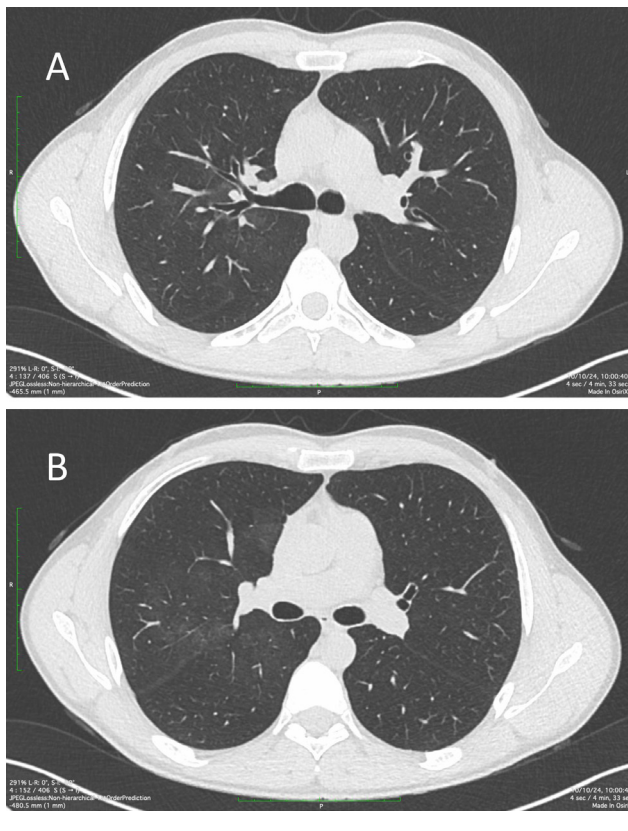
and declined because he did not want to be intubated. He was hospitalised and started on amoxicillin-clavulanic acid 875-125 mg twice a day (BID) for 10 days, methylprednisolone 16 mg BID for 14 days and then a 14-day taper, and omeprazole 20 mg daily. Hospital admission vital signs were blood pressure 126/70, heart rate 80, respiratory rate 15 per minute, peripheral oxygen saturation 97%, temperature 36.4°C. The diver remained asymptomatic.

On day six post-dive, a repeat CT scan showed “interval decreased extent and density of previous mild ground glass opacities.” (Figure 3). He was discharged with prescriptions to finish his course of antibiotics, steroids, and a proton pump inhibitor, and given instructions to return for a repeat CT 21 days post-dive.

CT day 21 post-dive showed “interval complete resolution of previous mild ground glass opacities. The tiny diverticula versus minimal fistulous connection between the main bronchi are unchanged.” The diver traveled back home the following week.

Figure 3

A – CT chest at level of the carina on day six post-dive showing decreased extent of ground glass opacities and unchanged bronchial diverticulum; B – CT chest at level below the carina on day six post-dive showing decreased extent of ground glass opacities



Discussion

Lung squeeze, or barotrauma of descent, is a sequela of a failed attempt to maintain pressure equilibrium in the chest cavity during a breath hold dive as the ambient pressure becomes too great. As a result, atelectasis, pulmonary edema, and bleeding from alveolocapillary rupture can occur. Symptoms typically present as dyspnoea, hypoxia, cough, throat soreness, hoarseness, chest pain.⁴ CT is of limited value in distinguishing the exact aetiology of alveolar consolidations presenting as ground-glass opacities and requires correlation with clinical context to separate e.g., haemorrhage from oedema.⁵ The initial CT of this diver showed ground glass opacities in the right middle and upper lobes, which could be signs of inflammation, pulmonary oedema, or alveolar haemorrhage.⁶ Given the diver's only symptom was haemoptysis after a dive, the ground glass opacities seen on his initial CT were likely alveolar haemorrhage. Without bronchoscopy or bronchoalveolar lavage to confirm the bleeding source the haemoptysis could have originated from the alveoli, bronchi, or trachea. The haemoptysis could also possibly be due to tracheobronchial barotrauma and the ground glass opacities may have arisen from upper airway bleeding down the right mainstem bronchus into the right and middle lobe alveoli. We believe this to be unlikely as gravity dependent bleeding would

also be expected in the left lung. For this reason it is also unlikely that the small 2 mm bronchial diverticulum is the source. Additionally, at 2 mm it is too small to be a pooling site for bleeding below or above the diverticulum. It is also noteworthy that the diver had findings in the right upper lobe, the same location reported with bleeding after squeeze studied with bronchoscopy.⁷

The freediver reported pulling on the rope three times with his right arm to begin ascent, likely increasing tensile stress on the right lung and causing alveolar haemorrhage. This stress may result from a compressed lung at depth being stretched during unilateral reaching that preferentially expands the right lung, leading to localised barotrauma, while the left lung remains atelectatic. Alveolar haemorrhage often presents as ground-glass or consolidative opacities, and depending on the mechanism of injury, will resolve radiographically and symptomatically within three to 21 days.^{6,8,9} The literature yields a few case reports of divers with haemoptysis, some also with dyspnoea, that show radiographic resolution of lung squeeze by 14 to 21 days post-dive. Kiyani et al., and Boussuges et al., report on healthy breath hold divers who experienced haemoptysis immediately post dive. One was found to have bilateral alveolar infiltration suggestive of alveolar haemorrhage on chest CT two hours later with a follow-up CT three weeks post dive showing resolution of alveolar injury. Another was found to have disseminated alveolar opacification on chest CT one day post-dive and confirmed alveolar haemorrhage on broncho-alveolar lavage 36 hours later. Three others showed no lung injury on chest CT two weeks post-dive.^{8,9} The present case is unique since the diver received three CTs, shedding light on the time course of resolution.

In this case, the initial CT scan showed ground glass opacities suggesting pulmonary haemorrhage from his dive two days prior. The second CT scan taken six days post-dive showed resolving ground glass opacities indicating the haemorrhage was self-limited and resolving. Clinical history of haemoptysis along with presence of alveolar consolidations six days post dive further suggest an exudative source (such as blood from barotrauma) versus a transudative source (such as immersion pulmonary oedema). Although subclinical fluid extravasation cannot be ruled out, overt immersion pulmonary oedema from extravasating fluid into the pulmonary tissue is unlikely as it typically resolves symptomatically and radiographically in 48 hours.^{7,10-13} The final CT scan showed complete resolution of the alveolar haemorrhage. These findings, consistent with haemorrhage on CT but with no hypoxia, dyspnoea, cough, throat or chest discomfort, could indicate that barotrauma of descent in freedivers may be more common than presently thought, and may last much longer.

Corticosteroids have been used previously to treat diving injuries such as decompression illness, barotrauma of the inner ear and sinuses, and swimming induced pulmonary oedema.^{14,15} However, new guidelines do not recommend

