Gastric barotrauma following submarine escape training

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Abstract

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Seventeen case reports of gastric barotrauma following diving have been published previously. We report the case of a 32-year-old healthy male suffering gastric barotrauma in 1987. The incident happened during a military submarine exercise. The patient escaped the submarine at 150 metres water depth but was entangled for a short time in the escape tower and, likely distressed and in a state of panic, swallowed significant amounts of air. He experienced abdominal pain during ascent. Given the special circumstances of this event, medical personnel primarily expected symptoms to be caused by decompression sickness and initiated therapeutic recompression on site. No improvement occurred during recompression, and he was admitted to hospital. Abdominal X-ray disclosed free abdominal gas which was exsufflated in the emergency room. Emergency abdominal surgery revealed a 9 cm rupture of the lesser gastric curvature which was sutured. Recovery was uneventful. We discuss the proper approach to divers experiencing abdominal pain following ascent.

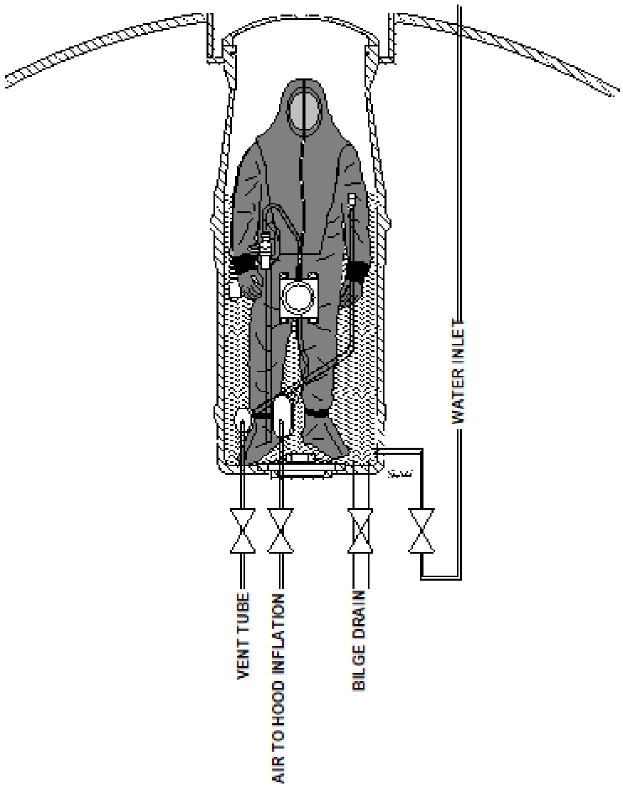
Introduction

Several rescue systems are located worldwide to allow safe evacuation of crewmembers trapped within a submarine disabled at sea bottom. These systems are conventionally based on a rescue vehicle that can connect to the rescue hatch of the submarine. Submariners may transfer from the submarine interior through the escape trunk and enter the rescue vehicle without exposure to water. The submarine rescue vehicle will transport the crew members to a surface vessel. While this is the preferred and usually safest route of evacuation, the mobilization time for these rescue systems may exceed expected survivability for the crew. For this reason, many nations prepare for an alternative, individual immersed ascent through the water column (‘single escape’).

In the event of a single escape the submariner will don a submarine escape immersion suit. The suit is equipped with an ‘ascent hood’, a flexible and transparent hood surrounding the head and fixed to the outside of the suit. The ascent hood is closed except for an opening on the chest allowing expanding air to escape. The suit is equipped with a hose allowing the hood to be filled with compressed air through a hood inflation system installed within the escape trunk. The submariner will enter the escape trunk, and the lower hatch will be closed. Verbal communication is not possible from this time, but the escapee and submarine crew may communicate with pre-defined messages using hammer signals. The escape trunk (Figure 1) will be filled with water venting the air into the submarine, which keeps the escape trunk at surface pressure until most of the air has escaped. The escapee will inflate the hood with air from the hood inflation system allowing normal breathing. In the last part of water filling, the internal vent will be closed and the pressure of the escape trunk will double approximately every four seconds. Once pressure is equalised to the surrounding water pressure, the upper hatch will open and the escapee will ascend through the water column. The expanding gas within the suit and hood will provide buoyancy as well as breathing gas during the ascent.

Many submariners are regularly trained for this procedure. For logistical and safety reasons, most training is done in a 20–30 metre deep submarine escape training tank rather than from a submarine. The most common complications of escape training are ear and sinus barotrauma, but pulmonary barotrauma and arterial gas embolism are recognised as more severe, though less frequent, complications. Here, we report a rather unique case of gastric barotrauma taking place during escape training from a submarine. Gastric barotrauma following conventional diving has been reported previously, such as the recent report by Ben Ayad et al.[1] However, we are not aware of this injury being reported following submarine escape training. In addition, we would like to discuss the

Figure 1
Drawing illustrating the escapee dressed in an escape suit within the escape trunk. Upper and lower hatch is closed. When water has reached the upper level of the vent tube, the valve will be closed, and further water ingress will increase internal pressure. The upper hatch will open once pressure is equalised with ambient water pressure. 'Air to hood inflation' – Hood inflation system. Reproduced with permission from Peter Arfert



optimal way to handle abdominal pain presenting shortly after surfacing a dive.

Case report

The incident occurred 38 years ago, and this report is based on review of his medical records written at the time of event, a personal interview with the patient, recollection from the surgeon treating him (NS) and an internal report, never published in the open domain, by the UK Royal Navy (RN) Institute of Naval Medicine.[2] The patient has reviewed the manuscript and approved it for publication.

In 1987 the RN completed a series of submarine escape exercises in Norwegian waters. The exercises were ethically approved by the UK Ministry of Defence and were completed to verify the performance of the Mk 8 escape suit during deep water escape. The subject was a 32-year-old male working as an instructor in the RN submarine escape training establishment. He had previously been admitted for appendectomy, suffered a middle ear barotrauma with perforated eardrum and one possible, but not medically attended or treated, incident of decompression sickness (DCS). He had not experienced any other abdominal illness. He had successfully completed ascents from 90 and 120 metres on two separate days earlier in the exercise. He had taken two tablets of ibuprofen for an unknown reason the preceding day. The incident occurred during escape from 150 metres.

During water filling of the escape trunk his arm got entangled in the rope to the signaling hammer and as a result of this incident, in the ensuring panic and anxiety, it is likely he unintentionally swallowed significant amounts of air during the process of getting free. During ascent, following the release from this rope, he focused on exhalation to avoid pulmonary barotrauma. He experienced increasing abdominal discomfort during ascent and vomited at surface. He was initially therapeutically recompressed to a pressure equivalent of 50 metres of seawater according to RN treatment table 63. He suffered severe abdominal pain and suffered haematemesis on three occasions during the treatment, but physical examination did not reveal peritonism or hypotension. The absent improvement and the need for opiate analgesia suggested an alternative diagnosis of a perforated viscus. A decision was made to surface him and admit him to Haukeland University Hospital for further treatment.

On admission he still suffered abdominal pain; his abdomen was distended, tender and a plain abdominal X-ray showed a large amount of intra-abdominal gas which was exsufflated bedside with a wide-bore intravenous cannula, partly relieving the symptoms. A laparotomy with upper midline incision revealed a rupture of the gastrocolic ligament. Following incision of the omental bursa, a 9 cm perforation starting approximately 10 cm from pylorus and running proximally on the gastric lesser curvature was found and sutured in two layers. No abdominal contamination was visible. Recovery was uneventful and he was discharged from the hospital after eight days.

Discussion

Molenat and Boussuges published a review on gastric barotraumas in 1995.[3] Panic, swallowing of water and deep dives preceded most of the 12 cases listed in that review. The present case shares many similarities though there is no suggestion of swallowing of water. This is the first published incident of gastric rupture following free ascent training. However, the mechanism is like that shared with divers breathing compressed gas. Gas within the stomach will expand during ascent and will distend it unless released through belching or through the pyloric channel. Cadaver experiments reported by Margreiter et al.[4] concluded that a constricted stomach will rupture if the transmural pressure exceeded 17 kPa. Distension of the stomach reduces the Angle of His which may cause the cardio-esophageal junction to act like a one-way valve, not allowing expanding gastric gas to pass through the oesophagus.[5] A rupture will most commonly present at the lesser curvature, possibly

Table 1
Symptoms and findings previouly suggested by the authors for diagnostic assessment of divers presenting with abdominal pain following diving; DCS – decompression sickness

Symptoms and findings suggesting DCS	Symptoms and findings suggesting other diagnosis
Additional extra-abdominal symptoms or findings characteristic of DCS (e.g. skin rash, joint pain, neurological symptoms or findings)	The onset of initial symptoms presenting before, during or several hours (> 3–6 h) after the dive
Improvement during normobaric oxygen treatment or therapeutic recompression	Low inert gas load (short and/or shallow dive)
Normal findings of abdominal physical examination	Abdominal distension
	Findings of physical examination, laboratory studies or diagnostic imaging characteristic of other diagnosis
	No improvement or worsening during therapeutic recompression

caused by differences in mucosa thickness, muscular thickness, ligament fixation and tensile forces due to the gastric geometry.[3,6]

Patients suffering acute abdominal pain, abdominal distension, guarding, rigidity or local tenderness would normally justify a diagnosis of 'acute abdomen' and further surgical referral. However, in divers such abdominal pain may be a symptom of decompression sickness (DCS). The differential diagnosis may be challenging if acute abdominal pain appears shortly after surfacing since gastric barotrauma is a rare event and only seventeen case reports have been published earlier.[1] We will discuss this in further detail below.

Abdominal distension and tenderness have been reported in some of the previous case reports of gastric barotrauma but was not present initially in this case. Paracentesis and exsufflation of a pneumoperitoneum may relieve symptoms as described in the present case as well as that shared by Ben Ayad et al.[1] However, pneumoperitoneum may develop without confirmed gastric barotrauma and can be successfully treated conservatively as discussed in an extensive review by Kot et al.[7] While gastroscopy can confirm a mucosal injury it can't be used to confidently define the depth of a gastric laceration, i.e. whether it is a perforation. The surgical approach for repair of gastric tears caused by diving barotraumas have usually been by laparotomy, though Ben Ayad[1] reported the first case of laparoscopic access for such purpose.

Abdominal pain may be a symptom of spinal DCS or intestinal venous gas embolism as discussed by Beale et al.[8] Immediate therapeutic recompression would usually be indicated in these cases. The increasing availability of point of care ultrasound may support diagnostics[9] and emergency hospital referrals if gastric barotrauma is suspected. However, divers suffering spinal or abdominal DCS may experience severe sequelae, and treatment delay may worsen the outcome.[8,10,11] To the best of our knowledge only one report has been published relating gastric rupture to a fatal diving accident. The rupture was identified post mortem following unsuccessful cardiopulmonary resuscitation (CPR).[12] Gastric rupture is a rare but well recognised complication of CPR.[13] We are unaware of sequelae following any of the other published cases of gastric barotraumas even though many of them were therapeutically recompressed initially and surgical treatment delayed for this reason. We support the notion of Kot et al.[7] recommending a multidisciplinary approach to abdominal pain appearing shortly after dives. To the best of our knowledge, no scientifically appraised clinical guideline has been published addressing diagnostic criteria discriminating DCS from other abdominal illnesses for divers suffering abdominal pain following diving. Based on our personal experience we suggest (Table 1) some aspects to be considered in the diagnostic process. We would still conclude that the general approach to diving accidents: 'if in doubt-recompress' seems valid.

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