Shallow Water Diving-Associated Alveolar Hemorrhage in an Active Duty Sailor: A Case Report

Capt Brannon L. Inman, MD, USAF, MC; CPT Rachel E. Bridwell, MD, FS, MC, USA*; Maj Amber Cibrario, DO, USAF, MC*; MAJ Sarah Goss, MD, MC, USA*; MAJ Joshua J. Oliver, MD, MC, USA†*

ABSTRACT Breath-hold diving is a common practice as a part of military dive training. An association between prior lung injury and a propensity for lung barotrauma may have the potential to impact mission readiness for combat divers, Pararescue, Combat Controllers, Army Engineer divers, and various units in Naval Special Warfare and Special Operations. Barotrauma is a common complication of diving, typically occurring at depths greater than 30 m (98.4 ft). Individuals with abnormal lung anatomy or function may be at increased risk of barotrauma at shallower depths than those with healthy lungs, rendering these service members unfit for certain missions. We describe the case of a 25-year-old male, with a remote history of polytrauma and resultant pulmonary pleural adhesions, whose dive training was complicated by lung barotrauma at shallow depths. In missions or training utilizing breath-hold diving, the association with secondary alterations in lung or thoracic anatomy and function may limit which service members can safely participate.

INTRODUCTION

Diving associated injuries are well-documented complications of diving using compressed air. However, there is a dearth of shallow water barotrauma cases in the literature. With the use of compressed air tanks, divers can descend further for longer durations, increasing the risk of decompression sickness, barotrauma, and nitrogen narcosis.[1,2] Special considerations are often taken with deep dives of depths greater than 180 m (590 ft), beyond which compressed air is no longer a safe practice and often requires the use of a mixture of compressed oxygen and Nobel gasses such as helium.[1] Diving injuries are of low-to-moderate frequency with an incidence of 7-35 events per 10,000 divers or 5-152 events per 10,000 dives.[3] Events in breath-hold divers are less common. Diver-specific factors such as preexisting medical issues, dive experience, and level of training were more often associated with barotrauma, depression sickness, drowning, and mortality.[3] Given the attention that compressed air diving injuries receive, it is possible that shallow water dives associated with breath-holding are being overlooked in the medical literature. However, it is also possible that shallow water diving injuries are being underreported. Despite the lack of reported cases in the medical literature, 140 cases were reported to the Diver's Alert Network (DAN) in 2017, including 52 fatalities.[4]

With breath-hold diving, divers typically take preemptive actions to maximize time underwater.[2] Before descent, breath-hold divers intentionally hyperventilate, followed by a maximal inspiration to total lung capacity.[2,5,6] This hyperventilation can predispose the breath-hold diver to shallow water blackout.[7] When increased external pressure compresses gases within the lung, it reduces the volume and the resultant alveolar collapse at depth and predisposes them to barotrauma.[2,5] Pulmonary hemorrhage becomes of particular concern as the diver descends to depths where lung volumes are compressed below residual volume.[7] At depths greater than 30 m (98.4 ft), the lungs of the average diver are compressed to their residual volume, and roughly 1 L of blood can be drawn into the intrathoracic space.[1,4,5] Although barotrauma is less often described in breath-hold diving, this technique is frequently practiced among military divers, recreational divers, seafood divers, and competitive athletes.[2,4] We present such a case in a military trainee.

CASE PRESENTATION

A 25-year-old male military trainee was brought to the Emergency Department (ED) after shallow water breath-hold diving with a resultant hemoptysis, syncope, and oxygen desaturations en route to the ED. His past medical history included a severe multisystem trauma 10 years prior with a prolonged period of mechanical ventilation and tracheostomy placement, multiple bilateral chest tube thoracostomies, and an exploratory laparotomy. His course was also complicated by pulmonary emboli. At the time of presentation, he had no known residual complications from this polytrauma, with no documented waivers from the trauma, and was a fully functioning military member. He had no recent illness, no shortness of breath, and no cough before diving that day.

*Department of Emergency Medicine, San Antonio Uniformed Services Health Education Consortium, Fort Sam Houston, TX 78234, USA

†Department of Emergency Medicine, Madigan Army Medical Center, Tacoma, WA 98431, USA

The view(s) expressed herein are those of the author(s) and do not reflect the official policy or position of Brooke Army Medical Center, the U.S. Army Medical Department, the U.S. Army Office of the Surgeon General, the Department of the Army, the Department of the Air Force and Department of Defense or the U.S. Government.

doi:https://doi.org/10.1093/milmed/usab046

The patient was performing shallow water breath-hold diving drills specific to Pre-Basic Underwater Demolition/Seals (BUDS) training in a swimming pool to a maximum depth of 12 ft (3.658 m). Based on history obtained from the patient, he was participating in informal non-unit-based pre-BUDS training. As part of the drills, the maximum time underwater was needed. Upon ascent, the patient reports that he began to cough with noted hemoptysis, followed by a syncopal event, after which fellow service members extricated him from the pool.

At the presentation to the ED, his pulse oximetry was 98% in room air, blood pressure 130/87 mm Hg, heart rate 68 beats per minute, temperature 37.1°C. He was well appearing but in mild respiratory distress and complaining of dyspnea. The physical exam was notable for scant rales in the bilateral lower lung fields and multiple thoracostomy scars on the chest wall bilaterally but was otherwise unremarkable. Laboratory evaluation was as follows: sodium of 138 mg/dL, potassium of 4.0 mg/dL, chloride of 95 mmol/dL, bicarbonate of 24 mmol/dL, blood nitrogen urea of 9 mg/dL, and creatinine of 1.1 mg/dL. Complete blood count demonstrated the following results: hemoglobin of 14.1 g/dL, hematocrit of 43%, white blood cell count of 9.8×10^3, and platelets of 223×10^3. D-dimer was 0.44 mcg/mL (upper limit 0.49 mcg/mL). The electrocardiogram showed sinus rhythm with normal axis and no evidence of right heart strain. Chest radiograph showed an elevated right hemidiaphragm and loss of the costovertebral angles bilaterally, consistent with pleural adhesions likely from previous thoracostomies (Fig. 1). Computed tomography angiography of the chest demonstrated bilaterally alveolar fluid with Hounsfield units consistent with more blood in the right than in left basilar lung fields, and evidence of pleural adhesions, though no evidence of pulmonary embolism was found (Figs. 2 and 3). The patient was admitted for observation and over the subsequent 24 hours his dyspnea resolved, and he was discharged in stable condition. Following discharge, he was placed on duty restriction, to include restriction from diving activities.

FIGURE 1. Anteroposterior chest radiograph with elevation of right hemidiaphragm and loss of bilateral costophrenic angles (red arrows).

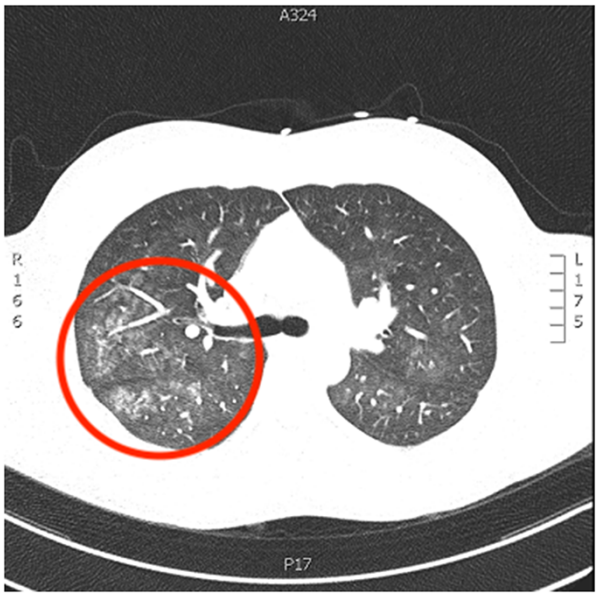

FIGURE 2. Computed tomography of the chest without contrast showing bilateral fluid with Hounsfield units consistent with more blood on the right side than left (red circle).

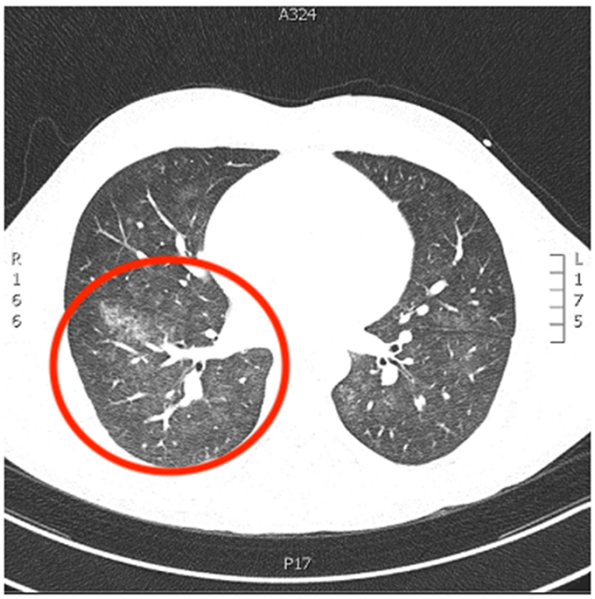

FIGURE 3. Computed tomography of the chest without contrast showing bilateral fluid with Hounsfield units consistent with more blood on the right side than on left (red circle).

DISCUSSION

Breath-hold diving is the practice of controlled descent without the use of compressed air and is practiced by many populations including military personnel.[1,2,6] Upon descent, increased ambient pressure and subsequent decreasing

intrathoracic pressures result in the shift of extrathoracic blood volume into the intrathoracic space.[2,6] The shifting of intrathoracic blood into the thorax leads to barotrauma of the lung via three mechanisms. First, increasing ambient pressures reduces gas volume and subsequently increases the risk of lung atelectasis. Second, increased intrathoracic fluid filters into the alveolar space increasing the risk of pulmonary edema. Finally, increased intrathoracic fluid can lead to alveolocapillary membrane rupture with resultant hemorrhage.[2,6] These factors predispose divers to lung barotrauma among shallow and deep-water divers alike.[2] Likely, the mechanisms described above exist along a continuum along which various phenotypic manifestations of pulmonary barotrauma exist, including pulmonary edema and alveolar hemorrhage. Derangements in pulmonary function and decreases in pulmonary compliance are further thought to increase the risk of barotrauma and pulmonary injury in divers.[1]

In the patient described, a prior history of trauma could have been an indicator that diving would not be appropriate. As per U.S. Naval diving clearance guidelines, traumatic pneumothorax is a disqualifying condition, though a waiver can be granted with appropriate pulmonary function testing, computed tomography of the chest, and clearance form a pulmonologist and the patient's uniformed medical officer.[8] British Thoracic Society guidelines do include recommendations on pre-diving screening for the recreational diver. British Thoracic Society guidelines typically include pulmonary function testing and in the case of this patient would likely have included a pre-diving chest x-ray or cross-sectional chest imaging.[9]

The presented patient experienced hemoptysis and alveolar hemorrhage during a breath-hold dive at a depth of 12 ft (3.65 m) with ∼1.3 atmospheres of pressure (atm), with time underwater maximized for military-specific drills.[2,6] Barotrauma of the lungs during decent is well described, but not often at such shallow depths.[1,4–6] Most reports of lung barotrauma with breath-hold dives occur at depths of 30 m or more.[6] At only 1.3 atm, alveolar hemorrhage would not likely be secondary to purely ambient pressure. The previous chest thoracostomies and resultant abnormal lung anatomy and pleural adhesions may have predisposed the patient to barotrauma at shallower depths, as pleural adhesions decrease this patient's chest wall elasticity, reducing this service member's tolerable dive depth.[2,6,10] Increasingly negative intrathoracic pressure may have caused a shift of extrathoracic blood volume into the chest resulting in stress failure of the alveolocapillary beds at shallower depths.[2,5,6,10] The predilection for pulmonary barotrauma at relatively shallow breath-hold dive depths has been described, but not typically at depths <12-13 m (39.4-42.6 ft).[5,10] This presents practical issues for military operations. Individuals with abnormal lung anatomy and physiology have a greater risk of barotrauma at disproportionally shallow depths, thus limiting overall mission effectiveness and unit safety in settings where such conditions must be tolerated. Unit providers should consider any previous anatomic or physiologic derangements before clearing service members for dive status.

CONCLUSION

This case raises the concern that military members with derangements in lung structure and function may not be able to tolerate missions requiring exposure to increased atmospheric pressures. This association has the potential to impact mission readiness for combat divers, Pararescue, Combat Controllers, Army Engineer divers, and a variety of Navy divers. Dive unit providers should carefully consider previous lung injury or trauma in any diving service member.

ACKNOWLEDGMENT

None declared.

FUNDING

None declared.

CONFLICT OF INTEREST STATEMENT

None declared.

REFERENCES

1. Segadal K, Gulsvik A, Nicolaysen G: Respiratory changes with deep diving. Eur Respir J 1990; 3(1): 101-8. Available at http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.952.8025&rep=rep1&type=pdf; published 1990; accessed October 22, 2020.
2. Fitz-Clarke JR: Breath-hold diving. Compr Physiol 2018; 8(2): 585-630.
3. Buzzacott PL: The epidemiology of injury in scuba diving. Med Sport Sci 2012; 58: 57-79.
4. DeWitt H, Moore A, Tillmans F: Breath-hold diving. Compr Physiol 2018; 8(2): 585-630. Available at https://www.ncbi.nlm.nih.gov/books/NBK562531/; published 2019; accessed October 29, 2020.
5. Kalemoglu M, Keskin O: Hemoptysis and breath-holding diving. Mil Med 2006; 171(7): 606-7.
6. Lindholm P, Lundgren CEG: The physiology and pathophysiology of human breath-hold diving. J Appl Physiol Am Physiol Soc 2009; 106: 284-92.
7. Bove AA: Diving medicine. Am J Respir Crit Care Med 2014; 189(12): 1479-86.
8. US Navy NP-117. Change 164 Manual of the Medical Department. 2018. Article 15-102, 15-76. Available at https://www.med.navy.mil/directives/Pub/MANMED%20CHANGE%20164.pdf; accessed December 30, 2020.
9. Published by Direction of Commander, Naval Sea Systems Command: U.S. navy diving manual. Available at https://www.navsea.navy.mil/Portals/103/Documents/SUPSALV/Diving/US%20DIVING%20MANUAL_REV7.pdf?ver=2017-01-11-102354-393; published October 15, 2011; accessed December 26, 2020.
10. Godden D, Currie G, et al British Thoracic Society Fitness to Dive Group, Subgroup of the British Thoracic Society Standards of Care Committee: British Thoracic Society guidelines on respiratory aspects of fitness for diving. Thorax 2003; 58(1): 3-13.
11. Kuschner WG, Gutsche M: Case report hemoptysis due to breath-hold diving following chemotherapy and lung irradiation. Clin Med Res 10: 137-9.