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Barotrauma and Arterial Gas Embolism: A Diving Emergencies Simulation Case for Emergency Medicine Residents

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Appendices

A. Simulation Case File.docx
B. Simulation Images.docx
C. Critical Actions.docx
D. Debriefing Materials.pptx
E. Follow-up Questions.docx

All appendices are peer reviewed as integral parts of the Original Publication.

Abstract

Introduction: Arterial gas embolism (AGE) is a rare but severe complication of scuba diving. While AGE is most commonly encountered in coastal areas with high volumes of recreational divers, at-risk populations exist throughout the United States, making basic knowledge of the disease important for all emergency medicine (EM) physicians. **Methods:** We used a hypothetical simulation case to train EM residents on diagnosis and management of AGE. A 32-year-old male presented with shortness of breath and unilateral neurologic deficits immediately after scuba diving. Residents were challenged to emergently diagnose and treat tension pneumothorax followed by diagnosis and treatment of AGE. A resident, attending, and simulation technician ran the case for four separate simulation teams in the simulation center with the addition of chest tube supplies to the basic resuscitation bay setup. Teams were allowed to use the internet in real time as a reference tool. **Results:** Most teams arrived at the correct diagnosis using real-time internet searches, but none found the Divers Alert Network Emergency Hotline. Learners were debriefed both immediately and in a formal lecture. A follow-up survey showed good retention of knowledge. **Discussion:** This case fills a significant knowledge and training gap for many EM physicians. AGE is a rare but highly morbid complication of diving, and EM residents should have knowledge of the disease and available consultation resources. Most EM residents will not have the opportunity to treat a diver during training, and the simulation environment provides a means to teach and practice this skill set.

Keywords

Simulation, Tension Pneumothorax, Emergency Medicine, Pneumothorax, Decompression Sickness, Arterial Gas Embolism, Scuba Diving, Hyperbaric, Hyperbaric Oxygenation, Decompression Illness

Educational Objectives

By the end of this activity, learners will be able to:

1. Identify symptoms of pulmonary barotrauma and arterial gas embolism in scuba divers.
2. Execute appropriate management for arterial gas embolism.
3. Recall the use of the Divers Alert Network Emergency Hotline for consultation and management of sick or injured divers.
4. Execute appropriate management for tension pneumothorax.

Introduction

Recreational scuba diving is a sport with an ever-increasing number of participants. Currently, there are between 2.5 and 3.7 million active scuba divers in the United States, with over six million active divers globally.[1] Fortunately, rates of decompression illness (DCI) among scuba divers are low. In 2015, one organization, the Divers Alert Network (DAN), logged 250 cases of DCI out of 11,500 medical inquires.[2] Unfortunately, DCI carries significant morbidity and mortality, with fatality from DCI estimated to be approximately 10%.[3,4] Despite DCI's being a highly morbid disease, emergency medicine (EM) residents are not being trained in its diagnosis and management in large portions of the United States. We aimed to use simulation as a modality for teaching EM residents about DCI.

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Recreational divers suffer from diving-related injury at an estimated rate somewhere between five and 152 injuries per 100,000 dives.[5] Diving-related injury is divided into two categories (Figure). The first is barotrauma, referring to disease and injury resulting from the expansion and contraction of gas. The second, DCI, represents both decompression sickness (DCS) and arterial gas embolism (AGE), which are diseases resulting from the formation of gas bubbles in the tissues of the body. The more common of these is DCS, also known as the bends. DCS was initially called caisson disease, a term coined to describe the constellation of symptoms affecting the caisson workers building the Brooklyn Bridge in 1873.[6] The nickname the bends came from the stooped posture of those workers affected by the pain associated with DCS.

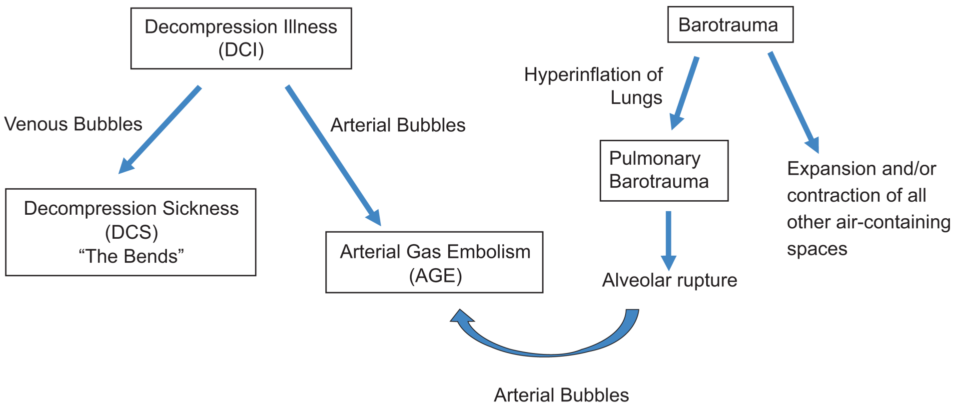

Figure. Flow diagram showing the interrelationships between different classifications of diving-related illness.

AGE is the second leading cause of death from underwater diving accidents after drowning [7] and occurs at a rate estimated to be less than one per 100,000 dives.[8] Approximately 4% of patients progress to collapse, loss of consciousness, seizure, and/or cardiac arrest.[8-10] AGE results from one of three mechanisms: direct bubble embolization after pulmonary barotrauma causes alveolar rupture, right to left shunt through a patent foramen ovale, or because venous bubble burden is so high that the pulmonary capillary beds cannot clear the gas into the alveoli fast enough. Symptoms of AGE present within minutes of surfacing from a dive. While recent research has shown that arterial gas bubbles are evenly distributed throughout the body, the organs most sensitive to bubbles are those with the most obvious resulting signs and symptoms, that is, the central nervous system and coronary arteries.[10] As a result, AGE often causes symptoms similar to acute coronary syndromes and stroke syndromes.

Emergency management for all forms of DCI is administration of oxygen via 100% nonrebreather mask and intravenous fluids followed by emergent transfer to hyperbaric oxygen therapy (HBOT). Despite symptoms that can mimic numerous other conditions such as stroke, myocardial infarction, vertigo, and myalgias, typical therapies for these conditions are of no use in DCI. The only definitive therapy for DCI is HBOT.[9-14] Patients suffering from AGE achieve best outcomes if HBOT is initiated rapidly, although there are case reports of good outcomes with HBOT initiation as long as 6 days after injury.[9,15-17] Emergency physicians need to be aware of local resources for the injured diver as well as DAN (www.diversalertnetwork.org), which is a nonprofit organization based in the United States created to promote diving safety and support divers in need through insurance, research, medical expertise, and evacuation assistance. DAN is the largest organization of its kind in the diving industry, with resources for the evacuation and treatment of divers spanning the globe.

Scuba diving injuries are not limited to places with high levels of recreational diving. Professional diving activities occur throughout America's coasts, waterways and aquariums, placing people at risk for diving-related injury even in landlocked environments. Additionally, tunnel workers, high-altitude aviators, and astronauts are all at risk for development of DCI.[18] This makes knowledge of diving-related illness important to the training of the emergency clinician, regardless of geography.

Finally, AGE is not limited to patients who have undergone significant decompression stress. Iatrogenic AGE is possible in health care settings and has been reported most commonly in procedures involving cardiopulmonary bypass, although it can occur with any procedure involving vascular access.[19] With recent advances in the availability of bedside extracorporeal membrane oxygenation as a treatment modality for critically ill patients, incidence of iatrogenic AGE might increase. As with diving injuries, treatment for iatrogenic AGE is also emergent HBOT.[19]

Rapid diagnosis of AGE relies upon obtaining and synthesizing pertinent history and examination findings, which can be best practiced in the simulated environment. A thorough review of *MedEdPORTAL* did not reveal any cases or educational modules on the diagnosis and management of pulmonary barotrauma or AGE in the scuba diver. As a result, we present a fictional simulation case used to teach EM residents a classic presentation of pulmonary barotrauma leading to AGE requiring participants to perform multiple levels of intervention and consultation. The case fulfills many of the Accreditation Council for Graduate Medical Education's EM milestones,[20] including (but not limited to) Performance of Focused History and Physical Exam, Emergency Stabilization, Observation and Reassessment, Procedures, Diagnosis, Disposition, Medical Knowledge, Patient-Centered Communication, and Team Management.

Methods

Development

A fictional simulation case (Appendix A) was written for EM residents to learn about the diagnosis and management of two life-threatening diving-related injuries: pulmonary barotrauma and AGE. The case was developed by a panel of three EM attendings (the simulation director and two faculty mentors) and a PGY 4 EM resident. The main goal of the simulation was to train EM residents in the rapid and calm assessment of a patient with injury and neurologic deficit from an unusual exposure that the residents were expected to have very little knowledge of, if any. The simulation is fully presented in the simulation appendices, including simulated laboratory results, X-rays, and EKG.

Equipment/Environment

This case is best run in a simulation center set up as an emergency room resuscitation bay in a low- or middle-income country. Either a manikin or a live actor can be used. We used a manikin that had a blood pressure cuff, pulse oximeter, and five-lead EKG attached to a monitor. The resuscitation room had readily available oxygen with a variety of administration modalities: nasal cannula, simple mask and nonrebreather mask, bag valve mask, laryngoscope and a selection of endotracheal tubes, scalpel, and chest tube insertion tray and chest tube. Additional resuscitation bay equipment was available as distractions, but the case required the use of the above-listed equipment. Finally, pre– and post–chest tube EKGs and chest X-rays were available for review by the team (Appendix B).

Personnel

Our simulation team consisted of a simulation technician to run the manikin, an actor to play the role of the dive buddy, and a supervising attending playing the role of registered nurse (RN) and consulting physicians. A live actor can be used instead of the manikin for the simulated patient, and an additional actor can play the roles of the consultant services, if resources are available.

Implementation

Our simulation was conducted as part of a multiple-simulation education day focusing on environmental emergencies. The target audience of this simulation day was EM residents from the PGY 1 to PGY 4 levels. Guest learners from the EM subinternship, EM physician assistant (PA) residency, and EM RN residency were also present. Each simulation team comprised a mixture of the above learners. The case was run by a simulation technician, senior EM resident, and teaching attending physician. A critical actions checklist was used to evaluate each team's performance during the simulation session (Appendix C).

Our learners participated in the activity by playing the roles they usually would. For example, EM RN residents played the roles of RNs, MD residents played MDs, and so on. In addition to the simulation technician, we utilized two confederates, a dive buddy (senior EM resident) and a consultant (EM attending). We used a high-fidelity manikin, and our teams were able to perform the chest tube placement procedure. Vital signs were changed in real time in concordance with performance of critical actions. Physical examination findings that we were unable to simulate on the manikin, such as facial droop or hemiparesis, were described concurrently with the team's examination of the patient. Once progression of the simulation case stalled, each group was allowed to designate one or two members of the resuscitation team who could use their cell phones to access the internet for more information.

Debriefing

Debriefing was separated into two main components. The first was bedside debriefing, and the second was a central debrief of all participants together at the end of the simulation day. The bedside debriefing immediately after completion of the case took approximately 5-10 minutes. The focus of this short debrief was teamwork skills, team resuscitation skills (e.g., closed-loop communication, clear role assignment, verbalized reassessments, etc.), and review of the critical actions checklist. A few individual questions pertaining to the case and diagnosis were addressed in the bedside debriefing, but most were held for the central debrief at the end of the day.

At the end of the multiple-simulation educational session, all simulation groups from the day gathered for joint debriefing of the disease processes and management modalities discussed in all cases that day. For this case, a PowerPoint presentation was used to review the physics, pathophysiology, and primary management of dysbarisms, with specific emphasis on DCI, barotrauma, and AGE (Appendix D). At this time, any and all questions pertaining to diagnosis and management of this case were addressed.

Assessment

Learners were assessed individually based upon their active participation in the case and debriefing. The team was assessed using a critical actions checklist. A voluntary survey of residents was conducted approximately 1 year after the simulation session to evaluate retention of learning objectives (Appendix E).

Results

This simulation was completed by four separate simulation teams during a themed multisimulation day on environmental emergencies. Learners were a mixed group of approximately 20 EM residents from PGY 1 to PGY 4 levels, six fourth-year medical student EM subinterns, four EM RN residents, and four EM PA residents. Each simulation team was designed to have a core of EM residents, with visitors as evenly distributed as possible (i.e., no team consisted only of visitors).

We observed that EM residents at all levels of training (PGY 1-PGY 4) easily identified and treated tension pneumothorax at the start of the case. Once the patient stabilized, residents were able to identify that the patient's illness was likely diving related, but they were unable to formulate a differential diagnosis for diving-related illness. Using real-time internet searches, teams were able to correctly diagnose AGE. Unfortunately, brief web search did not lead groups to the DAN Emergency Hotline for transfer assistance. Some of the groups contacted the local hyperbaric chamber, who accepted the patient and then referred the learners to DAN for evacuation assistance. Other groups were prompted by the nurse to call DAN.

Approximately 1 year after the simulation, residents from the program were asked to respond to two board review–style questions regarding the diagnosis and management of pulmonary barotrauma as well as AGE. A total of 13 residents responded to the questions, eight of whom had been participants in the simulation 1 year prior. Of the eight participants, seven were able to correctly identify and treat a tension pneumothorax as an example of expansion injury, whereas only one of the five nonparticipants was able to do the same ($p = .03$). Six of the eight simulation participants were able to correctly diagnose an AGE and alert DAN. Of the five respondents who did not attend the simulation, three were able to correctly diagnose an AGE and alert DAN ($p = .5$).

Discussion

Our program is located at a large urban academic center without significant amounts of local recreational diving and without a multiplace hyperbaric chamber. Residents do not receive exposure to diving-related injury except in the simulated environment. At least a basic knowledge of diving emergencies and how to get help is an important part of the education of any EM resident. This simulation case aimed to illustrate a classic diving emergency to teach residents management and consultation with DAN or the local hyperbaric team.

Resident lack of baseline knowledge about diving emergencies proved to be a significant challenge during implementation. Our case was not initially planned with the use of cell phones for real-time data search. When the first simulation team became stalled after stabilization of the patient but without successfully diagnosing AGE or initiating appropriate consultation and transfer, the decision was made to allow real-time internet searches on a smartphone. This was allowed because our simulated environment does not have computer stations and the ability to perform high-quality rapid internet searches to make patient care decisions has become a necessary skill for physicians in the 21st century. Subsequently, each group was allowed to progress as far as it could before being told that group members could use their cell phones. Future versions of the case may include a prebriefing learning module on the diagnosis and management of scuba diving emergencies, featuring local and international resources such as DAN, so that simulation time can be spent reinforcing this material.

Our results show that significantly more simulation participants than nonsimulation participants were able to correctly diagnose pneumothorax due to barotrauma in an injured diver; however, our sample size is far too small to draw lasting conclusions regarding the educational impact of this simulation. There was no statistically significant difference between groups on the knowledge retention survey regarding consultation with DAN. A larger percentage of the participants answered this question correctly compared to nonparticipants. The lack of significant difference may be due to small sample size but also may be due something inherent in medical practice—when you do not know what to do, phone a friend who does. Holding further simulation sessions to generate a larger sample size would be required to answer this question.

Our resource contains a number of limitations. Our experience is only with EM learners from a single institution with a single day of running the simulation. We did not formally collect real-time learning impressions of the simulation, but informal feedback was positive. Additionally, our knowledge retention questions were aimed only at what we considered to be the two most significant learning objectives of the case, specifically, the diagnosis of barotrauma leading to AGE and consultation with DAN. As this was a voluntary survey administered in a delayed fashion, the sample size for the knowledge retention evaluation is very small—smaller than the number of participants in the simulation—which prevents strong statistical conclusions from being drawn. Ideally, we would have modified the case and run it again prior to publication, but the cycle of the residency curriculum will not return to diving and hyperbarics for 3 years. Further limitations are evident as the case was presented as part of a themed multisimulation session on the topic of environmental emergencies, so learners were primed to assume that the recent history of scuba diving was highly relevant to the case. We invite any readers who choose to use the simulation to give us feedback at the contact information provided.

Overall, we feel that the case is generalizable to institutions without a hyperbaric service as an educational tool for teaching about a common presentation and management of a diving emergency with high morbidity and mortality. The simulated environment proved to be a useful tool for teaching about diving emergencies, and further work can be done in this area to teach other aspects of diving-related disease and marine injury or envenomation.

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