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Brief Reports

ACCURACY OF A SET OF SCREENING PARAMETERS DEVELOPED FOR THE DIAGNOSIS OF ARTERIAL GAS EMBOLISM: THE SANDHOG CRITERIA

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□ **Abstract—Background: Arterial gas embolism (AGE) is a major cause of morbidity and mortality in self-contained underwater breathing apparatus (SCUBA) diving and certain medical procedures. There are currently no well-defined criteria to diagnose AGE. Emergency physicians often find themselves facing a decision whether or not a patient with dive-related symptoms has an AGE and needs to be transferred to a hyperbaric facility. Objectives: The objective of this study was to test the accuracy of diagnostic criteria developed by the San Diego Hyperbaric Oxygen Group (SANDHOG) for the diagnosis of AGE. Methods: This was a retrospective review of consultations completed by the Hyperbaric Medicine Department (HBO) at the University of California San Diego where the diagnosis of AGE was considered. HBO staff blinded to the purpose of the study identified potential cases of AGE. The criterion standard was the final diagnosis by a panel of HBO specialists also blinded to the purpose of this study. Descriptive statistics and comparisons evaluating SANDHOG criteria compared to the criterion standard were performed. Results: Twenty-six patients were identified for inclusion. Twenty-three of 26 (88%) were SCUBA divers, 2 had intravascular gas injections, and 1 patient had a military training chamber accident. Nineteen of 26 (73%) patients were diagnosed with AGE. A SANDHOG score of 2 had 94.7% sensitivity (95% confidence interval [CI] 71.9–99.7), 85.7% specificity (95% CI 42.0–99.2), positive likelihood ratio of 6.6 (95% CI 1.1–40.8), and negative likelihood ratio of 0.06 (95% CI 0.01–0.43) for AGE. A SANDHOG score <2 had a negative predictive value of 100% for AGE. Conclusion: The SANDHOG criteria appear to be reliable in diagnosing AGE. AGE is unlikely with SANDHOG scores <2, whereas SANDHOG scores ≥2 resulted in high sensitivity and specificity for AGE. Emergency physicians may find this tool useful in evaluating patients for suspected AGE, and it may assist in determining whether to transfer the patient to a hyperbaric facility. Future studies should be performed to further examine and validate the accuracy and inter-rater reliability of this tool.** © **2015 Elsevier Inc.**

□ **Keywords—arterial gas embolism; barotrauma; diving injury; dysbarism; hyperbaric oxygen therapy**

INTRODUCTION

Self-contained underwater breathing apparatus (SCUBA) diving has become a mainstream recreational activity. Since its inception in 1967, the Professional Association of Diving Instructors (PADI)—one of the world's largest recreational certification agencies—has issued >17 million entry-level SCUBA certifications (1). Arterial gas embolism (AGE) is a leading cause of morbidity and mortality in SCUBA diving. Brauer first described AGE in 1913 in the setting of submarine escape training in which participants breathed compressed air at depth then performed rapid breath-holding ascents (2).

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The subsequent pulmonary overinflation caused by the decreasing surrounding atmospheric pressure and expanding lung volumes during breath-holding ascent (Boyle's law) resulted in pulmonary barotrauma. This facilitated entry of air bubbles into the pulmonary venous circulation in sufficient quantity to overwhelm the pulmonary capillary network and caused systemic arterial embolization of those bubbles (3,4).

Unlike decompression sickness, pulmonary barotrauma and AGE can occur any time a diver breathes compressed air, regardless of depth or duration of a given dive. In fact, AGE has been documented after breath-holding ascents of as little as 1 m (5). AGE is a time-sensitive clinical diagnosis that should be made without reliance on radiographic imaging (6–15). The definitive treatment for AGE involves recompression therapy, and it is important to make the diagnosis in a timely fashion to avoid delays in transport to a hyperbaric facility. In addition, clinical syndromes associated with AGE may include cerebral or less commonly cardiac ischemic symptoms; delays in diagnosis can therefore result in organ dysfunction. While no absolute time has been established beyond which hyperbaric oxygen (HBO) therapy is ineffective, it is generally accepted that initiation of treatment should occur within <24 hours and ideally within <6 hours. AGE is a clinical diagnosis based on exposure to barotrauma or air entry into the circulation from a number of different sources, and the presence of a number of clinical parameters. Hyperbaric Medicine Specialists are rare and there is no well-defined set of objective clinical criteria that can be easily applied by nonspecialists to diagnose AGE (9–15). As a result, the U.S. Navy has adopted a written policy that states that any diver breathing compressed air who surfaces from a dive "unconscious, loses consciousness, or has any obvious neurological symptoms within 10 minutes of reaching the surface, must be assumed to be suffering from arterial gas embolism" (7).

Based on the available literature—and extensive clinical experience—the San Diego Hyperbaric Oxygen Group (SANDHOG) developed a scoring system (Figure 1) that requires a total of ≤2 points to suggest the diagnosis of AGE and ≥3 points to strengthen the inference. The SANDHOG criteria are defined as follows: 3-point criteria include a sudden loss of consciousness (LOC), disorientation, aphasia (loss of ability to understand or express speech), or hemiplegia (unilateral paralysis or complete motor deficit) occurring <5 minutes after surfacing; 2-point criteria include hemi- or monoparesis (partial motor deficit), cortical blindness (loss of vision caused by a disturbance in the visual cortex as opposed to the eye), or seizure <5 minutes of surfacing; and 1-point criteria include rapid ascent in the water column, hemoptysis, barotrauma (i.e., pneumomediastinum, pneumopericardium, or pneumothorax) on a chest radiograph (Figure 2), and a creatinine phosphokinase (CPK) level ≥2 times the normal level. The objective of this study was to test the accuracy of the SANDHOG criteria for the diagnosis of AGE. If validated, these simple criteria may be applied by emergency physicians, hyperbaric specialists, trained telephone triage staff, or primary care physicians to objectively determine whether further evaluation, treatment, or hyperbaric consultation is indicated for a potential case of AGE.

Requires 2 or more points to suggest a diagnosis of AGE

3 Points

1. Any of the following signs or symptoms within 5 minutes of surfacing
   a. Sudden LOC
   b. Disorientation
   c. Aphasia
   d. Hemiplegia

2 Points

1. Any of the following signs or symptoms within 5 minutes of surfacing
   a. Hemiparesis or monoparesis
   b. Cortical blindness
   c. Seizures (no prior history of seizures/epilepsy)

1 Point

1. A rapid uncontrolled or any ascent with panic and the onset of symptoms
2. Hemoptysis
3. Presence of barotrauma on CXR
4. CPK greater than 2 times normal in the absence of musculoskeletal trauma

Figure 1. San Diego Hyperbaric Oxygen Group criteria for arterial gas embolism. AGE = arterial gas embolism; LOC = loss of consciousness; CXR = chest x-ray.

MATERIALS AND METHODS

Setting

The University of California at San Diego (UCSD) Emergency Department (ED) and Hyperbaric Medicine Department serve as a referral center for dive-related emergencies occurring within a 1500-mile radius. All dive-related injuries in that area are referred to, or present to, the UCSD ED.

Participants

The UCSD SANDHOG maintains a patient log that includes all requests for HBO consultation from the ED. This log was manually searched in the fields "indication for consultation" and "diagnosis" by hyperbaric staff members who were blinded to the purpose of this study. The inclusion criteria were patients in the HBO log for