You're the Flight Surgeon

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You're the flight surgeon on call in an overseas flight medicine clinic one morning when a 35-yr-old male Navy F-15 pilot (currently assigned to an Air Force fighter squadron) is dropped off at the clinic by his wingmen. He appears slightly pale and disheveled, reports feeling a bit "shaky," has a "knot" in his upper abdomen, and a terrible headache. These symptoms reportedly started abruptly after a strange pressurization problem with his jet.

1. What should your first action be?

A. Call the Emergency Department.
B. Call the hyperbaric specialist at the San Antonio Military Medical Center.
C. Get vital signs.
D. Contact the nearest hyperbaric facility.
E. Place the patient on 100% supplemental oxygen via a tight-fitting aviator's mask.

ANSWER/DISCUSSION

1. E. While all of the above-listed actions could be an appropriate part of the response and coordination of care for this patient, the top priority in this case is to initiate immediate treatment for presumed decompression illness (DCI), which is 100% oxygen via a tight-fitting aviator's mask, while coordinating definitive treatment of hyperbaric recompression therapy.[2]

The patient was immediately assessed and placed on 100% oxygen via a tight-fitting aviator's mask. His initial vital signs and full physical exam were completely within normal limits, aside from elevated blood pressure at 138/99 mmHg. He reported 9/10 pain at that time, in the form of a right frontal headache described as pounding/pressure. He reported (and medical chart review supported) no significant past medical history. He denied any medication or supplement use. He denied any scuba diving within the past 72 h. He denied any alcohol consumption the evening prior and reported that his last meal was breakfast at approximately 03:45 that morning, after 6 h of average sleep following a 10-h work shift the day prior.

That morning, he reported to preflight brief at 04:45, with takeoff at 07:20 and landing at 08:30. Shortly after takeoff, he noted that his cockpit pressure gauge was not working properly, reading zero throughout the ascent. He and his wingman paused to troubleshoot the pressure gauge and did not exceed an altitude of 4877 m (16,000 ft) above ground level. Because they could not correct the issue, they decided to abort the mission and return to base. He was on supplemental oxygen (not emergency supply) and noted slightly more resistance than normal breathing through his mask on the return flight, but otherwise felt fine and had an uneventful return and landing. As he parked, he realized that he had been on the wrong radio frequency during taxi, and several of his switches were in the wrong configuration based on the landing checklist that he was running. This indicated to him that perhaps his cognitive function was not 100% at landing. He continued the post-flight checklist. Per the checklist, because he felt that the cockpit was likely over-pressurized, he pulled the pressure dump handle. He felt a "pop" as the pressure dumped and, within 5 min, developed a flushing sensation and pounding headache. He quickly got the "shakes" and had significant increase in his difficulty concentrating. He soon developed a "knot" in his upper abdomen and felt "uneasy" in his stomach. He estimated this to be around 08:35 to 08:50. These feelings persisted throughout the process of egressing the jet and seeking help from fellow pilots, finally arriving at the flight medicine clinic at 09:20. He had been off of all supplemental oxygen for approximately 45 min at that point.

During evaluation at the clinic, he was kept on 100% oxygen and continuously monitored with serial vital signs and neurological exams, which remained normal throughout his stay (after his blood pressure normalized within 20 min of arrival). At 09:45 he started to complain of a stiff and sore neck, and this feeling spread into his low back and hips by 10:00. At 09:52 he complained of a transient tingling in both feet that resolved within 8 min. His right frontal headache persisted, improving from 10/10 to a 6/10 pain with supplemental oxygen.

2. With the continued symptoms, and presentation of additional symptoms while on 100% oxygen, what is the next best step in care?

A. Start intravenous (IV) fluids.
B. Expedite transfer to hyperbaric facility for recompression therapy.

DOI: 10.3357/AMHP.4689.2016

C. Call Neurology.
D. Assume this is not DCI and get immediate imaging to help elucidate the cause.
E. Give narcotics to ease his pain.

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2. B. All signs still point to DCI, which is worsening despite 100% oxygen and needs urgent recompression therapy. You must do whatever you can to expedite the process and get him definitive treatment. IV fluids have not been shown to have any benefit in the treatment of DCI. You have no indication at this point that you need to be looking for a different source and delaying treatment to get imaging studies would be detrimental to the patient's recovery. While consulting Neurology may be helpful or necessary at some point in the treatment, now is not the time.

After coordinating with hyperbaric specialists at the San Antonio Military Medical Center and at a local off-base hospital, the patient was transported via ambulance to the local hospital for hyperbaric recompression therapy. He remained on 100% oxygen throughout the transport and started his recompression therapy at 13:15 local time. He was treated according to the U.S. Navy Treatment Table 6 protocol (**Fig. 1**).[7] He initially reported feeling a bit numb and tingly all over, but rapidly improved, with reported pain steadily dropping until completely resolved at 15:45. By the end of treatment at 18:10, he was feeling 100% back to his baseline and his neurological exam remained normal.

3. Based on the history, clinical presentation, and response to treatment, what is the most likely diagnosis?

A. Arterial gas embolism (AGE).
B. Neurological decompression sickness (DCS).
C. "The bends".
D. Cerebrovascular accident.
E. Dehydration.

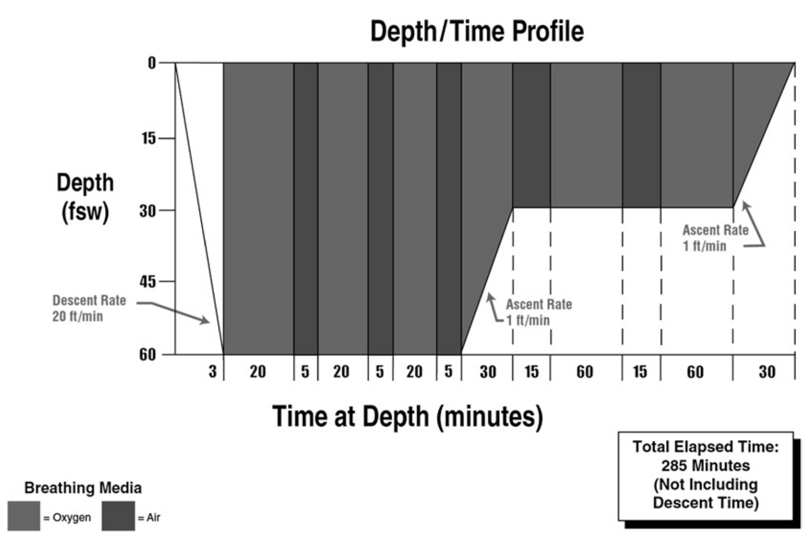

Fig. 1. U.S. Navy Treatment Table 6 (from the U.S. Navy Diving Manual).

ANSWER/DISCUSSION

3. A. This case highlights an atypical cause and presentation of AGE in a military fighter pilot. Pertinent to this case is the distinction between DCS and AGE. While both are manifestations of inert gas bubbles within the tissues and fluids of the body, and have overlapping clinical presentations and identical treatment protocols, there are some notable differences in the mechanism of injury and pathophysiology of the conditions. According to Dalton's law of partial pressures, as the barometric pressure increases, so do the pressures of the constituent gases.[2] This alters the pressure gradient and drives gas into solution within the body tissues. With each breath of compressed gas, a new equilibrium is established.[4] When breathing air, the most important component gas is nitrogen. Oxygen can be metabolized and used by tissues; however, nitrogen remains trapped within the tissue until the pressure gradients change and off-gassing can be accomplished. The amount of gas driven into solution is a function of pressure and time. If the barometric pressure is reduced slowly, the gas gradually comes out of solution and is eliminated via normal respiration. If, however, the reduction in pressure is too rapid, the gas is unable to come out of solution fast enough to be eliminated via normal mechanisms and thus becomes supersaturated, leading to bubble formation within the tissues or fluid where it is located.[3] Because of the high pressure in arterial circulation relative to venous circulation or the tissues, as well as the relatively steeper pressure gradient for the component gases in venous blood, these gas bubbles typically do not form within arterial blood. If they make their way into circulation at all, it is through the venous circulation, where they are returned to the lungs and, as part of normal gas exchange, are eliminated prior to gaining access to arterial circulation. These gas bubbles initiate the pathophysiology of DCS. The impact of these nitrogen bubbles can manifest in many ways, ranging from the earliest and best described "bends" characterized by deep, boring pain in large joints to dermatological (cutis marmorata), lymphatic, cardiopulmonary ("chokes"), spinal cord, and central nervous system manifestations.[4]

Arterial gas embolism, also a manifestation of inert gas bubbles within body fluids (in this case, specifically arterial blood), typically arises via different mechanisms.[1] It is one potential manifestation of pulmonary over-inflation syndrome. In addition to Dalton's law as mentioned above, another gas law strong at work under changing barometric pressures is Boyle's law, which describes the inverse relationship of pressure and volume ($P_1V_1 = P_2V_2$). At higher pressure, the volume of gas is smaller. Breathing at increased pressure for any length of time results in normal inflation of the lungs (more gas fits into the lungs at increased pressure because of this relatively decreased volume).[10] If there is then a rapid reduction in the ambient pressure, that volume will expand rapidly.[3] If the individual does not exhale, the gas has nowhere to go. The pressure in the lungs then increases to the point where the delicate alveoli rupture and gas escapes into the pleural space or into the pulmonary capillaries, which are damaged in the process of alveolar rupture.[12] When gas bubbles enter the damaged blood vessels, they migrate to the left side of the heart and are distributed systemically as emboli sent to areas determined by buoyancy. This can lead to chest pain, loss of consciousness, convulsions, paralysis, and blindness.[8] In less severe cases, the signs and symptoms can be minor and transient, often missed altogether. Most identified clinical manifestations result from gas bubbles within the cerebral vasculature. The bubbles can block small arteries (30- to 60-μm caliber), causing distal ischemia and edema. The mechanical stimulation creates activation of immune system components, which can further alter the normal physiology of the affected organs, leading to a wide spectrum of signs and symptoms with an equally wide spectrum of severity.[8]

Decompression illness is rare in the aviation community and would not necessarily be suspected based on a history such as that described in the case above. The pilot had not exceeded 4877 m (16,000 ft) above ground level, had a very short flight time, and had no evidence of rapid decompression of the cockpit during flight. He reported no recent scuba diving or other exposure to atypical pressurization. Yet he clearly had signs and symptoms concerning for DCI, which worsened despite 100% oxygen therapy while recompression treatment was arranged. We have no reason to believe that he had significant nitrogen tension based on his reported exposures; thus, risk of DCS would be considered to be very low. Review of pathophysiology as outlined above, however, reminds us that pulmonary barotrauma leading to AGE requires a pressure differential of just 50–100 mmHg (3–5 fsw) and often does not present with any respiratory distress or evidence of the initiating pulmonary barotrauma.[1] There is also evidence to suggest that during direct decompression from sea level to altitude, the threshold for formation of venous gas emboli is around 3600 m (11,811 ft), whereas the DCS threshold is about 5500 m (18,044 ft). While the patient in this case did not experience a decompression at altitude, the over-pressurization of the cockpit (with F-15 cockpit capacity to generate 5 psi, equivalent to 11.5 fsw) could have created a pressure differential plenty sufficient to cause AGE.[9] Clinically, AGE usually presents symptoms within 10 min of decompression, while DCS symptoms more often present later, with 50% within 1 h, 90% within 6 h, and 99% within 24 h.

4. Now that you have adequately treated this patient's DCI, what is the aeromedical disposition?

A. Permanent disqualification from flying duties.
B. Immediate return to flying duties.
C. Unclear, pending hyperbaric specialist follow-up.
D. Place pilot in "duties not including flying" (DNIF) status for 14 d, then return to flying duties if he remains asymptomatic with normal neurological exam.
E. DNIF until neurological evaluation, neurocognitive testing, and major command waiver approval.

ANSWER/DISCUSSION

4. D. This is a bit of a tricky question, because the disposition varies among the branches of military service and the Federal Aviation Administration. First and foremost, it should be specified that, as far as aeromedical dispositions are concerned, AGE and DCS are treated as one and the same and are collectively referred to as DCI. AGE from a non-pressure-related etiology (surgery, IV complications, etc.) is also treated using hyperbaric oxygen therapy. The dispositions below are for cases with resolution of all symptoms following treatment within the specified time. Any residual symptom would require an appropriate workup and waiver for that issue, as applicable.

For the U.S. Air Force, no waiver is required for altitude-induced DCI as long as it was not categorized as a severe case (with pulmonary or neurological involvement) and all symptoms resolve within 2 wk. The Aeromedical Standards Working Group recommends a minimum 72-h DNIF following resolution of all symptoms (provided that all symptoms resolved in less than 2 wk) and acceptable studies by a neurologist or hyperbaric specialist in consultation with the U.S. Air Force School of Aerospace Medicine Hyperbaric Medicine Branch. For cases of DCI with neurological or pulmonary involvement, categorized as severe, there is a minimum 1-mo DNIF required after symptom resolution (6 mo if all symptoms not initially resolved discontinue within 2 wk), along with an aeromedical waiver approved by the member's major command, documenting full response to recompression therapy, normal exam by a neurologist or hyperbaric specialist, normal neurocognitive testing at 1 mo, magnetic resonance imaging within 1 mo, consultation with the Hyperbaric Medicine Branch, and a Aeromedical Consultation Service review.[4] For DCI with neurological involvement, such as the case presented here, the Army does require a waiver for return to flying duties. These waivers are considered on a case-by-case basis and not sooner than 1 mo after the incident. To apply for a waiver, the member must have full resolution of symptoms and the treatment course and normal neurology and neuropsychological testing must be documented.[11] The Federal Aviation Administration's Guide for Aviation Medical Examiners does not specifically address DCI, but a disturbance of consciousness with no satisfactory medical explanation that makes the person unable to safely perform his or her duties would be disqualifying. If the cause of the disturbance is explained and there is no recurrence or residual issues, a medical certification may be possible.[5]

Because this patient is a U.S. Navy pilot, he falls under the guidance of the Naval Aerospace Medical Institute (NAMI), even though he is currently assigned to an Air Force fighter squadron. Per the U.S. Navy Aeromedical Reference and Waiver Guide, this scenario requires 14 d of grounding, consultation with NAMI, documentation of a normal evaluation by a neurologist, dive medical officer, or hyperbaric medical specialist, referral for hypoxic training using the reduced oxygen breathing device, and the offer of a bubble contrast echocardiogram.[6]

In accordance with the above guidance, the pilot was placed on DNIF status and released home to rest, with instructions on signs and symptoms that should prompt an immediate call to the on-call flight surgeon and repeat hyperbaric treatment. Because this individual was a U.S. Navy pilot, consultation was made with a local Navy flight surgeon and NAMI. The final disposition was that the member would be DNIF for 14 d, after which he could return to flying duties without a waiver as long as he had a normal neurological exam documented by a neurologist or dive medical officer and no recurrence of symptoms. The patient reported feeling exhausted for approximately 5 d after the incident, but had no other symptoms or residual effects. He had a normal evaluation by a neurologist on day 20 following the incident and was returned to full flying status at that time. He was referred for repeat hypoxia training using the reduced oxygen breathing device in the aerospace physiology department on base, and he was offered a bubble contrast echo, which he declined. The patient continues to function well 6 mo after the incident and has had no recurrence of symptoms.

Lenz CR, Shields JL, Morgan AO. *You're the flight surgeon: an unusual case of ground-level F-15 decompression illness.* Aerosp Med Hum Perform. 2016; 87(10):906–909.

ACKNOWLEDGMENTS

The authors would like to thank Dr. E. George Wolf for his input and guidance during the care of this patient, as well as his professional review of this article. The views expressed in this article are those of the authors and do not necessarily reflect the official policy or position of the Air Force, the Department of Defense, or the U.S. Government.

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