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UNCOMMON AND/OR UNUSUAL HEADACHES AND SYNDROMES (J AILANI, SECTION EDITOR)

Diving Headache

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Abstract
This review will focus on the most recent information regarding the ICHD-3 definition of diving headache as well as other important causes of diving headache that are not listed in the ICHD-3 classification system. The paper will discuss etiology, diagnosis, and management of these disorders, focusing, when possible, on the newest research available. ICHD-3 diving headache is due to hypercapnia and is treated accordingly with oxygen. Other causes of diving headache range from decompression sickness to external compression headache to primary headache disorders, such as migraine. Correctly determining the underlying cause of the diving headache is critical to management and relies on history taking and physical exam. The pathophysiology of newly described types of diving headache, such as diving ascent headache, remains under investigation but may be related to other homeostatic headache causes, such as airplane headache. Further investigation may yield more information regarding management as well as possible insight into other headache disorders.

Keywords Diving headache · Hypercapnia · Airplane headache · Homeostatic headache · Barotrauma · Decompression sickness

Introduction

Headache that occurs while or after diving is a common issue faced by recreational and professional divers. There are many potential causes for this. Here, we review the ICHD-3 diagnosis of diving headache, the etiology of which is thought to be due to hypercapnia. It is also important to consider secondary causes of and contributors to diving headache. Additionally, we will discuss diving ascent headache, a more recently described phenomenon not yet listed in ICHD-3 which may have different pathophysiological mechanisms.

This article is part of the Topical Collection on *Uncommon and/or Unusual Headaches and Syndromes*

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Epidemiology of Headache in Diving

There are few epidemiological studies to determine the prevalence of headache in SCUBA divers. Much of what is known about prevalence is anecdotal; however, most divers report they have experienced some form of cranial pain in relation to their time in the water. The best data available come from a 2011 study examining 201 professional male divers and the prevalence of common primary headache disorders (as defined by ICHD-2 criteria), migraine with and without aura and tension-type headache. A primary headache diagnosis was present in 16% of divers vs 22% of matched controls. Divers reported fewer attacks per month compared with a control population, but there were no significant differences in severity or age of onset [1]. The authors did not assess for the specific diagnoses of diving headache or diving ascent headache, and to date, clear epidemiologic data are lacking for these diagnoses which are still regarded as secondary disorders of disrupted homeostasis. In addition, divers can be prone to other headache types (to be discussed further below), but likewise, there was no assessment for them in this study.

ICHD-3 Diving Headache

Diving headache is defined by ICHD-3 (Fig. 1) with criteria that center on hypercapnia as an underlying cause. It is listed under category 10.1 along with 10.1.1 high-altitude headache, 10.1.2 headache attributed to airplane travel, and 10.1.4 sleep apnea headache. It is thought that each of these syndromes likely has a similar pathophysiologic mechanism, headache attributed to hypoxia and/or hypercapnia. More specifically, diving headache is defined as occurring during or after a dive to a depth greater than 10 m, often with symptoms of carbon dioxide (CO_2) intoxication, and in the absence of another ICHD-3 diagnosis or cause of the headache.

Physiologically, CO_2 causes relaxation of cerebrovascular smooth muscle; thus, hypercapnia can lead to cerebral vasodilatation with resultant increased intracranial pressure (ICP) and headache pain. Hypercapnia in diving can occur for many different reasons, but the central theme is hypoventilation. This may be the result of diver error. Those who intentionally hold their breath intermittently (so-called "skip breathing"), take shallow breaths, or engage in overly strenuous underwater exercise are most prone to it. Equipment can also be responsible. Excessively tight upper body clothing can restrict chest wall expansion, and dive equipment may function inefficiently in lower depths due to increased gas density leading to increased work of breathing [2].

For context and a better understanding of possible mechanisms, a brief discussion of other headache disorders can be instructive. High-altitude headache may share pathophysiology with diving headache in the form of increased ICP from hypercapnia-induced cerebral vasodilation. It develops during ascent above 2500 m and either worsens with continued ascent or resolves after returning to 2500 m or below. A proposed mechanism is hypoxia causing increased cerebral blood flow, decreased cerebral venous outflow, and cerebral edema. Hypoxia has been shown to significantly increase cranial artery circumference in subjects exposed to 180 min of normobaric hypoxia compared with controls in a magnetic resonance angiography and spectroscopy study [3]. Whether this increase leads directly to ICP elevation and pain remains under debate based on recent studies [4•]. Headache attributed to travel in space is surprisingly prevalent (12 of 17 astronauts surveyed) and may also be due to increased ICP from fluid and pressure shifts in microgravity. Additionally, microgravity alone can induce hypoxia and subsequently increased ICP. Most astronauts describe the pain as "exploding" or a "heavy feeling," which would be consistent with this theory [5]. A recent case report describes a 41-year-old man with airplane travel and high-altitude headache. Magnetic resonance imaging disclosed enlarged Virchow-Robin spaces in the insular cortex and basal ganglia, known areas of pain transmission [6]. This may suggest that ICP changes have effects in brain tissue beyond the cerebral vasculature that lead to pain.

Other Diving-Related Headaches

Some of the more commonly experienced head and facial pains felt by divers can be due to squeezes (diver failure to

ICHD-3 Diving Headache

Description:

Headache caused by diving to a depth greater than 10 metres, occurring during the dive but often intensified upon resurfacing, in the absence of decompression illness. It is usually accompanied by symptoms of carbon dioxide (CO_2) intoxication. It remits quickly with oxygen or, if this is not given, spontaneously within 3 days after the dive has ended.

Diagnostic criteria:

A. Any headache fulfilling criterion C
B. Both of the following:
- the patient is diving at a depth >10 metres
- no evidence of decompression illness

C. Evidence of causation demonstrated by at least one of the following:
- headache has developed during the dive
- either or both of the following:
  - a) headache has worsened as the dive is continued
  - b) either of the following:
    - headache has spontaneously resolved within 3 days of completion of the dive
    - headache has remitted within 1 hour after treatment with 100% oxygen
- at least one of the following symptoms of CO_2 intoxication:
  - a) mental confusion
  - b) light-headedness
  - c) motor incoordination
  - d) dyspnoea
  - e) facial flushing

D. Not better accounted for by another ICHD-3 diagnosis.

Fig. 1 ICHD-3 diving headache

equalize pressure) in the SCUBA mask or facial sinuses. In these circumstances, physical damage to the tissues (barotrauma) can occur. Divers with sinus inflammation due to cold or allergies are at increased risk for this. As the second most common disorder among divers (behind ear barotrauma), it must be included in the differential [7].

Equipment can also be a concern as a neck or headgear that is improperly sized or lacking adequate thermal protection can lead to external compression or cold-stimulus headache. A mask that fits too tightly can also cause pain at the supraorbital notches. Additionally, many of the compressors used to fill scuba tanks are oil-lubricated; some of these lubricants release carbon monoxide (CO) which can accumulate to unsafe levels, particularly if compressor equipment is poorly maintained. This leads to symptoms of CO poisoning, including headache [8].

Dehydration in general can be an inciting factor to headache in persons on land, but it is even more likely to provoke headache in divers. It can affect gas transfer as well as decrease delivery of oxygen to the brain. Decompression sickness (DCS), where dissolved nitrogen returns to gaseous form within the tissues, is a dreaded complication of overly rapid ascent and can be affected by dehydration also, with headache as presenting symptom in 24% of divers [9].

Primary headache disorders, including migraine and tension-type headache, should also be considered, particularly in divers who carry those pre-existing diagnoses. As noted above, there does not appear to be an increase in disease burden in divers with migraine; however, attacks can certainly occur before, during, or after a dive, with some divers occasionally noting migraine symptoms after decompression. Tension-type headache attacks can also occur during a dive, and those who experience primary exertional headache may be at increased risk of experiencing pain with vigorous underwater swimming [2].

Historically, cervical artery dissection has also been considered a possible cause of headache pain while diving, and a recent study suggests there may be a correlation with minor trauma [10]. The paucity of the literature suggests further research is needed. Trauma can also account for headache, as divers can be driven into rocks or the shoreline by strong currents or upon falling while attempting boat re-entry.

Diving ascent headache is a less well-recognized entity in medical literature but may be physiologically related to airplane headache. Recently, a case series of 200 patients affected by headache attributed to airplane travel found that of the 46 patients who had diving experience, 21 (45.6%) reported experiencing a nearly identical headache during or shortly after ascent from free diving, snorkeling, or SCUBA diving [11••]. Characteristically, the pain was short-lived, reaching a peak in a few minutes and self-resolving within 30 min.

Diagnosis and Management

The cornerstone of treating diving headache is determining the cause, as management will depend upon it. As always, taking a thorough history is also a key, as the timing of the headache and other symptoms aids in diagnosis, and uncovering a pre-existing primary headache diagnosis may yield a target for treatment. In some cases, determining the cause may be as straightforward as noticing that equipment is ill-fitting; however, the physical exam is important in evaluating the head for trauma and to check for reproducible pain, such as by palpation of the supraorbital notch in a patient with goggle-related headache. Trauma may also be apparent on an exam or through diver history and should be treated accordingly. The physical exam should never be limited to the head alone as systemic causes may be revealed by additional exam findings.

CO poisoning may be accompanied by confusion, tachypnea, and hemodynamic instability due to hemoglobin binding to CO with much higher affinity than to oxygen. Treatment includes 100% or hyperbaric oxygen, and in cases severe enough to require intubation, high positive end-expiratory pressure ventilation. Oxygen therapy speeds carboxyhemoglobin dissociation and should be administered as quickly as possible [12].

DCS, caused by the formation of nitrogen bubbles in the bloodstream and tissues, is classified in two categories based on severity. The more severe type is more often accompanied by headache. Diagnosis is made in the setting of a history of overly rapid ascent with failure to take decompression stops coupled with a physical exam supportive of the condition. Type I, commonly called "the bends," is less severe and characterized by mild malaise, fatigue, or generalized aching in the joints and muscles; headache is infrequent. Type II is more severe and often includes spinal cord damage. Divers also may experience cerebral symptoms including headache, ataxia, and visual disturbance. Pulmonary symptoms are less common but can be seen in type II when bubbles block pulmonary circulation or right heart outflow leading to pain or circulatory system collapse [13]. The gold standard of DCS treatment is hyperbaric oxygen initiated as quickly as possible, and until then, 100% oxygen administered by tight-fitting mask or endotracheal tube if necessary. Patients should also be given fluids (intravenously if possible) and kept supine (unless head down position is needed for circulatory concerns) [14].

Barotrauma is the most common diving-related injury and can occur in the lungs, ears, sinuses, and dental fillings, with headache often a significant symptom in the latter three scenarios. Otic barotrauma, particularly of the middle ear, is the most common form, but it can involve the external ear or inner ear as well. Otoscopy can reveal the injury in external or middle ear barotrauma, but a normal exam may not rule out inner ear barotrauma, so an otolaryngologist should be involved as soon as possible. External ear barotrauma is treated

with topical steroids/antibiotics while that of the middle ear is treated with topical and systemic decongestants along with antihistamines. Conversely, inner ear barotrauma is treated with bed rest, head elevation, and avoidance of maneuvers, such as Valsalva, that could increase ICP [15]. Sinus barotrauma presents with pain on a descent, and epistaxis is the second most common symptom. Pain can also occur on an ascent, but less commonly. Sinus barotrauma is often accompanied by middle ear barotrauma. Asking about pre-dive sinusitis is important as sinus blockage from congestion greatly increases risk. Divers should always forego diving when having sinusitis or rhinitis. They also should avoid vasoconstrictive decongestants for 12 h prior to diving as rebound congestion increases susceptibility to sinus barotrauma. Treatment ranges from symptomatic decongestants, corticosteroids, and saline irrigation to more definitive interventional procedures depending on severity [16]. Finally, dental barotrauma or squeeze can be seen in patients with infected teeth or fillings that do not fully obliterate caries. It presents with pain due to gas expansion and contraction during ascent and descent. Pain may be referred to the head and perceived minimally, if at all, in the mouth, so a dental evaluation may be appropriate.

As defined by the ICHD-3 criteria, diving headache occurs when a diver descends below 10 m and is often bifrontal, bitemporal, or bioccipital. Pain is typically throbbing in quality and can range from milder to more severe in intensity. Onset is gradual and worsens during the decompression stage or upon reaching the surface. With escalating degrees of hypercapnia, divers experience flushing in the face, lightheadedness, confusion, and ultimately loss of consciousness. Treatment includes 100% oxygen by face mask, which often works quickly. If untreated, the headache will often self-resolve within 3 days post dive. Prevention is the best strategy. Divers who breathe continuously with slow, deep breaths and avoid prolonged vigorous exertion underwater are significantly less likely to experience diving headache. As with CO poisoning, regular equipment maintenance and testing are important as CO_2 is removed by CO_2-absorbing material during exhalation. When the absorbing material is saturated or improperly installed, divers are at risk [2].

As previously discussed, diving ascent headache may be a similar phenomenon to that experienced by persons susceptible to headache attributed to airplane travel. Pain begins during the ascent phase, typically when SCUBA diving at depths greater than 20 m. It also can happen in snorkeling or free diving even within 10 m of the surface. Pain tends to be at its peak within a few minutes during (or soon after) ascent and spontaneously remits in 30 min. No specific treatment is well-described, but those who have had a history of headache with airplane travel, or who have previously noted headache with rapid descents from high altitude, should be aware that they may experience a similar phenomenon with diving ascent [11••]. It is worth noting that administering a triptan or non-steroidal anti-inflammatory drug 30 min before a flight can be effective in preventing headache with airplane travel, and theoretically, this may be true for diving ascent headache as well [17].

Divers who experience migraine with aura are important to recognize as they are at a significantly higher likelihood of having a patent foramen ovale (PFO) [18]. While possibly asymptomatic on land, having a PFO may double the odds of experiencing type II DCS [19]. This can happen even in divers who follow their diving computer or table calculations that are made to prevent this from occurring (so-called "unearned" DCS). Two diving societies, the South Pacific Underwater Medicine Society (SPUMS) and the United Kingdom Sports Diving Medical Committee (UKSDMC) released joint guidelines in 2015 addressing this issue. They recommend screening for PFO in divers with a history of migraine with aura with a transthoracic echocardiogram to evaluate for PFO. If present, they recommend divers limit the depth to 15 m or less and observe more conservative diving table calculations. In those who wish to return to full diving depth or do not wish to adhere to the conservative calculations, PFO closure can be considered [20••].

Conclusion

Headache while diving is a commonly experienced phenomenon with multiple etiologies. While the cause may be as simple as an ill-fitting mask needing adjustment, it can also be a multifactorial etiology with poor outcomes if not promptly diagnosed and treated accordingly. Additionally, the ICHD-3 only covers one specific type of diving headache, which is due to hypercapnia, but as discussed, this is but one of many types that divers may experience.

Research continues into further elucidating the pathophysiology of diving-related headache syndromes. Diving ascent headache appears to share commonalities with airplane headache, the pathophysiology of which remains under investigation, having been theorized to be due to differences in pressure inside the sinuses compared with the airplane cabin pressure. At takeoff, cabin pressure is lower than in the sinuses and at landing, the opposite is true. Alternatively, some studies have theorized that vasodilation in the cerebral arteries may play a role. When in a pressure chamber simulating flight conditions, prostaglandin E2, an inflammatory vasodilator, has been shown to be elevated in those who have experienced airplane headache compared with controls [21, 22]. In future ICHD editions, it may be worth considering the addition of diving ascent headache.

While research will continue to improve our understanding of these entities, divers and the physicians who treat them should stay up to date. Rapid diagnosis and treatment can improve outcomes, particularly in syndromes due to systemic causes. Prevention is a key part of diving headache; good

diver education/training, as an appropriate screening of divers for PFO and proper equipment management, can often prevent poor outcomes.

Compliance with Ethical Standards

Conflict of Interest The authors declare that they have no conflict of interest.

Human and Animal Rights and Informed Consent This article does not contain any studies with human or animal subjects performed by any of the authors.

References

Papers of particular interest, published recently, have been highlighted as:
• Of importance
•• Of major importance

1. Fabio RD, Vanacore N, Davassi C, Serrao M, Pierelli F. Scuba diving is not associated with high prevalence of headache: a cross-sectional study in men. J Headache Pain. 2011;52:385–92.
2. Cheshire WP, Ott MC. Headache in divers. J Headache Pain. 2001;41:235–47.
3. Arngrim N, Schytz HW, Britze J, et al. Migraine induced by hypoxia: an MRI spectroscopy and angiography study. Brain. 2015;139:723–37.
4.• Grewal P, Smith JH. When headache warns of homeostatic threat: the metabolic headaches. Curr Neurol Neurosci Rep. 2017;17. https://doi.org/10.1007/s11910-017-0714-5. **Good recent overall review of homeostatic headache disorders**.
5. Vein A, Koppen H, Haan J, Terwindt G, Ferrari M. Space headache: a new secondary headache. Cephalalgia. 2009;29:683–6.
6. Akyol A. Giant Virchow- Robin spaces may play a role at headache attributed to hypoxia and/or hypercapnia. Agri. 2018. https://doi.org/10.5505/agri.2018.98360.
7. Schipke JD, Cleveland S, Drees M. Sphenoid sinus barotrauma in diving: case series and review of the literature. Curr Pain Headache Rep. 2017;26:124–37.
8. Cheshire WP. Headache and facial pain in scuba divers. Curr Pain Headache Rep. 2004;8:315–20.
9. Newton HB. Neurologic complications of scuba diving. Am Fam Physician. 2001;63:2211–8.
10. Walters GK. Cervicocranial artery dissection and scuba diving: is there a link or is it serendipity? Undersea Hyperb Med. 2018;45:65–73.
11.•• Mainardi F, Maggioni F, Zanchin G. Aeroplane headache, mountain descent headache, diving ascent headache.. Three subtypes of headache attributed to imbalance between intrasinusal and external air pressure? Cephalalgia. 2017;38:1119–27. **Paper discussing the significance of airplane headache and possible correlation with diving ascent headache**.
12. Mcdermott JH, Reynard C, Perry J, Dear JW, Child F, Jenner R. Acute carbon monoxide toxicity in a paediatric cohort: analysis of 10 boys poisoned during a scuba diving lesson. Clin Toxicol. 2018;56:856–9.
13. Rosińska J, Łukasik M, Kozubski W. Neurological complications of underwater diving. Neurol Neurochir Pol. 2015;49:45–51.
14. Tetzlaff K, Shank ES, Muth CM. Evaluation and management of decompression illness—an intensivist's perspective. Intensive Care Med. 2003;29:2128–36.
15. Livingstone DM, Smith KA, Lange B. Scuba diving and otology: a systematic review with recommendations on diagnosis, treatment and post operative care. Diving Hyperb Med. 2017;47:97–109.
16. Livingstone D, Lange B. Rhinologic and oral-maxillofacial complications from scuba diving: a systematic review with recommendations. Diving Hyperb Med. 2018;48:79–83.
17. Ipekdal HI, Karadaş Ö, Öz O, Ulaş ÜH. Can triptans safely be used for airplane headache? Neurol Sci. 2011;32:1165–9.
18. Volta GD, Guindani M, Zavarise P, Griffini S, Pezzini A, Padovani A. Prevalence of patent foramen ovale in a large series of patients with migraine with aura, migraine without aura and cluster headache, and relationship with clinical phenotype. J Headache Pain. 2005;6:328–30.
19. Germonpre P, Balestra C. Risk of decompression illness among 230 divers in relation to the presence and size of patent foramen ovale. Eur Heart J. 2004;25:2173–4.
20.•• Smart D, Mitchell S, Wilmshurst P, Turner M, Banham N. Joint position statement on persistent foramen ovale (PFO) and diving. South Pacific Underwater Medicine Society (SPUMS) and the United Kingdom Sports Diving Medical Committee (UKSDMC). Diving Hyperb Med. 2015;45:129–31. **Guidelines from diving medicine societies regarding PFO screening and management in divers**.
21. Bui SBD, Gazerani P. Headache attributed to airplane travel: diagnosis, pathophysiology, and treatment – a systematic review. J Headache Pain. 2017;18. https://doi.org/10.1186/s10194-017-0788-0.
22. Bui SBD, Petersen T, Poulsen JN, Gazerani P. Simulated airplane headache: a proxy towards identification of underlying mechanisms. J Headache Pain. 2017;18. https://doi.org/10.1186/s10194-017-0724-3.