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

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Headache and Barometric Pressure: a Narrative Review

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Abstract

Purpose of Review Alterations in atmospheric pressure have been long associated with headaches. The purpose of this review article is to investigate the association of barometric pressure with headache, classifying into two broad categories primary headache disorders (barometric pressure triggering migraine or tension-type headache) and secondary headache disorders (barometric pressure triggering high-altitude headache and headache attributed to airplane travel), discussing the pathophysiology and possible treatments.

Recent Findings Multiple studies have been performed with inconsistent results regarding the directionality of the association between atmospheric pressure changes and triggering of primary headache disorders, chiefly headaches. Atmospheric pressure is also a trigger of two secondary headache disorders, i.e., high-altitude headache and headache attributed to airplane travel. Hypothesized mechanisms include excitation of neurons in trigeminal nucleus, central and peripheral vasoconstriction, barotrauma, and hypoxia. There are no randomized clinical trials regarding effective acute or preventive treatments.

Summary Greater understanding of pathophysiology may enable both acute and preventive treatments for headaches triggered by changes in barometric pressure. Further studies on the subject are needed.

Keywords Headache · Migraine · Barometric pressure · Atmospheric pressure · High-altitude headaches · Airplane headache

Introduction

Headache is one of the most common reasons that patients present to the emergency department (ED) [1] as well as primary care clinics, most commonly a migraine or tension-type headache [2, 3]. Headache, including migraine and other syndromes, contributes to an extensive amount of morbidity and lost workplace productivity [4–6]. According to the World Health Organization (WHO), headache (symptomatic at least once in a year) affects about 50% of the world population with the most common age group being 18–65 years [7]. Around forty-five million Americans visit an ED or primary care clinic annually to seek medical care for headache [8], mostly reported as migraine. Many triggers of migraine have been identified including different foods, stress, sleep, odors, pollen, sunlight, sounds, weather changes, and precipitation [9, 10]. About 7 to 82% of patients suffering from migraine self-report weather as a trigger, low atmospheric pressure being the precipitator [10–13]. Migraine can impair quality of life and affect personal, social, and professional life [14, 15].

Barometric pressure is defined as force per unit area exerted by the atmosphere at any given point, also referred to as the "weight of air." It is measured in millibars (mb) or millimeters of mercury (Hg). Normal barometric pressure averages around 30 in. of Hg or 1013 mb. For instance, when it is sunny outside, barometric pressure could be as high as 30.2–30.3 in., whereas when it is windy, barometric pressure could drop down to 29.2 in. or lower [16].

Barometric pressure also changes when a flight takes off [17, 18, 19••, 20] and with altitude [21]. In a 10-h flight, the average cabin pressure measured is approximately 846 mb compared with 1013 mb at sea level ($p < 0.001$) [22]. Headache attributed to airplane travel (HAAT) can occur with

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changes in cabin pressure which is usually seen at the time of departure and landing [17, 18, 19••, 20]. In a review article by Bui and Gazerani with a total of 275 patients, it was reported that HAAT was associated with descent in 76% patients, with ascent in 12% patients, and both in 6% patients [19••].

Also, high-altitude headaches (HAH) and high-altitude cerebral edema (HACE) are well-described clinical entities, which have been attributed to the lower partial pressure of oxygen in inspired air (lower percentage of oxygen molecules per breath) at higher altitudes [23]. Headaches are more common at altitudes above 4500 m [23, 24]. A study performed by Vardy et al. interviewed 150 recreation trekkers residing above 2500 m in teahouses in the Himalayan region. The results revealed that the incidence of headache as a part of acute mountain sickness (AMS), of which headache is one of the 5 cardinal symptoms, was 0% at elevations 2500–3000 m, 10% at 3000–4000 m, 15% at 4000–4500 m, 51% at 4500–5000 m, and 34% above 5000 m [24].

HAH (10.1.1) and HAAT (10.1.2) are included in the International Classification of Headache Disorders (ICHD-3) under 10.1 Headache attributed to hypoxia and/or hypercapnia (Boxes 1 and 2) [25].

Box 1 ICHD-3 diagnostic criteria of high-altitude headache (HAH) [25]

A. Headache fulfilling criterion C
B. Ascent to altitude above 2500 meters has occurred
C. Evidence of causation demonstrated by at least two of the following:
 1. Headache has developed in temporal relation to the ascent
 2. Either or both of the following:
 3. a) Headache has significantly worsened in parallel with continuing ascent
 4. b) Headache has resolved within 24 h after descent to below 2500 meters
 5. Headache has at least 2 of the following three characteristics:
  ▪ a) Bilateral location
  ▪ b) Mild or moderate intensity
  ▪ c) Aggravated by exertion, movement, straining, coughing, and/or bending
D. Not better accounted for by another ICHD-3 diagnosis

Box 2 ICHD-3 diagnostic criteria of high-altitude headache (HAH) [25]

A. At least two episodes of headache fulfilling criterion C
B. The patient is traveling by airplane
C. Evidence of causation demonstrated by at least two of the following:
 1. Headache has developed during the airplane flight
 2. Either or both of the following:
  ▪ a) Headache has worsened in temporal relation to ascent following takeoff and/or descent prior to landing of the airplane
  ▪ b) Headache has spontaneously improved within 30 min after the ascent or descent of the airplane is completed
 3. Headache is severe, with at least 2 of the following three characteristics:
  ▪ a) Unilateral location (side-shift may occur)
  ▪ b) Orbitofrontal location (can have parietal spread)
  ▪ c) Jabbing or stabbing quality (could be pulsating as well)
D. Not better accounted for by another ICHD-3 diagnosis (excluding sinus disorders)

Barometric pressure is a possible trigger of primary headache disorders, chiefly migraine. Most people report weather changes, sunlight, and precipitation as a trigger for their migraines [26–28]. A prospective cohort study of 1207 patients who met the ICHD-2 criteria for migraine recognized weather as the fourth most common trigger, affecting more than 50% of the patients [29]. However, in another study, analysis of 2–24 months of daily headache diaries collected from 77 people with migraine as per the ICHD-1 criteria seen in an American headache clinic reported a positive association of weather variables as collected from the United States National Weather Service with headache and that more patients noted weather as a contributory factor to their headaches (mean = 4.33, SE = 0.130) when compared with the control group (mean = 3.86, SE = 0.125) (p = 0.014). Out of the total 77 participants, 50.6% were determined by the researchers to have headaches affected by weather, although 62.3% of their participants believed that they were sensitive to weather conditions ($p < 0.05$). The researchers in this study determined that only 12.9% of participants had headache sensitivity to barometric pressure, while 33.7% of the participants were sensitive to absolute temperature and humidity and 14.3% were sensitive to changing weather patterns [30].

Published studies to date are inconsistent with regard to the directionality of the relationship between barometric pressure and primary headache disorders (Table 1).

Studies' Finding That Decrease in Barometric Pressure Increases Headache

A large study of 7054 patients seen over 7 years in the emergency department demonstrated that lower barometric pressure in the preceding 48–72 h was linked to an increased risk of presentation for acute headache (OR 0.939 per 5 mmHg; 95% CI 0.902–0.978; $p = 0.002$) [31]. A study of 34 patients performed in 2015 in the Isehara region of Japan revealed that migraine occurred most frequently when the barometric pressure decreased by 6–10 hPA relative to the standard pressure (range 1003–1007 hPa). Patients developed migraine at a rate of 23.5% when the atmospheric pressure ranged from 1005 to < 1007 hPa, and at a rate of 26.5% when the atmospheric pressure ranged from 1003 to < 1005 hPa. These proportions were significantly larger than those in controls with tension-type headache (both p values were < 0.05) [32]. Another study performed in Japan in 2011 associated migraine diagnosed as per the ICHD-2 criteria with decreased atmospheric pressure on the following day rather than on the day of migraine. The study reported increased frequency of migraine in the weather-sensitive group (18/28 patients) when the difference in atmospheric pressure was lower by more than 5 hPA on the day after the migraine ($p = 0.009$; odds ratio = 1.27). Another relevant finding of the study was that there was no association between headache frequency and monthly mean atmospheric pressure [33]. A prospective study gathered data from 52 drug stores in the western Shizuoka Prefecture in Japan sought to use loxoprofen consumption as a proxy for headache. They collected survey data on consumption of loxoprofen over a period of 1 year along with weather data from the Japan Meteorological Agency. They surveyed 891 people, with responses from 662, of whom 372 reported using loxoprofen to treat headache. The study demonstrated increased consumption of loxoprofen with decreased barometric pressure ($p = 0.029$), heavy rainfall ($p = 0.002$), and an increase in average humidity ($p = 0.004$) [34].

Studies' Finding That Increase in Barometric Pressure Increases Headache

Contrary to the above, a study of 20 patients performed by researchers at the University of Toronto in 2017 reported a positive association between migraine pain levels with an increase in temperature and atmospheric pressure. Participants reported their pain level in terms of visual analogue scale (VAS) scores over a period of 14 days. Significant positive association was reported between VAS scores and atmospheric pressure ($p = 0.027$). An explanation of this observation was lacking in the study [35]. Zebenholzer et al. performed prospective headache diary–based analysis on 238 patients suffering from migraine with or without aura over a period of 90 days. Increase in headache incidence was reported with high barometric pressure and lower mean daily wind speeds [36].

Studies' Finding: No Association Between Barometric Pressure and Headache

Elcik et al. analyzed headache diaries of patients that presented to EDs in the Research Triangle region of North Carolina for over a span of 7 years, and reported that there is no association between migraine headache ED visits and the magnitude of atmospheric pressure changes although they did find statistically significant differences between air mass types. Polar (cold) air masses resulted in the lowest frequency of ED headache visits whereas tropical (warm) air masses resulted in the highest frequency [37•]. Hoffmann et al. recruited 100 patients suffering from migraine with or without aura based on the ICHD-2 criteria and followed them over a year. Thirteen percent of patients were found to be weather sensitive (13%, 95% CI = 7.1–21.2%); however, when pooled data analysis was performed, the significance was lost. No association was found between the participant's beliefs and their factual susceptibility to weather variables based on multivariate analysis [38].

Symptoms

Sudden barometric pressure changes including humidity, temperature, storms, and thunder have long been believed to be triggers for migraines, but some patients have reported an association with tension headaches as well [27, 28]. Symptoms classically are somewhat different between migraine, HAH, HACE, and HAAT. As per the ICHD-3 criteria [25], migraine is a primary headache disorder with pain attacks lasting 4–72 h which is characteristically unilateral, pulsating with moderate-to-severe intensity associated with nausea or, photophobia, and phonophobia. Migraine is more common in females than in males with peak prevalence during years 25–55 of age, whereas HAAT has no gender predominance [19••]. HAAT is mostly unilateral with severe periocular pain and stabbing quality, lasting less than 30 min after ascent or descent is completed [19••]. On the other hand, HAH is bilateral in location with mild-to-moderate intensity [44]. Patients usually describe them as pulsatile- or oscillating-type quality. Some other uncommon symptoms include dizziness, nausea, anorexia, shortness of breath, sleep disturbance, and fatigue [45]. HACE is a severe form of HAH which is

Table 1 Association between barometric pressure and headache frequency in observational studies

Study	Sample size	Data collection	Alterations in atmospheric pressure
Mukamal et al. [31]	7054	ED visits	Low barometric pressure associated with an increase in headache
Kimoto et al. [33]	30	Headache diary	Low barometric pressure on the following day associated with an increase in migraine headache
Ozeki et al. [34]	~ 600,000	Medication sales	Decrease in atmospheric pressure associated with an increase in loxoprofen use
Okuma et al. [32]	34	Headache diary	Decrease in atmospheric pressure associated with an increase in migraine headache
Cioffi et al. [35]	20	Data logger	Increase in atmospheric pressure associated with an increase in migraine headaches
Zebenholzer et al. [36]	238	Headache diary	Increase in atmospheric pressure associated with an increase in headache
Elcik et al. [37•]	16,930	ED visits	No association between migraine and barometric pressure changes
Hoffmann et al. [38]	100	Headache diary	No association between pressure changes and migraine
Villeneuve et al. [39]	4039	ED visits	No association between headache and atmospheric pressure changes
Cull et al. [40]	44	Headache diary	Increase in barometric pressure caused an increase in migraine headache
Osterman et al. [41]	73	Headache diary	Increase in migraine with changes in atmospheric pressure
Schulman et al. [42]	75	Headache diary	No association between headache and barometric pressure changes
Gomersall et al. [43]	56	Headache diary	Rise in atmospheric pressure caused an increase in the frequency of migraine attacks

characterized by gait ataxia, psychiatric changes, confusion, and alterations of consciousness.

Pathophysiology

There are several theories as to how barometric pressure may cause headache.

1. Effects through spinal trigeminal nucleus: Messlinger et al. found that lowering barometric pressure increased discharge rates in the spinal trigeminal nucleus of anesthetized rats. In particular, the neurons in the trigeminal nucleus caudalis receiving afferent input from the cornea were affected, but not those receiving inputs from the dura mater or temporal muscles [46]. In this study, changes in atmospheric pressure (lowered within 8 min by a total of 40 hPa) increased discharge rates in a group of neurons in the trigeminal nucleus caudalis that receives afferent input from the cornea merging with input from the cranial dura mater [46]. This study also suggested that afferents in the inner ear, frontal sinus, or the eyeball may serve as nociceptive sensors following changes in barometric pressure [46].

2. Effects through the sympathetic nervous system: Sato performed experiments in a rat model of neuropathic pain and reported that decreasing the atmospheric pressure (20 mmHg below the natural atmospheric pressure in 8 min in a climate-controlled room) stimulated the sympathetic nervous system and adrenal medullary hormones which in turn constrict the peripheral vessels causing tissue ischemia, lower blood oxygen levels, and lower pH [47–49].

3. Effects of hypobaric hypoxia: Another theory is that hypobaric hypoxia, rather than the low barometric pressure, causes migraine and HAH. Cerebral blood flow is dependent on blood pressure and partial pressure of oxygen and carbon dioxide. There is a progressive decline in resting regional brain oxygen saturation during ascent to high altitudes [50, 51], leading to vasodilation and an increase in cerebral blood flow [52–54]. Vasodilatation can lead to activation of the trigeminovascular system, triggering a headache. HACE has been associated with both vasogenic and cytotoxic edema. Kallenberg et al. concluded that vasogenic edema occurs in isobaric hypoxia regardless of acute mountain sickness [55]. The cytotoxic edema could be due to a reduction in the activity of sodium/potassium (Na/K) ATPase pumps [55, 56].

4. Effects on sinus pressure: Another theory hypothesized was that the atmospheric pressure alters the sinus pressure triggering a headache. In a single-blinded, randomized controlled trial performed for the treatment of barometric pressure–related "sinus" headache, 35 participants were randomized to a treatment using a balloon catheter to dilate the affected sinus ostia (treatment) or the nasal cavity (placebo) [57]. The authors excluded all patients meeting the ICHD-3 beta criteria for migraine, cluster, medication overuse, and tension headache. A total of 35 participants were followed for 6 months, and Sinonasal Outcome Test-22 and Headache Impact Test-6 scores were calculated both pre and post procedures. There was no statistically significant difference in outcomes between the two

groups [57]. Airplane headaches are suspected to be associated with a similar mechanism termed as "paranasal barotrauma" [58]. During ascent or descent, there is a sudden decrease in cabin pressure which can lead to an expansion of paranasal sinus. In a person with structural abnormalities, they may be unable to equalize pressure which in turn can cause inflammation of paranasal sinuses from vacuum effect, subsequently leading to fronto-orbital pain [18, 19••, 58].

Investigations

It is essential to perform a thorough neurological examination to screen for focal neurological deficits; the neurological exam is normal in most primary headache disorders. Diagnosis is mostly clinical and is based on history and associated symptoms described by the patient. In the presence of red flag symptoms, imaging may be necessary to investigate for structural causes of secondary headache disorders. Work-up in the presence of red flags may include magnetic resonance imaging of the brain, magnetic resonance angiography or venography, and/or computed tomography of the head and sinuses.

Treatment

If an individual develops HAH, suggested treatments are hydration and to not ascend any higher until the headache is resolved, and the individual may need to be assisted to a lower altitude and placed on supplemental oxygen [59]. In severe cases of AMS or rapidly developing HACE, dexamethasone, acetaminophen, ibuprofen, and acetazolamide with a descent to about 300–500 m are recommended [60–63]. HAH can be prevented by using either acetazolamide 125–250 mg twice per day (first choice) [60, 61, 64, 65] or dexamethasone up to 8 mg per day (second choice) [62, 63, 66]; Dr. Marmura in an interview recommended topiramate as an alternative for those with migraine [67].

There are no specific guidelines regarding the treatment of HAAT, but it has been pre-treated with common analgesics like paracetamol, NSAIDs, and triptans [19••, 68]. In one study, Berilgen and Mungen prescribed naproxen 550 mg to prevent HAAT to 22 participants who had previously experienced HAAT in single-arm, open-label fashion [69]. Participants were suggested to take naproxen 550 mg 1 h prior to takeoff. The authors report that no headache occurred in 21 patients whereas the authors state that 1 patient had "partial relief due to drug treatment" [69]. In a series of 5 patients who reported prior HAAT, all patients reported effective HAAT prevention after using various triptans 30 min before their flights [70]. However, with regard to both of these studies, in the absence of controlled trials, conclusions cannot be made about efficacy. A systematic review published in 2017 by Bui and Gazerani reviewed 39 papers with a total of 275 patients, reported, "Relieving effects of the medications were reported by naproxen (n = 24/24), triptans (n = 9/12), paracetamol (n = 1/11), ibuprofen (n = 3/6), nasal decongestant (n = 1/4), aspirin (n = 1/3), antibiotics (n = 1/2), antihistamine (n = 2/2), and oxymetazoline (n = 1/1)" [19••]. Non-pharmacological treatments such as valsalva maneuvers, applying pressure to sinuses, chewing, pulling of the earlobe, and relaxation techniques are often tried, in one study by 55% of respondents with airplane headache [68]. In this study of 35 respondents, the investigators report response to such spontaneous maneuvers to be 46% with pressure on the headache pain, 27% with valsalva maneuver, 7% with relaxation methods, 2% with chewing, and 2% with extension of the ear lobes [68]. However, the authors report that these responses tended to be partial and temporary, with only one of these respondents reporting persistent and complete remission [68, 71•].

Otherwise, migraine and other headache treatments can be tried empirically, such as acute treatment with acetaminophen or non-steroidal anti-inflammatory drugs (NSAIDs) such as ibuprofen, diclofenac, or naproxen as well as triptans and D2-antagonist antiemetics (such as promethazine, prochlorperazine, metoclopramide) for migraines attributed to barometric pressure changes. A common recommendation to patients with migraines is to avoid triggers but, in this case, it is hard to avoid weather and pressure changes.

While there are commercial products being marketed directly to consumers such as specialized earplugs designed to help prevent headaches related to changes in atmospheric pressure and mobile phone applications that can notify patients about impending barometric pressure changes, we do not discuss these in this review since we were unable to find research in the peer-reviewed literature to support their efficacy.

Limitations to Studies

Limitations of the above studies include that most are observational using headache diaries, patient interviews, or surveys and are subject to recall bias. There is also likely selection bias; many of the studies assessed patients in the emergency department and, as a result, may not be representative of the overall population of patients with headache, most of whom either are managed in the clinic setting or self-manage. Some of these studies have small sample sizes.

Conclusion

Migraine and other headache disorders affect billions of people worldwide. Weather changes are among the triggers that patients commonly report. Studies involving headache diaries and patient interviews suggest atmospheric pressure as a possible migraine trigger; however, the results of these studies are inconsistent regarding their directionality and fail to establish a strong association. There are no evidence-based treatments at this time specifically for the prevention or treatment of headaches attributed to barometric pressure.

Compliance with Ethical Standards

Conflict of Interest The authors declare no conflicts of interest relevant to this manuscript.

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.

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71.• Nierenburg H, Jackfert K. Headache Attributed to airplane travel: a review of literature current pain and headache reports. 2018;22:48 **A very good review article about recent advancements in HAAT.**