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REVIEW ARTICLE

Pneumocephalus: Case Illustrations and Review

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Abstract
Background Pneumocephalus is commonly encountered after neurosurgical procedures but can also be caused by craniofacial trauma and tumors of the skull base and rarely, can occur spontaneously. Contributing factors for the development of pneumocephalus include head position, duration of surgery, nitrous oxide (N_2O) anesthesia, hydrocephalus, intraoperative osmotherapy, hyperventilation, spinal anesthesia, barotauma, continuous CSF drainage via lumbar drain, epidural anesthesia, infections, and neoplasms. Clinical presentation includes headaches, nausea and vomiting, seizures, dizziness, and depressed neurological status. In this article, we review the incidence, mechanisms, precipitating factors, diagnosis, and management of pneumocephalus. Search of Medline, databases, and manual review of article bibliographies. Considering four case illustrations that typify pneumocephalus in clinical practice, we discuss the common etiologies, and confirm the diagnosis with neuroimaging and management strategies. Avoidance of contributing factors, high index of suspicion, and confirmation with neuroimaging are important in attenuating mortality and morbidity. A significant amount of pneumocephalus can simulate a space-occupying lesion. Supplemental oxygen increases the rate of absorption of pneumocephalus.

Keywords Pneumocephalus · Postsurgical · Nitrous oxide · Mount Fuji sign · Air bubble sign

Introduction

Pneumocephalus, also known as intracerebral aerocele or pneumatocele is defined as the presence of gas within any of the intracranial compartments (intraventricular, intraparenchymal, subarachnoid, subdural, and epidural) of the cranial vault. The first description of intracranial pneumocephalus provided by Thomas in 1866 was discovered during the autopsy of a trauma patient [1]. Chiari in 1884 [2] followed this with a report on the autopsy findings from a patient who had pneumocephalus as a complication of chronic ethmoid sinusitis. Luckett used plain skull radiographs in 1913 for the diagnosis of pneumocephalus [3]. The term pneumocephalus was coined and first used by Wolff in 1914 [4].

Pneumocephalus is usually associated with disruption of the skull after head and facial trauma and tumors of the skull base, following neurosurgery or otorhinolaryngological procedures, and can rarely occur spontaneously. Clinical presentations in a series of 284 patients included headaches in 38%, nausea and vomiting, seizures, dizziness, and depressed neurological status [5]. In clinical practice, it is paramount to differentiate simple from tension pneumocephalus. The latter refers to a collection under pressure compared to the outside atmospheric pressure, when, in most circumstances, a valve mechanism allows air to enter the skull but prevents it from escaping, thus creating a pressure differential.

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Case Illustrations

Case 1: A 53-year-old male presented with a pituitary adenoma and underwent transphenoidal resection. Postoperatively, the patient did well initially, but was noted to develop a cerebrospinal fluid (CSF) leak that was accompanied by severe headaches. Non-enhanced computed tomography (CT) showed significant pneumocephalus as well as air bubbles in several cisterns (Fig. 1a and b). The patient underwent reconstruction of the sellar floor using abdominal fat graft and bone cement and was relieved from his symptoms and discharged to home 3 days later.

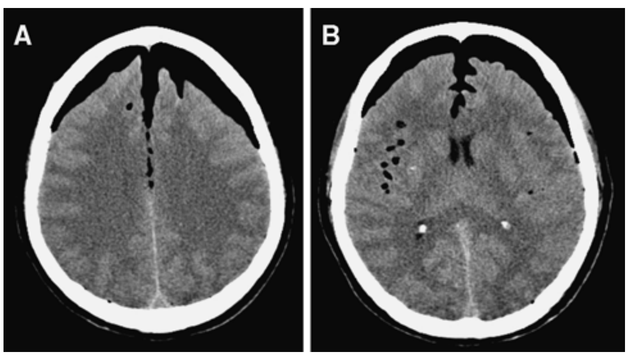

Fig. 1 Case 1. Postoperative axial brain CT scans of the 53-year-old man who underwent transsphenoidal resection for pituitary adenoma demonstrating the "Mount Fuji sign" (**a**) and the "air bubble sign" (**b**)

Case 2: A 79-year-old male with multiple medical problems including recurrent urinary tract infection, dementia, and Parkinson's disease, who presents with 2-day history of mental status change. His wife had noticed that he has been steadily declining in cognitive status, and there was no history of direct or indirect trauma to the head. CT revealed bilateral chronic subdural hematomas (Fig. 2a), and the patient underwent bilateral twist-drill evacuation using the Subdural Evacuating Port System (SEPS) (Medical Designs, LLC, Sioux Falls, SD) (Fig. 2b and c). On postoperative day 2, the output from the drains had tapered off, and a CT scan showed resolution of the subdural collections and bilateral frontal pneumocephalus. The patient was treated with supplemental oxygen, and a follow-up study showed resolution of the pneumocephalus (Fig. 2d), albeit with persistent subdural hygromas.

Case 3: A 61-year-old male who underwent bifrontal biorbital craniotomy and anterior skull base resection for squamous cell carcinoma. Soft tissue CT windows demonstrate a very dark frontal collection (Fig. 3a) that can be misdiagnosed for pneumocephalus. Widening of the window demonstrates the internal structure of the fat graft that had been placed at the time of surgery (Fig. 3b).

Case 4: A 10-year-old boy who underwent decompression of a Chiari I malformation. Following surgery, he was lethargic, with a dilated left pupil. A non-enhanced CT scan demonstrated pneumocephalus in the interpeduncular cistern with some mass effect on the anterior right midbrain (Fig. 4a and b). Following completion of the scan, the

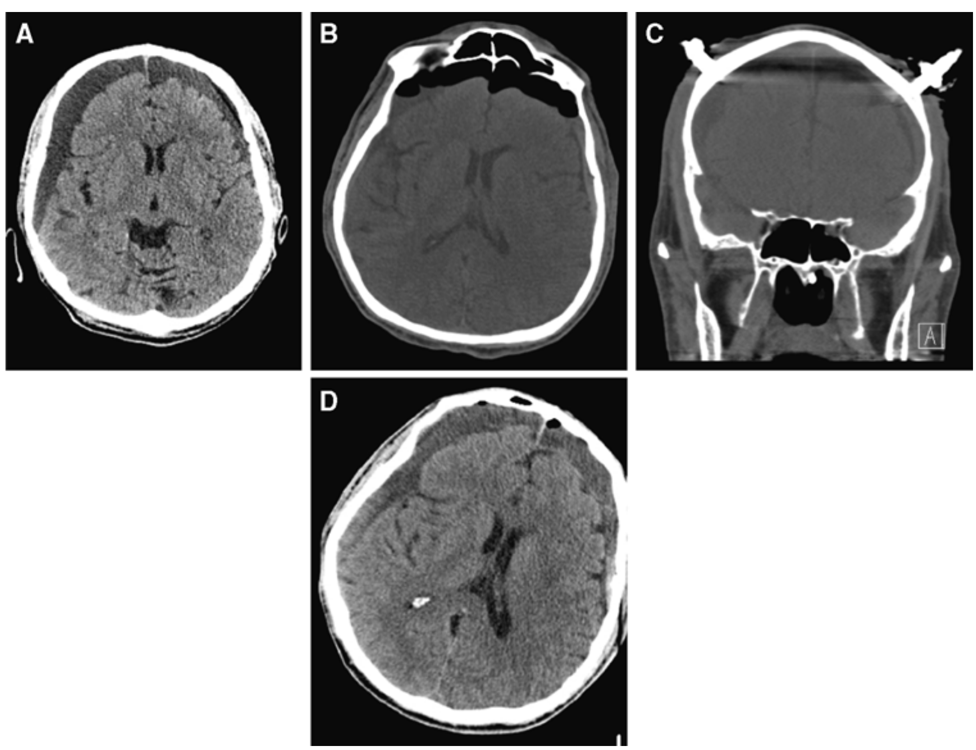

Fig. 2 Case 2. Axial CT scan from a 79-year-old patient's bilateral chronic subdural hematomas (**a**); Postoperative axial (**b**) and coronal (**c**) CT scan following bilateral twist-drill evacuation using SEPS demonstrating bifrontal pneumocephalus; and axial CT scan on postoperative day 2 (**d**) following removal of subdural drains and treatment with supplemental oxygen demonstrating resolution of pnemocephalus but persistent subdural hygromas

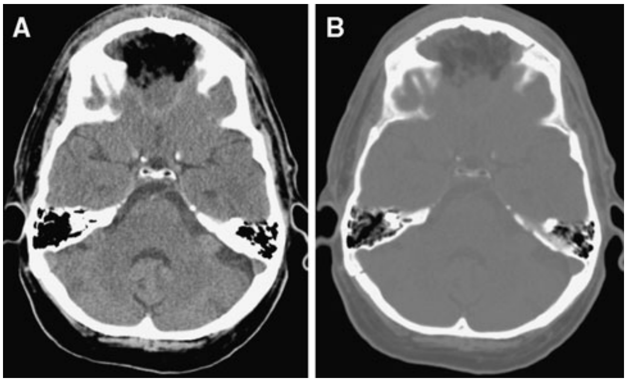

Fig. 3 Case 3. A 61-year-old male who underwent bifrontal biorbital craniotomy and anterior skull base resection for squamous cell carcinoma. Soft tissue CT windows demonstrate a very dark frontal collection (**a**) that can be misdiagnosed for pneumocephalus. Widening of the window demonstrates the internal structure of the fat graft that had been placed at the time of surgery (**b**)

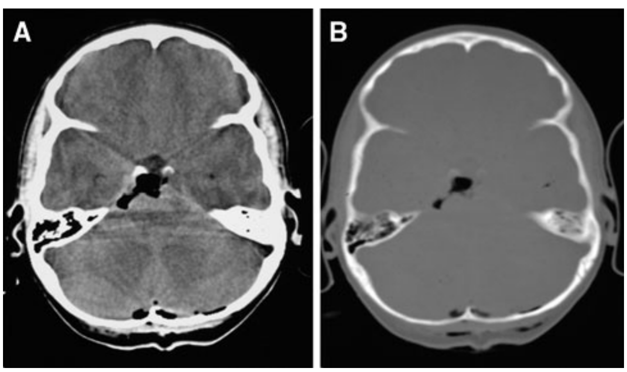

Fig. 4 Case 4. A 10-year-old boy who underwent decompression of a Chiari I malformation. Following surgery, he was lethargic, with a dilated left pupil. A non-enhanced CT scan demonstrated pneumocephalus in the interpeduncular cistern with some mass effect on the anterior right midbrain on soft tissue window (**a**) and bone window (**b**)

patient's left pupil became reactive, although it remained asymmetric.

Discussion

Classification and Subtypes

Various etiologies leading to pneumocephalus are classified and summarized in Table 1. Depending on local practice patterns and specialty, the common etiologies that a practitioner encounters will vary. Craniotomies are among the leading causes, and some amount of pneumocephalus is an inevitable result of a craniotomy [6]. Reasoner et al. reported that 66% of postcraniotomy CT scans demonstrated 5–10% of intracranial volume occupied by air on at least one axial CT section, and all postoperative scans demonstrated at least trace amounts of air [7]. Although typically asymptomatic in patients, pneumocephalus of sufficient volume has been implicated in postoperative lethargy, headaches, confusion, hemiparesis, and abducens nerve palsy [5, 8].

Table 1 Etiologies and classification of pneumocephalus

Skull defects
Post surgical
Craniotomy [5–8]
Transsphenoidal or endoscopic sinus surgery [9]
Shunt insertion [10, 11]
Twist-drill drainage of chronic subdural hematomas [12, 13]
Post-traumatic
Fracture through air sinus or skull base
Open fracture though cranial convexity with dural laceration
Congenital skull or tegmen tympani defects [14]
Neoplasms causing tumor erosion through the skull or skull base
Osteomas, Epidermoid, Pituitary tumors [15–18]
Infection with gas-producing organisms [19, 20]
Post invasive procedures
Lumbar puncture [21]
Ventriculostomy
Spinal anesthesia [22]
Barotrauma [23, 24]

Pneumocephalus is a rare complication of endoscopic sinus surgery (ESS) and microscopic skull base surgery (SBS). Postoperatively, patients often present with headache and altered mental status (Case 1). Associated unrepaired CSF leaks are associated with an increased risk of ascending meningitis [9]. Insertion of a ventriculo-peritoneal shunt that is frequently performed for such surgeries establishes a potential negative intracranial pressure gradient that can be associated with the development of tension pneumocephalus [10, 11].

Tension pneumocephalus has been described after drainage of subdural hematomas. Ishiwata et al. identified two signs that suggest increased tension of the subdural air: (1) Subdural air separates and compresses the frontal lobes, creating a widened interhemispheric space between the tips of the frontal lobes that mimics the silhouette of Mount Fuji ("Mount Fuji sign"; see Fig. 1). The presence of air between the frontal tips associated with massive air inclusion over the frontal lobes presumably indicates increased tension of the subdural air; and (2) The presence of multiple small air bubbles scattered through several cisterns ("air bubble sign"). Putatively, these air bubbles enter the subarachnoid space through a tear in the arachnoid membrane caused by increased tension of air in the subdural space. These two CT findings are helpful in making a diagnosis of subdural tension pneumocephalus following surgery for chronic subdural hematoma [12, 13].

Posttraumatic fractures through air sinuses or the skull base, compound skull fractures with dural lacerations and congential skull or tegmen tympani defects can all be associated with pneumocephalus, including tension pneumocephalus. Evaluation and management should include consideration of infection in the setting of trauma and follow the principles for postsurgical pneumocephalus [14]. Osteomas [15–17], epidermoid [18], and pituitary tumors are examples of neoplasms that can cause erosion through the skull base or skull. Infection with gas-producing organisms can generate intracranial air collections. Pneumocephalus associated with neonatal meningitis is extremely rare, has an acute presentation, and carries a poor prognosis [19, 20]. Diagnostic procedures, including lumbar puncture [21], ventriculostomy, and spinal anesthesia [22] can introduce intrathecal air collections that may lead to significant pneumocephalus. Barotrauma secondary to rapid changes of the surrounding air pressure such as air travel can turn otherwise benign cases of pneumocephalus into symptomatic cases of tension pneumocephalus that require urgent evaluation and treatment [23, 24].

Diagnosis

Air has a Houndsfield coefficient of −1000 on CT, which enables the sensitive and specific detection of even minute quantities of intracranial air. Fat, frequently encountered in the form of fat grafts after skull base surgery, can appear very dark on standard soft-tissue CT windows and may be misdiagnosed as pneumocephalus (Case 3; Fig. 3). As alluded to previously, significant quantities of air over the frontal convexities produce the characteristic “Mount Fuji sign,” and multiple small air bubbles scattered through several cisterns have become known as the “air bubble sign” [13]. Plain x-rays can also be used to demonstrate large air collections. Historically, intentional introduction of intracranial and intraventricular air has been used as pneumencephalogram for diagnostic purposes [25].

Perioperative Contributing Factors

Head position, duration of surgery, nitrous oxide (N_2O) anesthesia, hydrocephalus, intraoperative osmotherapy, hyperventilation, spinal anesthesia, barotauma, continuous CSF drainage via lumbar drain, epidural anesthesia, infection (otitis media), and neoplasms include some of the intra- and perioperative contributing factors in the development of pneumocephalus.

N_2O has been implicated in the evolution of tension pneumocephalus, a potential lifethreatening emergency. It is especially important when it is used for anesthesia in subsequent nonintracranial procedures or when patients with pneumocephalus are discharged and travel to a higher altitude [7, 26, 27]. Domino et al. have questioned the true impact of N_2O use during the craniotomy and its discontinuation before dural closure [28]. These investigators conducted a randomized study and concluded that continuation of N_2O after dural closure did not affect intracranial pressure (ICP) during the craniotomy closure, suggesting that it is not necessary to discontinue N_2O prior to dural closure [28]. Trapped air at room temperature expands when warming to body temperature, an effect thought to contribute to the development of tension pneumocephalus; however, the actual volume increase is modest at around 4% [29]. Other risk factors include skull base injury or incomplete reconstruction after skull base surgeries, and positive pressure events in the postoperative period such as coughing, straining, vomiting, or valsalva maneuver, including sneezing and nose blowing. Intravenous air in the cavernous sinus or large veins in the cranium can occur following cardiopulmonary resuscitation and can produce the erroneous appearance of pneumocephalus.

Postulated Mechanisms

The development of pneumocephalus follows two theories that can be called the “ball-valve” and the “inverted bottle” mechanisms. The ball-valve mechanism implies that positive pressure events, such as sneezing, coughing, and valsalva maneuvers, force air through a cranial defect, which then resists the spontaneous egress of the air. Significant resistance to the outflow of air leads to tension pneumocephalus [9]. In the inverted bottle theory, drainage of CSF leads to a negative ICP gradient which is relieved by the influx of air [30]. The amount of air is independent of the size of the defect, but smaller defects are more easily sealed by blood clots or granulation, allowing for gradual reabsorbtion and spontaneous resolution of the pneumocephalus [9].

Prevention and Avoidance of Contributing Factors

Some degree of postsurgical pneumocephalus occurs in all patients [31]. The decisive factor for the evolution of pneumocephalus is the position of the head during surgery and during closure [8, 31–34]. Other factors are the use of standard techniques during surgery that allow for easier and safer brain manipulation including drainage of CSF, dehydration with the use of diuretics or mannitol, hyperventilation and decompression, or resection of space-occupying lesions. In some cases, it may be possible to reposition the head during the final moments of dural closure in such a way that brings the remaining dural defect to the highest point of the cranial cavity and facilitates the escape of remaining air while refilling the intradural space with irrigation fluid.

Some authors have implied N_2O in the pathogenesis of postsurgical pneumocephalus [30, 35, 36], whereas others have questioned its role [28, 37–40]. Presently, there is no evidence, including data from randomized clinical trials, to show that any particular anesthetic technique can either increase or decrease the amount of pneumocephalus after neurosurgical procedures [28, 31, 40].

Bilateral chronic subdural collections pose a special challenge when it comes to minimizing the amount of pneumocephalus that is allowed to enter one or both sides during burr-hole drainage. The authors recommend prepping both sides of the head to allow rapid turning of the head after completion of drainage on one side. Incision can be made, and the burr hole can be placed on both sides with the dura left intact. In order to proceed then from one side to the next requires only turning the head and incision of the dura, thereby minimizing the time required to drain the second subdural collection after the first.

Complications

Tension pneumocephalus behaves in a similar way as an intracranial space-occupying lesion causing intracranial hypertension, potentially with ensuing downward herniation [41]. Air embolism and cardiac arrest are associated with pneumocephalus in rare circumstances [41, 42]. Ascending meningitis has been described in the literature as a serious complication of unrepaired skull base defects in patients with CSF leaks, with an incidence of about 30% and a cumulative 10-year risk of 85% [43, 44]. Occasionally, post-operative pneumocephalus may cause focal neurologic deficits (Case 4; Fig. 4).

Treatment and Management

Only a small number of studies of high-level evidence exist regarding the treatment of pneumocephalus. Continuation of N_2O after dural closure following craniotomy does not affect ICP [28]. Hernandez et al. prospectively studied the incidence and intensity of pneumocephalus in 90 consecutive patients undergoing a posterior fossa procedure in the sitting position and demonstrated that despite the hypothetical diverse effects of the three anesthetic techniques (propofol, isoflurane, and a combination of thiopental/N_2O/isoflurane) on cerebral hemodynamics, their results suggest that none of them had a substantial effect on the amount of intracranial air detected [31]. Turgut and collaborators confirmed the hypothesis that 5 cm H_2O of positive end-expiratory pressure (PEEP) reduces the incidence of pneumocephalus in patients who undergo spinal intradural tumor surgery [45]. The prophylactic administration of ceftriaxone for the prevention of meningitis in patients with acute traumatic pneumocephalus was not found to be an efficacious intervention in a prospective randomized study [46].

The treatment of pneumocephalus with supplemental O_2 is commonly used; several case reports demonstrate the hastened resolution of intracranial air collections [8]. Gore and coworkers randomized 13 patients with postoperative pneumocephalus to breathe 100% O_2 using a nonrebreather mask (treatment group), or to breathe room air (control group) for 24 h. The mean rate of pneumocephalus volume reduction in the group that received 68% FiO_2 delivered by nonrebreather mask was 65% over 24 h, significantly higher than 31% reduction over 24 h in the control group [6].

Dexter and Reasoner modeled the elimination of nitrogen from an intracranial gas pocket, taking into account the solubility of N_2O in blood and brain tissue, the diffusivity of N_2O within brain tissue, brain density, cerebral blood flow, the partial pressure of N_2O within the pneumocephalus, and the partial pressure of nitrogen, which is in turn inversely related to the inhaled O_2 (FiO_2) concentration within the blood [47]. They predicted (1) an increasing rate of pneumocephalus absorption with increasing FiO_2 concentration; (2) peak initial rate of absorption that diminishes as the size of the pneumocephalus decreases; and (3) increases in FiO_2 to greater than 40% yield only marginal additional increases of the rate of pneumocephalus absorption [47].

A standard treatment of pneumocephalus after endoscopic sinus surgery or skull base surgery has not been established in the literature. The association of pneumocephalus with a skull base defect is similar to the relation to postoperative CSF leaks and suggests that its treatment should be similar. DelGaudio et al. suggested that pneumocephalus resulting from small bone defects responds well to conservative measures including bed rest, head of bed elevation, avoidance of positive pressure, and pain control [9]. In their series, three patients with larger defects (>15 mm) failed to resolve their pneumocephalus with conservative therapy and underwent lumbar drainage, followed by surgical closure of the defect. For small amounts of pneumocephalus following ESS or SBS, surgical intervention may be delayed until after conservative management has failed, but the risk of meningitis from an unrepaired skullbase defect should be considered before deferring elective repair of such a defect [9].

Conclusions

Pneumocephalus is commonly encountered after neurosurgical procedures but can also be the result of trauma or infrequent causes. Most collections are small, behave benign, and respond to conservative therapy. Supplemental oxygen increases the rate of absorption of pneumocephalus. A significant amount of pneumocephalus may behave like any space-occupying lesion; a high index of suspicion is needed to make the diagnosis, prompt treatment, and remedy of the source of air to prevent unwanted morbidity and mortality. Patients should undergo serial imaging to ensure gradual reduction of the volume of intracranial air; CT has proven to be a quick and reliable method to follow intracranial air collections.

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