CASE REPORT

Traumatic pneumocephaly: trapped air from where?

Azam Basheer,¹ Mohamed Macki,² Asim Mahmood²¹Department of Neurosurgery, Henry Ford Health System, Detroit, Michigan, USA²Department of Neurosurgery, Henry Ford Hospital, Detroit, Michigan, USACorrespondence to
Dr Azam Basheer,
abashee1@hfhs.org

Accepted 16 August 2017

SUMMARY

Traumatic pneumocephaly is literally defined as 'air in the head' after trauma. While this phenomenon has been well described in the literature, our case report is unique in describing diffuse pneumocephalus in the subaponeurotic space, subdural space, subarachnoid space, brain and ventricles without a break in the cranial vault: a 26-year-old man fell from a =9 meter scaffolding in a water tower. Following an arduous and delayed extrication, the patient was unresponsive with loss of pulse requiring intubation, cardiopulmonary resuscitation and release of tension pneumothorax with bilateral thoracostomy tubes. Examination remained poor with a Glasgow Coma Scale of 3. Immediate exploratory laparotomy was performed for a small right retroperitoneal haematoma on Focused Assessment with Sonography for Trauma. Postoperative imaging revealed diffuse pneumocephaly without facial fractures. This case presentation explores unusual causes of fistulous connections with the atmosphere that may lead to air trapped in and around the cranial vault.

BACKGROUND

In 1852, the discovery of extracranial air in the mastoid cells erroneously gave rise to the term 'pneumocephaly.' It was not until 32 years later in 1884 that Chiari *et al* correctly defined the term on an autopsy.¹ Traumatic pneumocephaly, specifically, was radiographically identified by Luckett. Today, trauma is the most common cause of pneumocephaly (74%), accounting for 0.5%–1% of all head injuries.² While this phenomenon has been well described in the literature, diffuse pneumocephalus throughout the subaponeurotic space, subdural space, subarachnoid space, brain and ventricles is a unique finding in our case report. With such extensive air entrapment, several fistulous connections with the atmosphere likely exist. Such diverse aetiologies of traumatic pneumocephalus are

particularly interesting in the absence of radiographic evidence of facial fractures, which are common causes of air in and around the cranium. This presents an academic opportunity to review unorthodox causes of pneumocephaly.

CASE PRESENTATION

A 26-year-old healthy man was resurfacing the inside of a water tower, wherein the portable scaffolding (comparable with systems for window washers of tall skyscrapers) collapsed. The patient fell 10 meters to the metal floor of the tower basin. Because the basin itself was 100 feet above the ground, firefighters used a pulley system to lower the critically ill patient down the tower's tubular connection (figure 1). This arduous extrication unfortunately delayed the rescue mission. Approximately 1.5 hours after the fall, the patient presented to an outside hospital with a Glasgow Coma Scale (GCS) of 3. Following intubation, tension pneumothoraces were released with bedside placement of bilateral chest thoracostomy tubes. The uncomplicated procedure returned 900 cc of blood from the right chest tube and no return of blood from the left chest tube. Chest X-ray confirmed appropriate placement. During the Advanced Trauma Life Support protocol in the trauma bay, patient had prolonged periods of pulseless electrical activity requiring cardiopulmonary resuscitation (CPR) and massive transfusion protocol: 9 L of intravenous fluids, 2700 ml (9 units) of packed red blood cells, 6 units of fresh frozen plasma and 1 unit of platelets. After pulses returned, patient underwent emergent exploratory laparotomy for haemodynamic instability as well as a small right retroperitoneal haematoma on Focused Assessment with Sonography for Trauma. A 3 cm serosal laceration along the transverse colon was imbricated with a 3–0 Vicryl. A 1 cm grade 1 liver laceration just to the right of the falciform ligament did not require surgical treatment. A blood collection in the right retroperitoneum appeared stable and was thus never addressed. The patient was transported directly from the operating room to the CT scan, which revealed intraventricular haemorrhage within the trigone of the right ventricle with a questionable small subdural haematoma along the posterior interhemispheric falx (figure 2). No facial or cervical spine fractures were noted on the CT; however, CT of the chest, abdomen and pelvis was significant for right adrenal gland haemorrhage, grade 3 laceration of right kidney, and right retroperitoneal haemorrhage extending into the right

Figure 1 Images of (A) the difficult extrication from the water tower and (B) the water tower.

CrossMark

To cite: Basheer A, Macki M, Mahmood A. *BMJ Case Rep* Published Online First: [please include Day Month Year]. doi:10.1136/bcr-2017-219420

Figure 2 Head CT reveals intraventricular haemorrhage within the trigone of the right ventricle. No facial fractures noted.

pelvis (figure 3). Osseous injuries include left scapular fracture; right 5th to 7th rib fractures; vertebral body fractures of T7–L1 with comminution at T11, T12, L1 and L4; right L1–L4 transverse process fractures; and left displaced radial, ulnar and femur fractures. On transfer to the intensive care unit, the patient lost pulses, requiring CPR and resuscitation. Repeat head CT scan 46 hours after the last haematocrit

showed extensive pneumocephaly in both the cerebrospinal fluid (CSF) spaces and venous vasculature (figure 4). Again, no facial fractures could be delineated. Because of the concern for tension pneumocephaly causing caudal herniation, the patient was transferred to our tertiary academic institution for consideration of hyperbaric treatment.

Examination

On arrival to our hospital, the patient's GCS was still 3. His pupils were 6 mm, fixed and unreactive to light. No extra-ocular movements were noted on oculocephalic testing. There was no corneal reflex, nasal tickle, gag or cough reflex and no movement in any of the four extremities in response to central stimulation. Because of the poor examination, the patient was deemed not a candidate for further intervention.

DIFFERENTIAL DIAGNOSIS

The reason for interval development of pneumocephaly between the first and second head CT scans could not be definitively established. Because the air was present in both the intra-axial and extra-axial spaces, a differential diagnosis likely includes several aetiologies, which can be generally divided into two broad categories:

Pneumocephaly in the extravascular spaces

- ▶ Microfractures through the frontal sinus and/or mastoid air cell
- ▶ Undetected facial fractures that provided a conduit for air into the subdural and subarachnoid spaces
- ▶ Air travels through a conjunctival violation into the intra-conal space
- ▶ Dural fistula in the abdomen

Pneumocephaly in the vascular spaces

- ▶ Displaced long bone fractures that allowed for fat embolism
- ▶ Unsealed chest tube that leaked air into the vasculature
- ▶ Untouched retroperitoneal bleed that permitted air through the vena cava

Figure 3 CT of chest, abdomen and pelvis ((A) coronal image; (B) axial image)) was significant for right adrenal gland haemorrhage and right retroperitoneal haemorrhage, including the right psoas muscle, extending into the right pelvis.

Figure 4 Head CT after the exploratory laparotomy and second round of cardiopulmonary resuscitation. Notice the diffuse pneumocephalus in the subaponeurotic space, subdural space, subarachnoid space, brain and ventricles.

TREATMENT

On arrival to our institution, the family members advocated for full medical and surgical interventions. The patient was requiring increasing doses of vasoconstrictors—epinephrine, levophed and vasopressin—to maintain appropriate mean arterial pressure. Higher amiodarone doses were started after return of spontaneous circulation at the outside hospital. Because of cardiovascular instability, the patient was not a candidate for hyperbaric oxygenation.

Unlike subdural air collections that separate the bilateral frontal lobes from the frontal bone (the so-called ‘Mount Fuji’ sign), air collections in the subarachnoid and venous spaces are

Figure 5 CT of the abdomen reveals a fracture extending from the right retroperitoneum (at the level of the haematoma) through the T12 vertebral body, providing a potential fistulous connection.

not amenable to surgical decompression.³ CT scan of the head at our institution redemonstrated air in the subarachnoid and venous spaces without midline shift or significant caudal herniation; however, loss of grey–white matter differentiation was suggestive of cerebral oedema secondary to cerebral hypoxic injury. Neurosurgery recommended aggressive sodium goals with hypertonic saline to decrease the amount of cerebral oedema.

OUTCOME AND FOLLOW-UP

Despite maximal medical therapy, the patient’s condition did not improve. Per hospital ethics committee recommendations, care was withdrawn. The patient expired less than 48 hours after transfer to our hospital.

DISCUSSION

Pneumocephaly is defined as air in and around the skull. Historically, pneumocephaly was divided into intracranial or extracranial components.⁴ The latter refers to air pockets in the subaponeurotic space; these collections typically follow frontal sinus and/or mastoid air cell microfractures, which often go undetected on routine imaging. Commensurately, subcutaneous air in the present case report was appreciated in the scalp (figure 4) without identifiable facial fractures on serial images interpreted by independent radiologists at two different institutions. A -9 meter fall would undoubtedly generate enough momentum to fracture the frontal sinus and/or mastoid air cells; however, these microcommunications with the scalp do not explain the intracranial findings.

Intracranial pneumocephalus, the more common of the two types, is defined as air in the subdural space, subarachnoid space, brain parenchyma and/or the ventricle,⁴ usually from a skull fracture.^{5–8} Traumatic pneumocephaly of the subdural space is a well-described phenomenon in the literature.^{9–11} A skull base fracture through the posterior wall of the frontal sinus causes a dural rent that mimics a ‘ball-valve’ mechanism described by Dandy¹²: air that passes from the external atmosphere through the bony/dural defect is trapped in the cranium, commonly in the anterior fossa. The trapped air in the bilateral, frontal subdural spaces forms the classic Mount Fuji sign, which causes the frontal lobes to separate from the frontal bone.³ Such findings were not visualised on the present head CT scans. Because the patient developed only small subdural air collections (figure 4), the ball-valve postulate is unlikely the competing mechanism.

Subarachnoid pneumocephaly, on the other hand, follows violation of the posterior ethmoidal and sphenoidal cells. CSF leak, characterised by rhinorrhoea, is a pathognomonic clinical finding. Examination of the patient in this report did reveal trace, clear discharge at the nares. The clear fluid was at a lower viscosity than mucous, which increased our suspicion for a CSF leak. To that end, Horowitz postulated an ‘inverted-bottle’ mechanism, in which an occult CSF leak induces negative intracranial pressure.¹³ This vacuum effect pulls air in the intracranial space, typically from iatrogenic atmospheric connections (eg, thoracostomy tubes in the present case report). Another possibility of subarachnoid pneumocephaly is a dural fistula in the thoracic vertebrae.^{14 15} McCall *et al* published a case of pneumocephaly secondary to air that travelled from a tension pneumothorax through a comminuted thoracic spine fracture to the subarachnoid spinal space.¹⁴ The so-called ‘pleural dural fistula’ has already been reported by Katz *et al*.¹⁵ Extrapolating these reports to this case presentation, multiple comminuted thoracic spinal fractures were noted in the abdomen on the CT scans (no comminuted spinal fractures were observed in the thoracic

Figure 6 Orbital pressure postulate: head CT magnified on the right orbit demonstrates air tracking along the optic nerve (white arrows). Also note the air around the periorbital soft tissues.

cavity) (figure 5). A retroperitoneal dural fistula in the setting of a right-sided retroperitoneal haemorrhage and/or a peritoneal dural fistula in the setting of a serosal tear on the transverse colon are not unreasonable.

Although no facial or cranial fractures were seen, undetected facial fractures in the setting of pneumocephalus have been reported in the literature,^{16–18} and we cannot also completely rule out this possibility. In a review of literature on tension pneumocephalus, Pillai *et al* found that only 1 of the 18 previously published cases did not localise a cranial fracture.^{19,20} However, in that sole article by Dewaele *et al*,²⁰ the authors did identify a dural rent. Despite endoscopic repair of the CSF leak, the patient still passed from significant air burden in multiple organ systems. Similarly, the patient in the current report passed from significant intracranial air burden.

Alternative hypotheses have debunked speculation of occult fractures in favour of a scientifically sustained role of high-pressure air in the orbit.^{21–25} If the pressure exceeds 52,730 Kg/m² at the orbit, the compressed air will enter a conjunctival violation into the intraconal space and pass along the optic canal to the cranial vault vis-à-vis dissection of Tenon fascia, which ensheathes the orbital globe.^{21,22} Chung *et al* argue that a sensitive indicator of this hypothesis is orbital emphysema, which is demonstrated in our manuscript by CT scan of air tracking along the optic nerve (figure 6).

While appealing, the aforementioned mechanisms do not account for the intravascular air. Attention was initially directed

towards the left displaced radial, ulnar and femoral fractures, which have a strong correlation with fat emboli.²⁶ However, the Hounsfield units of the hypodense collections on head CT in this article's figures approached –1000 (air), not –100 (fat).²⁷

Finally, air embolism in the intravascular space cannot be excluded. During the laparotomy in our patient, a blood collection in the right retroperitoneum was never explored because the haematoma appeared stable during the operation (figure 3). A second theoretical connection is air leak at the thoracotomy site. Both of these suggestions would introduce air into the venous system. Thompson *et al* argues that air naturally ascends 'against the venous outflow of the jugular veins into the intracranial compartment'.²⁷ The authors justify their hypothesis with their operative experience, in which air can be visualised rising in the internal jugular vein during a carotid endarterectomy. A second, less likely possibility, eludes to a paradoxical embolus that travelled through a patent foramen ovale and/or pulmonary arteriovenous malformation²⁸; however, the patient's critical condition and rapid mortality obviated work-up (eg, echocardiogram) of these possibilities.

In summary, the exact cause of pneumocephaly in our case is unclear, but we have detailed various plausible mechanisms. Regardless of the mechanism of the fistulous connection with the atmosphere, CPR exacerbated the volume of air into the cranial vault. In other words, CPR likely explains the unprecedented extent of our patient's pneumocephalus, above and beyond that of which is reported in aforementioned articles. Whether the ball-valve mechanism, the inverted bottle mechanism, dural fistula or intraorbital pressure is adopted, pulsatile pressure during CPR continuously forced air into the cranium. Similarly, the ascension of intravascular air, be it from the retroperitoneal bleed or the leaking thoracotomy site, was facilitated by mechanical blood flow during CPR. In a review of intracranial gas after CPR in four patients, Imanishi *et al* postulated a 'thoracic pump' during CPR to explain the backflow of venous air to the intracranial and extracranial spaces alike.²⁹ In these patients, the lack of antegrade venous flow enabled air to flow more readily into the head. The impaired blood flow and subsequent trapped air eventually resulted in cerebral hypoxic injury in our case report.

Learning points

- Diffuse pneumocephaly, including the scalp, subdural space, subarachnoid/ventricular spaces and vasculature, likely arises from very different aetiologies.
- Understanding the different mechanisms of pneumocephaly may guide the treatment options if the patient's condition confers a favourable prognosis.
- Cardiopulmonary resuscitation following multiple injuries will facilitate fistulous connections with the atmosphere; therefore, haematocrit should be obtained immediately after the return of spontaneous circulation.

Contributors AB, MM and AM contributed to the conception and design of the work, as well as the acquisition, analysis and interpretation of data for the work. AB, MM and AM were all involved in drafting the manuscript as well as critical review and revision of the intellectual content. AB, MM and AM approved the final version of this submission and all are in agreement to be accountable for all aspects of the work and in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

Competing interests None declared.

Patient consent Detail has been removed from this case description/these case descriptions to ensure anonymity. The editors and reviewers have seen the detailed

information available and are satisfied that the information backs up the case the authors are making.

Ethics approval Institutional Review Board approval no 11145.

Provenance and peer review Not commissioned; externally peer reviewed.

© BMJ Publishing Group Ltd (unless otherwise stated in the text of the article) 2017. All rights reserved. No commercial use is permitted unless otherwise expressly granted.

REFERENCES

- Keskil S, Baykaner K, Ceviker N, *et al.* Clinical significance of acute traumatic intracranial pneumocephalus. *Neurosurg Rev* 1998;21:10–13.
- Vinken P, Bruyn G. Handbook of clinical neurology. 1969.
- Dabboub CB, Salas G, Silveira EN, *et al.* Review of the management of pneumocephalus. *Surg Neurol Int* 2015;6:155.
- Garland LH, Mottram ME. Traumatic pneumocephalus. *Radiology* 1945;44:237–40.
- Hadjigeorgiou GF, Singh R, Stefanopoulos P, *et al.* Traumatic pneumorrhachis after isolated closed head injuries: An up-to-date review. *J Clin Neurosci* 2016;34:44–6.
- Kara H, Akinci M, Degirmenci S, *et al.* Traumatic pneumorrhachis: 2 cases and review of the literature. *Am J Emerg Med* 2015;33:861e1–3.
- El-Halabi D, Alkandari T, Yaktien MM. Traumatic air in spinal canal (pneumorrhachis). *Anaesthesiol Intensive Ther* 2012;44:25–7.
- Gelalis ID, Karageorgos A, Arnaoutoglou C, *et al.* Traumatic pneumorrhachis: etiology, pathomechanism, diagnosis, and treatment. *Spine J* 2011;11:153–7.
- Markham JW. The clinical features of pneumocephalus based upon a survey of 284 cases with report of 11 additional cases. *Acta Neurochir* 1967;16:1–78.
- Steudel WI, Hacker H. Prognosis, incidence and management of acute traumatic intracranial pneumocephalus. A retrospective analysis of 49 cases. *Acta Neurochir* 1986;80:93–9.
- Briggs M. Traumatic pneumocephalus. *Br J Surg* 1974;61:307–12.
- Dandy WE. intracranial pneumatocele or aereocle. *Archives of Surgery* 1926;12:949–82.
- Horowitz M. Intracranial pneumocoele. An unusual complication following mastoid surgery. *J Laryngol Otol* 1964;78:128–34.
- McCall CS, Nguyen TQ, Vines FS, *et al.* Pneumocephalus secondary to tension pneumothorax associated with comminuted fracture of the thoracic spine. *Neurosurgery* 1986;19:120–2.
- Katz DS, Groskin SA, Wasenko JJ. Pneumorrhachis and pneumocephalus caused by pneumothorax and multiple thoracic vertebral fractures. *Clin Imaging* 1994;18:85–7.
- Choi YY, Hyun DK, Park HC, *et al.* Pneumocephalus in the absence of craniofacial skull base fracture. *J Trauma* 2009;66:E24–27.
- Bjerrum S, Rosendal F. A rare case of tension pneumocephalus after head trauma. *Int J Surg Case Rep* 2015;6C:300–2.
- Chung HJ, Lee BH, Hwang YJ, *et al.* Pneumocephalus due to compressed air injury without facial bone fracture 안구 압축 공기로 인해 안면골 골절 없이 발생한 기뇌종: 증례 보고. *J Korean Soc Radiol* 2011;65:333–5.
- Pillai P, Sharma R, MacKenzie L, *et al.* Traumatic tension pneumocephalus - Two cases and comprehensive review of literature. *Int J Crit Illn Inj Sci* 2017;7:58–64.
- Dewaele F, Caemaert J, Baert E, *et al.* Intradural endoscopic closure of dural breaches in a case of post-traumatic tension pneumocephalus. *Minim Invasive Neurosurg* 2007;50:178–81.
- Lubniewski AJ, Feibel RM. Traumatic air blast injury with intracranial, bilateral orbital, and mediastinal air. *Ophthalmic Surg* 1989;20:677–9.
- Williams TR, Frankel N. Intracerebral air caused by conjunctival laceration with air hose. *Arch Ophthalmol* 1999;117:1090–1.
- Yildiz A, Duce MN, Ozer C, *et al.* Disseminated pneumocephalus secondary to an unusual facial trauma. *Eur J Radiol* 2002;42:65–8.
- Kang BS. Disseminated head and neck emphysema with pneumocephalus due to air compressor injury into orbit. *Am J Emerg Med* 2007;25:223–5.
- Yuksel M, Yuksel KZ, Ozdemir G, *et al.* Bilateral orbital emphysema and pneumocephalus as a result of accidental compressed air exposure. *Emerg Radiol* 2007;13:195–8.
- Levy D. The fat embolism syndrome. A review. *Clin Orthop Relat Res* 1990;261:281–6.
- Thompson TP, Levy E, Kanal E, *et al.* Iatrogenic pneumocephalus secondary to intravenous catheterization. Case report. *J Neurosurg* 1999;91:878–80.
- Riding G, Daly K, Hutchinson S, *et al.* Paradoxical cerebral embolisation. An explanation for fat embolism syndrome. *J Bone Joint Surg Br* 2004;86:95–8.
- Imanishi M, Nishimura A, Tabuse H, *et al.* Intracranial gas on CT after cardiopulmonary resuscitation: 4 cases. *Neuroradiology* 1998;40:154–7.

Copyright 2017 BMJ Publishing Group. All rights reserved. For permission to reuse any of this content visit <http://group.bmj.com/group/rights-licensing/permissions>.
BMJ Case Report Fellows may re-use this article for personal use and teaching without any further permission.

Become a Fellow of BMJ Case Reports today and you can:

- Submit as many cases as you like
- Enjoy fast sympathetic peer review and rapid publication of accepted articles
- Access all the published articles
- Re-use any of the published material for personal use and teaching without further permission

For information on Institutional Fellowships contact consortiasales@bmjgroup.com

Visit casereports.bmj.com for more articles like this and to become a Fellow