International Journal of Surgery Case Reports 86 (2021) 106342

Contents lists available at ScienceDirect

International Journal of Surgery Case Reports

journal homepage: www.elsevier.com/locate/ijscr

Case report

Pneumocephalus secondary to a spinal surgery: A literature review and a case report

Osama J. Abu-Hamdiyah, Sarah Al Sharie *, Sajeda Awadi, Almu'atasim Khamees, Mohammad J. Athamneh

Faculty of Medicine, Yarmouk University, Irbid 22110, Jordan

ARTICLE INFO

Keywords:
Pneumocephalus
Spinal surgery
Gas forming bacteria
Post-operative infection
Citrobacter freundii

ABSTRACT

Introduction: We report a case of pneumocephalus, which is identified as the presence of air in the cranial cavity and is a rare complication after spinal surgeries, in addition to a literature review of similarly reported cases.
Case presentation: The patient is a 63-year-old male who developed pneumocephalus after undergoing a minimally invasive left side decompression at L3-L4 with left L4 foraminotomy even though there were no signs of dural tears or Cerebrospinal Fluid (CSF) leaks. After the diagnosis of pneumocephalus using brain Magnetic Resonance Imaging (MRI), the patient was treated conservatively and was discharged after 3 weeks without developing further complications.
Discussion: Pneumocephalus is defined as an abnormal accumulation of air within the cranial cavity. It can occur due to a variety of causes but rarely due to gas forming bacteria. Many theories are suggested concerning the pathophysiology of pneumocephalus, the inverted bottle theory, the ball valve theory, the Nitrous Oxide (N_2O) theory, and as we outweigh in our case, gas forming bacteria theory. Pneumocephalus can be treated surgically, nevertheless, conservative management methods of such cases are usually followed.
Conclusion: The aim of this study is to draw further attention to the management and diagnosis of such surgical complication. A more extended research is needed to provide a full comprehensive approach to deal with this problem if faced in the future. To the best of our knowledge, this study reports the first pneumocephalus case induced by a postoperative bacterial infection in the global English based medical literature.

1. Introduction

Pneumocephalus (PNC) also known as intracerebral aerocele or pneumatocele is a pathological collection of gas, usually air, within the cranial cavity. This definition was first established in 1914 by Wolff E [1,2]. PNC was first reported in 1866 by Thomas after performing an autopsy on a trauma patient [3]. Pneumocephalus can be induced by a variety of causes but occurs mostly after head traumas or cranial surgeries [4]. It is a complication that mostly develops after brain neuronal traumatic events that trap air in the cranial vault (especially with the presence of skull base fractures), intracranial neoplasms, infections, neurosurgical interventions, otolaryngological procedures (e.g. paranasal sinus surgeries) and diagnostic interventions (e.g. pneumoencephalography or lumbar puncture) [5–12]. Although spinal surgeries (e.g., lumbar decompression for degenerative spinal pathology) can be followed by several complications that are inevitable, pneumocephalus is just rarely reported as one of them [13,14]. Moreover, most of the published case reports about pneumocephalus after spinal surgeries have been associated with lumbar arthrodesis or similar spinal surgeries causing a dural leak [15]. For a better understanding and more effective management in the future this study will present an interesting neurosurgical case report of pneumocephalus that developed due to a gas forming bacteria originating from a post-operative lumbar spinal surgery wound infection with the absence of Cerebrospinal Fluid (CSF) leaks which is considered the first case in English global literature. In addition to a literature review of cases reporting pneumocephalus after spinal surgeries and their causes, which may help in outweighing some theories that stand behind pneumocephalus occurrence. This deep diving may also assist in clinical decision guidance when such incidents develop. This study was conducted in accordance with the SCARE guidelines for case reports [16].

* Corresponding author at: Yarmouk University, Irbid, Jordan.
E-mail address: Sarahalsharie2000@gmail.com (S. Al Sharie).

https://doi.org/10.1016/j.ijscr.2021.106342
Received 16 July 2021; Received in revised form 17 August 2021; Accepted 21 August 2021
Available online 25 August 2021
2210-2612/© 2021 The Author(s). Published by Elsevier Ltd on behalf of IJS Publishing Group Ltd. This is an open access article under the CC BY-NC-ND license (http://creativecommons.org/licenses/by-nc-nd/4.0/).

2. Case presentation

A 63-year-old male, presented at our clinic complaining from lower back pain, left lower limb sciatica at L3-L4 distribution, with neurogenic claudication. Labs were within normal. Magnetic Resonance Imaging (MRI) showed multi- level degenerative disk disease, most significant at L3-L4 level, compressing the left descending L4 nerve root mostly on the left side (Fig. 1). The patient underwent a minimally invasive left side decompression at L3-L4 with left L4 foraminotomy. Intraoperatively, the surgery went smoothly, no dural tears or CSF leaks were noticed. 12 days after the surgery, the patient started complaining of surgical site pain, swelling, and wound discharge. Blood culture and wound culture were taken directly prior to intravenous (IV) antibiotic administration. His biological inflammatory markers were significantly higher than normal (ESR: 98 mm/h, CRP: 457.8 mg/L). IV antibiotic was then administered. In less than 48 h after samples were taken, blood culture and wound culture showed a heavy growth of *Citrobacter freundii*; which was sensitive to Ertapenem and Ciprofloxacin. Spine MRI with IV contrast was requested for further evaluation and showed post-operative soft tissue changes with multiple small hypointense fossi suggesting gas bubbles at the level of L3- L4 (Fig. 2). The patient had no signs of intracranial hypotension. The patient underwent an exploration debridement of necrotic tissue and an abscess drainage. An intraoperative sample was taken and confirmed primary culture results. During this surgery, the neurosurgeon explored the dura and the surgical site looking for any dural tears or CSF leaks. Also, an intraoperative Valsalva maneuver was performed and confirmed the absence of any dural tears or CSF leaks as shown in (Supplementary data, Video 1). A Ready-vac drain was inserted under low pressure setting. Day 1- postoperative, the patient started complaining of headache consistent with intracranial hypotension, nausea, and dizziness without any meningeal signs. His vitals were stable. Ready-vac drain output remained with a normal amount of drainage (150 cm^3 per day). Day 2- postoperative, the output remained at the same rate of drainage and a lumbar spine and a brain MRI was ordered to assess the possibility of multiple brain abscesses as a result of *C. freundii* infection. Lumbar spine MRI showed post-operative soft tissue changes with multiple gas bubbles and elongated thin walled fluid collection overlying the paravertebral muscle at the site of the surgery measuring about 11.8 * 1.5 * 8 cm, containing air fluid level (Fig. 3). The brain MRI revealed multiple extra-axial air bubbles seen diffusely throughout the brain subarachnoid spaces thus indicating pneumocephalus (Fig. 4). As dural tears or CSF leaks absence was confirmed, and Nitrous Oxide (N_2O) was not used as an anesthetic agent, inverted bottle, ball valve, and nitrous oxide theories were excluded as causes for pneumocephalus, and because of the known gas-forming nature of *C. freundii* we suggest that gas forming bacteria may be the cause behind pneumocephalus for this case. MRI findings lead to the decision of removing the Ready-vac drain then pneumocephalus was treated conservatively by setting the patient's head in a 30° position, by O_2 supplementary therapy, and by complete bedrest. Patient's symptoms subsided after 24 h, without any kind of leaks at the surgical site or any progressive swelling. IV antibiotic administration continued for one month. Inflammatory biomarkers retained to normal limits within 3 weeks. After 6 weeks of the exploration operation, a follow up MRI was done and did not reveal any abnormal enhancement or any new collection. Patient's symptoms improved without developing further complications. The patient was satisfied with the medical treatment that he received after it was explained to him in each step thoroughly.

3. Discussion

Pneumocephalus is defined as a pathological collection of gas, usually air, within the cranial cavity.[1] It can be located intra-axially (epidural, subdural, subarachnoid) or extra-axially (parenchymal, intraventricular, intravascular) [17]. it is also categorized by severity into simple pneumocephalus, and tension pneumocephalus; which is a neurosurgical emergency, that requires urgent surgical intervention, represented by a mass effect upon the parenchyma of the brain and follows several conditions such as; traumatic head injuries, paranasal sinuses tumors, and spinal surgeries or procedures [18]. The incidence and mortality rates of pneumocephalus are conditional to the etiology and the causes behind this complication [19]. Furthermore, pneumocephalus can be divided by the duration of intracranial air accumulation into acute (<72 h) and delayed (>72 h) [20].

A literature review was conducted using the data bases PubMed, Web of Science, and Scopus. The keywords used were (Pneumocephalus) AND (Spinal surgery OR Discectomy OR Laminectomy OR Foraminotomy). Only cases reporting pneumocephalus occurring after spinal surgeries where included. Studies in languages other than English, studies lacking full text, audits, letters to editor, and irrelevant studies were excluded. A total of 24 cases were reviewed. We reviewed different aspects of each case including age, gender, type of the surgery,

Fig. 1. Sagittal (A) and axial (B) T2-weighted spine MRI showing multilevel degenerative disc disease, most significant at L3-L4 level compressing both descending L4 nerve root more on the left side with mild central canal stenosis, and mild to moderate bilateral foraminal stenosis at L3-L4 level compressing the left exiting L3 nerve root, with inflammatory changes noted in the extra foraminal part.

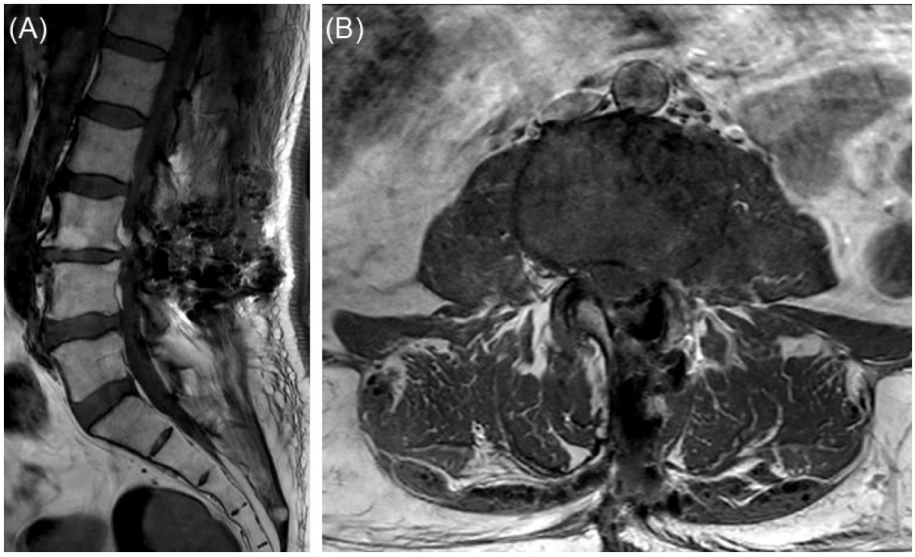

Fig. 2. Sagittal (A) and axial (B) T1-weighted spine MRI with contrast showing post-operative soft tissue changes with multiple small hypointense fossi suggesting gas bubbles at the level of L3-L4.

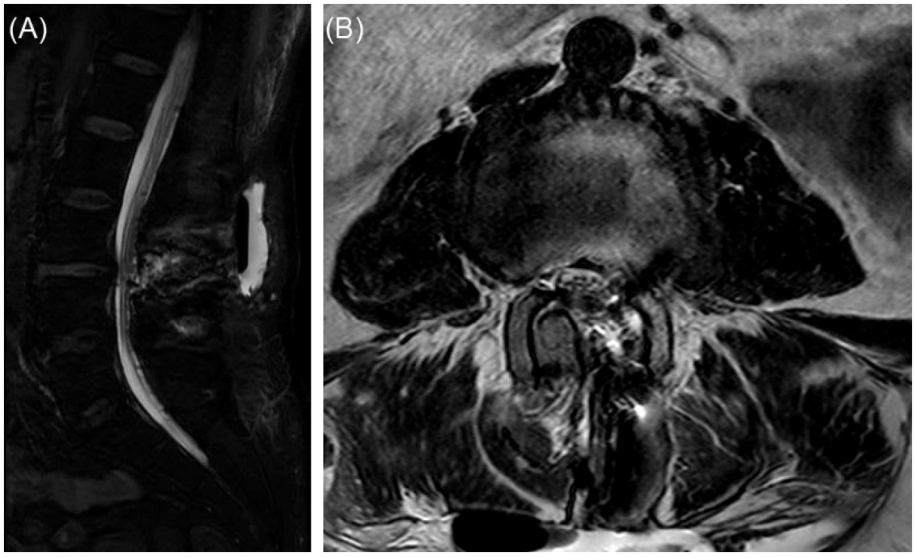

Fig. 3. Sagittal (A) and axial (B) T2-weighted lumbar spine MRI showing post-operative soft tissue changes with multiple gas bubbles and elongated thin-walled fluid collection overlying the paravertebral muscle at the site of the surgery measuring about 11.8 * 1.5 * 8 cm, containing air fluid level.

symptoms, method of conformation, treatment method, recovery time, and the presence of dural tears, drains, or CSF leaks. All those aspects were summarized and compared (Table 1). The literature review consisted of 24 patients who were diagnosed with pneumocephalus after going through a spinal surgery. The mean age of patients was 50.2 years, 15 of them were males and 9 of them were females.

Pneumocephalus is usually induced by a variety of causes including traumatic head injuries [5,6], gas forming bacteria leading to infection [7,8], brain or skull-based tumors and cranial surgeries [9], alongside the iatrogenic and idiopathic etiologies [10–12]. We have reviewed all reported cases of pneumocephalus occurring after spinal surgeries and most of them were after laminectomies, rod displacements, or discectomies as in our case.

PNC Patients present with many symptoms including headache, nausea, dizziness, altered consciousness, altered mental status, CSF rhinorrhea, vomiting, and convulsions [6,21–24].

Generally, there are 3 methods for the diagnosis of pneumocephalus. X-ray imaging can be used to diagnose pneumocephalus but is considered unreliable in the presence of Computed Tomography (CT) scanning and MRI as it requires at least 2 ml of intracranial air in order to detect it, consequently missing small quantities of air collections in the intracranial cavity [25].

CT imaging is the most reliable imaging technique for the diagnosis of pneumocephalus because of the low density of air presented on CT scans (approximately -1000 Hounsfield Units) and because they can even detect 0.55 ml of intracranial air [26]. There are three signs of pneumocephalus presented on CT scans, Firstly, Mount Fuji sign, which is described by a buildup of air in the frontal region of the cranial cavity adjoined by air separating the tips of the frontal lobe. This sign owes its name to its similarity to Mount Fuji of Japan and is considered a strong indicator of tension pneumocephalus [27]. Secondly, the air bubble sign, represented as multiple bubbles of air separated through subarachnoid cisterns [28]. And thirdly, the peaking sign, that is much like the Mount Fuji sign but differs from it as air does not cause frontal lobes

Fig. 4. Axial T2-weighted brain MRI showing multiple extra-axial air bubbles seen diffusely throughout the brain subarachnoid spaces indicating pneumocephalus.

separation [29].

MRI can be decisive in the diagnosis of pneumocephalus but is less sensitive than CT scans, in some cases pneumocephalus can be difficult to diagnose as air may be mistaken as blood products or flow voids and appears black on both T1-weighted and T2-weighted sequences [30–32]. All reported cases of the review stated CT scanning as the main method for the conformation of pneumocephalus, some used MRI, and X-ray imaging as a second method of conformation.

Dural tears are usually caused by trauma or following a surgery and may lead to CSF leakage [33]. Most of the published case reports about pneumocephalus after spinal surgeries have been associated with lumbar arthrodesis or similar lumbar surgeries causing a dural tear [34]. Dural tears, drains, or both were reported in the some of the reviewed cases. Some cases also mentioned the presence CSF leaks. Interestingly, as mentioned before, no CSF leaks or dural tears were detected in our case.

Many theories were suggested to elucidate the pathophysiology of pneumocephalus; Firstly, the inverted bottle theory that stands on the concept of negative pressure formation in the subarachnoid space due to CSF leakage and resulting in CSF being replaced by air until the intracranial pressure is equal to the atmospheric pressure [35]. Secondly, the ball valve theory suggesting that pneumocephalus is attributed to a dural defect acting as a one-way valve causing air to be trapped in the intracranial cavity [36]. Thirdly, Nitrous Oxide (N2O) theory that is commonly associated with anesthesia leading to tension pneumocephalus [37,38].

Pneumocephalus can be induced by gas forming bacteria and it is considered the fourth theory that explains such pathology [39,40]. A variety of microorganisms can induce pneumocephalus such as; *Citrobacter freundii*, *Clostridia*, *Bacteroides*, *Enterobacter*, *Escherichia coli*, *Peptostreptococcus*, *Klebsiella pneumonia*, and Pseudomonas [41–44].

Even though that the number of cases reporting pneumocephalus due to gas forming bacteria is scanty, all previously published studies of gas forming bacteria causing pneumocephalus were after a number of infections like subdural empyema, meningitis, pneumonia, or gastroenteritis [43–49]. Interestingly, after a thorough literature search in different databases, there have been no published cases reporting pneumocephalus occurring due to gas forming bacteria originating from a post-operative spinal wound infection as in our case.

In our case, we outweigh the gas forming bacteria to be the related hypothesis as we have ruled out the presence of CSF leaks or dural tears in our exploration surgery by the Valsalva maneuver, and because N_2O was not used in anesthesia, and after referring to the wound culture that shows a heavy growth of *C. freundii*, a microorganism known for its gas producing nature [50], we excluded the inverted bottle, the ball valve, and the nitrous oxide theories, and by that we present the first reported case of such etiology around the globe.

Pneumocephalus can be managed conservatively with bed rest, head elevation usually by 30°, oxygen supplementary therapy and many other methods [51–54]. Tension pneumocephalus is considered a neurosurgical emergency that usually requires urgent intracranial pressure relief by different surgical interventions such as craniotomy or twist-drill trephination [55–58]. In the case of gas forming bacteria leading to pneumocephalus, standardly, suitable antibiotics are administered to control the infection, then pneumocephalus can be treated conservatively by the previously mentioned methods [59]. Regarding the treatment and hospital outcomes of the included reviewed cases, most of cases were treated conservatively, and four cases were treated surgically. After performing head CTs to assure full recovery, patients were discharged.

4. Conclusion

In conclusion, pneumocephalus is considered a rare incidence after a spinal surgery and, therefore, needs a high index of suspicion to diagnose. But whenever a patient undergoes a spinal surgery and develops symptoms like unexplained headache or dizziness, this complication should be drawn to the attention; CT scan or brain MRI have to be ordered and if they suggest the presence of pneumocephalus an early proper management, mostly conservative, is imperative. In our case we add to the literature a supportive evidence for the theory that present the role of infection with gas forming bacteria in developing pneumocephalus after a spinal surgery wound infection and how it is managed afterward. A more extended research is needed to get more details about individual management of post-operative wound infections causing pneumocephalus; this will give a full comprehensive approach to deal with this problem if faced in the future.

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ijscr.2021.106342.

Source of funding

The author received no specific funding for this work.

Ethical approval

Ethical approval for case reports and case series are waived according to the ongoing regulations of Yarmouk University.

Consent

Written informed consent was obtained from the patient for publication of this case report and accompanying images. A copy of the written consent is available for review by the Editor-in Chief of this journal on request.

Author contributions

Osama J. Abu-Hamdiyah and Mohammad J. Athamneh and Sarah Al Sharie: Case report design and patient medical and surgical care.

Sarah Al Sharie and Sajeda Awadi and Almu'atasim Khamees: Wrote the initial draft of the case report.

Osama J. Abu-Hamdiyah and Sarah Al Sharie: revised the manuscript.

Osama J. Abu-Hamdiyah and Sarah Al Sharie have contributed

Table 1
Summary of cases characteristics of the literature review.

Study ID	Age	Sex	Time until developing PNC	Type of the surgery	Signs and symptoms	Method of conformation	Treatment	Recovery time	Related hypothesis	Dural tear/ drain	CSF leak
Akyüz et al. 2016 [60]	62	F	2 and a half months	L5 total laminectomy, L5-S1 bilateral foraminotomy and posterior fusion operation	Headache, fever	CT scan	Conservative	2 weeks	–	Dural tear	N
Ayberk et al. 2010 [61]	55	F	–	L4 total laminectomy and L3 and L5 partial laminectomy	Headache, nausea	CT scan	Conservative	–	Ball Valve	Drain	N
Denis et al. 2019 [62]	60	M	–	L2-L4 paraspinal muscle release and L2-L4 recalibration without laminectomy or discectomy	Headache, a tonic-clonic seizure	CT scan	Conservative	6 days	Inverted bottle	Dural tear	Y
Dhamija et al. 2011 [63]	63	F	24 h	laminectomy L3-L4 and L4-L5	Headache, confusion, restlessness, disorientation	CT scan	Conservative	5 days	Ball Valve	Dural tear	Y
Gader et al. 2019 [64]	40	F	6 h	L4 - L5 discal herniation's surgery	Generalized pallor with sweating, agitation, disorientation, 3 generalized tonic-clonic seizures	CT scan	Surgical	3 days	–	Dural tear	N
Gauthé et al. 2016 [65]	69	F	24 h	L2-L3 and L3-L4 fenestration and L2-L4 arthrodesis instrumented with pedicular screws	Tonic-clonic seizure	CT scan + MRI	Conservative	10 days	Inverted Bottle	Drain	N
Goodwin et al. 2016 [66]	21	M	7 days	C5-C6 ACDF	Fever, Altered mental status	CT scan	Surgical	–	–	Dural tear	Y
Gupta et al. 2019 [67]	70	M	1 month	Two-level decompressive laminoforaminotomy, L4-5 and L5-S1 levels	Headache	CT scan + MRI	Surgical	1 month	–	Dural tear + drain	Y
Jeremiah et al. 2018 [68]	66	M	1 month and 2 days	C3-C6 laminoplasty with bilateral C4-C5 and C5-C6 foraminotomies	Acute onset altered mental status, decreased mentation, lethargy, and a small 1 cm draining posterior cervical dehisced wound	CT scan	Surgical	5 days	–	Dural tear + drain	Y
Karavelioglu et al. 2014 [69]	56	M	24 h	Right L3, L4, L5 hemilaminectomy and discectomy, Medial facetectomy, placement of pedicle screws	Headache, nausea, dizziness	CT scan	Conservative	10 days	Inverted Bottle	Drain	N
Kieser et al. 2017 [70]	59	M	Two and a half months	Partial metal ware removal, with maintenance of sublaminar wires	Headache, confusion, and dysarthria	CT scan	Conservative	20 days	–	Dural tear + drain	Y
Kizilay et al. 2015 [71]	30	M	48 h	Bilateral hemilaminectomy	Headache, nausea, vomiting	CT scan	Conservative	6 days	Inverted Bottle	Dural tear	Y
Kozikowski et al. 2004 [11]	72	F	48 h	Lumbar puncture with an 18-gauge spinal needle	Headache, nausea, vomiting, short-term memory loss, nuchal rigidity, ataxic gait	CT Scan	Conservative	24 h	Inverted Bottle	–	N
Kumar et al. 2017 [72]	16	M	96 h	Spinal laminectomy for space occupying lesion (SOL)	2 generalized tonic–clonic seizures	CT scan	Conservative	10 days	Inverted Bottle	–	N
Lin et al. 2019 [73]	63	M	Immediately after operation	L3-L4 discectomy	Generalized tonic-clonic	CT scan	Conservative	24 h	Inverted bottle	Dural tear	Y
Nowak et al. 2011 [74]	12	F	14 h	Single rod instrumentation with transpedicular screws at the Th2 and Th4	Headache	CT scan	Surgical	3 weeks	Inverted Bottle	Dural tear + drain	Y
	25	M	72 h			CT scan	Conservative	3 days	Ball Valve		N

(*continued on next page*)

Table 1 (*continued*)

Study ID	Age	Sex	Time until developing PNC	Type of the surgery	Signs and symptoms	Method of conformation	Treatment	Recovery time	Related hypothesis	Dural tear/ drain	CSF leak
Özdemir 2017 [75]				Spinal tumor removal at level of L3	Headache, nausea, vomiting					Dural tear	
Ozturk et al. 2006 [76]	23	F	6 h	Rod placement for thoracolumbar scoliosis with posterior instrumentation and fusion	Headache, nausea, deterioration	CT Scan + MRI	Conservative	2 weeks	Inverted Bottle	Dural tear + drain	N
Pirris et al. 2013 [77]	65	M	–	L4-5 discectomy, and extension of fusion to L5 with pedicle screws and interbody cage placement	Diplopia	CT scan	Conservative	24 h	Inverted Bottle	–	N
Sasaki et al. 2010 [78]	76	M	48 h	Kurokawa's procedure	Headache, nausea, convulsion	CT scan + X-ray	Conservative	2 weeks	Inverted Bottle	Dural tear	Y
Turgut and Akyuz 2007 [79]	47	M	48 h	L4 right hemilaminectomy and discectomy	Headache, photophobia	CT scan	Conservative	13 days	Ball Valve	Dural tear + drain	N
Yilmaz et al. 2015 [80]	57	F	48 h	Revision surgery of posterior laminectomies (T11-L1) and posterior spinal fusion with bilateral transpedicular instrumentation from T10 to S1	Headache, somnolence, left hemiparesis	CT scan	Conservative	–	–	Drain	Y
Yun et al. 2010 [81]	59	M	24 h	L4 Subtotal laminectomy, L5 total laminectomy, and a pedicle screw fixation	Headache, dizziness	CT scan	Conservative	2 weeks	Inverted Bottle	Dural tear	N
Yun feng Han et al. 2017 [82]	40	M	–	Atlanto-Occipital Decompression With Dural Plasty surgery	Headache, oculomotor nerve palsy	CT scan	Conservative	4 days	–	Dural tear	N
Current Case	63	M	24 h	L3-L4 left side decompression with left L4 foraminotomy	Headache, nausea, dizziness	MRI	Conservative	2 days	Gas forming bacteria	Drain	N

(F): Female, (M): Male, (-): No Information, (Y): Yes, (N): No, ACDF: Anterior Cervical Discectomy and Fusion, CT: Computed Tomography, MRI: Magnetic Resonance Imaging.

equally to this work.

All authors read and approved the content of the submitted case report.

Research registration

This case report is not eligible for obtaining a research registry since it only contains a report of a known entity with no new surgical or medical interventions.

Guarantor

Sarah Al Sharie.

Availability of data and materials

All data related to the outcome are included in the manuscript. Mentioned video can be found in the supplementary materials.

Provenance and peer review

Not commissioned, externally peer-reviewed.

Declaration of competing interest

The authors declare no conflict of interest.

Acknowledgments

We want to thank our patient for consenting to the publication of the article.

References

[1] C.M. Schirmer, C.B. Heilman, A. Bhardwaj, Pneumocephalus: case illustrations and review, Neurocrit. Care. 13 (1) (2010) 152–158.
[2] Wolff EJMMW, in: Luftansammlung im rechten seitenventrikel des gehirns (Pneumozephalus) 61, 1914, p. 899.
[3] A.-L. Thomas, Du pneumatocele du crane: A. Delahaye, 1865.
[4] Z. Kizilay, A. Yilmaz, O. Ismailoglu, The effect of the previous craniectomy on the formation of tension pneumocephalus after spinal dural injury: a case report and review of the literature, Interdiscip. Neurosurg. 8 (2017) 60–63.
[5] A.L. Aguilar-Shea, N. Mañas-Gallardo, E. Romero-Pisonero, Post-traumatic pneumocephalus, Int. J. Emerg. Med. 2 (2) (2009) 129–130.
[6] P. Pillai, R. Sharma, L. MacKenzie, E.F. Reilly, P.R. Beery 2nd, T.J. Papadimos, et al., Traumatic tension pneumocephalus - two cases and comprehensive review of literature, Int. J. Crit. Illn. Inj. Sci. 7 (1) (2017) 58–64.
[7] A.S. Ansari, B.B. Dennis, D. Shah, W. Baah, An unusual case of infective pneumocephalus: case report of pneumocephalus exacerbated by continuous positive airway pressure, BMC Emerg. Med. 18 (1) (2018) 2.
[8] H.S. Kim, S.W. Kim, S.H. Kim, Spontaneous pneumocephalus caused by pneumococcal meningitis, J. Korean Neurosurg. Soc. 53 (4) (2013) 249–251.
[9] K. Kawajiri, Y. Matsuoka, K. Hayazaki, Brain tumors complicated by pneumocephalus following cerebrospinal fluid shunting–two case reports, Neurol. Med. Chir. 34 (1) (1994) 10–14.
[10] Z. Ihab, Pneumocephalus after surgical evacuation of chronic subdural hematoma: is it a serious complication? Asian J. Neurosurg. 7 (2) (2012) 66–74.
[11] G.P. Kozikowski, S.P. Cohen, Lumbar puncture associated with pneumocephalus: report of a case, Anesth. Analg. 98 (2) (2004) 524–526, table of contents.
[12] L.H. Pitts, C.B. Wilson, H.H. Dedo, R. Weyand, Pneumocephalus following ventriculoperitoneal shunt. Case report, J. Neurosurg. 43 (5) (1975) 631–633.
[13] A. Kumar, N.F. Maartens, A.H. Kaye, Evaluation of the use of BioGlue in neurosurgical procedures, J. Clin. Neurosci. 10 (6) (2003) 661–664.

[14] R. Nasser, S. Yadla, M.G. Maltenfort, J.S. Harrop, D.G. Anderson, A.R. Vaccaro, et al., Complications in spine surgery, J. Neurosurg. Spine 13 (2) (2010) 144–157.
[15] H.M. Schrijver, H.W. Berendse, Pneumocephalus by Valsalva's maneuver, Neurology 60 (2) (2003) 345.
[16] R.A. Agha, T. Franchi, C. Sohrabi, G. Mathew, A. Kerwan, The SCARE 2020 guideline: updating consensus surgical CAse REport (SCARE) guidelines, Int. J. Surg. 84 (2020) 226–230.
[17] M.A. Banu, O. Szentirmai, L. Mascarenhas, A.A. Salek, V.K. Anand, T.H. Schwartz, Pneumocephalus patterns following endonasal endoscopic skull base surgery as predictors of postoperative CSF leaks, J. Neurosurg. 121 (4) (2014) 961–975.
[18] J.J. Harvey, S.C. Harvey, A. Belli, Tension pneumocephalus: the neurosurgical emergency equivalent of tension pneumothorax, BJR Case Rep. 2 (2) (2016), 20150127.
[19] J.B. Jacobs, M.S. Persky, Traumatic pneumocephalus, Laryngoscope 90 (3) (1980) 515–521.
[20] V.K. Kankane, G. Jaiswal, T.K. Gupta, Posttraumatic delayed tension pneumocephalus: rare case with review of literature, Asian J. Neurosurg. 11 (4) (2016) 343–347.
[21] L.S. Governale, W.B. Gormley, L.S. Aglio, CHAPTER 20 - Anesthetic and intensive care management of the patient with a meningioma, in: M.N. Pamir, P.M. Black, R. Fahlbusch (Eds.), Meningiomas, W.B. Saunders, Philadelphia, 2010, pp. 297–309.
[22] H. Prüss, R. Klingebiel, M. Endres, Tension pneumocephalus with diplegia and deterioration of consciousness, Case Rep. Neurol. 3 (1) (2011) 48–49.
[23] A.J. Scumpia, G. Lai, M.I. Rodriguez, D.M. Aronovich, G. Dubrovich, S. Jimsheleishvili, Altered mental status secondary to extensive pneumocephalus, Clin. Pract. Cases Emerg. Med. 1 (4) (2017) 423–424.
[24] A. Tawfiq Abdulmohsen, Abdulrahman A. Mody, Delayed posttraumatic tension pneumocephalus: a rare case report and review of the literature, Dr Sulaiman Al Habib Med. J. 2 (1) (2020) 1–3.
[25] P. Tran, E.J. Reed, F. Hahn, J.E. Lambrecht, J.C. McClay, M.F. Omojola, Incidence, radiographical features, and proposed mechanism for pneumocephalus from intravenous injection of air, West J. Emerg. Med 11 (2) (2010) 180–185.
[26] Y.P. Chan, C.Y. Yau, R.R. Lewis, M.T. Kinirons, Acute confusion secondary to pneumocephalus in an elderly patient, Age Ageing 29 (4) (2000) 365–367.
[27] S.J. Michel, The Mount Fuji sign, Radiology 232 (2) (2004) 449–450.
[28] M Birat M Mubashir B Rizwan S. Faiq A Case of Diffuse Pneumocephalus With Air Bubble Sign.
[29] Y. Ishiwata, K. Fujitsu, T. Sekino, H. Fujino, T. Kubokura, K. Tsubone, et al., Subdural tension pneumocephalus following surgery for chronic subdural hematoma, J. Neurosurg. 68 (1) (1988) 58–61.
[30] C.C. Ani, B.O. Ismaila, Tension pneumoventricle: a report of two cases, Niger. J. Clin. Pract. 19 (4) (2016) 559–562.
[31] C.B. Dabdoub, G. Salas, N. Silveira Edo, C.F. Dabdoub, Review of the management of pneumocephalus, Surg. Neurol. Int. 6 (2015) 155.
[32] S.J. Yoon, G.S. Oh, S.J. Lee, B.R. Lee, J.U. Chun, I.K. Yu, Pneumocephalus in patients with orthostatic headache, J. Clin. Neurol. 4 (2) (2008) 89–93.
[33] J.C. Wang, H.H. Bohlman, K.D. Riew, Dural tears secondary to operations on the lumbar spine. Management and results after a two-year-minimum follow-up of eighty-eight patients, J. Bone Joint Surg. Am. 80 (12) (1998) 1728–1732.
[34] K.L. Chaichana, G. Pradilla, T.F. Witham, Z.L. Gokaslan, A. Bydon, The clinical significance of pneumorachis: a case report and review of the literature, J. Trauma 68 (3) (2010) 736–744.
[35] M. Horowitz, Intracranial Pneumocœle: an unusual complication following mastoid surgery, J. Laryngol. Otol. 78 (2) (1964) 128–134.
[36] W.E. Dandy, Pneumocephalus (intracranial penumatocele or aerocele), Arch. Surg. 12 (5) (1926) 949–982.
[37] H.J. Theilen, A.R. Heller, R.J. Litz, Nitrous oxide-induced tension pneumocephalus after thoracic spinal cord surgery: a case report, J. Neurosurg. Anesthesiol. 20 (3) (2008).
[38] J.F. Raggio, A.S. Fleischer, Y.F. Sung, J.C. Hoffman, Expanding pneumocephalus due to nitrous oxide anesthesia: case report, Neurosurgery 4 (3) (1979) 261–263.
[39] A. Penrose-Stevens, A. Ibrahim, R.M. Redfern, Localized pneumocephalus caused by Clostridium perfringens meningitis, Br. J. Neurosurg. 13 (1) (1999) 85–86.
[40] M.A. Klein, J.K. Kelly, I.G. Jacobs, Diffuse pneumocephalus from Clostridium perfringens meningitis: CT findings, AJNR Am. J. Neuroradiol. 10 (2) (1989) 447.
[41] J.N. Alviedo, B.G. Sood, J.V. Aranda, C. Becker, Diffuse pneumocephalus in neonatal citrobacter meningitis, Pediatrics 118 (5) (2006) e1576–e1579.
[42] B. Azar-Kia, M. Sarwar, S. Batnitzky, M. Schechter, Radiology of intracranial gas, Am. J. Roentgenol. Radium Ther. Nucl. Med. 124 (2) (1975) 315–323.
[43] M.J. Hasan, R. Rabbani, Extensive pneumocephalus caused by multidrug-resistant Klebsiella pneumoniae, World Neurosurg. 137 (2020) 29–30.
[44] A.A. Adamides, T. Goldschlager, S.J. Tulloch, J.H. McMahon, Pneumocephalus from gas-forming Escherichia coli subdural empyema, Br. J. Neurosurg. 21 (3) (2007) 299–300.
[45] R. Redhu, A. Shah, M. Jadhav, A. Goel, Spontaneous tension pneumocephalus in a patient with subdural empyema, J. Clin. Neurosci. 18 (8) (2011) 1123–1124.
[46] M.S. Parmar, Pneumocephalus associated with Bacteroides fragilis meningitis, J. Postgrad. Med. 50 (4) (2004) 272–273.
[47] M. Goyal, R. Sharma, M. Berry, Diffuse pneumocephalus due to meningitis: CT findings, Pediatr. Radiol. 26 (4) (1996) 278–279.
[48] P.C. Liliang, K.S. Hung, C.H. Cheng, H.J. Chen, I. Ohta, C.C. Lui, Rapid gas-forming brain abscess due to Klebsiella pneumoniae. Case illustration, J. Neurosurg. 91 (6) (1999) 1060.
[49] P. Sreejith, V. Vishad, J.M. Pappachan, D.C. Laly, R. Jayaprakash, V.T. Ranjith, Pneumocephalus as a complication of multidrug-resistant Klebsiella pneumoniae meningitis, Eur. J. Intern. Med. 19 (2) (2008) 140–142.
[50] D. Borenshtein, D.B. Schauer, The Genus Citrobacter, in: M. Dworkin, S. Falkow, E. Rosenberg, K.-H. Schleifer, E. Stackebrandt (Eds.), The Prokaryotes: a Handbook on the Biology of Bacteria Volume 6: Proteobacteria: Gamma Subclass, New York, NY, Springer, New York, 2006, pp. 90–98.
[51] K.M. Anandpara, Y. Aswani, P. Hira, The Mount Fuji sign, Clin. Med. 15 (6) (2015) 596.
[52] F. Dexter, D.K. Reasoner, Theoretical assessment of normobaric oxygen therapy to treat pneumocephalus, Anesthesiology 84 (2) (1996) 442–447.
[53] E. Pishbin, N. Azarfardian, M. Salarirad, B. Ganjeifar, Spontaneous nontraumatic pneumocephalus: a case report, Iran Red Crescent Med. J. 17 (7) (2015), e23920.
[54] A.S. Rathore, G.D. Satyarthee, A.K. Mahapatra, Post-traumatic tension pneumocephalus: series of four patients and review of the literature, Turk. Neurosurg. 26 (2) (2016) 302–305.
[55] A. Ehud, S. Jatin, B. Robert, C. Graziano, Tension pneumocephalus: treatment with controlled decompression via a closed water-seal drainage system, J. Neurosurg. 74 (1) (1991) 139–142.
[56] L.M. L'Hommedieu, M.W. Dingeldein, K.L. Tomei, B.J. Kilbane, Acute Management of Tension Pneumocephalus in a pediatric patient: a case report, J. Emerg. Med. 54 (1) (2018) 112–115.
[57] K. Machetanz, F. Leuze, K. Mounts, L. Trakolis, I. Gugel, F. Grimm, et al., Occurrence and management of postoperative pneumocephalus using the semi-sitting position in vestibular schwannoma surgery, Acta Neurochir. 162 (11) (2020) 2629–2636.
[58] G.G. Pulickal, Y.Y. Sitoh, W.H. Ng, Tension pneumocephalus, Singap. Med. J. 55 (3) (2014) e46–e48.
[59] H. Prabhakar, P.K. Bithal, Chapter 5 - Pneumocephalus, in: H. Prabhakar (Ed.), Complications in Neuroanesthesia, Academic Press, San Diego, 2016, pp. 35–39.
[60] O. Akyüz, D. Gökpinar, E. Aydin, S. Aydin, M. Duymus, G. Çigsar, et al., Pneumocephalus and pneumorrhachis after spinal surgery, Pol. J. Radiol. 81 (2016) 34–35.
[61] G. Ayberk, M.E. Yaman, M.F. Ozveren, Symptomatic spontaneous pneumocephalus after spinal fusion for spondylolisthesis, J. Clin. Neurosci. 17 (7) (2010) 934–936.
[62] B. Denis, Ledent MJAAB, in: Pneumocephalus as a Cause of Seizure After Lumbar Spine Surgery. A Case Report and Review 70, 2019, pp. 43–47, 1.
[63] B. Dhamija, A. Saxena, Pneumocephalus - a possible cause of post-spinal surgery confusion, J. R. Soc. Med. 104 (2) (2011) 81–83.
[64] G. Gader, N. Karmeni, I. Ben Saïd, H. Jemel, Symptomatic pneumocephalus: a rare complication of discal herniation's surgery, J. Spinal Cord Med. 42 (6) (2019) 810–812.
[65] R. Gauthé, C. Latrobe, C. Damade, E. Foulongne, X. Roussignol, M. Ould-Slimane, Symptomatic compressive pneumocephalus following lumbar decompression surgery, Orthop. Traumatol. Surg. Res. 102 (2) (2016) 251–253.
[66] C.R. Goodwin, C.E. Boone, J. Pendleton, B.D. Elder, Z. Wei, W. Hsu, et al., Pneumocephalus leading to the diagnosis of cerebrospinal fluid leak and esophageal perforation after cervical spine surgery, J. Clin. Neurosci. 26 (2016) 141–142.
[67] M. Gupta, K.K. Kumar Varma, Chhabra H. Singh, A rare case of concomitant pneumocephalus and pneumorachis after lumbar spine surgery with late presenting dural leak, Spinal Cord Ser. Cases 5 (2019) 86.
[68] J. Maupin, Z. Burrow, C. Shirazi, S. Vallurupalli, Tension pneumocephalus after cervical spine surgery: a case report with review of the literature, J. Neurol. Surg. Rep. 79 (4) (2018) e88–e92.
[69] E. Karavelioglu, O. Eser, A. Haktanir, Pneumocephalus and pneumorrhachis after spinal surgery: case report and review of the literature, Neurol. Med. Chir. 54 (5) (2014) 405–407.
[70] D.C. Kieser, D.T. Cawley, C. Tavolaro, T. Cloche, C. Roscop, L. Boissiere, et al., Delayed post-operative tension pneumocephalus and pneumorrhachis, Eur. Spine J. 27 (1) (2018) 231–235.
[71] Z. Kizilay, A. Yilmaz, O. Ismailoglu, Symptomatic pneumocephalus after lumbar disc surgery: a case report, Open Access Maced. J. Med. Sci. 3 (1) (2015) 143–145.
[72] B. Kumar, C. Banerjee, S.N. Ghosh, Pneumocephalus following dorsal laminectomy: an unusual complication, Asian J. Neurosurg. 12 (4) (2017) 772–773.
[73] C.H. Lin, S.M. Lin, T.Y. Lan, J.L. Pao, Pneumocephalus with conscious disturbance after full endoscopic lumbar diskectomy, World Neurosurg. 131 (2019) 112–115.
[74] R. Nowak, M. Maliszewski, L. Krawczyk, Intracranial subdural hematoma and pneumocephalus after spinal instrumentation of myelodysplastic scoliosis, J. Pediatr. Orthop. B 20 (1) (2011) 41–45.
[75] U. Özdemir, A rare complication of lumbar spinal surgery: pneumocephalus, Korean J. Neurotrauma 13 (2) (2017) 176–179.
[76] E. Ozturk, M. Kantarci, K. Karaman, C.C. Basekim, E. Kizilkaya, Diffuse pneumocephalus associated with infratentorial and supratentorial hemorrhages as a complication of spinal surgery, Acta Radiol. 47 (5) (2006) 497–500.
[77] S.M. Pirris, E.W. Nottmeier, Symptomatic pneumocephalus associated with lumbar dural tear and reverse trendelenburg positioning: a case report and review of the literature, in: Case Reports in Neurological Medicine, 2013, p. 792168.
[78] K. Sasaki, T. Matsumoto, T. Mizuno, S. Ikuta, T. Akisue, H. Fujioka, et al., Pneumocephalus associated with cerebrospinal fluid fistula as a complication of spinal surgery: a case report, Case Rep. Med. 2010 (2010), 328103.
[79] M. Turgut, O. Akyüz, Symptomatic tension pneumocephalus: an unusual post-operative complication of posterior spinal surgery, J. Clin. Neurosci. 14 (7) (2007) 666–668.

[80] B. Yilmaz, S. Isik, M. Eksi, E.E. Eksi, A. Akakin, Z.O. Toktas, et al., Multiple hemorrhages in brain after spine surgery supra- and infra-tentorial components together, J. Craniovertebral Junct. Spine 6 (4) (2015) 223–226.
[81] J.H. Yun, Y.J. Kim, D.S. Yoo, J.H. Ko, Diffuse pneumocephalus : a rare complication of spinal surgery, J. Korean Neurosurg. Soc. 48 (3) (2010) 288–290.
[82] Y. Han, J. Sun, Z. Wang, Pneumocephalus-induced oculomotor nerve palsy after atlanto-occipital decompression with dural plasty, J. Craniofac. Surg. 28 (6) (2017) e543–e545.