Does pneumocephalus affect the application of the pediatric brain injury guidelines?

Anastasia M. Kahan, MD, Kimble W. Mahler, BS, River Stevenson, BA, Sommer L. Glasgow, MS, Christopher E. Clinker, MD, Jack H. Scaife, MD, Aidyn K. Eldredge, BA, Hsuan-Yu Wan, PhD, Annika B. Kay, PA-C, Vijay M. Ravindra, MD, MSPH, Zachary J. Kastenberg, MD, Robert A. Swendiman, MD, *and* **Katie W. Russell, MD**, *Salt Lake City, Utah*

BACKGROUND: The pediatric brain injury guidelines (kBIG) are a newly established clinical triage tool for managing pediatric traumatic brain injuries (TBIs). However, the kBIG classification does not include pneumocephalus, raising uncertainty about how to classify and manage patients with this finding. In this study, we sought to determine the risk of neurosurgical intervention, injury progression, and intensive care unit (ICU) admission in children with low- to moderate-risk TBIs and pneumocephalus.

METHODS: We conducted a retrospective cohort study of pediatric trauma patients (younger than 18 years) after blunt mechanism trauma with an Abbreviated Injury Scale head score of >1 treated at a level 1 pediatric trauma center between January 2018 and April 2024. We applied the kBIG criteria to this cohort and excluded kBIG3 patients from the analysis. Demographics, presence of pneumocephalus, injury type, repeat head computed tomography, and neurosurgical intervention were extracted. Progression was defined as new or worsening bleed on repeat computed tomography. Neurosurgical treatment was defined as any operative intervention performed by a neurosurgeon.

RESULTS: We included 832 pediatric trauma patients classified as kBIG0, kBIG1, and kBIG2 TBIs. Pneumocephalus was present in 143 patients (18.1%). There was no significant difference in neurosurgical intervention rates (0.2% vs. 0.7%; $p = 0.5$), injury progression (12% vs. 9.8%; $p = 0.7$), ICU admission 8.1% vs. 9.7%; $p = 0.5$), or ICU length of stay (1 [1–1] vs. 1 [1–1], $p = 0.7$) between patients with and without pneumocephalus.

CONCLUSION: In this study, we found that pneumocephalus is an uncommon finding in low- to moderate-risk blunt head injuries. Patients with pneumocephalus had no increased risk of neurosurgical treatment or injury progression compared with those without. These findings suggest that pneumocephalus does not confer additional clinical risk and may be safely excluded from consideration when applying the kBIG classification to guide management in otherwise low- to moderate-risk patients. (*J Trauma Acute Care Surg.* 2026;00: 00–00.

LEVEL OF EVIDENCE: Retrospective Cohort Study; Level V.

KEY WORDS: Pneumocephalus; pediatric traumatic brain injury.

Pediatric traumatic brain injury (TBI) is a common indication for emergency department evaluation and treatment in children after blunt mechanism traumatic injury.[1] Air inside the cranial cavity,[2] or pneumocephalus, after these injuries is uncommon but clinically significant and occurs in approximately 1% of pediatric TBI cases.[3] Pneumocephalus after TBI with skull fracture in children is most commonly treated conservatively with observation, and neurosurgical intervention is often reserved only for patients with clinical or radiographic indications of tension pneumocephalus or persistent complications.[4,5] However, controversy remains regarding timing and necessity of surgical intervention. This is particularly true in cases where the clinical significance of pneumocephalus is unclear such as in pediatric patients with a mild TBI.[4,5] These patients are often hospitalized but rarely require neurosurgical intervention.[4,6] Currently, there are no standardized protocols in place for monitoring or escalating care for these patients, and management decisions are made on a case-by-case basis in conjunction with neurosurgeons.

The pediatric brain injury guidelines (kBIG) are a newly developed clinical triage tool designed to safely and effectively manage pediatric TBI.[7] The kBIG stratifies patients into low-, moderate-, and high-risk categories using clinical presentation data and initial computed tomography (CT) head findings. The kBIG has been shown to be safe in the management and triage of low- to moderate-risk pediatric TBI, and incorporation of pneumocephalus into the guideline is necessary for widespread adoption and success. However, the original kBIG did not specifically include pneumocephalus in its classification schema. As a result, there is no consensus on how to accurately classify and manage pediatric patients with pneumocephalus within the kBIG framework.

Submitted: September 27, 2025, Revised: November 10, 2025, Accepted: November 29, 2025, Published online: January 29, 2026.

From the Division of Pediatric Surgery, Department of Surgery (A.M.K., K.W.M., R.S., S.L.G., C.E.C., J.H.S., A.K.E., Z.J.K., R.A.S., K.W.R.), University of Utah; Department of Finance (H.-Y.W., A.B.K.), Intermountain Primary Children's Hospital; and Division of Pediatric Neurosurgery, Department of Neurosurgery (V.M.R.), University of Utah, Salt Lake City, Utah.

This study was presented at the 11th annual Pediatric Trauma Society (PTS) meeting November 5–8, 2026, in Austin, Texas.

Supplemental digital content is available for this article. Direct URL citations appear in the printed text, and links to the digital files are provided in the HTML text of this article on the journal's Web site (www.jtrauma.com).

Address for correspondence: Anastasia M. Kahan, MD, Division of Pediatric Surgery, Department of Surgery, University of Utah, 100 N Mario Capecchi Dr, Ste 3800, Salt Lake City, UT 84113; email: Sasha.kahan@hsc.utah.edu.

DOI: 10.1097/TA.0000000000004909

In this study, we applied kBIG to low- to moderate-risk TBI patients with pneumocephalus. Our primary outcome was the risk of neurosurgical intervention, progression on CT, and intensive care unit (ICU) admission in children with low- to moderate-risk TBIs and pneumocephalus. Our objective was to assess whether the existing kBIG framework adequately captures the risk profile of this subgroup and to inform future refinements of kBIG protocols. In doing so, we aim to expand kBIG to apply to all children with TBI, including those with pneumocephalus.

PATIENTS AND METHODS

Study Design and Data Source

Following approval from the institutional review board, we conducted a retrospective study of pediatric trauma patients (younger than 18 years) with the presence of any skull fracture and a TBI (defined as Abbreviated Injury Scale head score of >1) treated at our Level 1 pediatric trauma center between January 2018 and April 2024. Trauma registry data extraction and detailed chart review were used to then apply the kBIG criteria to this cohort. Low-risk and moderate-risk patients as well as kBIG0, kBIG1, and kBIG2 patients were included. All kBIG3 patients were excluded from the analysis (Fig. 1).

Presence of pneumocephalus on initial head CT was identified based on radiologist interpretation documented in the official CT report; volumetric quantification was not performed, as our intent was to reflect real-world clinical reporting and decision-making practices. Patients were grouped into positive or negative pneumocephalus cohorts by initial head CT findings. Pneumocephalus information was further extracted including sinus fracture information, open skull fractures, amount of pneumocephalus present, and location of the pneumocephalus. Pneumocephalus quantification was done through objective measurement of the number of foci of gas seen on head CT. Progression of initial intracranial hemorrhage (ICH) was defined as the development of a new or worsening ICH on repeat head CT. Neurosurgical treatment was defined as any operative intervention performed by a neurosurgeon. This included craniotomy, craniectomy, intraventricular drain (IVD), or bolt placement. Patients with polytrauma (defined as Abbreviated Injury Scale score of >2 in any other body region) were excluded from ICU, ventilator, and length of stay analyses.

Statistical Analysis

Data analysis was performed using R software (version 4.5.1; R Foundation for Statistical Computing, Vienna, Austria). Descriptive statistics were used to summarize patient demographics, baseline characteristics, and clinical outcomes. Continuous variables were presented as medians with interquartile ranges and analyzed using Mann-Whitney *U* test. Categorical variables were expressed as frequencies and percentages and analyzed using the χ^2 test or Fisher's exact test. To examine the association between pneumocephalus and clinical outcomes, univariate analyses were conducted to compare patients with and without pneumocephalus. Statistical significance was defined as a two-sided p value <0.05 (Supplemental Digital Content, Supplementary Data 1, http://links.lww.com/TA/E131).

RESULTS

A total of 832 pediatric trauma patients with skull fracture and TBI were identified. This cohort was classified into kBIG0 (317, 40.0%), kBIG1 (188, 23.7%), and kBIG2 TBIs (327, 41.3%). Pneumocephalus was present in 143 patients (18.1%) (Table 1). There was no significant difference between the pneumocephalus and nonpneumocephalus cohorts in terms of Glasgow Coma Scale (GCS), pupillary response on initial examination, or type of ICH found on initial head CT. Patients with pneumocephalus were more likely to have a higher Injury Severity Score and be transferred.

In looking at the primary outcome of clinically significant progression between groups, there was no statistically significant difference in bleed progression (12% vs. 9.8%; $p = 0.7$) between groups (Table 2). While pneumocephalus patients were more likely to get repeat head CT and neurosurgical consultation, they were not more likely to have a progression on the repeat scan. There was no significant difference in neurosurgical

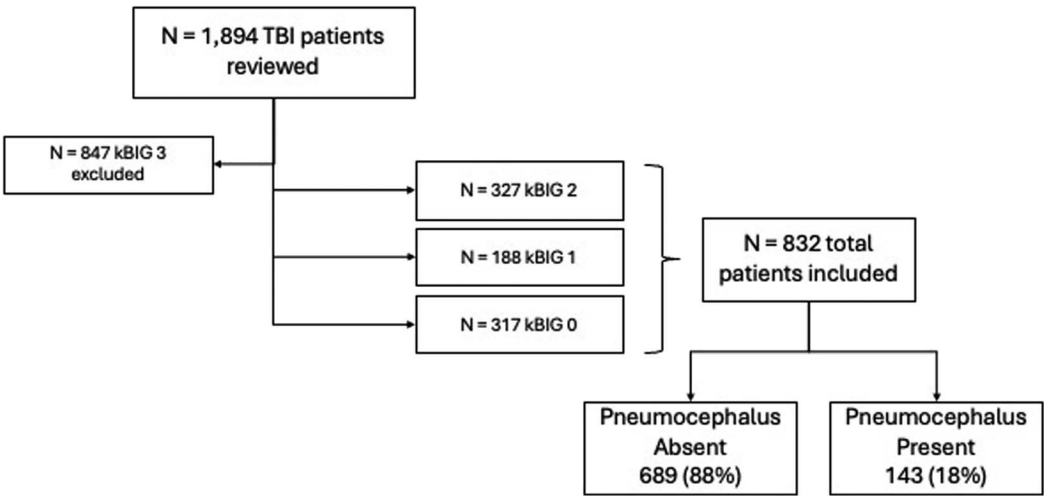

Figure 1. Cohort identification and inclusion flow diagram.

TABLE 1. Demographic Characteristics of Patients With and Without Pneumocephalus

	Pneumocephalus Absent n = 689 (88%)	Pneumocephalus Present n = 143 (18%)	*p*
ED GCS			0.082[a]
13	15 (2.2%)	8 (5.6%)	
14	62 (9.0%)	14 (9.8%)	
15	612 (89%)	121 (85%)	
Pupillary response			0.4[b]
Both	407 (100%)	66 (99%)	
None	0 (0.0%)	1 (1.5%)*	
One	1 (0.2%)**	0 (0%)	
Intracerebral hematoma/hemorrhage			0.5[b]
EDH	133 (33%)	17 (25%)	
IPH	12 (2.9%)	3 (4.5%)	
SAH	51 (12%)	7 (10%)	
SDH	213 (52%)	40 (60%)	
Isolated TBI	670 (97%)	141 (99%)	0.6[b]
ISS	9.0 (6.0–10.0)	10.0 (10.0–14.0)	**<0.001**[c]
Transferred	482 (70%)	118 (83%)	**0.002**[a]
kBIG categorization			0.2[a]
0	253 (37%)	64 (45%)	
1	157 (23%)	31 (22%)	
2	279 (40%)	48 (34%)	

*Patient with bilateral congenital cataracts and blindness.
**Patient with right orbital laceration and swelling prohibiting examination.
Data were analyzed using [a]χ^2 test, [b]Fisher's exact test, and [c]Mann-Whitney *U* test.
ED, emergency department; EDH, Epidural Hematoma; IPH, Intraparenchymal Hemorrhage; ISS, Injury Severity Score; SAH, Subarachnoid Hemorrhage; SDH, Subdural Hematoma.

intervention (0.3% vs. 0.7%; $p = 0.5$) between the pneumocephalus and nonpneumocephalus patients, with two patients in the pneumocephalus absent group and only one patient in the pneumocephalus present group undergoing craniotomy. All three of these patients were kBIG2 classification. Two patients required intubation because of GCS deterioration, and these two children were both kBIG2 classification. Additionally, there was no difference in ICU admission for the isolated TBI patients between groups (8.1% vs. 9.7%; $p = 0.5$), and the median ICU length of stay was identical between groups (1 [1–1] vs. 1 [1–1], $p = 0.5$). There was one child in the pneumocephalus group with frontal skull base fracture who was readmitted 2 weeks after discharge from the hospital with bacterial meningitis and was successfully treated. No other patients developed cerebrospinal fluid (CSF) leak on follow-up review.

Lastly, we analyzed skull and sinus fracture patterns in the pneumocephalus cohort (Table 3). The majority of pneumocephalus patients had an open skull fracture and/or a sinus fracture. The most

TABLE 2. Clinical Outcomes in Low-Risk Patients by Pneumocephalus on Presentation Head CT

	Pneumocephalus Absent n = 689 (88%)	Pneumocephalus Present n = 143 (18%)	*p*
Repeat head CT	183 (27%)	51 (36%)	**0.028**[a]
Progression on repeat head CT	22 (12%)	5 (9.8%)	0.7[a]
Neurosurgical consultation	536 (78%)	127 (89%)	**0.003**[a]
Neurosurgical intervention	2 (0.3%)	1 (0.7%)	0.5[b]
Craniectomy	0 (0%)	0 (0%)	
Craniotomy	2 (100%)	1 (100%)	
Intracranial Pressure (ICP) monitor	0 (0%)	0 (0%)	
ICU admission	56 (8.1%)	14 (9.7%)	0.5[a]
ICU median LOS (days)	1.00 (1.00–1.00)	1.00 (1.00–1.00)	0.7[c]
Ventilator required	0 (0%)	2 (14%)	0.9[b]
LOS (days)	1.00 (1.00–2.00)	2.00 (1.00–3.00)	**<0.001**[c]
ED bounce back	8 (1.2%)	2 (1.4%)	0.7[b]

Data were analyzed using [a]χ^2 test, [b]Fisher's exact test, and [c]Mann-Whitney *U* test.
LOS, length of stay. Bolded values represent clinical significance, defined as p <0.05.

common sinuses were mastoid (52%), frontal (25%), and ethmoid (9%). Notably, 60% of the pneumocephalus cohort had an open skull fracture, and over half of the patients with pneumocephalus demonstrated only trace or punctate volumes of intracranial air, typically visible on a single CT slice. All patients in this data set with a temporal bone fracture or extension to the temporal bone (n = 75) had pneumocephalus associated with their fracture. In this subset of temporal bone fracture patients, 39 of 75 (52%) had some degree of hearing loss after injury and 3 of 75 (4%) had facial nerve paralysis. In accordance with our local protocol, all patients with temporal bone fracture and cochlear injury, facial nerve injury, petrous bone involvement, hemotympanum, or CSF leak from the canal were seen by otolaryngology (ENT), and all patients were given ENT referrals on discharge if there were persistent hearing changes.

DISCUSSION

In this large cohort of children with low- and moderate-risk TBIs, we found that 18% (n = 143) of children had pneumocephalus associated with their skull fractures. The higher observed prevalence of pneumocephalus in our series likely reflects our study population, which included a greater proportion of patients with isolated skull fractures or fractures associated with minor ICH. Because pneumocephalus occurs more frequently in the presence of skull fractures, particularly those communicating with air-containing spaces, our findings are consistent with the known pathophysiology rather than indicative of an overall higher population incidence. Importantly, the presence of pneumocephalus did not significantly alter the clinical course in these patients: there was no significant difference in progression of head bleed on repeat CT, in the rate of neurosurgical intervention, or in ICU admission. Critically, the rate of neurosurgical intervention was extremely low across both groups (<1%). Additionally, ICU admission rates in the isolated TBI patients were similar across both pneumocephalus and nonpneumocephalus patients, and the ICU length of stay was identical across both groups. Pneumocephalus patients frequently had open skull fractures, mastoid sinus, and frontal sinus fractures. Taken together, our data suggest that pneumocephalus findings does not change outcomes in the low- to moderate-risk kBIG0, kBIG1, and kBIG2 patients, and utilization of the kBIG algorithm should be agnostic of pneumocephalus presence.

TABLE 3. Characteristics of Patients With Pneumocephalus on Initial CT

	Pneumocephalus Present n = 143 (18%)
Pneumocephalus quantification	
>1 Foci of air	66 (46%)
≤1 Focus of air	77 (54%)
Open skull fracture (any)	86 (60%)
Sinus fracture (any)	75 (52%)
Ethmoid sinus	7 (9.3%)
Frontal sinus	19 (25.3%)
Mastoid sinus	39 (52%)
Maxillary sinus	6 (8.0%)
Sphenoid sinus	3 (4.0%)

Interestingly, we found that the pneumocephalus patients were more likely to have neurosurgical consultation and repeat head CTs, despite having no change in the clinical outcomes. These findings suggest that, while pneumocephalus has influenced provider clinical behavior, it does not reflect an increase in underlying clinical severity.

Multiple prior studies support our findings: Blanchard et al.[6] and Hanalioglu et al.[4] have both conducted retrospective studies in smaller populations of children with isolated pneumocephalus (no other intracranial injuries) and found that the rate of adverse event is not increased by the presence of pneumocephalus alone. Our findings build on this prior body of evidence suggesting that pneumocephalus in the presence of skull fracture and/or ICH also does not increase the risk of adverse outcomes. Our findings should also be taken into the broader context of skull fracture management in low-risk head injury patients. In this study, we found a 60% open skull fracture rate. Other work by our research group has demonstrated that skull fracture patterns are similarly nonpredictive of outcome severity: Sommer et al. have shown that skull fracture location is not associated with adverse outcomes, so long as the patient meets all other kBIG0, kBIG1, or kBIG2 criteria.[8] Thus, despite the high rate of open fractures, it is important to recognize that pneumocephalus as a sequela of these fractures does not portend worse outcomes.

Lastly, it is important to note that this study was designed to evaluate the presence of pneumocephalus in the context of kBIG triage classifications, not to specifically address risk factors for complications such as CSF leak, hearing loss, or meningitis. Among patients with pneumocephalus and with temporal bone fractures, we found a high rate of hearing loss after injury (52%). Our institution's local protocol for management of these temporal bone fractures is based on best practice evidence to perform a thorough assessment of the ear canal, review of petrous bone, cochlear, and facial nerve involvement, and ENT consult while in the hospital to address these injuries.[9,10] To mitigate the risk of hearing loss, we also provide each patient treated at our institution for TBI with ENT follow-up in case of persistent hearing loss and return precautions. We did identify one patient in the pneumocephalus group with delayed presentation of meningitis who was initially discharged without a CSF leak. However, our institutional practice is in accordance with the Infectious Diseases Society of America, and we do not suggest that patients with pneumocephalus should be started on prophylactic antibiotics to prevent meningitis or other infectious complications.[11,12] As noted in this study, the outcomes for the pneumocephalus patients were equivalent to the nonpneumocephalus patients with low-risk head injury. Prophylactic antibiotics are not indicated, as they may increase the growth of antibiotic-resistant organisms.[12] Ultimately, while this study was not powered to evaluate hearing loss or infectious complications, our findings support the use of kBIG as a triage and initial treatment framework in patients with TBI who present with pneumocephalus, with local protocols to address specific fracture patterns and associated injuries. Although pneumocephalus was identified in 18.1% of patients, the majority represented tiny, radiographically detected air pockets associated with open skull fractures or sinus fractures, rather than clinically significant dural violations. Only one patient in the cohort had a documented CSF leak. Thus, while the presence of pneumocephalus should prompt careful assessment for CSF rhinorrhea or otorrhea, most cases in this population were incidental findings without

neurosurgical consequence. Importantly, our study was not designed to assess outcomes related to pneumocephalus, rather, to help guide decisions regarding transfer and initial treatment. Overall treatment decisions should, as previous to the publication of kBIG, continue to be guided by the overall clinical picture, including symptoms, air volume, and evidence of CSF communication. Although volumetric quantification of intracranial air was not performed, standardized radiology reports were used to identify cases, consistent with real-world clinical decision making. Future prospective, multicenter studies using volumetric assessment could refine risk thresholds for clinical significance.

There are inherent limitations to this study given its retrospective design, which relies on the quality of electronic medical record charting and may have introduced selection bias. Pneumocephalus quantification was not volumetrically quantified and was quantified based on the dispersion of gas foci, which may introduce error. Additionally, while the overall cohort includes a large sample of pediatric trauma patients, there were only a total of three children who required neurosurgical intervention, which may limit the power of this study in detecting differences between groups. Lastly, some children with very mild TBI who were discharged from outside emergency departments may not have been captured in our data set if they had complications, as the statewide tertiary pediatric trauma referral center and the majority of children with skull fractures or any intracranial finding are transferred or followed here, and we additionally have access to the Utah Pediatric Trauma Network telehealth that allows for statewide monitoring of adverse outcomes, minimizing the likelihood of missed complications and making a missed significant injury unlikely.

CONCLUSION

Pneumocephalus is a common finding in pediatric trauma patients with skull fractures and TBI, but the presence of pneumocephalus alone does not result in worse outcomes in otherwise low-risk patients. Pneumocephalus does not increase the risk of a low-risk kBIG0, kBIG1, or kBIG2 patient undergoing neurosurgical intervention or progression of their ICH. Despite a tendency for providers to have more intensive evaluation and treatment of these children, kBIG categorization should be applied agnostic of pneumocephalus presence.

AUTHORSHIP

A.M.K. conceptualized the study, collected and analyzed data, interpreted results, and drafted and critically revised the manuscript. K.W.M., R.S., S.L.G., C.E.C., J.H.S., and A.K.E. contributed to data collection and chart review. H.-Y.W. performed the statistical analyses and assisted with data interpretation. A.B.K., V.M.R., Z.J.K., R.A.S., and K.W.R. provided methodological oversight, critical editing and revisions, and supervision of the study. All authors reviewed and approved the final manuscript.

DISCLOSURE

Conflicts of Interest: Author Disclosure forms have been supplied and are provided as Supplemental Digital Content (http://links.lww.com/TA/F132).

REFERENCES

1. Cunningham RM, Walton MA, Carter PM. The major causes of death in children and adolescents in the United States. *N Engl J Med*. 2018; 379(25):2468–2475.
2. Martin RJ, Holthouse DJ, Wayne TG. Localising the source of pneumocephalus: a diagnostic problem. *J Clin Neurosci*. 2002;9(2):216–218.
3. Nigrovic LE, Kuppermann N. Children with minor blunt head trauma presenting to the emergency department. *Pediatrics*. 2019;144(6):e20191495.
4. Hanalioglu D, Elbir C, Sahin OS, et al. Clinical significance of pneumocephalus in pediatric mild traumatic brain injury. *Pediatr Emerg Care*. 2023;39(11): 836–840.
5. Kuppermann N, Holmes JF, Dayan PS, et al. Identification of children at very low risk of clinically-important brain injuries after head trauma: a prospective cohort study. *Lancet*. 2009;374(9696):1160–1170.
6. Blanchard A, Cabrera KI, Kuppermann N, Dayan PS. Acute outcomes of isolated pneumocephali in children after minor blunt head trauma. *Pediatr Emerg Care*. 2018;34(9):656–660.
7. Kay AB, Glasgow SL, Kahan AM, et al. Small change, BIG impact: proposal of the brain injury guidelines for kids (kBIG). *J Pediatr Surg*. 2025; 60(8):162372.
8. Glasgow SL, Scaife JH, Clinker CE, et al. Evaluation of isolated skull fractures in children. *J Pediatr Surg*. 2025:162766. doi: 10.1016/j.jpedsurg.2025.162766.
9. Johnson F, Semaan MT, Megerian CA. Temporal bone fracture: evaluation and management in the Modern era. *Otolaryngol Clin North Am*. 2008; 41(3):597–618, x.
10. Kanona H, Anderson C, Lambert A, et al. A large case series of temporal bone fractures at a UK major trauma centre with an evidence-based management protocol. *J Laryngol Otol*. 2020;134(3):205–212.
11. Wang HP, Reif RJ, Kalkwarf KJ, Jensen HK, Jenkins AK, Bhavaraju A. Prophylactic antibiotics in patients with traumatic pneumocephalus or cerebrospinal fluid leak. *Am Surg*. 2023;89(7):3037–3042.
12. Tunkel AR, Hasbun R, Bhimraj A, et al. 2017 Infectious Diseases Society of America's clinical practice guidelines for healthcare-associated ventriculitis and meningitis. *Clin Infect Dis*. 2017;64(6):e34–e65.

