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Recurrent Venous Air Embolism During Burr Hole Drainage for Chronic Subdural Hematoma: A Case Report

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Abstract

Venous air embolism (VAE) is a potentially life-threatening complication of neurosurgery but is uncommon during burr hole procedures. We report a 77-year-old man with bilateral chronic subdural hematomas (CSDHs) who underwent burr hole drainage under local anesthesia and sedation with spontaneous ventilation and the head elevated by 15°. During right-sided drilling, before dural incision, he developed sudden coughing, severe desaturation (SpO_2 in the 70s), and frequent premature ventricular contractions. The procedure was immediately stopped, and both wounds were closed. Postoperative computed tomography (CT) showed air in the superior sagittal sinus (SSS), internal jugular vein, and cervical venous plexus, while transthoracic echocardiography demonstrated multiple microbubbles in the left cardiac chambers. His condition improved after 100% oxygen and hyperbaric oxygen therapy. After preoperative CT showed no visible venous air the following day, bilateral drainage was completed. Despite immediate application of bone wax to the burr hole edges, postoperative CT again showed a small amount of venous air in the SSS. He was discharged home on postoperative day 3. This case highlights that clinically significant VAE can occur during burr hole drilling before dural incision, even under local anesthesia with spontaneous ventilation. Diploic or emissary veins may provide a route for air entry, and sudden desaturation or arrhythmia should prompt consideration of VAE. The reappearance of a small amount of venous air despite early application of bone wax highlights the need for careful perioperative monitoring.

Categories: Neurosurgery
Keywords: burr hole drainage, chronic subdural hematoma, diploic veins, emissary veins, local anesthesia, neurosurgery, venous air embolism

Introduction

Burr hole drainage is a common procedure for chronic subdural hematoma (CSDH). Venous air embolism (VAE) is a potentially life-threatening complication that classically occurs when open venous structures communicate with the atmosphere at a level above the right atrium [1, 2]. Burr hole neurosurgery is generally considered a low-risk procedure for VAE, but the risk is not zero [3]. The calvarial bone contains diploic veins, which communicate with dural venous sinuses and extracranial veins. Emissary veins traverse the skull and connect the intracranial and extracranial venous systems, including the venous network of the scalp [4]. Injury to these venous channels during drilling may provide a route for air entry, even when the dura remains intact and no dural venous sinus is directly injured. In patients breathing spontaneously, negative intrathoracic pressure generated during inspiration may transiently lower central venous pressure, thereby increasing the pressure gradient favoring air entrainment [5, 6]. This mechanism may be relevant during procedures performed under local anesthesia with spontaneous ventilation [7]. Sudden coughing and oxygen desaturation may also be early clinical manifestations of VAE in such patients [8]. VAE has been reported during burr hole drilling before dural incision in patients undergoing craniotomy and during awake deep brain stimulation (DBS) procedures [7-10]. However, VAE during burr hole drainage for CSDH under local anesthesia with spontaneous ventilation remains poorly characterized. We describe a patient who developed clinically significant VAE during burr hole drainage for bilateral CSDH under local anesthesia and sedation, before the dura had been opened. Postoperative CT after repeat surgery also revealed a small amount of venous air despite early application of bone wax to the burr hole edges.

Case Presentation

Patient information and preoperative imaging

A 77-year-old man was referred to our hospital with a two-month history of dizziness while walking and a sensation of heaviness in his head. As his symptoms had persisted, he underwent head computed tomography (CT), which revealed bilateral CSDHs. Preoperative CT showed bilateral multiloculated CSDHs, measuring up to 23 mm on the left and 18 mm on the right (Figure *1A*, *1B*). There was no clear history of head trauma. His medical history included acute myocardial infarction treated with percutaneous coronary intervention and paroxysmal atrial fibrillation. His regular medications included edoxaban 60 mg, dapagliflozin 10 mg, atorvastatin 10 mg, vonoprazan 20 mg, and esaxerenone 2.5 mg. The last dose of

edoxaban was taken on the morning of the day before surgery. Laboratory testing on the day before surgery showed a blood urea nitrogen level of 25.3 mg/dL and a creatinine level of 0.86 mg/dL. The patient had received no oral food or fluids since the morning of surgery. An intravenous infusion of normal saline was initiated immediately before the procedure.

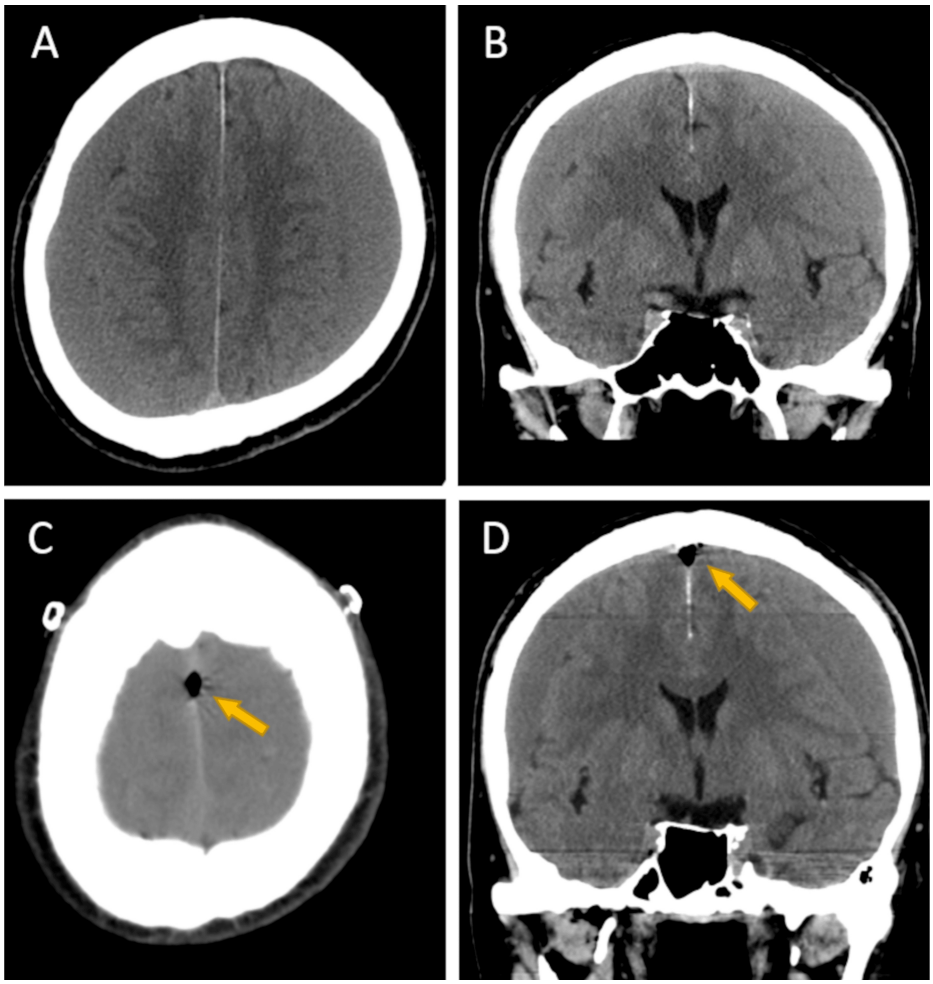


FIGURE 1: Preoperative and postoperative head CT of the first procedure

(A, B) Preoperative CT showing bilateral chronic subdural hematoma. (C, D) Postoperative CT showing air within the superior sagittal sinus (yellow arrows).

CT, computed tomography

First procedure and acute deterioration

The procedure was initiated under local anesthesia, with pentazocine (15 mg) and diazepam (5 mg) administered for analgesia and sedation. The patient maintained spontaneous ventilation and remained responsive to verbal commands. His head was elevated by 15°, and 4 cm skin incisions were made bilaterally, centered on the intersection of the coronal suture and superior temporal line, which served as the landmark for burr-hole placement. On the left side, a burr hole was created using a hand-operated drill. The dura was coagulated and covered with normal saline-moistened gauze but was not incised. During this stage, SpO_2 remained at 99%, and systolic blood pressure was approximately 130 mmHg. Detailed heart rate and respiratory rate values were not available in the records, and end-tidal carbon dioxide ($EtCO_2$) was not monitored.

Approximately one minute after drilling began on the right side, the patient suddenly began coughing, and SpO_2 fell to approximately 90%. He remained responsive and denied chest pain. Despite increasing oxygen delivery via face mask to 10 L/min, SpO_2 fell further into the 70s, and frequent premature ventricular contractions were noted on electrocardiographic monitoring. Systolic blood pressure remained approximately 150 mmHg, with no clear ST-segment changes documented. A nasopharyngeal airway was inserted, and the procedure was immediately terminated. Both surgical wounds were closed without dural

incision, after which SpO_2 promptly recovered to 95%.

Postoperative head CT and contrast-enhanced CT of the neck and chest revealed multiple air collections in the superior sagittal sinus (SSS) (Figure *1C*, *1D*), as well as air in the internal jugular vein and cervical venous plexus (Figure *2A*, *2B*). Transthoracic echocardiography demonstrated multiple microbubbles in the left atrium and left ventricle (Figure *2C*). Chest CT showed no obvious airway obstruction or clear findings to explain the acute desaturation. Based on the clinical presentation and imaging findings, VAE was diagnosed. The patient was maintained on 100% oxygen and underwent hyperbaric oxygen therapy (HBOT), and his clinical condition improved later that day. Brain magnetic resonance imaging (MRI) showed no evidence of new cerebral infarction (Figure *2D*).

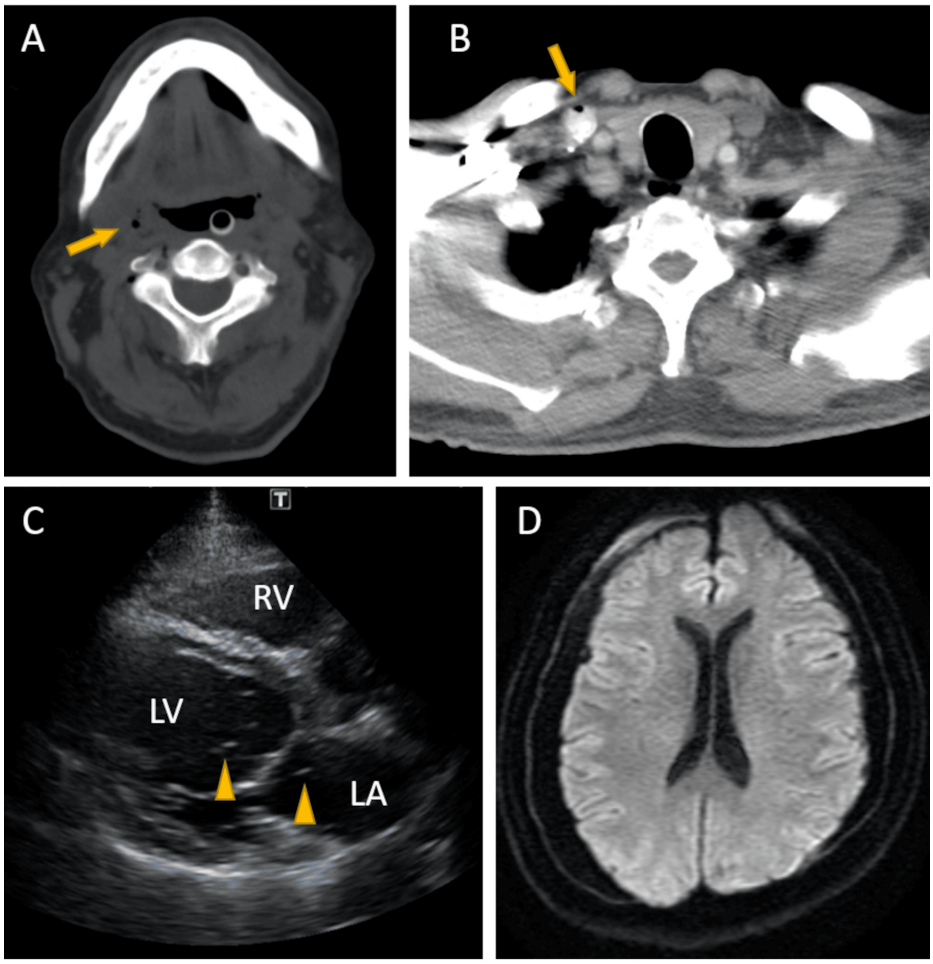


FIGURE 2: Imaging findings suggestive of VAE after the first procedure

(A) CT image showing air in the cervical venous plexus (yellow arrow). (B) Contrast-enhanced CT image showing air in the internal jugular vein (yellow arrow). (C) Transthoracic echocardiographic image showing microbubbles in the left atrium and left ventricle (yellow arrowheads). (D) Diffusion-weighted MRI of the brain showing no evidence of acute infarction.

VAE, venous air embolism; CT, computed tomography; MRI, magnetic resonance imaging

Second procedure and outcome

The next day, bilateral hematoma drainage was performed under the same anesthetic and positioning conditions. After reopening the right incision, bone wax was promptly applied to the edges of the burr hole. The dura and outer membrane of the hematoma were then opened, and dark-red hematoma was evacuated. The hematoma cavity was irrigated with normal saline using a drainage catheter, and a drain was placed. On the left side, bone wax was similarly applied to the burr hole edges immediately after reopening the incision, followed by hematoma evacuation and irrigation. Drains were placed bilaterally, the burr holes were covered with burr hole caps, and the wounds were closed (Figure *3*). During hematoma evacuation, SpO_2 transiently decreased to approximately 90% but recovered spontaneously.

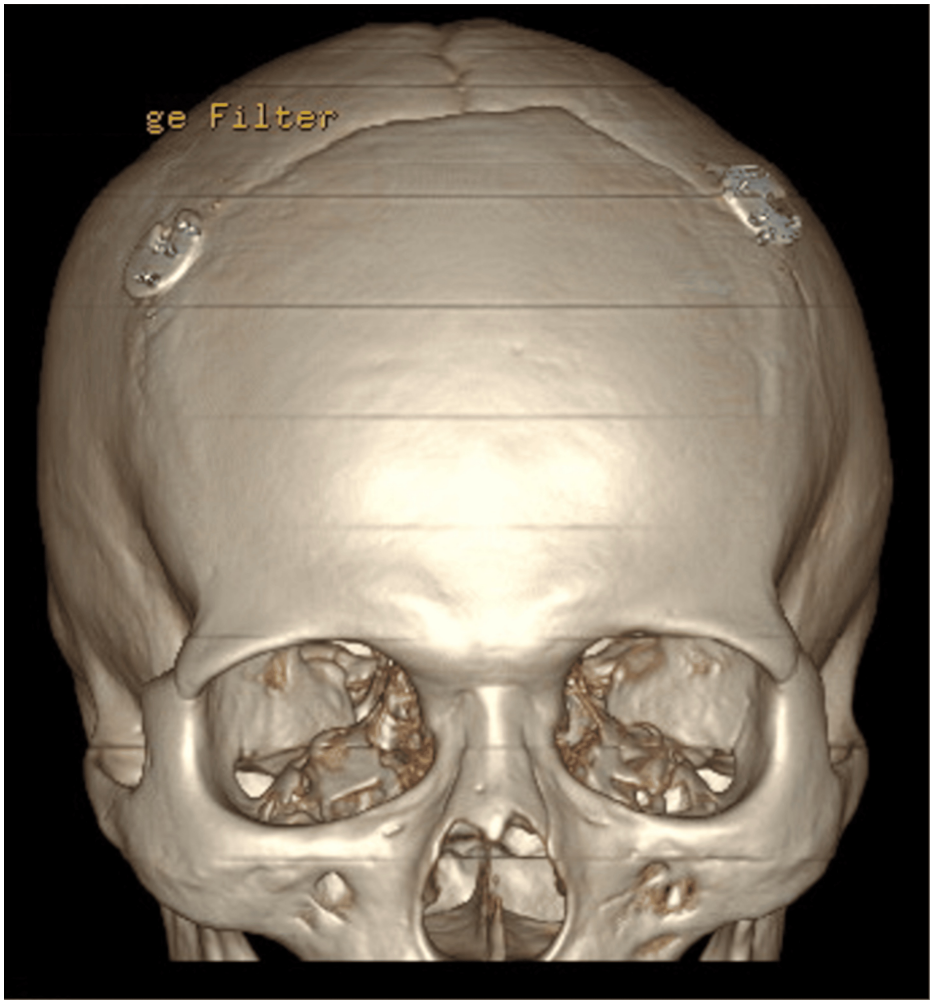


FIGURE 3: Postoperative 3D reconstruction of the skull showing the burr hole sites

Bilateral burr holes were placed at the intersection of the coronal suture and superior temporal line and covered with burr hole caps.

Although no venous air was visible on CT before the second procedure (Figure *4A*, *4B*), postoperative CT showed a small amount of air again in the SSS (Figure *4C*, *4D*). The patient's head heaviness and other symptoms improved, and he was discharged home on postoperative day 3, walking independently.

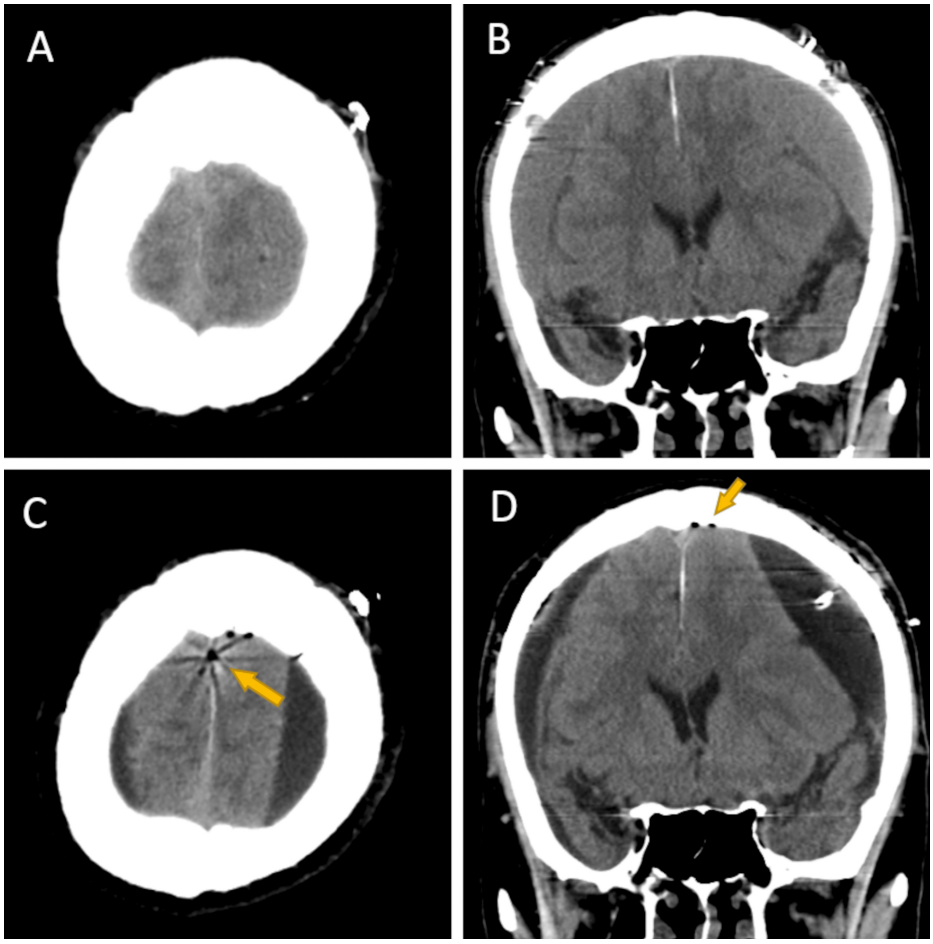


FIGURE 4: Preoperative and postoperative head CT of the second procedure

(A, B) Preoperative CT showing no visible venous air before the second procedure. (C, D) Postoperative CT showing air again within the superior sagittal sinus and adjacent venous structures (yellow arrows).

CT, computed tomography

Discussion

VAE has been reported during burr hole drilling before dural incision, including two cases occurring during or immediately after drilling in patients undergoing head-up craniotomy [9]. It has also been described during awake DBS surgery [7, 8, 10]. The present case adds to these reports by demonstrating that clinically significant VAE can occur during routine burr hole drainage for CSDH under local anesthesia with spontaneous ventilation, even before dural incision. In addition, postoperative imaging after the second procedure revealed a small amount of venous air despite early application of bone wax to the burr hole edges.

Risk factors and preventive considerations for VAE during CSDH surgery

VAE can occur when air enters an open venous channel through a pressure gradient, particularly when venous pressure at the surgical site falls below atmospheric pressure [1, 2]. Diploic veins drain into dural venous sinuses or veins, whereas emissary veins connect the intracranial and extracranial venous systems. Injury to either during drilling may provide a route for air entry [4]. However, venous injury alone does not necessarily result in VAE, as air entry depends on the pressure gradient between the open vein and the atmosphere.

Head elevation can lower venous pressure at the operative site relative to atmospheric pressure, thereby favoring air entry. In patients breathing spontaneously, negative intrathoracic pressure generated during inspiration may transiently decrease central venous pressure (CVP), thereby increasing the pressure gradient between the venous system and the atmosphere and potentially facilitating air entrainment [5, 6]. This

mechanism may be relevant during procedures performed under local anesthesia with spontaneous ventilation. Nevertheless, CVP was not monitored in our patient, and the contribution of this mechanism cannot be determined.

Patient factors may also contribute to VAE. Dehydration or reduced circulating blood volume can lower CVP, further facilitating air entry [5]. Poor oral intake may contribute to volume depletion in some patients with CSDH. In the present case, the patient had received no oral fluids since the morning of surgery, and intravenous normal saline was initiated immediately before the procedure. However, his intravascular volume status was not objectively assessed, and the potential contribution of volume depletion to VAE remains uncertain. Preoperative assessment of volume status and correction of clinically significant hypovolemia may be reasonable, although their effectiveness in preventing VAE during CSDH surgery has not been established.

An anatomical MRI study found that, in adults, diploic veins draining into the lacunae laterales, which communicate with the SSS, were most numerous in the frontal and parietal regions just anterior and posterior to the coronal suture [11]. In CSDH surgery, the coronal suture is often used as a landmark for burr hole placement to help avoid injury to the motor cortex [12, 13]. This anatomical distribution raises the possibility that burr hole placement near the coronal suture may increase the risk of injuring diploic venous channels. However, whether avoiding this region reduces the risk of VAE remains unclear, and further studies are warranted. Burr hole placement should be determined based on the surgical requirements of each individual case.

Interpretation of left-sided cardiac microbubbles

The detection of microbubbles in the left-sided cardiac chambers on postoperative transthoracic echocardiography raises the possibility that air had reached the left-sided circulation. Although no specific evaluation for an intracardiac or pulmonary shunt was performed, an occult right-to-left shunt, such as a patent foramen ovale or pulmonary arteriovenous shunt, cannot be excluded and may have provided a route for air to enter the left-sided circulation. Postoperative brain MRI showed no cerebral infarction or other new ischemic lesions.

Acute management and prevention of VAE

Sudden coughing, desaturation, or arrhythmia during burr hole drilling should prompt consideration of VAE, even before dural incision. Immediate management includes stopping the procedure, covering the suspected entry site with saline, sealing exposed bony edges with bone wax when feasible, administering 100% oxygen, and providing cardiopulmonary support as needed [2]. In our patient, the procedure was immediately terminated, and both surgical wounds were closed, followed by prompt recovery of oxygen saturation. The patient subsequently received 100% oxygen and HBOT, after which his clinical condition improved. Early HBOT has been associated with favorable outcomes in patients with iatrogenic cerebral arterial gas embolism [14]; however, its specific contribution to the favorable outcome in this case cannot be determined.

During the second procedure, bone wax was promptly applied to the bone edges of both burr holes. Nevertheless, postoperative CT revealed a small amount of air in the SSS. Because the timing of air entry could not be determined, this finding does not establish whether bone wax failed to prevent air entry at the treated sites. Incomplete sealing or air entry through other venous channels may be possible explanations, although these mechanisms remain speculative. Although application of bone wax may be a reasonable preventive measure, its effectiveness cannot be determined from this single observation, and it should not be regarded as providing complete protection against VAE.

Limitations

Several limitations should be acknowledged. First, this is a single case, and the findings cannot establish the incidence, causation, or generalizability of VAE during CSDH burr hole drainage. Second, the exact route of air entry could not be identified, and direct injury to a specific venous channel was not documented. Although diploic or emissary veins represent plausible routes, this mechanism remains speculative. Third, CVP and end-tidal carbon dioxide were not monitored, and the patient's intravascular volume status was not objectively assessed. Therefore, the proposed hemodynamic mechanisms remain hypothetical. Fourth, although microbubbles were detected in the left-sided cardiac chambers, no specific evaluation for an intracardiac or pulmonary shunt was performed. Fifth, the postoperative CT findings after the second procedure do not establish when air entered the venous system or whether the transient desaturation was related to air embolism. Consequently, the effectiveness of bone wax in preventing VAE cannot be determined from this case. Finally, although the patient received HBOT and subsequently recovered without radiologically apparent cerebral infarction, the contribution of HBOT to the favorable outcome cannot be established. Further studies with dedicated venous imaging and detailed intraoperative physiological monitoring are warranted to clarify the mechanisms and preventive strategies for VAE during burr hole procedures.

Conclusions

VAE should be considered when acute respiratory deterioration or arrhythmia occurs during burr hole drainage for CSDH, even before dural incision and under local anesthesia with spontaneous ventilation. Injury to diploic or emissary veins may provide a route for air entry, even when the burr hole is distant from a dural venous sinus. Prompt cessation of the procedure, coverage of the suspected entry site, application of bone wax to exposed burr hole edges, and administration of high-concentration oxygen are important initial management measures, with HBOT considered when indicated. Although VAE is a rare complication of burr hole surgery, clinicians should remain aware of its potential occurrence, and careful perioperative monitoring and prompt management are essential.

Additional Information

Author Contributions

All authors have reviewed the final version to be published and agreed to be accountable for all aspects of the work.

Concept and design: Mao Yamamoto, Keisuke Miura, Kohei Funato

Acquisition, analysis, or interpretation of data: Mao Yamamoto, Kensuke Kato

Drafting of the manuscript: Mao Yamamoto

Critical review of the manuscript for important intellectual content: Mao Yamamoto, Keisuke Miura, Kohei Funato, Kensuke Kato

Supervision: Keisuke Miura

Disclosures

Human subjects: Informed consent for treatment and open access publication was obtained or waived by all participants in this study. **Conflicts of interest:** In compliance with the ICMJE uniform disclosure form, all authors declare the following: **Payment/services info:** All authors have declared that no financial support was received from any organization for the submitted work. **Financial relationships:** All authors have declared that they have no financial relationships at present or within the previous three years with any organizations that might have an interest in the submitted work. **Other relationships:** All authors have declared that there are no other relationships or activities that could appear to have influenced the submitted work.

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