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Risk Factors for Pneumocephalus Following the Surgical Management of Chronic Subdural Hematoma

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ABSTRACT

Introduction: Chronic subdural hematoma is an important type of hemorrhage that can cause morbidity and mortality in older people. The burr hole technique is employed in surgical treatment; however, postoperative pneumocephalus is a common complication of this surgery. To assess factors affecting the postoperative development of pneumocephalus in patients with chronic subdural hematoma.

Methods: We analyzed 32 patients who underwent surgical treatment for chronic subdural hematoma using the burr hole technique at our clinic. Baseline and postoperative clinical and radiological data were evaluated. Variables that may affect the development of pneumocephalus, such as age, gender, neurological status, localization of subdural hematoma, thickness, unilaterality or bilaterality, and midline shift, were documented. These variables were analyzed and compared between patients with and without pneumocephalus.

Results: The incidence of postoperative pneumocephalus was significantly higher in patients with bilateral hematoma than in those with unilateral hematoma ($p=0.037$; $p<0.05$). There was a significant difference between burr hole localizations among the patients based on the incidence of postoperative pneumocephalus ($p=0.042$; $p<0.05$). The incidence of pneumocephalus was high in patients undergoing surgery using the posterior approach.

Conclusion: In the surgical treatment of chronic subdural hematoma, the burr hole technique is considered a safe option because it is effective, minimally invasive, and carries a low risk of complications. However, the occurrence of postoperative pneumocephalus and subsequent recurrent hemorrhage may necessitate reoperation. To prevent the development of pneumocephalus, the burr hole should be created as close to the anterior side as possible.

Keywords: Chronic subdural hematoma, hematoma, hemorrhage, pneumocephalus

Introduction

Chronic subdural hematoma is a significant aspect of neurosurgical practice that can occur spontaneously or because of minor trauma, predominantly affecting older people, and can result in morbidity and mortality (1). These hematomas often arise because of bleeding from subdural bridging veins, which become stretched because of cerebral atrophy (2). Symptomatic and advanced chronic subdural hematomas require surgical treatment. Although it is mostly unilateral, hematomas can occur bilaterally in 8%-35% of patients (3). The burr hole technique, which is often regarded as a minor surgical procedure, is frequently employed in surgical treatment. If necessary, single- or double-sided burr holes can be created. One of the major complications of this surgical technique is pneumocephalus. Pneumocephalus is defined as the presence of air in any intracranial space. It often occurs in small amounts and typically remains asymptomatic. Pneumocephalus can lead to seizures, headaches, irritability, nausea, and dizziness (4,5). In addition, postoperative pneumocephalus following drainage of chronic subdural hemorrhage has been identified as a risk factor for reaccumulation (5-8). Tension pneumocephalus is a rare but life-threatening pathology after intracranial surgical intervention. Tension pneumocephalus occurs when intracranial air is trapped by the check valve system. It behaves like a space-occupying mass and creates an intracranial space that can be life-threatening. Therefore, it must be differentiated from simple pneumocephalus, and its early diagnosis and surgical intervention are crucial.

Although many studies have discussed pneumocephalus and tension pneumocephalus in the context of chronic subdural hematoma, few studies have explored the risk factors. This study presents the risk factors and treatment approaches for pneumocephalus and tension

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pneumocephalus occurring after surgical treatment of chronic subdural hematomas using the burr hole technique.

Methods

This study retrospectively analyzed patients with chronic subdural hematoma who were surgically treated using the burr hole technique at Atlas University Medicine Hospital between 2006 and 2023.

The study was approved by the Atlas University Non-Invasive Scientific Research Ethics Committee (approval number: 10/10, date: 18.12.2023).

Age, gender, neurological status, history of trauma, duration from trauma to presentation, use of anticoagulants, comorbidities, localization, thickness, unilateral or bilateral occurrence of subdural hematoma, midline shift, recurrence, and pneumocephalus were recorded. All patients underwent preoperative computed tomography (CT) and magnetic resonance imaging (MRI) scans. Cranial CT was performed for postoperative control. Patients with and without postoperative pneumocephalus were compared and analyzed.

Hematomas located anterior and posterior to the coronal suture are called anteriorly and posteriorly localized, respectively. Pre- and postoperative clinical assessments of the patients were conducted using the Markwalder grading system (Table 1).

Operative Technique

The surgical procedures were performed using patients in the supine position under either general or local anesthesia. The head position was adjusted to the right or left side based on the localization of the hematoma, whereas a neutral head position was maintained in cases of bilateral hematomas. Depending on the localization of the hematomas, 2.5 cm linear incisions were made, followed by subcutaneous dissection and placement of self-retaining retractors. A 1 cm burr hole was created using a drill. The dura was cauterized and then incised. After hematoma flow was observed, the irrigation catheter was advanced into the subdural space. Irrigation was continuously performed with 0.9% saline solution in all directions until sufficient hematoma was aspirated. Irrigation was completed once the irrigation fluid had attained a transparent appearance. In appropriate cases, the pia was opened through a small incision under microscopic visualization. The subdural catheter was inserted, secured to the skin using a suture, and its opposite end was connected to a closed drainage reservoir system. The burr hole was sealed using gel foam. The layers were closed according to their anatomical order.

Table 1. Neurological grading system of Markwalder et al. (9)
0: Patient neurologically normal.
1: Patient alert and oriented; mild symptoms, such as headache; absent or mild neurological deficit, such as reflex asymmetry.
2: Patient drowsy or disoriented with variable neurological deficits, such as hemiparesis.
3: Patient stuporous but responding appropriately to noxious stimuli; severe focal signs, such as hemiplegia.
4: Patient comatose with absent motor responses to painful stimuli; decerebrate or decorticate posturing.

Postoperative Follow-up

A cranial CT scan was routinely performed on the first postoperative day for control. The drainage was maintained for 2-3 days until hemorrhagic drainage ceased. After removing the catheter, a follow-up CT scan was performed. Patients with stable clinical conditions and no significant problems detected on follow-up cranial CT scans were discharged and followed up through outpatient control visits. After one month, another cranial CT scan was performed for the control. Residual pneumocephalus or subdural hemorrhage was monitored with follow-up CT scans until complete resolution was observed.

Statistical Analysis

During the evaluation of the study findings, statistical analysis was conducted using the Number Cruncher Statistical System (NCSS) 2020 Statistical Software (NCSS LLC, Kaysville, Utah, USA). When evaluating the study data, quantitative variables were expressed as mean, standard deviation, median, and minimum and maximum values. Qualitative variables were expressed using descriptive statistics such as frequency and percentage. The Shapiro-Wilk test and box plot graphs were used to assess the fitness of the study data to a normal distribution. Fisher's exact test and Fisher-Freeman-Halton test were employed to compare qualitative data. The results were assessed at a 95% confidence interval, and significance was determined at $p<0.05$.

Results

The study involved 32 patients, comprising 15 (46.9%) males and 17 (53.1%) females. The patients were aged 38.39-90.00 years, with a mean age of 68.36±16.47 years. Among the patients, 34.4% (n=11) were below 65 years of age, while 68.3% (n=21) were ≥65 years of age. Headache, hemiparesis, imbalance, disturbance of consciousness, speech disturbance, dizziness, and epileptic seizures were reported in 25 (78.12%), 6 (18.75%), 6 (18.75%), 5 (15.62%), 5 (18.75%), 4 (12.50%), and 3 (9.37%) patients, respectively (Table 2).

The rate of postoperative pneumocephalus was not significantly different according to the gender and age of the patients ($p>0.05$). The incidence of postoperative pneumocephalus was significantly higher in patients with bilateral hematoma than in those with unilateral hematoma ($p=0.037$; $p<0.05$).

There was a statistically significant difference between the burr hole positions of the patients according to the occurrence of postoperative pneumocephalus ($p=0.042$; $p<0.05$). The incidence of pneumocephalus was higher in patients undergoing intervention using a posterior approach. The incidence of pneumocephalus was not significantly different according to hematoma thickness, shift measurements, and pre-operative and postoperative clinical grades ($p>0.05$) (Table 3).

There was no mortality in this study, and recurrence of chronic subdural hematoma was observed in two patients (6.25%). Postoperative pneumocephalus was in both recurrent cases. The recurrent patients underwent drainage surgery using a burr hole, and subsequent postoperative follow-up revealed the disappearance of both the hematoma and pneumocephalus, with no observed neurological deficits. No postoperative seizures were observed as complications. Antiepileptic

Table 2. Distribution of descriptive characteristics

		n (%)
Gender	Male	15-46.9
	Female	17-53.1
Age	Mean ± SD	68.36±16.47
	Median (min.-max.)	75.14 (38.39-90)
	<65 years	11-34.4
	≥65 years	21-65.6
Unilateral or bilateral hematoma	Unileteral	24-75.0
	Bilateral	8-25.0
Hematoma side	Right	10-31.3
	Left	14-43.8
	Bilateral	8-25.0
Burr-hole position	Anterior	6-18.8
	Posterior	6-18.8
	Anterior + posterior	20-62.5
Interval between trauma and surgery (months)	Mean ± SD	2.44±0.85
	Median (min.-max.)	3 (1-4)
Cause of trauma (n=16)	Falling	11-68.8
	Impact	4-25.0
	Traffic accident	1-6.3
Use of anticoagulants	No	25-78.1
	Yes	7-21.9
Additional disease	HT	10-58.8
	DM	6-35.3
	Other	8-47.1
Hematoma thickness (cm)	1-2 cm	18-56.3
	>2 cm	14-43.8
Midline shift (mm)	<5 mm	20-62.5
	≥5 mm	12-37.5
Postoperative pneumocephalus	No	16-50.0
	Yes	16-50.0
Length of hospital stay (days)	Mean ± SD	5.69±2.39
	Median (min.-max.)	5-3-12
Pre-op. grade (Markwalder)	Grade 1	10-31.3
	Grade 2	19-59.4
	≥ Grade 3	3-9.4
Postop. grade (Markwalder)	Grade 0	15-46.9
	Grade 1	14-43.8
	≥ Grade 2	3-9.4

SD: Standard deviation, min.: Minimum, max.: Maximum, HT: Hypertension, DM: Diabetes mellitus, preop: Preoperative, postop: Postoperative

therapy was started in patients who experienced preoperative epileptic seizures and was maintained for a minimum duration of six months.

Postoperatively, tension pneumocephalus occurred in two (6.25%) patients, who were described as follows:

Case 1: A 75-year-old male hypertensive patient presented to the emergency department with complaints of headache, weakness, nausea, and vomiting but had no neurological deficit. Cranial CT and MRI revealed bilateral chronic subdural hematoma with a thickness of 1.8 cm at its widest point (Figure 1). It was discovered that the patient had experienced mild head trauma from a fall two months earlier. The patient underwent subdural hematoma drainage with bilateral anterior and posterior burr holes under general anesthesia. The operation proceeded without any complications, and the patient experienced regression of headaches and other complaints during the early postoperative period, which was uneventful. On the second postoperative day, the patient began exhibiting signs of altered consciousness and agitation. Control CT scans revealed massive subdural pneumocephalus along with the Mount Fuji sign (Figure 2). The patient underwent a reoperation, during which the burr hole incision site was reopened. Air was aspirated during the procedure. The subdural space was filled with saline solution. A catheter was inserted. Two hours after surgery, the patient's agitation and changes in consciousness started to regress. The follow-up cranial CT scan indicated a reduction in pneumocephalus (Figure 3). The catheter was removed on day 3. Follow-up cranial CT scans with intervals revealed a gradual reduction in pneumocephalus. By day 30, the cranial CT scan showed complete disappearance of pneumocephalus, with no remaining hematoma (Figure 4). The patient was scheduled for follow-up at the outpatient clinic without neurological deficits.

Table 3. Comparison of descriptive characteristics according to the occurrence of pneumocephalus

Absent, (n=16)		Pneumocephalus		p
		Present, (n=16)		
Gender	Male	9-56.3	6-37.5	**0.288**[a]
	Female	7-43.8	10-62.5	
Age	<65 years	5-31.3	6-37.5	**0.710**[a]
	≥65 years	11-68.8	10-62.5	
Unilateral or bilateral hematoma	Unileteral	15-93.8	9-56.3	**0.037**[b]
	Bilateral	1-6.3	7-43.8	
Burr-hole position	Anterior	6-37.5	0-0	**0.042**[c]
	Posterior	2-12.5	4-25.0	
	Ant. + post.	8-50.0	12-75.0	
Hematoma thickness (cm)	1-2 cm	10-62.5	8-50.0	**0.476**[a]
	>2 cm	6-37.5	8-50.0	
Midline shift (mm)	<5 mm	11-68.8	9-56.3	**0.465**[a]
	≥5 mm	5-31.3	7-43.8	
Preoperative grade (Markwalder)	Grade 1	7-43.8	3-18.8	**0.201**[c]
	Grade 2	7-43.8	12 (75)	
	≥ Grade 3	2-12.5	1-6.3	
Postoperative grade (Markwalder)	Grade 0	9-56.3	6-37.5	**0.436**[c]
	Grade 1	5-31.3	9-56.3	
	≥ Grade 2	2-12.5	1-6.3	

[a]Pearson's chi-square test, [b]Fisher's exact test, [c]Fisher-Freeman-Halton test, $p<0.05$

Case 2: A 78-year-old man with diabetes mellitus and hypertension presented to the emergency room with headache and confusion. Cranial CT revealed a chronic subdural hematoma, measuring 2.5 cm at its widest point, located in the right frontoparietal region. A burr hole was created in the right frontoparietal region, and the hematoma

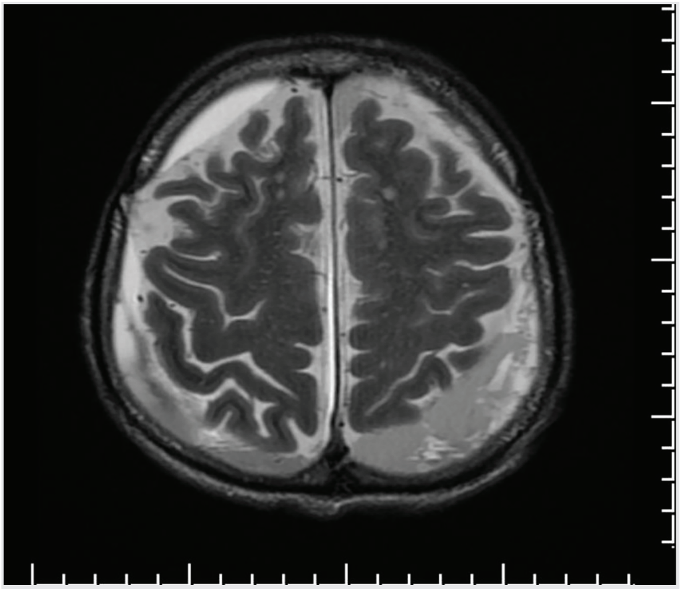

Figure 1. Preoperative axial T2-weighted cranial magnetic resonance imaging reveals chronic hematoma with a thickness of 1.5 cm at its widest point in both subdural spaces

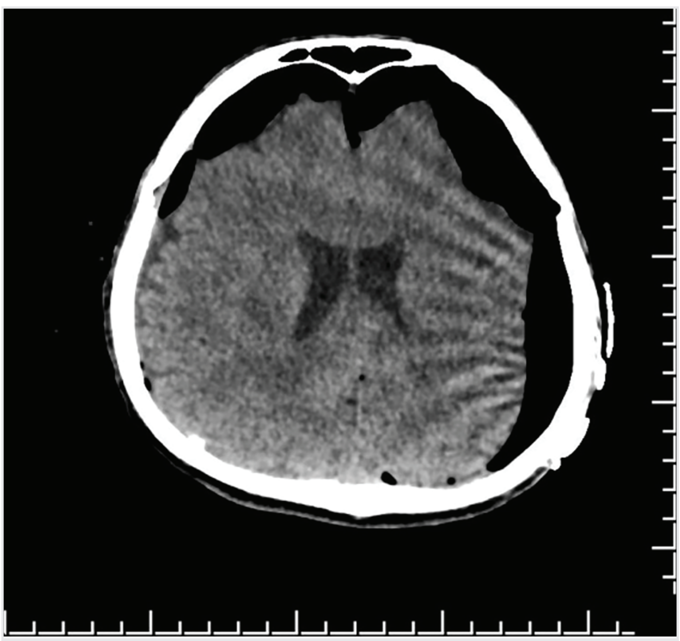

Figure 2. Postoperative axial computed tomography imaging in the parenchymal window after the burr hole technique for the evacuation of subdural hematoma. Widespread air densities consistent with pneumocephalus were observed in the subdural space. The Mount Fuji sign is in the left frontal region

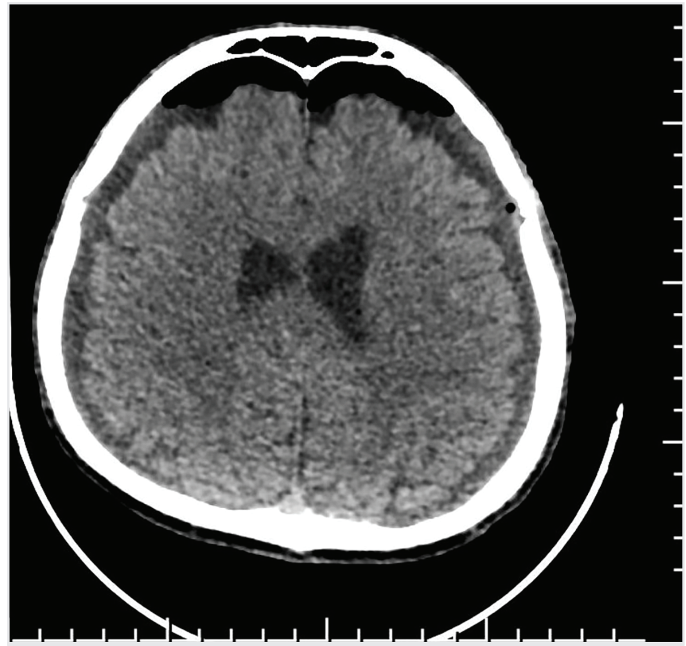

Figure 3. During the second surgery, air aspiration was performed, and the subdural space was filled with physiological saline solution. Postoperative axial computed tomography imaging in the parenchymal window revealed reduced pneumocephalus in both subdural spaces. Air densities secondary to the operation are in both frontal regions

Figure 4. Axial computed tomography imaging in the parenchymal window 1 month after the second surgery. It is observed that the subdural collection and air densities regressed

was drained. The state of confusion improved during the postoperative period, and the hematoma showed regression in the follow-up cranial CT scan. The catheter was removed on the third day. However, on the fourth day, the patient developed headache and confusion, prompting a repeat cranial CT scan. Cranial CT revealed subdural pneumocephalus and a 3 mm midline shift in the same location. Upon making the skin incision, pressurized air was observed emanating from the subdural space. It was considered that air might have been drawn through the hole in the skin after the catheter was withdrawn. The subdural space was filled with saline solution, followed by the insertion of a catheter. During follow-up, both pneumocephalus and hemorrhage had resolved on cranial CT scan, and no neurological deficits were observed.

Discussion

The development of cavities within the cranial subdural space due to atrophy in advanced ages may increase the susceptibility to the development of chronic hemorrhage. Similarly, the surgical treatment of chronic subdural hematoma using the burr hole technique may lead to the development of pneumocephalus and recurrent hemorrhage within the subdural space in the postoperative period. Postoperative simple pneumocephalus can occur after burr hole evacuation of chronic subdural hematoma. It is often asymptomatic because it does not exert significant pressure or compression, generally not necessitating treatment unless it remains asymptomatic. Reports have indicated its resorption and eventual disappearance within days to weeks (10,11). However, it can sometimes be symptomatic or cause recurrent hemorrhage (4-6,12).

It has been reported in the literature that the recurrence rates following surgical treatment of subdural hematoma range from 10% to 33% (5). To prevent recurrence, some authors advocate the placement of a subperiosteal catheter between the calvarium and periosteum rather than a subdural catheter. Therefore, they observed no damage to the neural parenchyma or bridging veins and reported a reduced recurrence rate (13,14). One of the most important causes of recurrence is believed to be the development of postoperative pneumocephalus (10). Postoperative pneumocephalus leads to recurrence through various mechanisms. Pneumocephalus within the subdural space induces negative pressure, resulting in the reaccumulation of blood (15). According to You and Zheng (5) air bubbles are displaced by the movement of the patient and cause rupture of the bridging veins and rebleeding. Therefore, although postoperative pneumocephalus is usually asymptomatic, it contributes to recurrence and significantly influences the outcome of surgical treatment for chronic subdural hematoma.

The incidence of pneumocephalus in the early postoperative phase ranges between 14% and 44% (16,17). However, in our series, this rate was observed to be 50%. We believe that the high rate of pneumocephalus was due to the inclusion of patients with a small volume of pneumocephalus. Various reasons for developing pneumocephalus have been reported. Dobran et al. (18) and You and Zheng (5) emphasized the importance of creating the burr hole at the highest point possible by properly positioning the patient during the intervention. They also reported that air entering through the burr hole during surgery could ascend to the upper parts of the subdural space and become trapped there (5,18). In our study, pneumocephalus was more common in patients undergoing surgery using a posterior approach. The hemorrhagic cerebrospinal fluid within the subdural space drains out because of its fluidity and the force of gravity, allowing air to enter and substitute for the hemorrhagic cerebrospinal fluid. Furthermore, insufficient head rotation in patients with bilateral hematomas poses an increased risk, particularly when both anterior and posterior burr holes are opened. This allows fluid to drain from the lower burr hole while allowing air to enter through the upper burr hole. To prevent air from entering the subdural space around the catheter, during catheter advancement and initiation of irrigation to drain the hemorrhage, the potential air entry site in the burr hole must be covered with materials such as gel foam.

The authors have devised various surgical strategies to prevent the development of postoperative pneumocephalus. In their study, Chavakula et al. (15) conducted hematoma evacuation through a 3 cm craniotomy. They then inserted a catheter and aspirated air from the catheter using a syringe. This method facilitates brain expansion and decreases the incidence of pneumocephalus and subsequent recurrence (15).

Some authors have proposed an alternative method for preventing pneumocephalus by precisely determining the localization of the inserted subdural catheter. Nakaguchi et al. (19) reported in a study involving 63 patients that the position of the subdural catheter tip influenced the occurrence of postoperative pneumocephalus. They demonstrated that occipital and parietal catheters resulted in a higher incidence of pneumocephalus than frontal catheters. Cecchini (20) used two subdural drainage catheters in their study. They reported that pneumocephalus can be prevented by using one catheter for irrigation and the other for air aspiration. Zakaraia et al. (16) and Erol et al. (1) conducted completely different studies. In their study, one group of patients underwent irrigation, whereas the other group did not receive irrigation. They reported that pneumocephalus was less frequent in cases where irrigation was not used.

After surgical treatment of chronic subdural hematoma using the burr hole technique, there exists a risk of tension pneumocephalus, a condition less frequent than simple pneumocephalus but characterized by a distinct clinical course. The mechanism of tension pneumocephalus involves a valve system that permits air to enter but inhibits its release. This initiates a process that results in gradual neurological deterioration, necessitating urgent intervention.

In the literature, the risk of developing tension pneumocephalus after treatment of chronic subdural hematoma using the burr hole technique has been reported to range from 2.5% to 16% (21). In our series, tension pneumocephalus occurred in two patients (6.25%). There is no clear information in the literature regarding the causes and prevention of tension pneumocephalus. In our first case, we believe that the hemorrhagic cerebrospinal fluid drained through the catheter placed in the posterior burr hole, yet a substantial volume of air remained within the space. In our series, we noticed a higher incidence of pneumocephalus in relation to the burr holes created to evacuate posterior hematomas. To prevent this occurrence, we suggest placing the burr hole as high as possible and extending the catheter frontally. We believe that this approach will allow the drainage of potential subdural air because it will be situated at the top when the patient is placed in the supine position, while positioning the fluid advantageously at the bottom. Otherwise, after the drainage of hemorrhagic cerebrospinal fluid, the catheter may allow the entry of air after draining the fluid. In the second case in this study, we believe that upon catheter withdrawal, air might have been drawn through the catheter site opening, leading to the development of tension pneumocephalus. To prevent this from happening in subsequent patients, a gel was applied to both the catheter exit site and the incision site after catheter removal, aiming to prevent the entry of air.

Study Limitations

This study is a retrospective analysis conducted at a single center and may be limited because of the small number of cases. A multicenter prospective study with a larger number of patients can be conducted.

Conclusion

The burr hole technique is a safe, effective, and minimally invasive option for the surgical treatment of chronic subdural hematoma, offering a low risk of complications. However, postoperative complications associated with this technique, such as pneumocephalus and recurrent hemorrhage, may necessitate repeat surgical intervention. In addition, these complications might extend the duration of hospitalization. During the use of this technique, positioning the burr hole as close to the anterior region as possible can decrease the risk of pneumocephalus development.

Ethics Committee Approval: The study was approved by the Atlas University Non-Invasive Scientific Research Ethics Committee (approval number: 10/10, date: 18.12.2023).

Informed Consent: Retrospective study.

Authorship Contributions: Surgical and Medical Practices - H.D.; Concept - H.D.; Design - H.D.; Data Collection or Processing - H.D.; Analysis or Interpretation - H.D., D.A.; Literature Search - H.D., D.A.; Writing - H.D., D.A.

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