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The Sitting Position in Neurosurgery: Is it Safe?

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ABSTRACT

Objective: This study aimed to analyze data from patients who underwent surgery in the sitting position in our clinic and to investigate the advantages and disadvantages of this position in terms of surgery and anesthesia. By doing so, we aimed to provide a comprehensive understanding of the safety and efficacy of the sitting position in neurosurgery.

Materials and Methods: Patients who underwent surgery in the sitting position in our clinic between January 2021 and December 2023 were retrospectively reviewed.

Results: Of the 73 patients in this study, 31 (42.5%) were men, and 42 (57.5%) were women. The mean age of the patients was 35.27±19.66 years (min–max: 4–75 years). Patients were diagnosed with cerebellar tumors (n=34), chiari malformations (n=31), and cerebellopontine angle tumors (n=8). Nine patients developed tension pneumocephalus, and seven had postoperative complications. VAE occurred in 11 patients (15.1%). The rate of VAE was significantly higher in patients with cerebellar tumors ($p<0.05$). The rate of VAE was also significantly higher in patients with PFO upon TEE ($p<0.05$) and in those who underwent prolonged or emergency surgery ($p<0.05$).

Conclusion: The sitting position can be used more safely in surgical operations for cerebellopontine angle tumors. However, it can be hazardous, especially in patients with cerebellar tumors, those with PFO upon TEE, and those undergoing emergency operations.

Keywords: Air embolism, neurosurgery, posterior, sitting position, venous

INTRODUCTION

The sitting position was first introduced in the early twentieth century and remained the method of choice until the 1970s. However, it is now decreasingly used in neurosurgery.[1–3] This position is mainly used for posterior fossa surgery and upper cervical spine surgeries.[2,4,5]

Although this position provides certain advantages to the surgeon, it can cause severe challenges for the anesthesiologist regarding complications and case management.[2,6] The advantages of the position for the surgeon are the ease of access to the posterior fossa structures (gravity-induced drainage of blood and cerebrospinal fluid [CSF]) and a significant reduction in swelling of the cerebellum; for the anesthesiologist, it is associated with certain advantages, including ventilation with lower airway pressure, less impairment of diaphragm movement, more accessible access to airways and vascular structures, and easier intraoperative neuromonitoring.[3,6–9]

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However, serious complications such as venous air embolism (VAE), hypotension, central cord syndrome, quadriplegia, subdural hemorrhage, and tension pneumocephalus are considered disadvantages of the position.[2,6]

We sought to investigate the advantages and disadvantages of this position in terms of surgery and anesthesia. By doing so, we aimed to provide a comprehensive understanding of the safety and efficacy of the sitting position in neurosurgery.

MATERIALS AND METHODS

Patient Population

Patients who underwent surgery in the sitting position in our clinic between January 2021 and December 2023 were retrospectively reviewed. Overall, 73 patients who underwent surgery were included in the study. Clinical data, including age, sex, pathological diagnosis, comorbidities, history of preoperative hydrocephalus (HSF), preoperative ventriculoperitoneal shunt (VPS) application, timing of surgery, duration of surgery, pre- and postoperative complications, and transesophageal echocardiography (TEE) results, were retrieved from medical records. Indications for using the sitting position were determined based on the underlying pathology and the surgeon's preference.

Patients with Chiari malformations (CM) underwent cranio-cervical decompression surgery (suboccipital decompression, removal of the posterior arch of the first cervical vertebra [C1], and dural duplication). A neurosurgeon performed all surgical steps.

All patients underwent preoperative TEE. Patients with patent foramen ovale (PFO) and right-to-left shunts on TEE were not operated on in the sitting position and were therefore excluded from the study. Patients with PFO on TEE but without right-to-left shunts were included in the study.

Intraoperative ultrasonography (USG) was used in cerebellar tumor patients (to determine tumor localization) and CM patients (to evaluate CSF passage). Early brain computed tomography (CT) was performed to evaluate postoperative surgical results and possible complications.

Anesthesia Protocol

All information regarding the anesthesia protocol was retrieved retrospectively from the anesthesia medical records.

The same anesthesiologist administered anesthesia management for all patients. Patients were monitored according to the standards of the American Society of Anesthesiologists. BIS (Bispectral Index) monitoring was performed before the induction of anesthesia.

KEY MESSAGES

- The sitting position is used in both adults and children for posterior fossa lesions and posterior fossa decompression.
- There is ongoing debate regarding the use of the sitting position in both neurosurgery and neuroanesthesia.
- Various complications, particularly VAE, may occur in association with the sitting position. The risk is especially high in patients with cerebellar tumors, those with PFO on TEE, and those who undergo emergent operations.

Anesthesia induction was performed using 0.6 mg/kg rocuronium, 2–3 mg/kg propofol, and 1 μg/kg fentanyl, administered under BIS monitoring in all patients through IV administration. In pediatric patients without IV access, anesthesia induction was performed with sevoflurane. Total intravenous anesthesia was used for the maintenance of anesthesia.

A central venous catheter was placed under USG guidance following endotracheal intubation, with the right internal jugular vein used for this procedure. An arterial catheter was placed in all patients, and invasive arterial monitoring was performed. After intubation, minute ventilation was adjusted to obtain an end-tidal carbon dioxide pressure ($EtCO_2$) of 32–36 mmHg.

VAE was intraoperatively monitored based on $EtCO_2$ levels. VAE diagnosis was defined as a drop in $EtCO_2$ greater than 4 mmHg.

Surgical Preparations and Positioning

All information regarding surgical preparations and positioning was retrieved retrospectively from the anesthesia medical records and surgical notes.

All patients underwent a standard surgical procedure. IV antibiotics (cefazolin) were administered 30 minutes preoperatively to prevent surgical site infections. In all cases, the patient's skull was meticulously fixed using a Mayfield skull clamp. Patients with lesions in the cerebellopontine angle were subject to thorough intraoperative electrophysiological monitoring.

Patients were carefully elevated to the sitting position while monitoring arterial blood pressure. Depending on the patient's age and individual anatomy, either the entire operating table

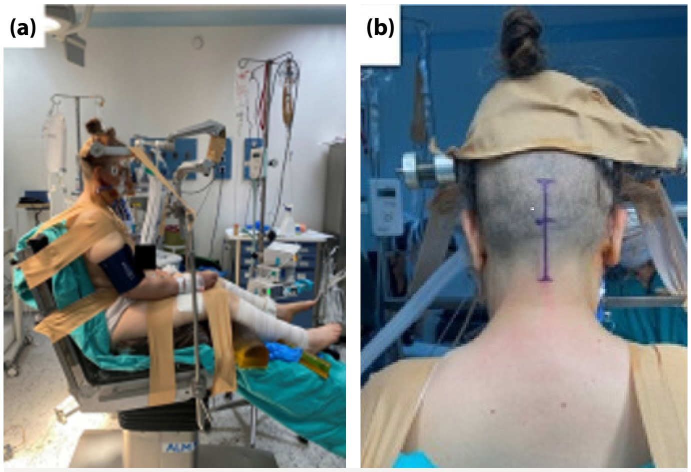

Figure 1. Sitting position for posterior fossa surgery. **(a)** Lateral view, **(b)** posterior view: the incision runs from the occipital external process to the spinal process of C2.

or only the upper body section was adjusted. In pediatric patients, surgical pads were used to support the sitting position. Patients were securely and comfortably positioned on the table with appropriate support to prevent significant compression. The head was placed in either a flexed or neutral position based on the surgical requirements (Fig. 1a, b).

The study was approved by the Local Ethics Committee (No: 2024/156; Date: 04/09/2024). Moreover, informed consent was obtained from the patients and/or their legal guardians.

Statistical Analysis

The Statistical Package for the Social Sciences (SPSS, IBM) software package version 21 (SPSS Inc., Chicago, IL, USA) was used to analyze the study data. The Shapiro–Wilk test was used to determine whether the study data met the normal distribution hypothesis.

For descriptive statistics, frequency, percentage, mean value, standard deviation, median value, and highest and lowest (min–max) values were used. Pearson's Chi-squared test was used for the statistical analysis of categorical data, and Fisher's Exact Test was applied to values below five.

Since the quantitative data in the independent groups were not normally distributed, the Mann–Whitney U test was used for comparisons between two groups, and the Kruskal–Wallis test (post hoc Dunn's test) was employed for comparisons among more than two groups. A difference with a p-value<0.05 was considered statistically significant.

The post hoc power analysis of the study was performed using G*Power 3.1.9.4.

RESULTS

Of the 73 patients in the study, 42 (57.5%) were women, and 31 (42.5%) were men. Moreover, 72.6% (n=53) were 18 years or above, and 27.4% (n=20) were pediatric patients. The mean age of all patients was 35.27±19.66 years (min–max: 4–75 years). The mean age of adult and pediatric patients was 44.43±14.68 years (min–max: 18–75 years) and 11.00±4.55 years (min–max: 4–17 years), respectively. Patients were diagnosed with cerebellar tumor (n=34), CM (n=31), and cerebellopontine angle tumor (n=8) (Table 1). There was no significant difference between pediatric and adult patients in terms of the frequency of radiologic diagnoses (p>0.05).

PFO was observed in 11 patients on TEE, and there was no significant difference in the occurrence of PFO between pediatric and adult patients. Seven patients had preoperative HSF, which was more prevalent in children. During the preoperative period, a VPS was performed in six patients (Table 2).

Median opening was preferred in the majority of patients (74%), and only four (5.5%) patients underwent emergent operations; 69 patients (94.5%) were operated under elective conditions. VAE occurred in 11 patients (overall incidence: 15.1%; incidence in children: 15% [3 patients]; incidence in adults: 15.1% [8 patients]). Nine patients had tension pneumocephalus, and seven had postoperative complications (CSF fistula in four patients, hemorrhage at the surgical site in two patients, and wound infection in one patient). No significant difference was observed between pediatric and adult patients regarding surgical and postoperative changes (p>0.05) (Table 3).

There was no significant difference regarding VAE and sex (p>0.05). Regarding the type of surgical opening, no VAE was observed in the retrosigmoid opening, and the difference was not significant. The rate of VAE was significantly higher in patients with cerebellar tumors (p<0.05), and VAE was considerably higher in patients with PFO on TEE (p<0.05). Of the 11 patients with VAE, three underwent an emergent operation, and eight were operated under elective conditions. VAE was significantly higher in patients who underwent emergency operations (p<0.05) (Table 4).

The mean duration of surgery was 138.63±50.77 minutes (min–max: 75–220 minutes). Although the surgical time was slightly lower in women, there was no significant difference (p=0.052). The duration of surgery was higher in patients with VAE and those who underwent emergency operations, but no statistically significant difference was observed (p>0.05). Moreover, surgery duration was significantly lower for surgical opening via the median approach than the retrosigmoid angulation (p<0.05) (Table 5).

Table 1. Classification of patients by diagnoses

	Total (n=73)	Child (n=20)	Adult (n=53)
Cerebellar tumors	34	10	24
Metastatic tumors	11	2	9
Lung tumor	5	–	5
Gastrointestinal tumor	3	1	2
Breast tumor	2	–	2
Germ cell tumor	1	1	–
Meningioma	5	–	5
Medulloblastoma	3	2	1
Pilocytic astrocytoma	5	2	3
Ependymoma	2	2	–
Glioneuronal tumor	1	–	1
Diffuse large b-cell lymphoma	2	–	2
High grade glial tumor	1	–	1
Diffuse astrocytoma, grade 2	1	1	–
Hemangioblastoma	2	–	2
Spindle cell tumour/hemangiopericytoma	1	1	–
Cerebellopontine angle tumor	8	–	8
Schwannom	4	–	4
Meningioma	3	–	3
Epidermoid Cyst	1	–	1
Chiari malformation	31	10	21

DISCUSSION

There is ongoing debate regarding sitting positions in both neurosurgery and neuroanesthesia. The sitting position offers numerous advantages to the neurosurgeon but also poses severe challenges to the anesthesiologist. It is well established that sitting may cause hypotension and decreased cardiac function, creating difficulties for neuroanesthesia in ensuring adequate cerebral blood pressure and oxygen delivery.[8] Despite the clear advantages of the sitting position, many centers do not prefer this position due to severe complications, including VAE.[3,6]

In posterior fossa lesions and posterior fossa decompression (PFD) cases, the sitting position is used in both adults and children.[10] A study by Himes et al.[2] suggested that the sitting position was a safe method for surgical access, provided that it was used appropriately with modern anesthesia techniques. Hermann et al.[5] reported that the semi-sitting position could be safely used in experienced centers to resect tumors in the posterior fossa in children under four years of age. Gupta et al.[11] referred to the sitting position as a safe option in the pediatric population with adequate anesthesia and surgical planning. In the present study, the sitting position was used in patients diagnosed with CM and posterior fossa tumors.

The advantages of the sitting position include better anatomical orientation and surgical exposure. Intraoperative gravity drainage of CSF and blood from the surgical site, which would otherwise occupy the site, contributes to visual clarity and surgical field dominance for the surgeon. It also enables easier surgical access to the anterior parts of the posterior fossa. Specifically, the reduced swelling of the cerebellum is considered an important advantage of the sitting position. Decreased intracranial pressure, shorter surgical time, better control over bleeding, reduced blood loss due to gravity drainage, and less accumulation of blood in the surgical site may contribute to better outcomes in patients operated on in the sitting position.

Furthermore, the anesthesiologist has several advantages, including easier ventilation with lower airway pressure, free diaphragm movements, and easier access to the tracheal tube, anterior chest, and extremities with arterial and venous cannulas.[3,6,8,9,12]

Table 2. Features in pediatric and adult patients

Variables	Patients						p	Effect size	Power
	All patients (n=73)		Child (n=20)		Adult (n=53)				
	n	%	n	%	n	%			
Radiological diagnosis							0.178*	0.218	0.461
Cerebellar tumor	34	46.5	10	50.0	24	45.3			
CM	31	42.5	10	50.0	21	39.6			
Cerebellopontine angle tumor	8	11.0	0	0.0	8	15.1			
TEE-PFO							0.270**	0.173	0.315
Yes	11	15.1	1	5.0	10	18.9			
No	62	84.9	19	95.0	43	81.1			
Comorbidity							0.145*	0.171	0.309
Yes	20	27.4	3	15.0	17	32.1			
No	53	72.6	17	85.0	36	67.9			
Pathological diagnosis							0.424	0.094	0.127
Yes	42	57.5	10	50.0	32	60.4			
No	31	42.5	10	50.0	21	39.6			
Pre-operative HSF							0.084**	0.217	0.458
Yes	7	9.6	4	20.0	3	5.7			
No	66	90.4	16	80.0	50	94.3			
Pre-operative VPS							**0.044**		
Yes	6	8.2	4	20.0	2	3.8			
No	67	91.8	16	80.0	51	96.2			

Column percentage was used. *: Pearson Chi-squared; **: Fisher's Exact Test; VPS: Ventriculoperitoneal shunt; CM: Chiari malformation; TEE: Transesophageal echocardiography; PFO: Patent foramen ovale; HSF: Hydrocephalus.

However, the sitting position is also associated with significant disadvantages. Hemodynamic changes may occur when moving the patient from a supine to a sitting position. A decrease in cerebral perfusion pressure and cerebral hypoxia may result from systemic hypotension in the event of a rapid transition to the sitting position. This may worsen in cases of jugular vein compression due to inappropriate head and neck positioning.

Srivastava et al.[13] suggested that patients should be gradually positioned, dehydration should be avoided by adequate intravenous fluid infusion, and intermittent compression devices could be applied to the lower extremities. The anesthesiologist should always have easy access to the patient without disturbing the surgical site to prevent the hemodynamic imbalances associated with this position. Himes et al.[2] suggested that head positioning should ideally be performed under neurophysiological monitoring to avoid spinal cord ischemia due to hypotension or cord compression caused by excessive neck flexion.

In the present study, the sitting position was applied gradually under colloid and crystalloid fluid support, and blood pressure values were measured at each stage. Hypotension was avoided throughout the operation. Excessive hyperflexion of the head was prevented to avoid jugular vein compression. Neuromonitoring was used only for cranial nerve electrophysiological examination in cases of pontocerebellar corner tumors. No cerebral or spinal cord hypoxia was observed in the patients included in the study.

The most crucial reason why certain neurosurgeons and anesthesiologists do not prefer the sitting position despite its potential advantages is the likelihood of VAE. VAE occurs when air passes through the operation site into the venous system. When the patient's head is positioned above heart level in the sitting position, it may lead to negative intracranial venous pressure. Negative pressure in the calvarium and cranial veins may result in air aspiration. The air enters the venous system, which may induce air embolism. This can usually occur during craniotomy, opening or closing of the dura, tumor excision, and muscle incision.

Table 3. Surgical procedures and complications in pediatric and adult patients

Variables	**Patients**						**p**	**Effect size**	**Power**
	All patients (n=73)		**Child (n=20)**		**Adult (n=53)**				
	n	**%**	**n**	**%**	**n**	**%**			
Surgical opening							0.117	0.242	0.543
Median	54	74.0	18	90.0	36	67.9			
Paramedian	12	16.4	2	10.0	10	18.9			
Retrosigmoid	7	9.6	0	0.0	7	13.2			
VAE occurrence							0.999	0.001	0.050
Yes	11	15.1	3	15.0	8	15.1			
No	62	84.9	17	85.0	45	84.9			
Postoperative complications							0.665	0.096	0.130
Yes	7	9.6	1	5.0	6	11.3			
No	66	90.4	19	95.0	47	88.7			
Fuji sign tension pneumocephalus							0.429	0.137	0.216
Yes	9	12.3	1	5.0	8	15.1			
No	64	97.7	19	95.0	45	84.9			
Type of surgery							0.301	0.122	0.181
Emergent	4	5.5	2	10.0	2	3.8			
Elective	69	94.5	18	90.0	51	96.2			

Percentage of columns used. Fisher's Exact Test. VAE: Venous air embolism.

VAE can produce diverse systemic effects. For example, paradoxical air embolism (PHE) may occur via the PFO.[3,14–16] Nevertheless, Fathi et al.[3] suggested that not every VAE results in PHE, and clinical outcomes depend on the amount of air passing into the arterial circulation.

Intraoperative monitoring for VAE can be performed based on $EtCO_2$ levels, Doppler USG, or intraoperative TEE.[2,6,7] Intraoperative TEE has been reported to be the most sensitive monitoring technique for VAE.[6,14,17] Ganslandt et al.[6] reported that there was a difference between the incidence of VAE detected by Doppler USG or TEE (19%) and the incidence of clinical symptoms, including drops in peripheral oxygen saturation (SpO_2) (3.3%) levels or $EtCO_2$ (10%).Nevertheless, certain studies have suggested that measuring $EtCO_2$ alone is sufficient for VAE monitoring in the sitting position.[18,19] VAE is defined by a 3–5 mmHg decrease in $EtCO_2$.[6,18] Intraoperative VAE monitoring was performed by measuring $EtCO_2$ levels (decrease >4 mmHg) for the patients included in the present study.

The incidence of VAE in the sitting position varies widely according to the relevant literature (1%–76%).[2,3,6–8,18,20,21] A lower incidence of VAE (9.3%–33%) has been reported in pediatric patients due to the relatively higher dural sinus pressure in children compared to adults.[19,22] In the present study, VAE was observed in 11 of 73 patients, with an overall incidence of 15.1%. There was no significant difference between children and adults (15% and 15.1%, respectively). Intraoperative treatment was required in three patients with VAE, with an incidence rate of 4.1%.

The incidence of VAE may also vary depending on the monitoring technique.[6,7] Ganslandt et al.[6] reported that the rate of VAE in patients monitored with Doppler USG was 9.4%, while the rate of VAE in patients monitored with TEE was 25.6%. Feigl et al.[7] reported that the incidence of VAE was 42.3% when assessed using TEE, whereas it was only 3.8% when defined by a decrease in $EtCO_2$ pressure of more than 3 mmHg.

Previous studies have suggested that the incidence of VAE is also associated with the duration of the operation and the surgical procedure. The incidence of VAE was higher in suboccipital craniotomy (2.7%) and cervical intradural cases (1.8%) compared to deep brain stimulation (0.3%) and cervical extradural cases (0.5%).[2] Fathi et al.[3] reported that the incidence of VAE was approximately three times higher in cranial cases

Table 4. VAE occurrence in patients and some likely associated variables

Variables	VAE				p	Effect size	Power
	Yes		No				
	n	%	n	%			
Sex					0.999	0.025	0.055
Female	6	14.3	36	85.7			
Male	5	16.1	26	83.9			
Radiological diagnosis					**0.036**		
Cerebellar tumor	9	26.5	25	73.5			
CM	2	6.5	29	93.5			
Cerebellopontine angle tumor	0	0.0	8	100.0			
TEE-PFO					**0.009**		
Not remarkable	6	9.7	56	90.3			
Yes	5	45.5	6	54.5			
Comorbidity					0.160	0.171	0.309
Yes	5	25.0	15	75.0			
No	6	11.3	47	88.7			
Pathological diagnosis					0.103	0.207	0.424
Yes	9	21.4	33	78.6			
No	2	6.5	29	93.5			
Pre-operative HSF					0.283	0.123	0.183
Yes	2	28.6	5	71.4			
No	9	13.6	57	86.4			
Pre-operative VPS					0.999	0.013	0.051
Yes	1	16.7	5	83.3			
No	10	14.9	57	85.1			
Surgical opening					0.503	0.137	0.216
Median	9	16.7	45	83.3			
Paramedian	2	16.7	10	83.3			
Retrosigmoid	0	0.0	7	100.0			
Postoperative complications					0.999	0.007	0.050
Yes	1	14.3	6	85.7			
No	10	15.2	56	54.8			
Fuji sign tension pneumocephalus					0.338	0.158	0.271
Yes	0	0.0	9	100.0			
No	11	17.2	53	82.8			
Type of surgery					**0.010**		
Emergent	3	75.0	1	25.0			
Elective	8	11.6	61	88.4			

Percentage of columns used. Fisher's Exact Test. TEE: Transesophageal echocardiography; PFO: Patent foramen ovale; VPS: Ventriculoperitoneal shunt; CM: Chiari malformation; VAE: Venous air embolism; HSF: Hydrocephalus.

Table 5. Duration of operation and some likely associated variables

Variables, n (%)	**Duration of operation (minute)**		**p**	**Effect size**	**Power**
	Median	**Min–Max**			
Sex			0.052*	0.551	0.611
Female, 42 (57.5)	90.0	75–220			
Male, 31 (42.5)	180.0	75–210			
Age			0.488*	0.156	0.088
Child, 20 (27.4)	120.0	75–210			
Adult, 53 (72.6)	150.0	75–220			
Comorbidity			0.508*	0.320	0.217
Yes, 20 (27.4)	150.0	80–200			
No, 53 (72.6)	100.0	75–220			
Pathological diagnosis			<**0.001***		
Yes, 42 (57.5)	180.0	140–220			
No, 31 (42.5)	80.0	75–100			
Radiological diagnosis			<**0.001****		
Cerebellar tumor, 34 (46.6)[b]	180.0	140–220			
CM, 31 (42.5)[a]	80.0	75–100			
Cerebellopontine angle tumor, 8 (11.0)[b]	195.0	170–210			
Surgical opening			**0.001****		
Median, 54 (74.0)[a]	90.0	75–220			
Paramedian, 12 (16.4)[ab]	170.0	140–200			
Retrosigmoid, 7 (9.6)[b]	200.0	170–210			
VAE occurrence			0.237*	0.504	0.317
Yes, 11 (15.1)	180.0	80–200			
No, 62 (84.9)	150.0	75–220			
Type of surgery			0.340*	0.825	0.339
Emergent, 4 (5.5)	165.0	150–200			
Elective, 69 (94.5)	150.0	75–220			

The groups responsible for the difference are represented by different letters. *: Mann–Whitney U test; **: Kruskal–Wallis test (post hoc Dunn's test); Min: Minimum; Max: Maximum; VAE: Venous air embolism; CM: Chiari malformation.

than in cervical ones. Dilmen et al.[19] suggested that the incidence of VAE was higher in posterior fossa procedures compared to upper spinal and supratentorial procedures.

In the present study, VAE was observed in patients with cerebellopontine angle tumors operated on via the retrosigmoid opening. In contrast, the rate of VAE was high and statistically significant in patients who underwent surgery for cerebellar tumors. This may be attributed to the calvarium being thin and composed of cortical bone in cerebellopontine angle craniotomy, whereas it is thicker and composed of spongiosa bone in midline craniotomy.

Regarding the relationship between the duration of surgery and VAE, Gharabaghi et al.[23] reported shorter operation durations and a lower incidence of VAE in their study. Consistently, in the present study, the duration of surgery was longer in patients with VAE, but no statistically significant difference was observed. Nevertheless, VAE was significantly higher in patients who underwent emergent operations than in those who underwent elective surgery. This may be attributed to the need for faster action in emergencies, inadequate intravascular fluid support, and partially inadequate bleeding control (insufficient coagulation of open vessels and failure to close bone openings).

It is essential to consider hemodynamic or respiratory deterioration associated with VAE rather than the mere detection of VAE. Girard et al.[20] suggested in a study of 342 patients that VAE occurred in seven cases, and four of them had tachycardia or hypotension. Ganslandt et al.[6] reported that the operation had to be terminated due to uncontrolled VAE in only three cases, and there was no mortality. Leslie et al.[18] suggested that there was no severe incidence of desaturation or hypotension in patients with VAE. Gale et al.[24] reported in a study of six different series that the incidence of severe VAE associated with hypotension ranged between 1% and 6%. A study by Feigl et al.[7] reported that no VAE resulted in hemodynamic instability requiring resuscitation.

In the present study, a decrease of more than 4 mmHg in $EtCO_2$ pressure was considered a significant indication of VAE. VAE-related hypotension occurred in 1 of 11 patients with VAE. Ephedrine (10 mg) was administered due to a >20% drop in blood pressure. In cases of persistent hypotension, noradrenaline infusion (0.2 µg/kg/min) was administered with fluid support and discontinued during the postoperative period. No operation was terminated due to intraoperative VAE. There was no mortality associated with any of the observed complications. Furthermore, no major intraoperative complications occurred.

The treatment of VAE aims to close the air entry site, remove air from the circulatory system, and maintain hemodynamic stability. Upon the occurrence of VAE, identifying the venous entry point is important; however, it is often impossible. The edges of the craniotomy are covered with bone wax, and the operation site is continuously irrigated with saline to prevent venous air entry. Patients are placed on the left side, and air is aspirated through the central venous catheter. Other possible interventions include external compression of the jugular veins, increasing inspiratory oxygen to 100%, and lowering the patient's head level.[15,20,24]

Himes et al.[2] reported that most VAEs responded to minimal interventions, including coagulation of open vessels, sealing bone edges with bone wax, or irrigation with copious amounts of saline. Dilmen et al.[19] emphasized that air aspiration through a central venous catheter is essential in VAE treatment.

In the present study, no additional treatment was required in eight of the 11 patients with intraoperatively detected VAE. In contrast, intracardiac air aspiration was performed via a central venous catheter in two patients. In one patient, catecholamine (0.2 µg/kg/min noradrenaline infusion) and fluid support were provided. In all other cases, the air embolism was eliminated intraoperatively through interventions such as closure of the bone opening with bone wax and vascular coagulation.

Although VAE is prevalent in the sitting position, it is not a complication unique to this position during neurosurgical procedures. It has been reported that VAE may also occur in supine and prone positions.[3,25] Fathi et al.[3] reported the incidence of VAE in the horizontal position as 0%–12%. Faberowski et al.[25] reported that the rate of VAE upon craniotomy performed in the prone position was 10%–17%.

The presence of PFO in a patient is considered a crucial criterion when determining the suitability of the sitting position. Although some neurosurgeons prefer to perform surgery in the sitting position even in the presence of PFO, others avoid it due to the risk of VAE-induced paradoxical embolism, which may lead to cerebral ischemia.[3,15] Porter et al.[26] suggested that a patent ventriculo-atrial shunt, PFO, cerebral ischemia in an upright position while awake, and right atrial pressure exceeding left atrial pressure should be considered absolute contraindications. Additionally, advanced age, uncontrolled hypertension, and chronic obstructive pulmonary disease were identified as relative contraindications.

Fathi et al.[3] reported that PFO occurs in 5%–33% of neurosurgical patients and suggested that PFO screening and closure should be considered in cases where the sitting position is preferred. Furthermore, PFO is recognized as a potential source of paradoxical emboli. In the case of PFO with intracardiac right-to-left shunts, air embolism may result in a paradoxical embolism in the brain or heart.[2,3,15,27,28] Due to the risk of paradoxical embolism, some experts consider PFO a contraindication for the sitting position and advocate for preoperative screening to identify patients with potential PFO before surgery.[20,21,26,29,30]

However, a systematic review by Klein et al.,[15] which included 977 patients (82 of whom had PFO) who underwent cervical spine or posterior fossa surgery, reported that air embolism occurred in 33 of 82 patients (40.2%), yet none experienced paradoxical embolism. The overall incidence of paradoxical embolism was low, suggesting that surgery could be safely performed without PFO closure. Nevertheless, if a PFO (>4 mm) or a persistent right-to-left shunt is present—especially in cases of pulmonary hypertension—preoperative PFO closure was recommended as these patients would be at a higher risk.[7,15]

In the present study, the incidence of PFO detected by preoperative TEE was 15% (11/73), and no preoperative closure procedure was performed for PFO. VAE was significantly higher in patients with PFO on TEE ($p<0.05$). Of the 11 patients with PFO, five (45.4%) had controllable VAE during the operation. Nevertheless, none of these cases developed paradoxical embolism.

Pneumocephalus, hypotension, central cord syndrome, and quadriplegia are among the other complications frequently associated with the sitting position.[6] Pneumocephalus is a common gravity-induced condition during cranial procedures. Consequently, its incidence in the sitting position is expected to be higher than in surgeries performed in the horizontal position.[2] Nevertheless, tension pneumocephalus, though rare, may also occur. The specific radiologic sign for tension pneumocephalus is the 'Mount Fuji' sign, characterized by the compression and separation of the frontal lobes due to subdural free air accumulation. Air may also become trapped in the subarachnoid and ventricular spaces in addition to the subdural space. Patients may present with Cushing's triad or epileptic seizures during the postoperative period.[13] However, tension pneumocephalus is not exclusively seen in the sitting position.[2,31]

Di Lorenzo et al.[32] reported that although pneumocephalus was observed in all patients, none developed tension pneumocephalus or neurological symptoms. Standefar et al.[33] reported that eight of 488 patients (1.6%) had symptomatic pneumocephalus, yet none required surgical intervention. However, a study of pediatric patients by Gupta et al.[11] found that postoperative tension pneumocephalus occurred in six (6.1%) patients. Among these, three developed epileptic seizures and were treated conservatively, whereas the remaining three required surgical evacuation via a twist drill burr-hole.

To prevent the occurrence of pneumocephalus, it has been recommended to flush the subdural space with saline, avoid nitrous oxide administration, and prevent hyperventilation before dura closure.[13] In the present study, pneumocephalus was observed in all patients, and only nine exhibited the Mount Fuji sign. However, none of these patients developed neurological symptoms, and no surgical intervention was required.

Several rare complications associated with the sitting position have also been described in previous studies. These include peripheral nerve palsies, subdural hemorrhage, piriformis syndrome, tension pneumoventricle, acute parotitis, spinal cord injury, sciatic nerve injury, and other cranial nerve palsies such as anosmia and delayed lateral rectus palsy.[2,11,33–39]

Previous studies in the relevant literature have compared the sitting position to the prone position.[8,9] Luostarinen et al.[8] reported in their prospective study comparing these two positions that the sitting position did not require more fluid therapy than the prone position. They also demonstrated that stable hemodynamics could be achieved in both operative positions with targeted fluid administration and moderate use of vasoactive drugs. Baro et al.[9] investigated the neurological outcomes and complications in patients who underwent posterior fossa surgery in either the sitting or prone position and reported no intergroup differences in operative data or neurological status.

Limitations

The retrospective design of the present study is its major limitation. As discussed, previous studies in the relevant literature are heterogeneous, highlighting the ongoing need for prospective studies.

In terms of patient population, the number of patients with cerebellopontine angle tumors in this study is lower compared to other diagnoses. Additionally, the use of $EtCO_2$ for VAE monitoring and the opportunity for simultaneous preoperative TEE in the sitting position were not available, which may also be considered limitations of the present study.

CONCLUSION

Various complications, particularly VAE, may occur in association with the sitting position. In the present study, VAE did not occur in pontocerebellar corner tumor operations performed in the sitting position. The sitting position can be used more safely in surgical operations for cerebellopontine angle tumors. However, the risk is elevated, especially in patients with cerebellar tumors, those with PFO on TEE, and those who undergo emergent operations.

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