Article

Analytical Assessment of Perioperative Complications in Neurosurgical Procedures Performed in the Sitting Position

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AIM: This study aimed to investigate the incidence and risk factors of perioperative complications in two types of neurosurgical procedures performed in the sitting position: deep brain stimulation (DBS) electrode placement and suboccipital craniotomy/craniectomy, with a focus on comparing their outcomes.
METHODS: This retrospective analysis included 259 patients who underwent sitting-position neurosurgery (DBS electrode placement, n = 104; suboccipital craniotomy/craniectomy, n = 155) between January 2019 and June 2024. Complications, including venous air embolism (VAE), tension pneumocephalus, and hemorrhage, were analyzed separately for each group. Multivariate logistic regression and subgroup analyses were performed to identify independent risk factors specific to each procedure.
RESULTS: The overall complication rate was higher in suboccipital craniotomy/craniectomy (14.19%) than in DBS (5.77%). For DBS, diabetes (odds ratio (OR) = 6.000, $p = 0.039$) was identified as a key risk factor. For suboccipital craniotomy/craniectomy, independent risk factors included age $\geq$60 years (OR = 2.152, $p = 0.006$), diabetes (OR = 3.412, $p = 0.020$), heart disease (OR = 3.262, $p = 0.048$), American Society of Anesthesiologists (ASA) grade III (OR = 2.346, $p = 0.007$), and prolonged operative time (OR = 1.983, $p = 0.015$).
CONCLUSIONS: Neurosurgery in the sitting position demonstrates varying complication risks depending on surgical type and patient-specific factors. Strict perioperative monitoring and individualized positioning strategies are essential, particularly for elderly patients and those with comorbidities. These findings provide valuable insights for optimizing surgical safety and guiding future prospective studies.

Keywords: neurosurgical procedures; sitting position; perioperative complications; risk factors; deep brain stimulation

Introduction

In neurosurgical practice, patient positioning directly impacts surgical exposure and safety [1–3]. The sitting position, once widely used, offers advantages such as improved visualization of deep structures, reduced cerebellar traction, and enhanced venous drainage [4–6]. However, it is associated with risks like venous air embolism (VAE), tension pneumocephalus, and hemorrhage [7,8], which vary by procedure complexity.

Debate persists regarding the use of the sitting position, with some surgeons avoiding it due to complication concerns, while others advocate for its benefits in specific cases [9,10]. Recent studies suggest complication rates can be controlled with strict monitoring [11,12], but variability in reported outcomes and understudied risk factors necessitate further investigation.

This study focuses on two distinct sitting-position neurosurgical procedures—deep brain stimulation (DBS) electrode placement (a minimally invasive intervention) and suboccipital craniotomy/craniectomy (an open, high-complexity procedure). By analyzing their perioperative complications and risk factors separately, we aim to provide targeted guidance for clinical decision-making.

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Materials and Methods

Baseline Information

This study included 259 patients who underwent sitting-position neurosurgery (DBS electrode placement or suboccipital craniotomy/craniectomy) at Zhongnan Hospital of Wuhan University between January 2019 and June 2024. Collect information on the reasons for patients' surgeries. Among them, the reasons for surgery in patients undergoing DBS electrode implantation include Parkinson's disease, essential tremor, and dystonia. The reasons for surgery in patients undergoing suboccipital craniotomy/craniotomy resection include cerebellar tumors, Chiari malformation, posterior fossa vascular malformations, and other posterior fossa lesions (such as meningiomas in the foramen magnum area). These reasons were respectively included in the corresponding baseline data tables for statistics. The study was approved by the Ethics Committee of Zhongnan Hospital of Wuhan University (Approval No. 2023152K) and followed the Declaration of Helsinki. Informed consent was obtained from all patients.

Fig. 1. Schematic diagram of the sitting position. (A) The right side of the patient in sitting surgery. (B) The left side of the patient in sitting surgery. (C) The rear of the patient in sitting surgery.

Patient Selection Criteria

The inclusion criteria for patient selection were as follows: ① Patients aged $\geq$18 years; ② Undergoing DBS electrode placement or suboccipital craniotomy/craniectomy in the sitting position; ③ With complete clinical data (medical records, anesthesia records, surgical reports, imaging).

The exclusion criteria were as follows: ① Percutaneous surgeries; ② Refusal to participate; ③ Severe cardiopulmonary dysfunction, abnormal coagulation, or other surgical contraindications; ④ Intraoperative position changes (not maintaining sitting position); ⑤ Incomplete clinical data; ⑥ American Society of Anesthesiologists (ASA) grade IV or V (due to critical systemic disease precluding elective sitting-position surgery). (ASA IV: severe life-threatening illness; ASA V: moribund patients not expected to survive without surgery), which contraindicates elective neurosurgical procedures in the sitting position. The sitting position may exacerbate hemodynamic instability in high-risk patients, increasing perioperative mortality. Additionally, ASA IV–V patients often require emergent interventions, which were beyond the scope of this study focused on elective surgeries.

Initially, 386 patients were screened; 127 were excluded (percutaneous surgeries, n = 32; position changes, n = 45; incomplete data, n = 28; ASA IV–V, n = 22), leaving 259 for analysis.

Treatment Protocols

Surgical Approaches

(1) DBS electrode placement: Electrodes were implanted using stereotactic guidance (based on preoperative magnetic resonance imaging/computed tomography (MRI/CT)) to target specific deep brain nuclei (e.g., subthalamic nucleus, globus pallidus). The procedure involved burr hole creation, stereotactic frame fixation, and electrode insertion under neurophysiological monitoring.

(2) Suboccipital craniotomy/craniectomy: For lesions involving the posterior fossa (e.g., cerebellar tumors, Chiari malformations), a midline suboccipital incision was made, followed by craniotomy/craniectomy to expose the dura. The dura was opened to resect or decompress the lesion, with careful preservation of cranial nerves and vascular structures.

Intraoperative Position Management

The patients were positioned in a sitting posture using a standardized protocol. The head was immobilized using a Mayfield Skull Clamp System (Integra LifeSciences, Plainsboro, NJ, USA), which allows multi-axis adjustment for precise alignment. For craniocerebral surgeries (e.g., suboccipital craniotomy), the head was fixed in a neutral position, with the Mayfield clamp pins placed symmetrically along the superior temporal line (1 cm anterior to the external auditory meatus and 2 cm above the orbital rim) to maintain anatomical neutrality. The head was then bent 15°–20° to optimize surgical visibility of the posterior fossa. In cervical spine surgeries, the head was gently extended (10°–15°) to align the cervical vertebrae parallel to the floor, with the Mayfield clamp positioned at the parietal eminence to avoid pressure on the occipital nerves. All positioning adjustments were made based on preoperative imaging (MRI/CT) to avoid vascular compression (e.g., vertebral artery) and ensure a safe surgical corridor. Intraoperative neuromonitoring, such as somatosensory evoked potential, was used to confirm the absence of neural compromise during positioning (Fig. 1).

Intraoperative Monitoring

Intraoperative monitoring utilizes a variety of approaches to ensure the early detection and timely prevention of potential complications. For VAE monitoring, precordial Doppler ultrasound (LOGIQ E9 systems, GE Healthcare, Wauwatosa, WI, USA) was applied with a 2-MHz continuous-wave transducer placed over the right parasternal border (third to fifth intercostal spaces) to detect gas emboli in the right atrium. A positive VAE was identified as the presence of characteristic ‘mill-wheel’ murmurs or $\geq$3 consecutive gas bubble signals within 10 seconds. For sitting craniocerebral surgeries, this method was supplemented with transesophageal echocardiography (TEE) and central venous pressure monitoring to increase sensitivity. In DBS surgeries, only precordial Doppler ultrasound was utilized due to the simplicity of the procedure.

Anesthesia Management

General anesthesia was administered using a standardized protocol for hemodynamic control. The target blood pressure ranges were set with a mean arterial pressure (MAP) of 65–90 mmHg and a systolic blood pressure (SBP) of 90–140 mmHg, individualized based on preoperative baselines. Invasive arterial monitoring was applied to guide real-time adjustments. Norepinephrine infusion (0.05–0.3 µg/kg/min) was initiated for hypotension (MAP decrease $>$20% or SBP $<$90 mmHg), with ephedrine boluses (5–10 mg IV) used for refractory cases. Hypertension (SBP $>$140 mmHg) was managed with urapidil (10–25 mg IV) or sevoflurane titration. Fluid therapy followed goal-directed protocols with stroke volume variation maintained $<$13%. These measures aimed at minimizing hemodynamic fluctuations that could lead to complications (e.g., venous air embolism).

Furthermore, fluid therapy followed goal-directed protocols, maintaining stroke volume variation below 13%. Close monitoring and controlling fluid balance were essential to ensure stable circulatory function. Appropriate fluid administration helped prevent hypovolemia-induced hypotension and complications like pulmonary edema from hypotension, which could potentially increase the risk of perioperative issues. Additionally, maintaining stable fluid levels is crucial for normal tissue perfusion and oxygen delivery during surgery, which ultimately supports overall outcomes and reduces the risk of complications.

Management of Complications

Appropriate preventive measures were implemented to address potential complications like VAE, tension pneumocephalus, and subdural or intracranial hemorrhage. For instance, during the surgical procedure, special attention was given to keeping the surgical site unobstructed and preventing any damage to blood vessels. In the case of VAE, careful adjustments of the patient's position and specific surgical techniques were employed to minimize the likelihood of air embolism. If complications occur, immediate treatment is initiated. For VAE, different therapeutic measures were taken depending on severity, which may include repositioning the patient, supplying oxygen, and using vasopressors. For tension pneumocephalus, puncturing and draining the affected area may be necessary.

Observational Indicators

Observational indicators assessed during the study were as follows:

(1) Complication-related indicators: These indicators included the incidence and severity (moderate/severe) of VAE, the incidence of tension pneumocephalus, and intraoperative/postoperative hemorrhage. Moderate complications required medical interventions (e.g., vasopressors for hypotension and antibiotic therapy for infection) but did not result in life-threatening outcomes or permanent disability. Severe complications included life-threatening events (e.g., cardiac arrest from VAE and tension pneumocephalus requiring decompression) or those leading to permanent neurological deficit (e.g., quadriplegia). Severity was independently evaluated by a multidisciplinary team (neurosurgeons, anesthesiologists, and intensivists) who were blinded to patient demographics and surgical details. Any discrepancies were resolved through consensus.

(2) Surgery-related indicators: Procedure type, operative time, intraoperative blood loss.

(3) Patient-related indicators: Patient age, underlying diseases (diabetes, hypertension, heart disease), and ASA classification (grades I–III) were recorded. Age was categorized into two subgroups (18–60 years and 61–76 years) based on clinical consensus and physiological relevance. Although the World Health Organization (WHO) defines individuals aged $\geq$65 years as 'elderly', the threshold of 60 years was selected to align with the surgical risk stratification typically used in neurosurgical practice.

(4) Intraoperative systolic blood pressure fluctuation is defined as a difference of $\geq$30 mmHg between the maximum and minimum systolic blood pressures recorded during surgery.

(5) The imaging-related indicator is the maximum diameter of the lesion before surgery, categorized as $\geq$3 cm or $<$3 cm.

Statistical Analysis

Statistical analyses were performed using SPSS 25.0 (IBM Corp., Armonk, NY, USA). Categorical variables were presented as frequencies and percentages, while continuous variables were described using statistical measures such as means and standard deviations. Categorical variables were analyzed and compared using the chi-square test or Fisher's exact test. The Shapiro-Wilk test was used to assess normality across continuous variables. Normal distribution continuous variables are expressed as mean $\pm$ standard deviation, and non-normal distribution variables are expressed as median and interquartile range. Multivariate analysis was conducted using a logistic regression model, with the odds ratio (OR) and its 95% CI computed to evaluate the association between risk factors and the incidence of complications.

Variables for the multivariate logistic regression model were selected based on: ① univariate association with complications ($p < 0.1$); ② clinical relevance as supported by prior research (e.g., age, comorbidities, and procedure duration). Variables exhibiting multicollinearity (e.g., surgical type and lesion size) were excluded to maintain model stability. Final variables were retained using stepwise regression ($p < 0.05$). A significance level of $p < 0.05$ was used to determine statistical significance.

Furthermore, subgroup analyses were conducted to evaluate the interaction between clinical factors (e.g., age, diabetes, etc.) and surgical types (e.g., DBS, suboccipital craniotomy). Complications across subgroups were compared using chi-square or Fisher's exact tests. Interaction terms were incorporated into multivariate logistic regression models to test for subgroup differences ($p < 0.05$).

Table 1. Baseline data of patients with DBS electrode placement.

Variable	DBS electrode placement (n = 104)
Age, median (min–max), years	51 (18–72)
Male, n (%)	57 (54.8)
BMI, mean ± SD, kg/m²	23.8 ± 3.1
Comorbidities, n (%)	
- Diabetes	18 (17.3)
- Hypertension	8 (7.7)
- Heart disease	10 (9.6)
ASA classification, n (%)	
- Grade I	32 (30.8)
- Grade II	58 (55.8)
- Grade III	14 (13.5)
Operative time, mean ± SD, min	120 ± 20
Intraoperative blood loss, mean ± SD, mL	50 ± 10
SBP fluctuation ≥30 mmHg, n (%)	42 (40.4)
Reasons for surgery (case, %)	
Parkinson's disease	68 (65.4)
Essential tremor	22 (21.2)
Dystonia	14 (13.5)

Note: BMI, body mass index; DBS, deep brain stimulation; ASA, American Society of Anesthesiologists; SBP, systolic blood pressure.

Table 2. Baseline data of patients with suboccipital craniotomy/craniectomy.

Variable	Suboccipital craniotomy/craniectomy (n = 155)
Age, median (min–max), years	55 (22–76)
Male, n (%)	85 (54.8)
BMI, mean ± SD, kg/m²	24.3 ± 3.3
Comorbidities, n (%)	
- Diabetes	23 (14.8)
- Hypertension	15 (9.7)
- Heart disease	16 (10.3)
ASA classification, n (%)	
- Grade I	88 (56.8)
- Grade II	92 (59.4)
- Grade III	90 (58.1)
Operative time, mean ± SD, min	185 ± 25
Intraoperative blood loss, mean ± SD, mL	200 ± 30
SBP fluctuation ≥30 mmHg, n (%)	88 (56.8)
Reasons for surgery (case, %)	
Cerebellar tumor	76 (49.0)
Chiari malformation	45 (29.0)
Posterior fossa vascular malformation	24 (15.5)
Others	10 (6.5)

Results

Analysis of Baseline Information Across Study Participants

The baseline characteristics of patients who underwent DBS electrode implantation and those who underwent suboccipital craniotomy/cranioresection are summarized in Tables 1,2, respectively. The DBS group mainly had functional diseases (Parkinson's disease accounted for the highest proportion, reaching 65.4%), while the suboccipital craniotomy group mainly had organic lesions (cerebellar tumor accounted for the highest proportion, reaching 49.0%), which is consistent with the clinical treatment positioning of the two surgeries.

Incidence of Complications

DBS Electrode Placement

Overall complication rate: 5.77% (6/104). Specific complications: moderate/severe VAE (0.96%, 1/104), hemorrhage (0.96%, 1/104), tension pneumocephalus (3.85%, 4/104) (Table 3).

Table 3. Incidence of complications in patients undergoing DBS electrode placement (n = 104).

Complication	Cases (n)	Incidence rate (%)
Overall	6	5.77
Moderate/severe VAE	1	0.96
Tension pneumocephalus	4	3.85
Hemorrhage	1	0.96

Note: VAE, venous air embolism.

Table 4. Incidence of complications in patients undergoing suboccipital craniotomy/cranioresection (n = 155).

Complication	Cases (n)	Incidence rate (%)
Overall	22	14.19
Moderate/severe VAE	11	7.10
Tension pneumocephalus	5	3.22
Hemorrhage	6	3.87

Suboccipital Craniotomy/Craniectomy

Overall complication rate: 14.19% (22/155). Specific complications: moderate/severe VAE (7.10%, 11/155), tension pneumocephalus (3.22%, 5/155), hemorrhage (3.87%, 6/155) (Table 4).

Risk Factors for Complications

DBS Electrode Placement

Univariate analysis showed diabetes (p = 0.042) was associated with complications. Multivariate analysis confirmed diabetes as an independent risk factor (OR = 6.000, 95% CI = 1.099–32.758, p = 0.039). Other factors (age, ASA grade, operative time) showed no significant association ($p > 0.05$) (Fig. 2).

Suboccipital Craniotomy/Craniectomy

Univariate analysis identified age $\geq$60 years (p = 0.005), diabetes (p = 0.008), heart disease (p = 0.049), ASA grade III (p = 0.009), and operative time $\geq$200 min (p = 0.017) as associated with complications (Fig. 3). Multivariate analysis confirmed:

Age $\geq$60 years (OR = 0.319, 95% CI = 0.122–0.834, p = 0.020).

Diabetes (OR = 3.412, 95% CI = 1.208–9.637, p = 0.020).

Heart disease (OR = 3.262, 95% CI = 1.010–10.538, p = 0.048).

Subgroup Analysis: Impact of Clinical Factors on the Incidence of Complications

In the subgroup analysis, we presented the occurrence of complications associated with different clinical factors in various surgical procedures using a forest plot. In sitting-position DBS electrode placement surgery, patients with diabetes had a substantially higher risk of complications compared to those without diabetes (OR = 6.000, 95% CI = 1.099–32.758, p = 0.039) (Fig. 2). In individuals undergoing suboccipital craniotomy/craniectomy in sitting position, younger patients (18–60 years old) had fewer complications than older patients (61–76 years old) (OR = 0.319, 95% CI = 0.122–0.834, p = 0.020) (Fig. 3). Furthermore, patients with diabetes had a higher likelihood of complications than those without diabetes (OR = 3.412, 95% CI = 1.208–9.637, p = 0.020), and patients with heart disease had a higher risk of complications compared to those without heart disease (OR = 3.262, 95% CI = 1.010–10.538, p = 0.048). These observations indicate that elderly patients and those with diabetes or heart disease are at an increasing risk of complications during sitting-position suboccipital craniotomy/craniectomy and may require more intensive intraoperative and postoperative monitoring, or even a change in surgical position.

Discussion

In this study, we conducted a comprehensive analysis of the perioperative complications in 259 patients who underwent neurosurgical procedures in the sitting position. In terms of specific types of complications, the incidence of moderate/severe VAE in the DBS group was only 0.96%, while that in the suboccipital craniotomy group reached 7.10%. This is likely due to the larger surgical field in suboccipital surgeries, which exposes venous sinuses (e.g., transverse sinus) to atmospheric pressure, creating a higher risk of air entry. In contrast, DBS avoids significant sinus exposure, explaining its lower VAE risk. Tension pneumocephalus rates were comparable between groups (3.85% in DBS vs. 3.22% in suboccipital procedures), suggesting this complication is more related to sitting-position physiology (e.g., intracranial pressure fluctuations) than procedure type. Hemorrhage incidence was low in both groups (0.96% vs. 3.87%).

Hervías *et al*. [13] reported that the incidence of VAE was 21.5% in craniotomy, which was slightly higher than the incidence observed in our study. In another study involving 740 sitting-position surgeries, Al-Afif *et al*. [14] reported a VAE incidence of 16.1%. These differences may be dure to several factors. For example, the proficiency of surgical techniques can vary across research centers, with advanced surgical skills potentially reducing the risk of certain complications. Furthermore, differences in monitoring methods may also affect the identification rate of complications; for instance, more accurate monitoring equipment can detect potential VAE more quickly [15]. Additionally, patient-related factors, such as overall health status and the complexity of the lesion, also play a vital role. Regarding the influence of clinical factors on complications, several studies align with the findings of our study. For example, factors like age and underlying diseases have also been confirmed to be associated with the occurrence of complications in other studies, although the specific degree of association and the influence of these factors may vary depending on the study population and research setting [16,17]. These similarities and differences provide additional valuable insights for further clarifying the occurrence patterns

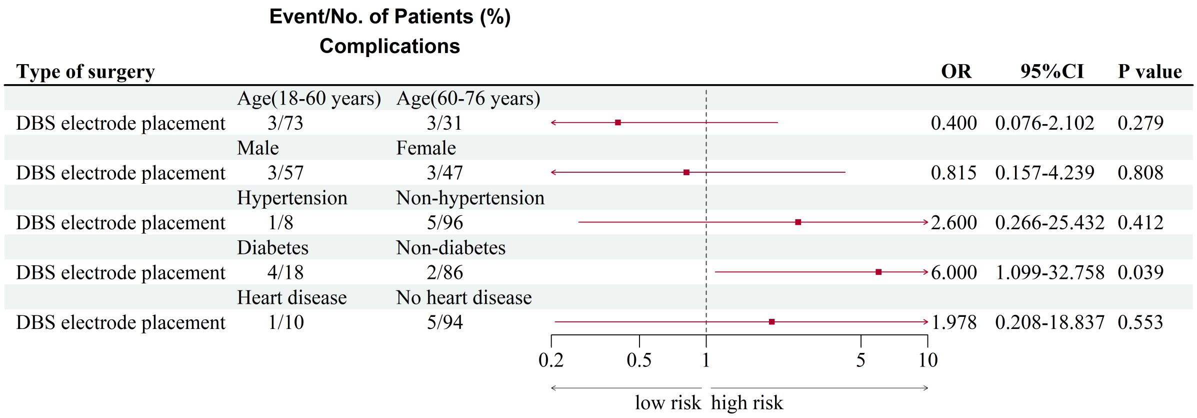

Fig. 2. Subgroup analysis using forest map for DBS electrode placement.

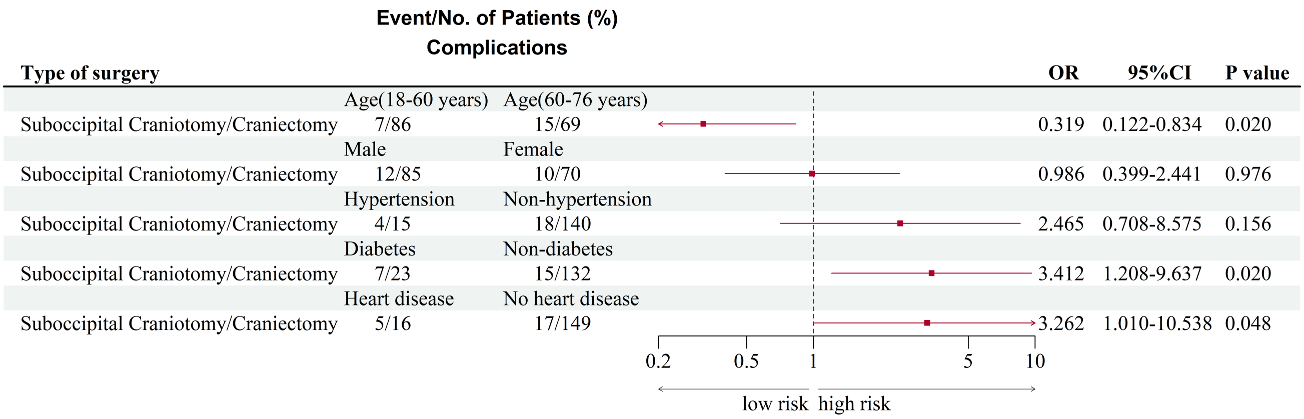

Fig. 3. Subgroup analysis using forest map for suboccipital craniotomy/craniectomy.

of complications in neurosurgical procedures conducted in the sitting position, which can inform clinical practice and guide subsequent research.

In suboccipital craniotomy/craniectomy, multiple independent risk factors were identified. Age $\geq$60 years was associated with a 2.152-fold increased risk (95% CI = 1.320–3.513, p = 0.006), likely due to age-related physiological decline (e.g., reduced cardiopulmonary reserve, vascular elasticity) that increases vulnerability to hemodynamic instability [18]. Diabetes also elevated risk (OR = 3.412, 95% CI = 1.208–9.637, p = 0.020), potentially via impaired hemostasis and tissue repair that heighten risks of hemorrhage and surgical site infection. Patients with heart disease faced a 3.262-fold higher risk (95% CI = 1.010–10.538, p = 0.048), as cardiac dysfunction can exacerbate hemodynamic compromise from VAE. ASA grade III (OR = 2.346, 95% CI = 1.277–4.325, p = 0.007) indicated poor baseline health, reducing tolerance to surgical stress, while operative time $\geq$200 min (OR = 1.983, 95% CI = 1.152–3.424, p = 0.015) increased cumulative VAE risk via extended venous sinus exposure. These factors collectively highlight the need for careful patient selection in suboccipital surgeries; for high-risk groups (e.g., elderly patients with diabetes or heart disease), alternative positions (e.g., prone) should be considered unless the technical benefits of sitting (e.g., improved visualization) clearly outweigh risks.

In this study, no substantial association was observed between gender and the complication rate ($p > 0.05$). This indicates that, under current research conditions, gender may not be a significant factor affecting the occurrence of complications in neurosurgical procedures conducted in the sitting position. However, other studies may reach different conclusions due to specific characteristics of the research participants or differences in sample size. From a physiological perspective, although there are certain differences in the physiological structures of men and women, these differences may not play a leading role in the occurrence of complications in sitting-position surgeries or may be masked by other factors.

In this study, we observed that DBS electrode placement surgery is relatively simple and flexible in terms of positioning. The sitting position offers certain advantages in this surgery. From the perspective of surgical convenience, the sitting position allows surgeons to accurately place the electrode in the target brain area. Furthermore, this may offer patients great comfort, reducing the discomfort associated with extended surgery. However, although the complication rate is relatively low, individual differences still need to be considered. For example, diabetic patients showed a higher risk of complications, suggesting that extra caution should be taken when selecting the sitting position for surgery in such patients, and perioperative management should be strengthened.

This surgery is technically complex and carries a high risk of complications. For patients in good physical condition and with an experienced surgical team, the sitting position may be a feasible option under strict monitoring. In such cases, the sitting position can take advantage of gravity to improve the surgical field of view, reduce cerebellar retraction, and facilitate the surgical procedure. However, for patients with poor physical conditions and multiple underlying diseases (such as elderly patients with diabetes or heart disease), the significantly increased risk of complications warrants a comprehensive evaluation of the surgical risk and benefits. In these cases, other positions should be considered to reduce surgical risk and ensure patient safety.

In posterior cervical spine surgery, epidural surgery carries a relatively lower risk of complications than intradural surgery. For epidural surgery, when the patient's physical condition permits, the sitting position provides a better surgical field of view and operational convenience, enabling surgeons to more clearly expose the surgical site, perform precise operations, and reduce the risk of damage to surrounding tissues. Conversely, intradural surgery inherently carries a higher risk of complications, such as the higher incidence of VAE found in this study. Consequently, more cautious evaluation is required when selecting the sitting position for intradural procedures. Factors such as the patient's age and underlying diseases should be carefully considered, weighing the advantages of enhanced visualization and procedural ease against the potential risks of complications.

Individual characteristics play a crucial role in selecting the appropriate surgical position. As patients age, physical function declines, and their tolerance for surgical trauma reduces. For example, in suboccipital craniotomy/craniectomy, elderly patients experience an elevated risk of complications. Therefore, more caution is needed when selecting the surgical position, with a comprehensive assessment of the patient physical condition to determine their ability to tolerate sitting-position surgery. The presence, type, and severity of underlying diseases also significantly impact the decision. Patients' conditions, such as diabetes, hypertension, or heart disease can impair physiological functions, increasing the possibility of surgical risks and complications. For example, hypertensive patients may be at higher risk for blood pressure fluctuations during sitting-position surgery, affecting the safety of the procedure. Therefore, in clinical practice, personalized position plans should be formulated based on individual patient factors, including age, underlying diseases, and overall health, to minimize complications, optimize surgical outcomes, and ensure better patient prognosis.

Through the multivariate logistic regression model, this study identified age $\geq$60 years, diabetes, heart disease as independent risk factors for complications in craniocerebral surgeries. These findings are consistent with previous results of Scheer *et al*. [19], which showed that blood glucose fluctuations in diabetic patients can affect wound healing and significantly increase the risk of infection. Pertsch *et al*. [20] also confirmed that prolonged operation time is positively correlated with the risk of complications. This study further quantified the independent effects of each variable by adjusting for confounding factors, suggesting that in clinical practice, perioperative management should be optimized for elderly patients, diabetic patients, and those with ASA III grade. Furthermore, the high incidence of VAE in suboccipital craniotomy/craniectomy indicates that the anesthesia team should precisely regulate hemodynamics to reduce such complications.

Multivariate analysis by surgical approach shows that complications in craniocerebral surgeries vary by procedure type: DBS electrode placement is primarily associated with diabetes, while suboccipital craniotomy/craniectomy is associated with age $\geq$60 years, diabetes, heart disease. This suggests the need for tailored risk management methods depending on the specific craniocerebral procedure.

Despite promising outcomes, this study possesses several limitations. Firstly, the retrospective study design may introduce selection and information biases, which could affect the external validity and accuracy of the findings. Although the sample size is significant, the statistical power for analyzing rare complications or complex factors may be insufficient. Secondly, limited intraoperative monitoring methods may lead to a missed diagnosis of complications or inaccurate evaluations. Differences in monitoring equipment and inconsistencies in the definition and evaluation standards for complications limit the reliability, consistency, and comparability of the outcomes. Thirdly, this study did not comprehensively analyze potential factors such as surgeons experience, anesthesia duration, patients psychological state, and preoperative medication, which may affect the comprehensiveness and accuracy of the results and hinder the understanding of the mechanisms behind complication occurrence. Fourthly, the exclusion of ASA IV–V patients (due to contraindications for elective sitting-position surgery) limits the generalizability of the results to critically ill populations, potentially underestimating the accurate risk profile of these procedures. Fifthly, while the age cutoff of $\geq$60 years aligns with neurosurgical risk stratification guidelines, the absence of direct frailty assessments (e.g., Modified Frailty Index-5) limits our ability to distinguish between chronological age and biological vulnerability.

In terms of clinical practical significance, this study provides valuable guidance for neurosurgeons in selecting sitting-position surgeries. For example, in DBS electrode placement surgery, the sitting position can be preferentially considered under appropriate conditions, with special attention given to high-risk groups. For suboccipital craniotomy/craniectomy, a comprehensive assessment of the patient's condition is required to choose the optimal position, with enhanced observation and care. In terms of future research directions, prospective studies with larger sample sizes should be performed, monitoring techniques and methods should be improved, and the definition and evaluation standards for complications should be standardized. Further investigation of potential influencing factors and the development of new surgical and position management strategies will help enhance the understanding and handling ability of complications in neurosurgical procedures conducted in the sitting position.

Conclusions

This study systematically analyzed perioperative complications in neurosurgical procedures conducted in the sitting position, identifying the occurrence of complications across different surgical types, and the influence of relevant clinical factors. Although there are certain limitations, the results provide valuable insights for clinical practice, helping neurosurgeons in making more informed decisions regarding surgical position selection and patient management. Furthermore, the study outlines directions for future research, with the expectation that subsequent studies will further improve the understanding and management of complications in neurosurgical procedures performed in the sitting position, ultimately enhancing surgical safety and patient prognosis.

Availability of Data and Materials

The data analyzed are available from the corresponding author upon reasonable request.

Author Contributions

KZ and GZ conceived and designed the study. XG and YX analyzed the data. YX contributed to the data curation. KZ wrote the original draft. GZ participated in the writing-review and editing. All authors have been involved in revising it critically for important intellectual content. All authors gave final approval of the version to be published. All authors have participated sufficiently in the work to take public responsibility for appropriate portions of the content and agreed to be accountable for all aspects of the work in ensuring that questions related to its accuracy or integrity.

Ethics Approval and Consent to Participate

This study was conducted in adherence to the guidelines of the Declaration of Helsinki and officially approved by the Ethics Committee of Zhongnan Hospital of Wuhan University (Approval No. 2023152K). Furthermore, informed consent was obtained from all patients after explaining to them the study's objectives.

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Conflict of Interest

The authors declare no conflict of interest.

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