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Total intravenous anesthesia versus inhalational anesthesia in craniotomy: A comparative analysis

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Abstract

Background: Craniotomy requires precise anesthetic management to ensure brain relaxation, hemodynamic stability, and rapid recovery. Total intravenous anesthesia (TIVA) offers better intracranial pressure control and reduced post-operative nausea, while inhalational anesthesia allows faster emergence. This study aims to compare TIVA and inhalational anesthesia in elective supratentorial craniotomy, focusing on intraoperative stability, recovery, and post-operative outcomes.

Methods: This prospective comparative study included 100 adults undergoing elective supratentorial craniotomy, randomized to receive either TIVA with propofol–fentanyl or inhalational anesthesia with isoflurane/sevoflurane and opioids. Conducted at (study place) from (start) to (end), it enrolled American Society of Anesthesiologists I–III patients over 18 years, excluding emergencies, severe systemic disease, or drug allergies. Intraoperative hemodynamics, anesthetic use, emergence, post-operative scores, and complications were analyzed using the Statistical Package for the Social Sciences 26; $P < 0.05$ was considered significant.

Results: The TIVA group showed slightly better post-operative neurological recovery, with more patients maintaining higher GCS scores at 24 h. Intraoperatively, TIVA provided greater hemodynamic stability with significantly lower heart rates during induction and craniotomy. Fentanyl and vasopressor use were higher in the inhalational group. Recovery was faster in TIVA patients, with significantly shorter times to extubation, eye opening, following commands, and mobilization (P <0.001). Post-operative sedation decreased, and pain increased over time in both groups. Complication rates, including nausea, infection, seizures, and thromboembolism, were low and comparable.

Conclusion: TIVA and inhalational anesthesia are both safe for adult craniotomy. However, TIVA offers faster recovery and better early neurological outcomes, making it a suitable choice when prompt post-operative assessment is essential.

Keywords: Craniotomy, inhalational anesthesia, recovery profile and hemodynamic stability, total intravenous anesthesia

Introduction

Craniotomy remains one of the most frequently performed neurosurgical procedures worldwide, indicated for tumors, vascular lesions, trauma, and other intracranial pathologies. Globally, brain and central nervous system tumors account for approximately 296,851 new cases and 241,037 deaths annually, representing about 1.6% of all cancers and 2.5% of global cancer mortality.[1] More than half of these cases occur in Asia, where resource limitations often complicate perioperative management.[2] Given this substantial surgical burden, optimizing anesthetic management is critical for improving perioperative safety and neurological outcomes. Anesthesia for neurosurgery presents unique challenges. The goals include maintaining cerebral perfusion pressure, preventing rises in intracranial pressure (ICP), ensuring adequate brain relaxation for surgical access, and enabling rapid post-operative neurological evaluation.[3] Two principal techniques are commonly employed: Inhalational anesthesia, typically using isoflurane or sevoflurane, and total intravenous anesthesia (TIVA) using propofol and short-acting opioids, such as fentanyl. Despite decades of use, there remains no universal consensus regarding the superior technique for craniotomy, and anesthetic practices vary widely among institutions.[4] Pharmacologically, the two techniques exert distinct effects on cerebral physiology. Propofol-based TIVA reduces the cerebral metabolic rate and causes cerebral vasoconstriction, thereby decreasing both cerebral blood flow (CBF) and ICP.[3] This produces a relaxed brain and improves surgical conditions. Volatile agents, by contrast, produce dose-dependent cerebral vasodilation and may increase ICP at higher concentrations, although sub-MAC levels may limit this effect.[5] TIVA also appears to preserve cerebrovascular autoregulation and maintain more stable intraoperative hemodynamics compared to inhalational agents.[6] In a randomized study, propofol anesthesia resulted in lower ICP and higher cerebral perfusion pressure than sevoflurane during neurosurgery.[7] Moreover, patients receiving TIVA generally experience less intraoperative fluctuation in heart rate (HR) and mean arterial pressure (MAP).[8] Beyond intraoperative physiology, anesthetic technique influences post-operative recovery and complications. Propofol-based TIVA is consistently associated with a lower incidence of post-operative nausea and vomiting (PONV), a crucial benefit in neurosurgery, where vomiting can raise ICP and jeopardize surgical outcomes.[9] Large meta-analyses have shown that propofol reduces PONV risk by approximately 30–40% compared to inhalational agents.[9] Furthermore, TIVA provides smoother and calmer emergence, with lower rates of agitation and hemodynamic surges.[10] Propofol may also modestly reduce early post-operative pain and opioid requirements.[11] Inhalational anesthesia, however, retains several advantages. Modern agents, such as sevoflurane and desflurane possess low blood-gas solubility, allowing rapid titration and faster emergence from anesthesia. Some studies have found shorter extubation and recovery times with sevoflurane compared to propofol.[12,13] Nonetheless, these differences are often minor and may not hold significant clinical relevance in neurosurgical contexts, where controlled and smooth awakening is prioritized over speed. While multiple studies have compared TIVA and inhalational techniques, their findings remain inconsistent. Meta-analyses indicate no significant differences in overall mortality or major morbidity between the two methods when used appropriately.[4] Few studies have comprehensively assessed both intraoperative stability and post-operative recovery profiles in the same cohort using standardized protocols. Moreover, data from South Asian populations where the burden of intracranial pathology is substantial and resource constraints differ remain scarce. Therefore, a prospective, controlled comparison in this regional context is warranted. This study aims to compare TIVA and inhalational anesthesia in adult patients undergoing elective supratentorial craniotomy.

Methods

This prospective comparative study was conducted at the Department of Neuro-Anaesthesia, National Institute of Neurosciences and Hospital (NINS),

Dhaka, Bangladesh, from July, 2024 to June, 2025. A total of 100 patients undergoing elective craniotomy were included in the study. The participants were randomly assigned into two equal groups (n = 50 each) to receive either TIVA or inhalational anesthesia as the primary anesthetic technique. Patients aged above 18 years with American Society of Anesthesiologists (ASA) grade I–III, and requiring supratentorial craniotomy were included. Exclusion criteria comprised emergency surgeries, ASA grade IV or above, known allergies to anesthetic drugs, severe hepatic or renal dysfunction, and patients on long-term sedatives or anticonvulsants. Pre-operative assessment included demographic data, neurological status through the Glasgow Coma Scale (GCS),[14] and ASA classification.[15] Standardized anesthesia protocols were followed, with the TIVA group receiving propofol and fentanyl infusions, while the inhalational group was maintained on isoflurane or sevoflurane with adjunct opioids and neuromuscular blockers. Intraoperative parameters, including HR and MAP, were recorded at pre-defined intervals. Drug consumption, emergence characteristics (time to extubation, eye opening, and command following), and sedation-pain scores at different post-operative intervals were also recorded. Complications, such as hypotension, bradycardia, post-operative nausea, infection, seizures, and deep vein thrombosis (DVT) were closely monitored. Informed consent was taken from each patient. Ethical clearance was taken from the Institutional Ethics Committee.

All data were analyzed using the Statistical Package for the Social Sciences version 26. Continuous variables were expressed as mean ± standard deviation (SD) and compared using the independent t-test, based on normality. Categorical variables were presented as frequencies and percentages and analyzed using Chi-square test. A $P < 0.05$ was considered statistically significant. To identify predictors of post-operative complications, binary logistic regression was performed with adjustment for potential confounders, including age, ASA grade, duration of surgery, and intensive care unit (ICU) stay. Adjusted odds ratios (ORs) with 95% confidence intervals (CIs) were reported. Results were further illustrated using a forest plot and stacked bar chart to visually compare complication patterns and regression outcomes between the two anesthetic techniques.

Results

The study included 100 patients undergoing craniotomy, evenly divided between the TIVA and inhalational anesthesia groups (50 patients each). The majority of participants were between 40 and 60 years of age (48%), followed by those under 40 years (34%) and over 60 years (18%). Males comprised a slightly higher proportion of the study population (59%) compared to females (41%) [Table 1].

Pre-operatively, most patients in both groups had a GCS score between 13 and 15, indicating relatively preserved neurological function, with a slightly higher proportion in the TIVA group (68%) compared to the inhalational group (58%). At 24 h post-operatively, a mild decline in GCS scores was observed in both groups; however, a greater proportion of patients in the TIVA group (64%) maintained a high GCS (13–15) compared to the inhalational group (50%). Conversely, moderate GCS scores (9–12) were more frequent in the inhalational group post-operatively [Table 2].

Intraoperative hemodynamic trends showed that both groups had comparable baseline HR and MAP values, with no significant differences before induction. Following induction and during craniotomy, the TIVA group demonstrated slightly lower HR and MAP values compared to the inhalational group (P = 0.045) and during craniotomy (P = 0.037). At emergence, both groups exhibited comparable hemodynamic parameters without significant variation [Table 3].

The intraoperative drug utilization profile revealed significant differences between the TIVA and inhalational groups. As expected, total propofol consumption was markedly higher in the TIVA group (1020 ± 110 mg) compared to the inhalational

group (180 ± 45 mg) ($P < 0.001$), reflecting its primary use as the main anesthetic agent in TIVA. Conversely, the inhalational group required significantly more fentanyl (220 ± 30 mcg vs. 180 ± 25 mcg; $P = 0.022$) and vasopressors (14 ± 4 mL vs. 10 ± 3 mL; $P = 0.031$), indicating a greater need for hemodynamic support. Atracurium use was similar between the two groups ($P = 0.183$) [Table 4].

Patients receiving TIVA achieved earlier extubation (6.8 ± 1.2 min vs. 9.3 ± 1.7 min), quicker eye opening (8.4 ± 1.5 min vs. 11.1 ± 2.0 min), and faster response to verbal commands (9.7 ± 2.1 min vs. 12.6 ± 2.3 min), with all differences being highly significant ($P < 0.001$). In addition, time to first mobilization was notably shorter in the TIVA group (420 ± 40 min) compared to the inhalational group (510 ± 55 min) ($P < 0.001$). These results indicate that TIVA facilitates a more rapid and smooth recovery profile, allowing earlier post-operative neurological assessment and mobilization [Table 5].

Post-operative assessments showed a progressive decline in sedation levels and a gradual increase in pain intensity over time in both groups. At 0 h post-operatively, patients exhibited moderate sedation (median score 3 [2–4]) with low pain scores (Visual Analog Scale [VAS] 2.5 ± 0.8). By 2 h, sedation decreased (median 2 [1–3]), while pain scores increased significantly (VAS 3.6 ± 1.1; $P = 0.011$). At 6 h, sedation was minimal (median 1 [1–2]), and pain reached its peak level (VAS 4.8 ± 1.5; $P = 0.006$) [Table 6].

The incidence of post-operative complications and adverse events was generally low and comparable between the TIVA and inhalational groups. Post-operative nausea occurred in roughly one-third of patients in both groups, with no significant difference observed (32% vs. 28%). The need for reoperation, prolonged ICU stay (>24 h), and post-operative infection rates were slightly higher in the TIVA group, but without significant clinical disparity. Neurological complications, such as seizures and DVT were rare and similar across both groups. Intraoperative awareness was minimal, occurring in 2% of TIVA patients and 6% of inhalational patients. Hemodynamic complications, such as hypotension and bradycardia were observed in a small proportion of patients in both groups, while bronchospasm and arrhythmia were infrequent [Table 7].

Discussion

This comparative analysis of TIVA and inhalational anesthesia in adult craniotomy patients highlights important differences in hemodynamic stability, recovery characteristics, and early post-operative neurological outcomes. Our findings align with a growing body of literature supporting the benefits of TIVA in neurosurgical settings while reaffirming the safety and viability of both techniques. Our study observed marginally better intraoperative hemodynamic stability in the TIVA group, evidenced by significantly lower HR and MAP following induction and during the craniotomy phase. This supports previous

Table 1: Demographic and baseline characteristics of the study population (n=100)

Variable	Category	n (%)
Age group	<40	34 (34.0)
	40–60	48 (48.0)
	>60	18 (18.0)
Gender	Male	59 (59.0)
	Female	41 (41.0)
Study group	TIVA	50 (50.0)
	Inhalational	50 (50.0)

TIVA: Total intravenous anesthesia

Table 2: Comparison of pre- and post-operative Glasgow Coma Scale Scores between groups

Variable	Category	TIVA n (%)	Inhalational n (%)
Pre-operative GCS	13–15	34 (68.0)	29 (58.0)
	9–12	11 (22.0)	17 (34.0)
	≤8	5 (10.0)	4 (8.0)
Post-operative GCS (24 h)	13–15	32 (64.0)	25 (50.0)
	9–12	13 (26.0)	20 (40.0)
	≤8	5 (10.0)	5 (10.0)

GCS: Glasgow Coma Scale, TIVA: Total intravenous anesthesia

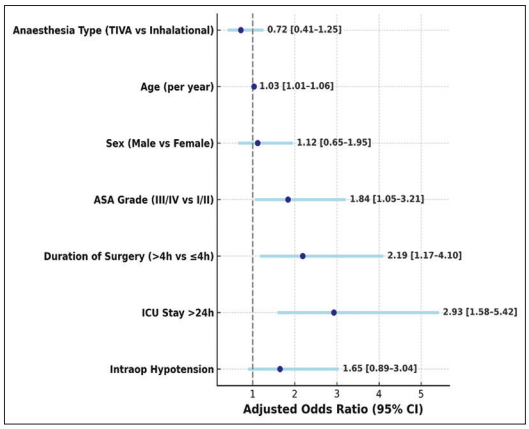

Figure 1: Forest plot of predictors of post-operative complications following craniotomy under Total intravenous anaesthesia (TIVA) versus Inhalational Anaesthesia. The forest plot presents the adjusted odds ratios (ORs) with 95% confidence intervals (CIs) for predictors of post-operative complications following craniotomy under TIVA versus Inhalational Anaesthesia. Anaesthesia type itself was not found to be a statistically significant independent predictor of complications (OR: 0.72; 95% CI: 0.41–1.25; P = 0.245), suggesting that both modalities offer a comparable safety profile in the post-operative period. However, several clinical variables emerged as significant contributors. Increasing patient age was associated with a slight but significant increase in complication risk (OR: 1.03/year; P = 0.017). Patients with higher ASA grades (III/IV) were nearly twice as likely to experience complications compared to those with American Society of Anesthesiologists I/II (OR: 1.84; P = 0.033), indicating that underlying comorbidity status plays a vital role. Longer surgical duration exceeding four hours significantly increased complication risk (OR: 2.19; P = 0.014), as did the need for prolonged intensive care unit stay beyond 24 h (OR: 2.93; P < 0.001), both reflecting higher intraoperative and early post-operative burden. Other factors, such as sex and intraoperative hypotension, did not reach statistical significance [Figure 1]

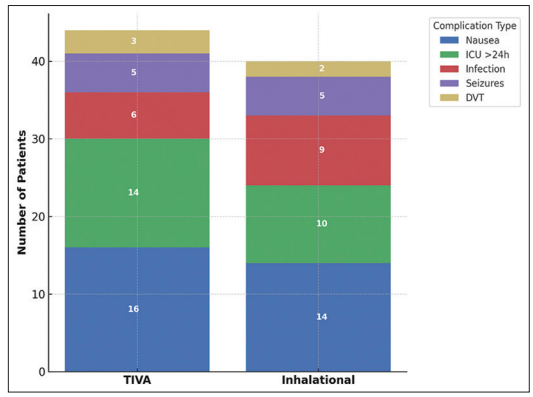

Figure 2: Stacked Bar chart of post-operative complications by Anaesthesia type (Total intravenous anaesthesia [TIVA] vs. Inhalational). This stacked bar chart displays the frequency and distribution of major post-operative complications observed in patients undergoing craniotomy under TIVA versus Inhalational Anesthesia. Each bar represents the total number of patients per group (n = 50), segmented by complication type, including post-operative nausea, intensive care unit (ICU) stay over 24 h, infections, seizures, and deep vein thrombosis (DVT). The visual comparison shows that post-operative nausea and ICU stay >24 h were relatively more common in the TIVA group (32% and 28%, respectively) than in the inhalational group (28% and 20%). Conversely, post-operative infections were slightly higher among patients receiving inhalational agents (18% vs. 12%). The incidence of seizures was equal in both groups (10%), while DVT was infrequent and comparable (TIVA: 6%; Inhalational: 4%) [Figure 2]

findings that propofol attenuates sympathetic responses more effectively than volatile agents, such as sevoflurane or isoflurane.[4,16] Propofol's vasodilatory and sympatholytic properties reduce CBF and ICP, enhancing brain relaxation, a key advantage in neurosurgery.[17] Jiang *et al*. reported similar findings,[18] demonstrating improved brain relaxation and lower ICP with propofol-based anesthesia compared to desflurane in supratentorial tumor surgeries. Conversely, studies reported no significant differences in hemodynamic parameters when depth of anesthesia and adjunct medication use were optimized in both groups, suggesting that clinical equivalence can be maintained with careful intraoperative management.[19,20] The present study also demonstrated significantly faster emergence and recovery in the TIVA group, including earlier extubation, eye opening, and response to verbal commands. These findings are similar to previous studies, which show that patients receiving propofol-based anesthesia recovered more rapidly and demonstrated improved neurological clarity in the immediate post-operative period.[21,22] This rapid emergence is attributed to the favorable pharmacokinetics of propofol, which lacks the tissue accumulation seen with volatile agents, thereby enabling prompt neurological examination,

Table 3: Intraoperative hemodynamic parameters at different time points

Time point	Parameter	TIVA (Mean±SD)	Inhalational (Mean±SD)	*P*-value
Baseline	HR (bpm)	78.2±6.3	80.5±6.1	0.112
	MAP (mmHg)	92.4±7.8	95.1±8.0	0.158
Post-induction	HR (bpm)	70.1±5.5	73.3±5.9	0.045
	MAP (mmHg)	85.7±6.2	88.3±6.5	0.081
During craniotomy	HR (bpm)	68.4±6.9	71.2±6.6	0.037
	MAP (mmHg)	82.5±5.8	84.9±6.1	0.069
At emergence	HR (bpm)	86.2±7.3	89.7±7.5	0.124
	MAP (mmHg)	97.4±8.1	99.8±8.4	0.167

HR: Heart rate, MAP: Mean arterial pressure, SD: Standard deviation, TIVA: Total intravenous anesthesia

Table 4: Intraoperative drug utilization profile between TIVA and inhalational groups

Drug used	TIVA (Mean±SD)	Inhalational (Mean±SD)	*P*-value
Total propofol (mg)	1020±110	180±45	<0.001
Fentanyl (mcg)	180±25	220±30	0.022
Atracurium (mg)	40±6	42±5	0.183
Vasopressors (mL)	10±3	14±4	0.031

SD: Standard deviation, TIVA: Total intravenous anesthesia

Table 5: Comparison of recovery characteristics between study groups

Recovery parameter	TIVA (Mean±SD)	Inhalational (Mean±SD)	*P*-value
Time to extubation (min)	6.8±1.2	9.3±1.7	<0.001
Time to eye opening (min)	8.4±1.5	11.1±2.0	<0.001
Time to follow commands (min)	9.7±2.1	12.6±2.3	<0.001
Time to first mobilization	420±40	510±55	<0.001

SD: Standard deviation, TIVA: Total intravenous anesthesia

Table 6: Post-operative sedation and pain scores at different time intervals

Time point (post-operative)	Sedation score (Median [IQR])	Pain score (VAS, Mean±SD)	*P*-value
0 h	3 [2–4]	2.5±0.8	0.027
2 h	2 [1–3]	3.6±1.1	0.011
6 h	1 [1–2]	4.8±1.5	0.006

IQR: Interquartile range, VAS: Visual Analog Scale, SD: Standard deviation

Table 7: Incidence of post-operative complications and adverse events

Event	Category	TIVA, *n* (%)	Inhalational, *n* (%)
Post-operative nausea	No	34 (68.0)	36 (72.0)
	Yes	16 (32.0)	14 (28.0)
Reoperation needed	No	41 (82.0)	43 (86.0)
	Yes	9 (18.0)	7 (14.0)
ICU stay >24 h	No	36 (72.0)	40 (80.0)
	Yes	14 (28.0)	10 (20.0)
Post-operative infection	No	44 (88.0)	41 (82.0)
	Yes	6 (12.0)	9 (18.0)
Seizures	No	45 (90.0)	45 (90.0)
	Yes	5 (10.0)	5 (10.0)
DVT	No	47 (94.0)	48 (96.0)
	Yes	3 (6.0)	2 (4.0)
Intraoperative awareness	No	49 (98.0)	47 (94.0)
	Yes	1 (2.0)	3 (6.0)
Hypotension	No	40 (80.0)	38 (76.0)
	Yes	10 (20.0)	12 (24.0)
Bradycardia	No	44 (88.0)	46 (92.0)
	Yes	6 (12.0)	4 (8.0)
Bronchospasm	No	48 (96.0)	47 (94.0)
	Yes	2 (4.0)	3 (6.0)
Arrhythmia	No	49 (98.0)	48 (96.0)
	Yes	1 (2.0)	2 (4.0)

DVT: Deep vein thrombosis, ICU: Intensive care unit, TIVA: Total intravenous anesthesia

a critical factor in post-operative neurosurgical care.[23] Notably, our study found a higher proportion of patients maintaining a high GCS

score at 24 h post-operatively in the TIVA group. Wu *et al*. similarly observed improved GCS recovery in traumatic brain injury patients who received propofol rather than sevoflurane, suggesting possible neuroprotective effects of propofol.[22] While the precise mechanisms remain unclear, experimental data suggest that propofol reduces oxidative stress, suppresses inflammatory cytokines, and preserves cerebral autoregulation.[24] Nevertheless, not all studies confirm this benefit. For example, Zhang *et al*. found no significant difference in GCS outcomes between the two modalities in patients undergoing tumor resection,[25] implying that other perioperative variables may modulate recovery. Pain and sedation trends in our study followed expected trajectories, with no clinically significant differences between groups. Both groups experienced mild sedation post-operatively that decreased over time, alongside a gradual increase in pain scores. These results are consistent with previous studies, where they reported comparable post-operative analgesic profiles between TIVA and inhalational groups when multimodal analgesia protocols were followed.[10,26] However, our observation that the inhalational group required significantly more fentanyl and vasopressors intraoperatively aligns with literature suggesting that volatile agents may provide less intraoperative antinociception and sympathetic suppression compared to propofol.[17,27] Post-operative complications were low in both groups and did not differ significantly, reinforcing findings from multiple large-scale analyses and meta-analyses.[19,20] Daccache *et al*. analyzed over 140 randomized controlled trials and found no difference in 30-day morbidity or mortality between TIVA and volatile anesthesia in neurosurgical patients.[19] Our logistic regression analysis supports this, identifying patient-specific factors, such as age, ASA status, and prolonged surgery, not anesthetic technique, as key predictors of post-operative complications.

Nonetheless, the trend toward fewer infections and ICU stays >24 h in the TIVA group echoes findings from a study reported reduced post-operative infection rates and improved survival in glioblastoma patients undergoing craniotomy under TIVA.[28] These outcomes are hypothesized to result from propofol's immunomodulatory properties.[24] However, other retrospective studies found no survival difference, underscoring the need for randomized trials to clarify these long-term effects.[20,29] Clinically, the choice between TIVA and inhalational anesthesia should be individualized. TIVA may be preferable when early neurological assessment, lower PONV risk, and hemodynamic stability are priorities. In contrast, inhalational agents, especially desflurane, may be advantageous in shorter procedures due to rapid washout and ease of titration.

Limitations of the study

This single-center study is limited by its small sample size, lack of long-term cognitive outcome assessment, and absence of standardized depth-of-anesthesia monitoring. It also did not stratify results by surgical indication, which may influence the generalizability of findings.

Conclusion

Both TIVA and inhalational anesthesia are safe and effective for adult craniotomy, offering comparable intraoperative stability and post-operative complication rates. However, TIVA demonstrated advantages in faster emergence, better early neurological recovery, and reduced need for intraoperative adjuncts. These findings support the use of TIVA, particularly when early post-operative assessment and smooth recovery are clinical priorities.

Recommendations

Based on the findings, we recommend considering TIVA as the preferred anesthetic technique for adult craniotomy when rapid emergence and early neurological assessment are clinically important. Future multicenter, larger-scale studies with long-term neurocognitive and functional outcome evaluation are warranted to validate these results further and guide individualized anesthetic planning.

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Conflict of Interest

None declared.

Ethical Approval

The study was approved by the Institutional Ethics Committee.

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