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Original Research Article

Comparison of patient state index and end tidal anaesthetic concentration monitoring on recovery profile in desflurane based anaesthesia in neurosurgical population

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Abstract

Background and Objective: A variety of EEG-derived monitors have emerged to track cerebral electrical patterns during general anaesthesia with the goal of improving emergence quality. This study aimed to evaluate recovery characteristics when guiding desflurane based anaesthesia by either the patient state index (PSI) or by measuring end tidal anaesthetic concentration (ETAC) in neurosurgical patients.
Materials and Methods: A total of 108 adult patients (aged 18–65 years) undergoing elective neurosurgery were enrolled in this randomised controlled trial to compare two strategies for anaesthetic depth monitoring: one based on end-tidal anaesthetic concentration (ETAC) and the other on the Patient State Index (PSI). All patients received a standardized general anaesthetic regimen consisting of oxygen, nitrous oxide, and desflurane. In the ETAC group, anaesthetic depth was maintained at a minimum alveolar concentration (MAC) of 0.8–1, whereas in the PSI group, the target was a Patient State Index (PSI) between 25 and 50. Recovery parameters included the emergence time, the ability to respond to verbal commands, and the duration until extubation. Additionally, intraoperative hemodynamic parameters, along with total consumption of desflurane and fentanyl, were documented.
Results: The mean emergence time was 4.94 ± 1.63 minutes in the ETAC group compared to 4.00 ± 1.78 minutes in the PSI group (P = 0.005). The time to respond to verbal commands averaged 5.46 ± 1.80 minutes in the ETAC group versus 4.35 ± 1.66 minutes in the PSI group (P = 0.001). Extubation occurred at 8.07 ± 1.80 minutes in the ETAC group and at 6.65 ± 2.31 minutes in the PSI group (P = 0.001). Desflurane usage was similar between the groups, with the PSI group receiving 18.15 ± 5.88 ml and the ETAC group 18.7 ± 6.21 ml (P = 0.634). Hemodynamic parameters remained stable and comparable across both groups.
Conclusion: Monitoring the depth of anaesthesia with the Patient State Index facilitates a more rapid postoperative recovery compared to ETAC-guided anaesthesia in neurosurgical patients receiving desflurane, without adversely affecting hemodynamic stability.

Keywords: Patient state index, End-tidal anaesthetic concentration, Recovery profile, Desflurane.

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1. Introduction

General anaesthesia is essential for most surgical procedures in order to maintain a state of reversible loss of consciousness, immobility absence of awareness and lack of response to painful stimuli and amnesia. Intraoperative awareness may be experienced in case of inadequate general anaesthesia, leading to complications such as post traumatic stress disorder. Similarly, overdosing of anaesthetic agents leads toprolonged recovery, increasing risk of postoperative complications. Hence it is important to maintain the optimal balance between the drug dosage and the patient's level of consciousness.

Various cerebral monitoring devices have been designed to detect alterations in electrophysiological activity of the

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brain during general anaesthesia to avoid intraoperative awareness and hasten recovery.[1]

The Patient State Index (PSI) is calculated using four-channel EEG recordings, incorporating a quantitative analysis of electrical activity across alpha, beta, delta, and theta frequency bands. It also evaluates the spatial and temporal variations among these frequencies that occur with changes in anaesthetic depth.[2] The power distribution across these frequency bands is influenced by anaesthetic agents in a dose-dependent manner. Analysing these gradients is a distinctive feature of the PSI monitor, setting it apart from other EEG monitors.[2,3] PSI has a range from 0-100. A range of 25-50 has been used to maintain adequate depth of anaesthesia.[2-4] End-tidal anaesthetic concentration (ETAC) monitoring provides continuous, real-time data on the alveolar levels of inhaled anaesthetic agents through a gas analyser based on infrared absorption technology. This approach enables precise, target-guided administration of volatile agents and is widely regarded as a practical method for assessing anaesthetic depth.[5,6] MAC of 0.7-1.3 is desired to achieve adequate depth of anaesthesia.[5,7]

Apart from monitoring depth of anaesthesia for enhancing recovery, short acting anaesthetic agent can beused for rapid emergence. It helps in early detection of postoperative deficits in neurosurgeries.[8] Desflurane is a short acting inhalational agent with low blood gas solubility, has quicker emergence, including eye opening, response to commands, and orientation that favour rapid emergence from anaesthesia.[1,9]

This study aimed to evaluate and compare the recovery profile in desflurane based neurosurgeries guided by PSI and ETAC monitoring. Optimising anaesthetic depth is critical in neurosurgical procedures, where rapid and smooth emergence from anaesthesia can significantly impact postoperative neurological assessment and overall outcomes. Given desflurane's pharmacokinetic properties that support faster emergence, this study aimed to determine which approach offers more precise control over anaesthetic depth and optimizes postoperative recovery.

2. Materials and Methods

This prospective, randomised study enrolled neurosurgical patients between the ages of 18 and 65 years, classified as American Society of Anaesthesiologists (ASA) Physical Status I or II, who were scheduled for elective procedures which exceeded three hours, at a Bengaluru-based super specialty hospital between February 2021 and June 2022.

The study received approval from the institutional review board and ethics committee (MSRMC/EC/PG-66/10-2021) prior to its commencement and was registered with the Clinical Trial Registry of India (CTRI/2021/05/033897). Patients were excluded if they had a history of psychiatric illness, alcohol or substance abuse, or were receiving neuropsychiatric medications. Additional exclusion criteria included a Glasgow Coma Scale (GCS) score of less than 15 before surgery, a body mass index (BMI) greater than 30, or computed tomography (CT) evidence of increased intracranial pressure. Patients with intracranial aneurysms or arteriovenous malformations, those requiring intravenous anaesthetic infusions such as propofol or dexmedetomidine for intracranial pressure management or as part of somatosensory or motor-evoked potential (SSEP/MEP) monitoring, and those requiring postoperative mechanical ventilation due to intraoperative complications were also excluded.

A total of 108 eligible neurosurgical patients were randomly assigned into two equal groups (n = 54) using a computer-generated sequence. Group A underwent anaesthetic depth monitoring with the Patient State Index (PSI), while Group B was monitored using End-tidal anaesthetic concentration (ETAC). Informed written consent was obtained from all participants prior to inclusion. All patients received a standardised anaesthetic protocol comprising fentanyl (2 mcg/kg), propofol (2 mg/kg), and vecuronium (0.1 mg/kg), with routine ASA monitoring in place. After intubation, ventilator settings included an FiO2of 35-45%, flow rate of 0.5-0.7 L/min, tidal volume of 6-8 mL/kg, and a respiratory rate adjusted to maintain EtCO2 between 25-35 mmHg.

2.1. ETAC was recorded using an airway gas monitor integrated into the GE workstation

Patient State Index was recorded using SEDline technology (Masimo Corporation, USA). Temperature was monitored with a nasopharyngeal probe, and normothermia was maintained using warming blankets. Invasive blood pressure monitoring was achieved through radial artery cannulation, with central venous catheterisation performed at the anaesthetist's discretion. For craniotomies, a 20 mL scalp block of 0.2% Ropivacaine was administered; for spine procedures, the incision site was infiltrated with 0.5% Bupivacaine, adhering to maximum allowable doses.

Anaesthetic maintenance in both groups involved the use of oxygen, nitrous oxide, and desflurane. In Group B (ETAC), desflurane was regulated to maintain a minimum alveolar concentration (MAC) within the range of 0.8 to 1.0. In contrast, in Group A (PSI), the desflurane concentration was adjusted to keep the Patient State Index between 25 and 50. Intraoperative analgesia with fentanyl being given at the discretion of the anaesthetist. Fifteen minutes before the anticipated end of surgery, anaesthesia was reduced by 50%. Desflurane was purged from the system at 10 L/min once skull pins were removed or the patient was positioned for extubation.

Recovery from anaesthesia was assessed using three main indicators. Emergence time was noted to be the interval between the discontinuation of the anaesthetic agent and the patient's spontaneous eye opening. The time to respond to verbal commands was recorded as the duration from the end of anaesthesia to the patient's first appropriate response to auditory stimuli. Extubation time was measured from the cessation of the anaesthetic agent to the successful removal of the endotracheal tube.

Baseline hemodynamic values, including heart rate (HR), systolic blood pressure (SBP), diastolic blood pressure (DBP), and mean arterial pressure (MAP), were measured and recorded continuously every 5 minutes until the patient was positioned for surgery. Afterward, they were monitored every 15 minutes until the completion of surgery, followed by 5-minute intervals up to 5 minutes post-extubation.

The total volume of desflurane used was documented using the system status option, an inbuilt software feature of the workstation that measures agent consumption during procedures, allowing for comparison between the two groups.

Additionally, the total duration of surgery and anaesthesia, as well as the intraoperative fentanyl usage, were recorded and analysed between the groups. Patients requiring postoperative ventilation due to intraoperative complications or changes in the surgical plan were excluded from the study.

2.2. Statistical analysis

In the study conducted by Sudhakaran et al, it was observed that the emergence time with ETAC was 5.1 ± 1.53 minutes and 5.0 ± 2.12 minutes with BIS1. Based on these results, it was estimated that 54 subjects in each group would be required, with 80% power, a 95% confidence level, and an effect size of 0.55, to evaluate outcomes between PSI and ETAC.

Descriptive and inferential statistical analyses were performed. Continuous data were presented as mean ± standard deviation, while categorical data were presented as frequency (number) and percentage. Statistical significance was assessed at the 5% level. An unpaired t-test was used to compare means across different groups for various clinical variables.

3. Results

This randomized control trial compared the recovery profiles in desflurane-based neurosurgeries guided by either Patient State Index (PSI) or end-tidal anaesthetic concentration (ETAC) monitoring. The objective was to identify the approach that provides more precise anaesthetic depth control and promotes faster, smoother postoperative recovery.

A total of 108 patients who underwent elective neurosurgeries were divided into two groups, each consisting of 54 subjects. The demographic data were comparable between the two groups (**Table 1**). The types of surgeries included in the study were categorized based on factors such as the duration of surgery and anaesthesia, which could influence the volume of inhalational agent and opioid used. The primary diagnoses included single or multiple-level spine surgeries or craniotomy procedures. Additionally, the time required to position the patient for surgery after anaesthesia was considered when categorising the types of surgeries (**Table 2**).

Table 1: Comparison of demographic data between the two group

	Group PSI (n=54)	Group ETAC (n=54)
Age (years) (Mean±SD)	46.5 ± 13.85	51.9 ±11.51
Weight (kilograms) (Mean±SD)	66.29±7.35	65.98 ± 7.86
Height (meters) (Mean±SD)	1.62 ± 0.07	1.63 ± 0.08
BMI (kg/m^2) (Mean±SD)	24.4 ± 1.85	25.1 ± 1.63
ASA (1/2)	23/31	30/24

Table 2: Different categories of surgeries included in the study

Category	Surgery	Estimated duration of surgery
1	2-3 level lunar laminectomy, laminoforaminotomy, single level transforaminal interbody lumbar fusion	3-4 hours
2	Intracranial procedures- small extra-axial convex its lesions (meningioma), depressed skull fracture elevation without brain parenchymal involvement with GCS 15/15	4-5 hours
3	1-2 level anterior cervical discectomy and fusion	3-5 hours
4	2-3 level thoracolumbar interbody fusion	4-6 hours

The total number of surgeries across various categories, along with the duration of both the surgeries and anaesthesia, showed no significant differences between the two groups. Similarly, the anaesthesia duration for each category was consistent across both groups. The study involved both spine surgeries and craniotomies, which influenced factors such as the length of surgery, patient positioning, total anaesthesia time, desflurane consumption, and opioid usage.

These factors can influence the recovery and postoperative neurosurgical effects on the patient. However, in our study, the two groups had a similar distribution of various categories of the surgeries listed above. Therefore, any bias arising due to the above-mentioned factors was avoided.

The emergence time, verbal response time, and extubation time were significantly shorter in the PSI group compared to the ETAC group. The total amount of desflurane administered was 18.15 ± 5.88 ml in the PSI group and 18.7 ± 6.21 ml in the ETAC group, with no statistically significant difference (P = 0.634). Fentanyl consumption was 277.7 ± 24.01 mcg in the PSI group and 280.7 ± 20.89 mcg in the ETAC group (P = 0.4). Heart rate and mean arterial pressure at different anaesthesia time points showed no significant differences between the groups. Additionally, no variation was observed between the two groups in terms of SpO2 and EtCO2 levels at any time points (**Table 3**).

Table 3: Comparison of recovery profile between the two groups

	Group	MEAN (Minutes)	Standard deviation	p-value
Emergence Time	PSI	4.15	1.39	0.007*
	ETAC	4.94	1.6	
Verbal Response Time	PSI	4.43	1.22	0.009*
	ETAC	5.13	1.49	
Extubation Time	PSI	7.06	2.1	0.042*
	ETAC	7.81	1.73	

4. Discussion

This study examined the recovery profiles in neurosurgical procedures involving desflurane, comparing the use of Patient State Index (PSI) and End-Tidal Anaesthetic Concentration (ETAC) monitoring. Maintaining the appropriate anaesthetic depth is critical to prevent intraoperative awareness and reduce the excessive use of anaesthetic agents. Accurate assessment of consciousness ensures smooth recovery, physiological stability, and patient satisfaction.

ETAC monitoring is widely accepted due to volatile agents' steep dose-response curve,[10] minimal opioid interference (15% MAC reduction),[11] and the ability to measure concentration continuously. EEG signal processing advancements have enabled development of monitors like BIS and PSI, which correlate well with physiological responses. Previous study by Musialowicz T et al. indicates both EEG-based and ETAC-guided protocols are effective in monitoring depth of anaesthesia.[12]

This study evaluated PSI, an EEG-based monitor, versus ETAC monitoring in desflurane anaesthesia for neurosurgeries. BIS and PSI-guided anaesthesia have demonstrated faster recovery and reduced drug consumption.[12] The B-Aware trial found a reduced incidence of intraoperative awareness with BIS monitoring.[13] Sudhakaran et al. demonstrated that emergence, extubation, and name recall times were significantly shorter in the BIS and ETAC groups compared to standard practice.[1] Similarly, Drover et al. found that the PSI group experienced a faster emergence time. 2 In our study, PSI group recovery times were shorter: emergence (4.15 ± 1.39 min vs. 4.94 ± 1.6 min), verbal command response (4.43 ± 1.22 min vs. 5.13 ± 1.49 min), and extubation (7.06 ± 2.1 min vs. 7.81 ± 1.73 min) compared to ETAC. Although statistically significant, the clinical impact may be minimal.

Both BIS and PSI predict unconsciousness accurately. However, PSI is reportedly superior in detecting consciousness.[14,15] Chen et al. noted PSI values may not return to baseline post-orientation, likely reflecting residual anaesthetic effects. PSI sensors are compact and can be placed on the maxilla when forehead access is limited.[14]

Low-flow anaesthesia effectively reduces volatile agent use. Automated systems, such as the GE AisysCarestation™ (GE Healthcare, Madison, WI, USA), optimise delivery by digitally adjusting gas flow and vaporiser output.[16,17] These systems decrease anaesthetic consumption, reduce manual intervention, and lower greenhouse gas emissions.[17-19] In our study, desflurane consumption was comparable: 18.15 ± 5.88 ml in the ETAC group vs. 18.7 ± 6.21 ml in the PSI group (p = 0.634). Given the surgery duration (225.4 ± 15.6 to 363.3 ± 52 min), this low usage reflects the efficiency of low-flow ET control.

Punjasawadwong et al. analysed 985 patients and found BIS-guided anaesthesia reduced volatile agent requirements by 0.65% MAC.[20] Chaudhuri et al. reported similar recovery times between BIS and ETAC groups, but lower sevoflurane uses in the ETAC group.[21] Although not statistically significant in our study, desflurane usage was slightly lower in the PSI group. This could be due to fewer adjustments needed, as PSI allows a broader acceptable range (25–50), while ETAC requires frequent modifications to maintain MAC between 0.8–1.0. Operating theatre artefacts like diathermy and pacemakers can interfere with EEG signals, especially with BIS monitoring. PSI has shown less susceptibility to such interference and provides bilateral EEG data,[14,22] unlike BIS, which only uses unilateral input.[13]

EEG-based monitors capture drug-specific brain activity and provide a more detailed assessment of anaesthetic depth. Anaesthesia increases neural oscillations 5–20 fold, visible on EEG and spectrograms.[23,24] Each agent produces characteristic patterns: ether-based agents (sevoflurane, isoflurane, desflurane) show theta waves at 1 MAC; nitrous oxide increases beta/gamma and reduces delta activity;

propofol induces delta and alpha waves; ketamine shows fast beta/gamma oscillations, complicating EEG monitoring; dexmedetomidine causes delta waves with spindles that disappear at deeper sedation levels.[23,25]

EEG is also beneficial in procedures like carotid endarterectomy, where post-clamping EEG changes may indicate the need for shunting, independent of backpressure.[26] Burst suppression, defined by alternating phases of cortical activity and electrical silence, is commonly observed in unconscious patients. It can be induced by high doses of anaesthetic agents such as propofol, barbiturates, and inhaled ethers, as well as by hypothermia 23. In surgical settings requiring deliberate hypothermia and total circulatory arrest, EEG monitoring may help mitigate hypoxic-ischemic brain injury 24. Considering these factors, PSI offers individualised anaesthetic delivery, aiding in faster recovery and reducing the risk of awareness. It is a cost-effective alternative to BIS with comparable functionality.

The B-Unaware trial compared BIS and ETAC protocols in 1,941 patients using the Brice questionnaire to assess intraoperative awareness 27. No significant differences were found in awareness incidence or anaesthetic consumption. Awareness occurred despite BIS <60 in 55% of patients and ETAC <0.7 MAC in 74.5%, indicating that intraoperative awareness can still occur within recommended ranges. Moreover, low BIS values suggest anaesthesiologists may not rely solely on EEG monitors to titrate anaesthesia, questioning the superiority of EEG monitoring over conventional methods. Our study used PSI, which showed shorter recovery times and faster emergence- hence focusing more on the recovery profiles of the patients.

However, this study had certain limitations. Intraoperative awareness could not be fully assessed, as patients were not followed beyond their stay in the post-anaesthesia care unit (PACU). Moreover, the findings may not be applicable to total intravenous anaesthesia, as real-time monitoring of plasma concentrations of intravenous agents is not currently feasible.

5. Conclusion

Patient State Index (PSI)-guided anaesthesia provides recovery profiles that are similar to those achieved with end-tidal anaesthetic concentration (ETAC) monitoring, ensuring precise control over anaesthetic depth. It promotes a faster and smoother emergence, which is particularly important in neurosurgical procedures. Therefore, PSI appears to be a reliable and effective alternative for monitoring anaesthetic depth in these surgeries. However, further research is necessary to confirm its effectiveness and support its broader clinical use.

6. Source of Funding

None.

7. Conflict of Interest

None.

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