Research Article

EEG-GUIDED ANAESTHESIA FOR PREVENTION OF POSTOPERATIVE DELIRIUM AND COGNITIVE DYSFUNCTION AFTER CARDIAC SURGERY: A PROSPECTIVE RANDOMIZED CONTROLLED STUDY

Nitesh Sinha[1], Pratibha Alice Xess[2], Vaibhav Shahi[3], Neeraj Kumar[4]

[1]Assistant Professor, Department of Cardiac Anaesthesia, Rajendra Institute of Medical Sciences (RIMS), Ranchi, Jharkhand, India
[2]Senior Resident, Department of Cardiac Anaesthesia, Rajendra Institute of Medical Sciences (RIMS), Ranchi, Jharkhand, India
[3]Associate Professor, Department of Anaesthesia, Mahant Indresh Hospital, Dehradun, Uttarakhand, India
[4]Associate Professor, Department of Cardiothoracic and Vascular Surgery (CTVS), LPS Institute of Cardiology,

Abstract: Postoperative delirium (POD) and postoperative cognitive dysfunction (POCD) are common neurological complications following cardiac surgery and are associated with increased morbidity, prolonged intensive care unit (ICU) and hospital stay, and poorer functional recovery. Electroencephalography (EEG)-guided anesthesia enables individualized titration of anesthetic depth and may reduce the incidence of these postoperative neurocognitive disorders. The objective is to evaluate the effectiveness of EEG-guided anesthesia in preventing postoperative delirium and cognitive dysfunction in adult patients undergoing elective cardiac surgery. **Materials and Methods:** This prospective randomized controlled trial was conducted at the Department of Anaesthesiology, Rajendra Institute of Medical Sciences (RIMS), Ranchi, from January 2020 to December 2021. A total of 120 adult patients undergoing elective cardiac surgery with cardiopulmonary bypass were randomly allocated into Group A (EEG-guided anesthesia, n = 60) and Group B (standard anesthesia, n = 60). In Group A, anesthetic depth was maintained using continuous EEG monitoring, whereas Group B received conventional anesthesia without EEG guidance. The primary outcome was the incidence of postoperative delirium assessed using the Confusion Assessment Method for the Intensive Care Unit (CAM-ICU). Secondary outcomes included postoperative cognitive dysfunction assessed using the Mini-Mental State Examination (MMSE), anesthetic consumption, duration of mechanical ventilation, ICU stay, hospital stay, and postoperative complications. **Results:** Group A demonstrated a significantly lower incidence of postoperative delirium than Group B (13.3% vs. 30.0%, P = 0.028). Postoperative cognitive dysfunction occurred in 16.7% of patients in Group A compared with 35.0% in Group B (P = 0.021). Group A also required lower anesthetic doses and had significantly shorter durations of mechanical ventilation, ICU stay, and hospital stay (P < 0.05). No significant differences were observed in major postoperative complications or in-hospital mortality. **Conclusion:** EEG-guided anesthesia significantly reduced postoperative delirium and cognitive

Received : 02/17/2022
Received in revised form : 02/25/2022
Accepted : 03/09/2022
Available online : 03/24/2022

Keywords:

EEG-guided anesthesia; postoperative delirium; postoperative cognitive dysfunction; cardiac surgery; CAM-ICU; randomized controlled trial.

Corresponding Author:
Nitesh Sinha
E-mail; dr.niteshsinha@gmail.com
http://dx.doi.org/10.29228/jamp.531000

Int J Acad Med Pharm,
2022; 4 (1); 110-116

INTRODUCTION

Cardiac surgery remains one of the most effective treatment modalities for patients with coronary artery disease, valvular heart disease, congenital heart disease, and other complex structural cardiac disorders. Advances in surgical techniques, cardiopulmonary bypass (CPB) technology, myocardial protection, anesthetic management, and perioperative intensive care have substantially improved operative outcomes and long-term survival. Despite these achievements, neurological complications continue to be a major cause of postoperative morbidity, prolonged hospitalization, delayed functional recovery, increased healthcare costs, and reduced quality of life. Among these complications, postoperative delirium (POD) and postoperative cognitive dysfunction (POCD) are the most common perioperative neurocognitive disorders encountered after cardiac surgery, particularly in elderly patients and those with multiple cardiovascular comorbidities.[1,2]

Postoperative delirium is an acute neuropsychiatric syndrome characterized by disturbances in attention, awareness, and cognition with a fluctuating clinical course that typically develops within the first few postoperative days. In contrast, postoperative cognitive dysfunction is characterized by impairments in memory, executive function, attention, learning, and information processing that may persist for weeks or months following surgery, thereby adversely affecting functional independence and quality of life.[2,3] Both disorders have been associated with prolonged mechanical ventilation, increased intensive care unit (ICU) and hospital stay, delayed rehabilitation, higher healthcare expenditure, and increased short- and long-term mortality. Previous studies have reported that postoperative delirium occurs in approximately 20–50% of patients after cardiac surgery, while early postoperative cognitive dysfunction has been observed in 30–60% of patients depending on patient characteristics, surgical complexity, and assessment methods.[3,4]

The pathophysiology of perioperative neurocognitive disorders is multifactorial and involves a complex interaction between patient-related and procedure-related factors. Advanced age, diabetes mellitus, hypertension, cerebrovascular disease, frailty, and pre-existing cognitive impairment are well-recognized predisposing factors.[5] Intraoperative contributors such as prolonged cardiopulmonary bypass, cerebral hypoperfusion, systemic inflammatory response, microembolic events, oxidative stress, hypothermia, haemodynamic instability, and excessive exposure to anesthetic agents may further increase the risk of postoperative neurological injury.[5,6] Because many of these intraoperative factors are potentially modifiable, strategies aimed at optimizing anesthetic management have attracted considerable attention.

Among these modifiable factors, the depth of anaesthesia has emerged as an important determinant of postoperative neurological recovery. Conventionally, anesthetic depth is assessed using indirect physiological parameters such as heart rate, arterial blood pressure, lacrimation, sweating, patient movement, and end-tidal anesthetic concentration. However, these variables primarily reflect autonomic responses rather than direct cerebral cortical activity and may fail to identify episodes of excessively deep anaesthesia. Excessive anesthetic administration may produce electroencephalographic burst suppression, delayed emergence, haemodynamic instability, and an increased risk of postoperative delirium and cognitive dysfunction.[7]

Processed electroencephalography (EEG)-guided anaesthesia provides continuous real-time monitoring of cerebral electrical activity, allowing individualized titration of anesthetic agents according to the patient's cortical response. Processed EEG monitors generate numerical indices that correlate with the level of hypnosis, facilitating maintenance of an optimal depth of anaesthesia while minimizing unnecessary anesthetic exposure. By avoiding excessively deep anaesthesia and prolonged burst suppression, EEG-guided anesthetic management may reduce anesthetic consumption, preserve cerebral autoregulation, facilitate earlier recovery, and improve postoperative neurocognitive outcomes.[7,8]

Several randomized controlled trials have evaluated the effectiveness of EEG-guided anaesthesia in reducing postoperative delirium and cognitive dysfunction. Although many studies have demonstrated reduced anesthetic requirements, lower delirium rates, and improved postoperative recovery, others have reported inconsistent effects on postoperative cognitive function. Differences in study populations, anesthetic techniques, monitoring protocols, and neurocognitive assessment methods may explain these variable findings.[8,9]

Recent systematic reviews and meta-analyses have further examined the role of processed EEG monitoring during general anaesthesia. Overall, the available evidence suggests that individualized EEG-guided anesthetic management may reduce the incidence of postoperative delirium, particularly in elderly patients undergoing major surgery, although evidence regarding prevention of postoperative cognitive dysfunction remains less conclusive.[10] In response to the growing evidence, professional organizations including the American Society for Enhanced Recovery and the Perioperative Quality Initiative have recommended individualized anesthetic titration using processed EEG monitoring in patients at increased risk of perioperative neurocognitive disorders as part of comprehensive perioperative brain health strategies.[11]

Patients undergoing cardiac surgery constitute a particularly vulnerable population because cardiopulmonary bypass, aortic manipulation, cerebral microembolization, systemic inflammation, and perioperative haemodynamic fluctuations substantially increase the likelihood of cerebral injury.[5,12] Despite encouraging evidence from non-cardiac surgical populations, relatively few prospective randomized studies have specifically evaluated the efficacy of EEG-guided anaesthesia in adult patients undergoing elective cardiac surgery. Furthermore, uncertainty remains regarding its influence on postoperative cognitive recovery, duration of mechanical ventilation, ICU and hospital stay, and overall postoperative complications.[9,13]

Given the substantial clinical burden of postoperative delirium and postoperative cognitive dysfunction, together with the increasing availability of processed EEG monitoring, further high-quality clinical evidence is required to define its role in contemporary cardiac anaesthesia practice.[10,11,14] Therefore, the present prospective randomized controlled study was undertaken to evaluate the effectiveness of EEG-guided anaesthesia in preventing postoperative delirium and postoperative cognitive dysfunction in adult patients undergoing elective cardiac surgery. In addition to neurocognitive outcomes, the study compared anesthetic requirements, duration of mechanical ventilation, length of ICU and hospital stay, and postoperative complications between patients managed with EEG-guided anaesthesia and those receiving conventional anesthetic management.[15]

MATERIALS AND METHODS

Study Design: This prospective, single-center, randomized controlled trial was conducted to evaluate the effect of electroencephalography (EEG)-guided anesthesia on the incidence of postoperative delirium (POD) and postoperative cognitive dysfunction (POCD) in adult patients undergoing elective cardiac surgery. The study was designed in accordance with the Consolidated Standards of Reporting Trials (CONSORT) guidelines.

Study Setting and Period: The study was conducted in the Department of Anaesthesiology in collaboration with the Department of Cardiothoracic and Vascular Surgery, Rajendra Institute of Medical Sciences (RIMS), Ranchi, Jharkhand, India, over a period of 24 months from January 2020 to December 2021.

Study Population: The study included adult patients (≥18 years) scheduled to undergo elective cardiac surgery under general anesthesia with cardiopulmonary bypass (CPB). Consecutive eligible patients attending the pre-anesthetic evaluation clinic were screened for eligibility. After obtaining written informed consent, patients fulfilling the inclusion and exclusion criteria were enrolled. A total of 120 patients were randomized equally into Group A (EEG-guided anesthesia, n = 60) and Group B (standard anesthesia, n = 60).

Sample Size Calculation: The sample size was calculated based on the primary outcome of postoperative delirium. Assuming an incidence of postoperative delirium of 35% in patients receiving conventional anesthesia and an expected reduction to 15% with EEG-guided anesthesia, with a confidence level of 95%, power of 80%, and a two-sided alpha error of 0.05, the minimum required sample size was 54 patients per group. Considering an anticipated dropout rate of approximately 10%, the final sample size was increased to 60 patients in each group, resulting in a total sample size of 120 participants.

Eligibility Criteria

Inclusion Criteria

- Adult patients aged 18 years or older.
- Scheduled for elective cardiac surgery (coronary artery bypass grafting, valve surgery, or combined procedures) under general anesthesia with cardiopulmonary bypass (CPB).
- American Society of Anesthesiologists (ASA) physical status II–IV.
- Preoperative Mini-Mental State Examination (MMSE) score ≥24.
- Willing and able to provide written informed consent.

Exclusion Criteria

- Patients undergoing emergency or redo cardiac surgery.
- History of dementia, Alzheimer's disease, Parkinson's disease, or other neurodegenerative disorders.
- Previous stroke with residual neurological deficits or pre-existing cognitive impairment (MMSE <24).
- Severe hepatic or renal dysfunction, or major psychiatric illness.
- Inability to complete postoperative neurological assessments or refusal to participate in the study.

Randomization and Allocation Concealment: Eligible patients were randomly assigned in a 1:1 ratio to either Group A (EEG-guided anesthesia) or Group B (standard anesthesia) using a computer-generated randomization sequence prepared by an independent investigator who was not involved in patient recruitment, perioperative management, or outcome assessment. Allocation concealment was maintained using sequentially numbered, opaque, sealed envelopes (SNOSE). Each envelope contained the group assignment and was opened by the attending anesthesiologist immediately before induction of anesthesia. Owing to the nature of the intervention, blinding of the anesthesiologist was not feasible. However, the investigators responsible for postoperative delirium assessment, cognitive evaluation, data collection, and statistical analysis remained blinded to the treatment allocation throughout the study to minimize assessment bias.

Anaesthetic Management: All patients underwent a standardized anesthetic protocol. Preoperative fasting was maintained according to institutional guidelines, and routine cardiac medications were continued unless contraindicated. Upon arrival in the operating room, standard monitoring was established, including five-lead electrocardiography, pulse oximetry, invasive arterial blood pressure, central venous pressure, capnography, nasopharyngeal temperature, urine output, and arterial blood gas analysis. General anesthesia was induced with intravenous fentanyl (3–5 μg/kg), propofol (1–2 mg/kg), and rocuronium (0.6–1.0 mg/kg) to facilitate endotracheal intubation. Mechanical ventilation was instituted using an oxygen–air mixture, with ventilatory settings adjusted to maintain normocapnia (end-tidal carbon dioxide 35–40 mmHg). Anesthesia was maintained with sevoflurane, supplemented with intermittent doses of fentanyl and rocuronium as required to ensure adequate anesthesia and muscle relaxation throughout the procedure.

Cardiopulmonary bypass (CPB) was performed using standardized institutional protocols under mild systemic hypothermia (32–34°C). Hemodynamic parameters were maintained within 20% of baseline values using intravenous crystalloids, vasopressors, or inotropic agents whenever necessary. Patients allocated to Group A underwent continuous processed electroencephalographic (EEG) monitoring, and anesthetic depth was titrated to maintain an EEG index between 40 and 60, thereby avoiding excessively deep anesthesia and burst suppression. Patients in Group B received conventional anesthetic management without EEG guidance, with anesthetic depth adjusted according to routine clinical parameters, including heart rate, arterial blood pressure, end-tidal anesthetic concentration, and the anesthesiologist's clinical judgment. At the completion of surgery, patients were transferred to the cardiothoracic intensive care unit, where postoperative care, analgesia, sedation, and ventilatory management were standardized for both groups.

Study Intervention

Group A (EEG-Guided Anaesthesia Group): Patients allocated to Group A received continuous intraoperative electroencephalographic (EEG) monitoring using a processed EEG monitor. Disposable frontal EEG electrodes were applied after induction of general anesthesia according to the manufacturer's recommendations. The processed EEG index was maintained between 40 and 60 by adjusting the concentration of inhalational anesthetics and intravenous anesthetic agents throughout the surgical procedure. The anesthesiologist aimed to avoid excessively deep anesthesia and prolonged periods of burst suppression while ensuring adequate hypnosis, analgesia, and hemodynamic stability. EEG values were continuously monitored until completion of surgery.

Group B (Standard Anaesthesia Group): Patients allocated to Group B received conventional anesthetic management without EEG monitoring. The depth of anesthesia was guided by routine clinical parameters, including heart rate, invasive arterial blood pressure, end-tidal anesthetic concentration, patient movement, and the attending anesthesiologist's clinical judgment. Anesthetic agents were administered according to standard institutional practice to maintain adequate anesthesia and hemodynamic stability throughout the procedure. All other aspects of perioperative management, including surgical technique, cardiopulmonary bypass management, fluid therapy, analgesia, and postoperative intensive care, were standardized and identical in both study groups.

Postoperative Assessment: Following completion of surgery, all patients were transferred to the cardiothoracic intensive care unit (ICU) for standardized postoperative management. Mechanical ventilation, analgesia, sedation, hemodynamic support, and fluid therapy were provided according to institutional protocols. Patients were extubated once they fulfilled standard extubation criteria, including hemodynamic stability, adequate oxygenation, normothermia, satisfactory neurological status, and acceptable arterial blood gas parameters.

Postoperative delirium was assessed twice daily during the first five postoperative days using the Confusion Assessment Method for the Intensive Care Unit (CAM-ICU) by trained investigators who were blinded to the treatment allocation. Cognitive function was evaluated using the Mini-Mental State Examination (MMSE) one day before surgery, on postoperative day 5 or before hospital discharge, and at one month after surgery. Additional postoperative outcomes recorded included duration of mechanical ventilation, time to extubation, length of ICU stay, length of hospital stay, postoperative complications, and in-hospital mortality.

Outcome Measures

Primary Outcome: The primary outcome of the study was the incidence of postoperative delirium (POD) during the first five postoperative days, assessed twice daily using the Confusion Assessment Method for the Intensive Care Unit (CAM-ICU) by trained investigators blinded to the study group allocation.

Secondary Outcomes

- Incidence of postoperative cognitive dysfunction (POCD), assessed using the Mini-Mental State Examination (MMSE) before surgery, on postoperative day 5 (or before hospital discharge), and at one-month follow-up.
- Total intraoperative anesthetic consumption, including inhalational and intravenous anesthetic agents.
- Duration of mechanical ventilation and time to tracheal extubation.
- Length of intensive care unit (ICU) stay and total hospital stay.
- Incidence of major postoperative complications, including atrial fibrillation, stroke, acute kidney injury, re-exploration for bleeding, surgical site infection, and in-hospital mortality.

Data Collection: Data were collected prospectively using a standardized case record form by trained research personnel throughout the study period. Baseline demographic and clinical characteristics, including age, sex, body mass index (BMI), American Society of Anesthesiologists (ASA) physical status, comorbidities, type of cardiac surgery, and preoperative Mini-Mental State Examination (MMSE) scores, were recorded before surgery. Intraoperative variables, including duration of surgery, cardiopulmonary bypass time, aortic cross-clamp time, anesthetic drug consumption, processed EEG index

Table 1: Baseline Demographic and Clinical Characteristics of the Study Population

Variable	Group A (n = 60)	Group B (n = 60)	P value
Age (years)	63.4 ± 8.2	64.1 ± 8.7	0.648
Male sex, n (%)	39 (65.0)	41 (68.3)	0.701
Female sex, n (%)	21 (35.0)	19 (31.7)	-
BMI (kg/m²)	25.8 ± 3.4	26.1 ± 3.6	0.635
ASA II, n (%)	24 (40.0)	22 (36.7)	0.709
ASA III, n (%)	36 (60.0)	38 (63.3)	-
Hypertension, n (%)	37 (61.7)	39 (65.0)	0.707
Diabetes mellitus, n (%)	22 (36.7)	24 (40.0)	0.705
Baseline MMSE score	28.5 ± 1.2	28.3 ± 1.3	0.384
CABG, n (%)	41 (68.3)	40 (66.7)	0.847
Valve surgery, n (%)	19 (31.7)	20 (33.3)	-

Note: DValues are presented as mean ± SD or number (%). BMI, body mass index; ASA, American Society of Anesthesiologists; MMSE, Mini-Mental State Examination; CABG, coronary artery bypass grafting.

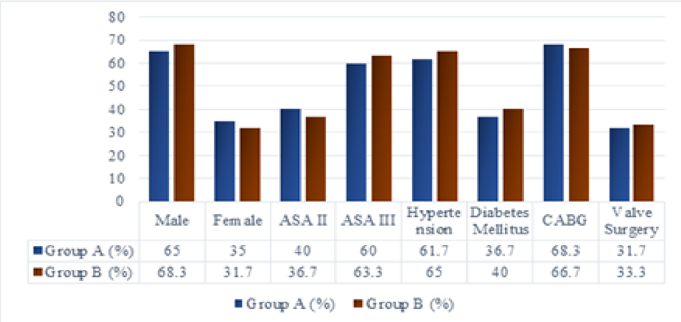

Figure 1: Comparison of Baseline Demographic and Clinical Characteristics Between Group A and Group B

Figure legend: Clustered bar chart showing the distribution of baseline categorical characteristics among patients in the EEG-guided anaesthesia group (Group A) and the standard anaesthesia group (Group B). No statistically significant differences were observed between the two groups for any baseline characteristic (P > 0.05), indicating successful randomization and comparable baseline characteristics.

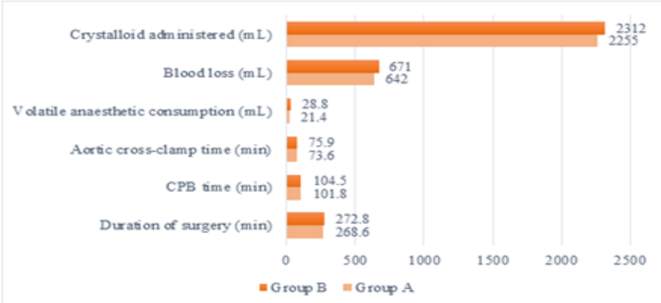

Figure 2: Comparison of Intraoperative Continuous Variables Between the EEG-Guided Anaesthesia Group (Group A) and the Standard Anaesthesia Group (Group B)

Figure legend: Clustered bar chart comparing the intraoperative continuous variables between Group A and Group B, including duration of surgery, cardiopulmonary bypass time, aortic cross-clamp time, volatile anaesthetic consumption, blood loss, and crystalloid administration. Volatile anaesthetic consumption was significantly

Table 2: Comparison of Intraoperative Characteristics Between the Study Groups

Variable	Group A (n = 60)	Group B (n = 60)	P value
Duration of surgery (min)	268.6 ± 36.9	272.8 ± 39.7	0.548
CPB time (min)	101.8 ± 17.6	104.5 ± 19.1	0.418
Aortic cross-clamp time (min)	73.6 ± 13.4	75.9 ± 14.2	0.362
Volatile anaesthetic consumption (mL)	21.4 ± 4.3	28.8 ± 5.1	<0.001
Burst suppression, n (%)	5 (8.3)	17 (28.3)	0.005
Blood loss (mL)	642 ± 146	671 ± 158	0.298
Crystalloid administered (mL)	2255 ± 385	2312 ± 402	0.429
Blood transfusion, n (%)	10 (16.7)	13 (21.7)	0.484
Vasopressor requirement, n (%)	18 (30.0)	21 (35.0)	0.562

Table Note: Values are expressed as mean ± SD or number (%). CPB, cardiopulmonary bypass.

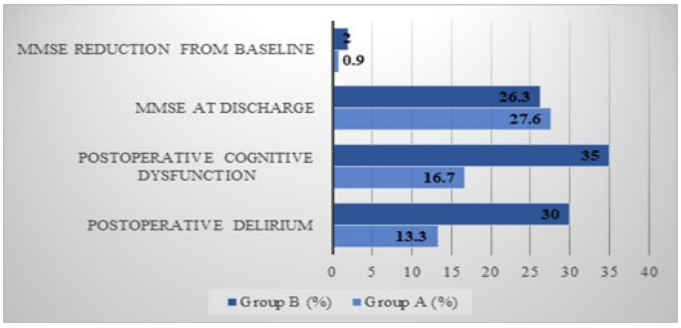

Figure 3: Comparison of Postoperative Neurocognitive Outcomes and MMSE Scores Between Group A and Group B.

Figure Note: Values are presented as mean ± SD or percentage. EEG-guided anaesthesia (Group A) significantly reduced postoperative delirium and cognitive dysfunction and improved MMSE scores compared with standard anaesthesia (Group B) (all P < 0.05).

Intraoperative Characteristics: The intraoperative characteristics are summarized in [Table 2]. Patients managed with EEG-guided anaesthesia required significantly lower volatile anaesthetic consumption than those receiving conventional anaesthetic management (P < 0.001). The incidence of intraoperative burst suppression was also significantly lower in Group A. There were no statistically significant differences between the groups regarding duration of surgery, cardiopulmonary bypass time, aortic cross-clamp time, estimated blood loss, intraoperative fluid administration, blood transfusion requirements, or vasopressor use (all P > 0.05), indicating comparable surgical complexity and intraoperative management.

Postoperative Delirium and Cognitive Outcomes: The primary postoperative outcomes are presented in [Table 3]. The incidence of postoperative delirium during the first five postoperative days was significantly lower in the EEG-guided group than in the standard anaesthesia group (13.3% vs. 30.0%; P = 0.026). Likewise, postoperative cognitive dysfunction assessed using the MMSE occurred significantly less frequently in Group A than in Group B (16.7% vs. 35.0%; P = 0.021). Patients receiving EEG-guided anaesthesia also demonstrated significantly better postoperative cognitive recovery, reflected

Table 3: Comparison of Postoperative Delirium and Cognitive Outcomes Between the Study Groups

Outcome	Group A (n = 60)	Group B (n = 60)	P value
Postoperative delirium, n (%)	8 (13.3)	18 (30.0)	0.026
Postoperative cognitive dysfunction, n (%)	10 (16.7)	21 (35.0)	0.021
MMSE at discharge	27.6 ± 1.5	26.3 ± 1.8	<0.001
MMSE reduction from baseline	0.9 ± 0.7	2.0 ± 1.0	<0.001

Table Note: Values are presented as mean ± SD or number (%). MMSE, Mini-Mental State Examination.

Secondary Postoperative Outcomes: Secondary postoperative outcomes are summarized in [Table 4]. Group A showed significantly shorter durations of mechanical ventilation, earlier tracheal extubation, reduced intensive care unit (ICU) stay, and shorter total hospital stay compared with Group B (all P < 0.05). Although postoperative pain scores and overall recovery profiles were favorable in the EEG-guided group, no significant differences were observed in postoperative hemodynamic instability or re-exploration for bleeding.

Table 4: Comparison of Secondary Postoperative Outcomes Between the Study Groups

Outcome	Group A (n = 60)	Group B (n = 60)	P value
Mechanical ventilation (hours)	8.5 ± 2.1	10.8 ± 2.7	<0.001
Time to extubation (hours)	9.6 ± 2.4	12.1 ± 3.1	<0.001
ICU stay (days)	2.7 ± 0.8	3.6 ± 1.0	<0.001
Hospital stay (days)	8.8 ± 1.9	10.4 ± 2.3	<0.001

Table Note: Values are presented as mean ± SD or number (%). ICU, intensive care unit.

Postoperative Complications: Postoperative complications are presented in [Table 5]. The incidence of atrial fibrillation, acute kidney injury, stroke, surgical site infection, and in-hospital mortality was lower in Group A than in Group B; however, these differences were not statistically significant (all P > 0.05). No complications attributable to EEG monitoring or device-related adverse events were observed

Table 5: Comparison of Postoperative Complications Between the Study Groups

Complication	Group A (n = 60)	Group B (n = 60)	P value
Atrial fibrillation	6 (10.0)	10 (16.7)	0.279
Acute kidney injury	3 (5.0)	7 (11.7)	0.185
Stroke	1 (1.7)	3 (5.0)	0.309
Surgical site infection	2 (3.3)	5 (8.3)	0.239
Re-exploration for bleeding	1 (1.7)	2 (3.3)	0.558
In-hospital mortality	1 (1.7)	2 (3.3)	0.558

Table Note: Values are presented as number (%). Fisher's exact test was used where appropriate.

Multivariable Logistic Regression Analysis: The results of the multivariable logistic regression analysis are presented in [Table 6]. After adjustment for clinically relevant covariates, conventional anaesthetic management, increasing age, prolonged cardiopulmonary bypass duration, and lower baseline MMSE score were identified as independent predictors of postoperative delirium. Conversely, EEG-

Table 6: Multivariable Logistic Regression Analysis of Independent Predictors of Postoperative Delirium

Variable	Adjusted OR	95% CI	P value
Standard anaesthesia (vs EEG-guided)	2.81	1.18–6.72	0.020
Age (per year increase)	1.06	1.01–1.12	0.024
CPB time (per minute increase)	1.03	1.01–1.05	0.009
Baseline MMSE score	0.73	0.57–0.94	0.016

Table Note: OR, odds ratio; CI, confidence interval; CPB, cardiopulmonary bypass; MMSE, Mini-Mental State Examination. Variables with P < 0.10 in the univariate analysis were included in the multivariable logistic regression model. A two-tailed P < 0.05 was considered

(Group A), hemodynamic parameters, vasopressor requirements, intraoperative blood loss, fluid administration, and blood transfusion requirements, were documented. Postoperative data included the incidence of postoperative delirium assessed using the Confusion Assessment Method for the Intensive Care Unit (CAM-ICU), postoperative cognitive dysfunction assessed using MMSE, duration of mechanical ventilation, time to tracheal extubation, length of intensive care unit (ICU) stay, total hospital stay, postoperative complications, and in-hospital mortality. All collected data were verified for completeness and accuracy before being entered into the study database for statistical analysis.

Ethical Considerations: The study was conducted in accordance with the ethical principles of the Declaration of Helsinki and Good Clinical Practice guidelines. The study protocol was reviewed and approved by the Institutional Ethics Committee prior to the commencement of the study. Written informed consent was obtained from all participants before enrollment after explaining the study objectives, procedures, potential benefits, and possible risks. Participation was voluntary, and participants were free to withdraw from the study at any time without affecting their standard medical care. The confidentiality and privacy of all participant information were strictly maintained by anonymizing the collected data and restricting access to the study records to the research team.

Statistical Analysis: Data were entered into Microsoft Excel and analyzed using IBM SPSS Statistics for Windows, Version 26.0 (IBM Corp., Armonk, NY, USA). Continuous variables were assessed for normality using the Shapiro–Wilk test and presented as mean ± standard deviation (SD) for normally distributed data or median with interquartile range (IQR) for non-normally distributed data. Categorical variables were expressed as frequencies and percentages. Baseline characteristics and outcome variables were compared between Group A and Group B using the independent-samples Student's t-test for normally distributed continuous variables or the Mann–Whitney U test for non-normally distributed variables. Categorical variables were compared using the Chi-square test or Fisher's exact test, as appropriate. Changes in Mini-Mental State Examination (MMSE) scores over time were analyzed using repeated-measures analysis of variance (ANOVA). Multivariable logistic regression analysis was performed to identify independent predictors of postoperative delirium after adjusting for clinically relevant covariates. Statistical significance was defined as a two-tailed P value <0.05, and 95% confidence intervals (CIs) were calculated where appropriate.

RESULTS

Patient Enrollment and Study Population: During the study period, 120 adult patients scheduled for elective cardiac surgery fulfilled the eligibility criteria and were enrolled in the study. Patients were randomized equally into Group A (EEG-guided anaesthesia, n = 60) and Group B (standard anaesthesia, n = 60). All randomized patients completed the study protocol and were included in the final statistical analysis. No patient was excluded after randomization, and complete perioperative and postoperative outcome data were available for all participants.

Baseline Demographic and Clinical Characteristics: The baseline demographic and clinical characteristics of the study participants are presented in [Table 1]. The mean age of the study population was comparable between the two groups, with no significant differences in sex distribution, body mass index (BMI), American Society of Anesthesiologists (ASA) physical status, prevalence of hypertension, diabetes mellitus, baseline Mini-Mental State Examination (MMSE) score, or type of cardiac surgery (all P > 0.05). These findings indicate that the study groups were well matched at baseline before the intervention.

DISCUSSION

The present prospective randomized controlled trial demonstrated that EEG-guided anaesthesia significantly improved early postoperative neurological and recovery outcomes in adult patients undergoing elective cardiac surgery with cardiopulmonary bypass. Compared with conventional anaesthetic management, EEG-guided anaesthesia significantly reduced the incidence of postoperative delirium and postoperative cognitive dysfunction, improved postoperative MMSE scores, decreased volatile anaesthetic consumption, reduced intraoperative burst suppression, and shortened the duration of mechanical ventilation, ICU stay, and hospital stay. Furthermore, conventional anaesthetic management, increasing age, prolonged cardiopulmonary bypass duration, and lower baseline MMSE score were identified as independent predictors of postoperative delirium. These findings indicate that individualized titration of anaesthetic depth using processed EEG may improve perioperative brain protection and enhance postoperative recovery.

Postoperative delirium and postoperative cognitive dysfunction remain major neurological complications after cardiac surgery and are associated with prolonged hospitalization, impaired functional recovery, increased healthcare costs, and higher mortality. Their development is multifactorial, involving advanced age, pre-existing comorbidities, systemic inflammation, cerebral hypoperfusion, and embolic events related to cardiopulmonary bypass. Consequently, strategies that optimize intraoperative cerebral protection are increasingly recognized as important components of perioperative care.[1]

The significant reduction in postoperative delirium observed in the present study is consistent with the findings of Chan et al., who demonstrated that BIS-guided anaesthesia reduced postoperative delirium and cognitive decline by avoiding unnecessarily deep anaesthesia and excessive anaesthetic exposure.[2] Likewise, Radtke et al. reported that processed EEG monitoring significantly reduced postoperative delirium, although its influence on postoperative cognitive dysfunction was less pronounced.[3] Our findings extend this evidence to adult cardiac surgery, where additional neurological insults associated with cardiopulmonary bypass may further increase the risk of perioperative neurocognitive disorders.

The beneficial effects of EEG-guided anaesthesia are biologically plausible. Conventional clinical indicators such as heart rate and blood pressure provide only indirect information regarding cerebral cortical activity and may fail to detect excessive anaesthetic depth. In contrast, processed EEG allows continuous assessment of brain activity and enables individualized adjustment of anaesthetic administration, thereby reducing unnecessary hypnotic exposure and limiting prolonged burst suppression.[4] Standardized recommendations for perioperative neurocognitive disorders further emphasize the importance of distinguishing postoperative delirium from delayed neurocognitive recovery and postoperative cognitive dysfunction when evaluating perioperative outcomes.[5]

Despite encouraging evidence, the role of EEG-guided anaesthesia remains debated. The ENGAGES trial did not demonstrate a significant reduction in postoperative delirium despite successfully reducing EEG burst suppression in elderly surgical patients.[6] Differences in patient populations, surgical procedures, perioperative management, and baseline neurological risk may explain these contrasting findings. In contrast, the American Society for Enhanced Recovery and the Perioperative Quality Initiative recommend individualized EEG-guided titration of anaesthesia, particularly in patients at increased risk of perioperative neurocognitive disorders, as part of comprehensive brain-health strategies.[7] Furthermore, a recent meta-analysis concluded that EEG-guided anaesthetic delivery reduces postoperative delirium and unnecessary anaesthetic exposure, particularly in patients undergoing major surgery.[8]

The lower incidence of postoperative cognitive dysfunction observed in our study is clinically important because postoperative cognitive impairment remains a frequent complication after major surgery. Although its pathophysiology is multifactorial, excessive anaesthetic exposure has been proposed as one potentially modifiable contributor.[9] Consistent with previous reports, increasing age independently predicted postoperative delirium in our cohort, emphasizing the vulnerability of elderly cardiac surgical patients.[10] Therefore, EEG-guided anaesthesia should be considered one component of a multimodal perioperative cognitive protection strategy that includes optimization of cerebral perfusion, haemodynamic stability, adequate analgesia, early mobilization, and routine delirium screening.[11] Nevertheless, assessment of cognitive dysfunction remains challenging because different studies employ varying neuropsychological tests and follow-up periods. Although the MMSE is practical and widely accepted, it may underestimate subtle cognitive impairment, highlighting the need for comprehensive neuropsychological evaluation in future studies.[12]

An important intraoperative finding was the significantly lower incidence of burst suppression in the EEG-guided group. Burst suppression reflects profound cortical depression and has been associated with delayed neurological recovery in susceptible patients.[13] Processed EEG monitoring provides continuous assessment of cortical electrical activity and assists clinicians in maintaining an appropriate depth of anaesthesia while avoiding excessive cerebral depression.[14] The observed reductions in volatile anaesthetic consumption and burst suppression in the present study likely contributed to the improved neurological recovery and shorter ICU and hospital stay.

The strengths of this study include its prospective randomized design, standardized perioperative management, blinded postoperative neurological assessment, and comprehensive evaluation of both delirium and cognitive dysfunction. Comparable baseline characteristics minimized potential confounding, while multivariable logistic regression identified independent predictors of postoperative delirium. However, several limitations should be acknowledged. This was a single-centre study with a relatively modest sample size, limiting the generalizability of the findings. Cognitive function was assessed using the MMSE, which may not detect subtle neurocognitive deficits, and long

-term cognitive outcomes were not evaluated. In addition, biomarkers of neuronal injury and neuroinflammation were not measured. Future multicentre randomized trials should adopt standardized nomenclature, comprehensive neuropsychological assessment, and longer follow-up to determine whether the early neurological benefits of EEG-guided anaesthesia translate into sustained improvements in cognitive function and quality of life.[15]

Overall, the present study demonstrates that EEG-guided anaesthesia significantly reduces postoperative delirium and early cognitive dysfunction while improving postoperative recovery in adult patients undergoing elective cardiac surgery. These findings support the incorporation of processed EEG monitoring into routine perioperative management of high-risk cardiac surgical patients to optimize anaesthetic delivery and enhance neurological outcomes.

Limitations: This study has several limitations. It was conducted at a single center with a relatively small sample size, which may limit the generalizability of the findings. Postoperative cognitive function was assessed using the Mini-Mental State Examination (MMSE), which may not detect subtle cognitive changes. Cognitive outcomes were evaluated only during the early postoperative period, and long-term follow-up was not performed. In addition, serum biomarkers of neuronal injury and neuroinflammation were not assessed. Larger multicenter studies with longer follow-up are needed to confirm the benefits of EEG-guided anaesthesia after cardiac surgery.

CONCLUSION

EEG-guided anaesthesia significantly reduced the incidence of postoperative delirium and postoperative cognitive dysfunction in adult patients undergoing elective cardiac surgery compared with conventional anaesthetic management. Individualized titration of anaesthetic depth using processed EEG monitoring was associated with lower anaesthetic consumption, earlier postoperative recovery, shorter mechanical ventilation, and reduced intensive care unit and hospital stay without increasing perioperative complications. These findings support the incorporation of EEG-guided anaesthesia as an effective perioperative strategy to improve neurological outcomes and enhance postoperative recovery following cardiac surgery. Further large-scale, multicentre randomized controlled trials with long-term follow-up are warranted to validate these findings and establish its routine clinical application.

Acknowledgments: The authors sincerely thank all the patients who participated in this study for their valuable cooperation. The authors also acknowledge the contributions of the anaesthesia, cardiothoracic surgery, intensive care, nursing, and research staff involved in patient care and data collection throughout the study.

Conflict of interest

Authors declare that they have no financial interests or personal conflicts that may affect the study in this article.

Financial disclosure

The authors declared that this study has received no financial support.

REFERENCES

1. Deiner S, Silverstein JH. Postoperative delirium and cognitive dysfunction. Br J Anaesth. 2012;108(Suppl 1):i41-i46. doi:10.1093/bja/aer473.
2. Chan MTV, Cheng BCP, Lee TMC, Gin T; CODA Trial Group. BIS-guided anesthesia decreases postoperative delirium and cognitive decline. J Neurosurg Anesthesiol. 2013;25(1):33-42. doi:10.1097/ANA.0b013e3182712fba.
3. Radtke FM, Franck M, Lendner J, Krüger S, Wernecke KD, Spies CD.