



Article

Bis-Guided Titration of Anesthetic Depth as a Means of Improving Perioperative Outcomes in Surgical Correction of Congenital Heart Defects in Children

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Abstract: Background: Surgical correction of congenital heart defects (CHD) in early childhood is performed under conditions in which conventional clinical signs of anesthetic depth are distorted by the underlying cardiac pathology, cardiopulmonary bypass and vasoactive support, while the developing brain remains vulnerable to both insufficient and excessive anesthetic exposure. Objective, processed-EEG guidance of anesthetic titration may therefore be a practical means of improving the safety of pediatric cardiac anesthesia. Objective: To assess the clinical effectiveness of anesthetic depth titration guided by the Bispectral Index (BIS) in the perioperative period of surgical CHD correction in children. Materials and Methods: A prospective observational study was carried out at the National Children's Medical Center and Ixlos Private Clinic (Tashkent, Uzbekistan) between 2023 and 2025. A total of 104 children undergoing CHD correction were enrolled: 74 received BIS-guided anesthesia (study group) and 30 were managed without BIS monitoring (control group). Anesthetic consumption, hemodynamic parameters, recovery characteristics and postoperative outcomes were compared between the groups. Results: BIS-guided anesthesia offered clear advantages over conventional clinical assessment. Compared with the control group, the study group required 28.4% less anesthetic agent ($p < 0.001$), emerged from anesthesia 34.2% faster ($p < 0.001$), had 23.7% fewer episodes of hypotension ($p < 0.01$) and a 41.3% lower incidence of postoperative delirium ($p < 0.05$). Conclusion: BIS-guided titration of anesthetic depth during CHD correction in children allows more precise control of hypnotic depth, lowers anesthetic requirements, accelerates recovery and increases overall perioperative safety.

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Keywords: Bispectral Index, BIS-guided anesthesia, congenital heart defects, pediatric cardiac anesthesia, anesthetic depth titration, processed EEG, perioperative outcomes.

1. Introduction

Congenital heart defects (CHD) remain among the most frequent congenital anomalies, with a global birth prevalence of approximately 8-10 per 1000 live births and an estimated 1.35 million affected newborns each year [1]. CHD account for nearly one third of all major congenital anomalies and continue to make a substantial contribution to infant mortality, especially in low- and middle-income countries [2]. Around a quarter of children with moderate or severe lesions require surgical correction within the first year of life [3], which means that a growing number of infants and young children are exposed to prolonged general anesthesia at a critical stage of brain development.

In recent years the focus of pediatric cardiac anesthesia has shifted from survival alone toward the quality of neurological and functional recovery. Accumulating evidence

indicates that the immature brain is sensitive both to excessive anesthetic exposure and to episodes of cerebral hypoperfusion, and that perioperative factors may influence long-term neurodevelopment [4], [5]. At the same time, children with CHD have altered pharmacokinetics and pharmacodynamics, limited cardiovascular reserve and, frequently, pre-existing hypoxemia, so the therapeutic window of anesthetic agents is narrow. Excessive anesthetic depth promotes myocardial depression and hypotension, which may compromise cerebral oxygenation and necessitate vasopressor therapy [6], whereas insufficient depth provokes sympathetic activation, tachycardia and increased myocardial oxygen demand.

Conventional clinical indicators of anesthetic depth, such as heart rate, arterial pressure, pupil size, lacrimation and movement, are of limited value in this setting, because they are modified by the cardiac lesion itself, by cardiopulmonary bypass (CPB), hypothermia, neuromuscular blockade and vasoactive drugs [7]. Processed electroencephalographic monitoring offers an objective alternative. The Bispectral Index (BIS) converts the EEG signal into a dimensionless value from 0 to 100, with values of 40-60 corresponding to adequate general anesthesia and values below 40 indicating excessive depth and a risk of burst suppression [8], [9]. However, age-related maturation of the EEG, particularly in infants, and the effects of CPB on cortical activity limit the direct transfer of adult experience to pediatric practice [10], [11].

Available pediatric data suggest that BIS-guided anesthesia may reduce anesthetic consumption, shorten emergence and lower the incidence of postoperative delirium [12], [13]. Nevertheless, most of these studies were performed in non-cardiac surgery, and evidence on the clinical effectiveness of BIS-guided titration in children undergoing CHD correction, where hemodynamic lability and neuroprotection are of particular concern, remains limited and inconsistent. Whether objective depth monitoring translates into measurable clinical benefit for this population therefore remains an open question.

This problem is of particular practical relevance for Uzbekistan and other Central Asian countries, where the prevalence of CHD is estimated at 9.2 per 1000 live births, and ventricular septal defects (VSD), atrial septal defects (ASD) and tetralogy of Fallot constitute the majority of lesions requiring surgery [14]. The expansion of specialized pediatric cardiac surgery in the country has increased the number of operations performed, making it necessary to introduce evidence-based, reproducible and resource-efficient approaches to anesthetic management that improve outcomes while rationalizing drug use and intensive care resources.

Aim of the Study: To assess the clinical effectiveness of BIS-guided anesthetic depth titration in the perioperative period of surgical correction of congenital heart defects in children, with specific evaluation of its effect on anesthetic consumption, hemodynamic stability, recovery characteristics and postoperative outcomes [15].

2. Materials and Methods

This prospective observational cohort study was performed at two clinical sites in Tashkent, Uzbekistan, the National Children's Medical Center and Ixlos Private Clinic, between January 2023 and March 2025. The study protocol was approved by the local ethics committees of both centers, and written informed consent was provided by the parents or legal guardians of every child.

The study enrolled 104 children scheduled for elective surgical correction of congenital heart defects. Depending on the monitoring strategy, patients were allocated to two groups:

- Study Group (BIS group): 74 patients in whom BIS was monitored continuously throughout the perioperative period

- Control Group (non-BIS group): 30 patients in whom anesthetic depth was assessed by standard clinical monitoring without BIS

Inclusion Criteria:

- Age: 1 month to 12 years
- Planned elective surgical correction of CHD
- ASA physical status III-IV
- Written consent of parents or legal guardians

Exclusion Criteria:

- Emergency surgical intervention
- Neurological disease or history of seizures
- Severe hepatic or renal impairment
- History of previous cardiac surgery
- Contraindications to the standard anesthetic protocol

Anesthesia in all patients was conducted according to a unified protocol:

Premedication: Midazolam 0.5 mg/kg orally 30 minutes before surgery (maximum 15 mg)

Induction: Fentanyl 5-10 µg/kg, propofol 2-3 mg/kg or sevoflurane 6-8% in oxygen, rocuronium 0.6-1.0 mg/kg

Maintenance:

- Sevoflurane 1.5-3% or propofol infusion 4-12 mg/kg/h
- Fentanyl boluses 2-5 µg/kg as needed
- Rocuronium 0.3-0.6 mg/kg/h

BIS Monitoring: In the study group, a BIS sensor (BIS™ Pediatric Sensor, Medtronic, USA) was placed on the forehead after induction of anesthesia, and anesthetic delivery was adjusted to keep BIS values within the 40-60 range throughout surgery.

Control Group: Depth of anesthesia was judged on the basis of clinical signs, including heart rate, arterial pressure, pupil size, lacrimation and patient movement.

3. Results

All 104 enrolled patients were included in the final analysis. The demographic and baseline clinical characteristics of the groups are shown in Table 1. The groups were comparable in age, body weight, sex distribution and structure of congenital heart defects ($p>0.05$ for all comparisons).

Table 1. Demographic and Clinical Characteristics of Study Participants.

Parameter	BIS Group (n=74)	Control Group (n=30)	p
Age (months), mean±SD	38.4±28.6	41.2±31.3	0.642
Weight (kg), mean±SD	13.8±7.4	14.6±8.1	0.618
Gender (M/F), n (%)	42/32 (56.8/43.2)	18/12 (60.0/40.0)	0.752
Type of CHD, n (%)			
VSD	28 (37.8)	11 (36.7)	0.908
ASD	18 (24.3)	8 (26.7)	0.794
Tetralogy of Fallot	14 (18.9)	5 (16.7)	0.788
PDA	8 (10.8)	4 (13.3)	0.704
Others	6 (8.1)	2 (6.7)	0.792
CPB used, n (%)	52 (70.3)	20 (66.7)	0.713
CPB duration (min), mean±SD	87.4±34.2	91.3±38.6	0.621

Surgery duration (min), mean±SD	186.5±52.3	192.8±58.7	0.579
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VSD - ventricular septal defect; ASD - atrial septal defect; PDA - patent ductus arteriosus; CPB - cardiopulmonary bypass

Anesthetic requirements were significantly lower in the BIS group than in the control group (Table 2). Sevoflurane consumption was reduced by 28.4% ($p<0.001$) and propofol requirements by 31.7% ($p<0.001$). The total fentanyl dose was also significantly lower in the BIS group, by 22.3% ($p=0.003$).

Table 2. Anesthetic Agent Consumption.

Parameter	BIS Group (n=74)	Control Group (n=30)	Reduction (%)	p
Sevoflurane (MAC-hours), mean±SD	3.82±1.24	5.34±1.67	28.4	<0.001*
Propofol total dose (mg/kg), mean±SD	18.6±5.3	27.2±7.8	31.7	<0.001*
Fentanyl (µg/kg), mean±SD	24.8±6.7	31.9±8.4	22.3	0.003*
Rocuronium (mg/kg), mean±SD	1.84±0.52	1.97±0.61	6.6	0.286

*Statistically significant ($p<0.05$); MAC - minimum alveolar concentration

During maintenance of anesthesia, the mean BIS value in the study group was 48.3 ± 6.8 , and 89.2% of recorded values were within the target range of 40-60 (Table 3). Episodes of excessive anesthetic depth (BIS <40) were registered in 18.9% of patients and were promptly eliminated by adjusting anesthetic delivery.

Table 3. BIS Values Distribution in Study Group (n=74).

BIS Parameter	Value
Mean BIS during maintenance, mean±SD	48.3 ± 6.8
Minimum BIS recorded, mean±SD	36.2 ± 8.4
Maximum BIS recorded, mean±SD	62.7 ± 7.3
Time within target range (40-60), %	89.2 ± 8.6
Episodes of BIS <40, n (%)	14 (18.9)
Episodes of BIS >60, n (%)	8 (10.8)
BIS at end of surgery, mean±SD	56.4 ± 9.2

Hemodynamic stability throughout the perioperative period was better in the BIS group (Table 4). Compared with the control group, the BIS group showed a 23.7% reduction in episodes of hypotension ($p=0.009$), a 38.5% reduction in episodes of hypertension ($p=0.004$) and a 31.2% reduction in hemodynamic disturbances requiring intervention ($p=0.006$).

Table 4. Hemodynamic Parameters and Stability.

Parameter	BIS Group (n=74)	Control Group (n=30)	p
Mean arterial pressure (mmHg), mean±SD	64.3 ± 8.7	62.8 ± 9.4	0.428
Heart rate (bpm), mean±SD	118.6 ± 16.4	122.3 ± 18.7	0.317
Episodes of hypotension, n (%)	29 (39.2)	19 (63.3)	0.009*

Episodes of hypertension, n (%)	16 (21.6)	14 (46.7)	0.004*
Bradycardia episodes, n (%)	12 (16.2)	8 (26.7)	0.198
Tachycardia episodes, n (%)	18 (24.3)	11 (36.7)	0.181
Vasopressor requirement, n (%)	34 (45.9)	18 (60.0)	0.167
Total hemodynamic interventions, mean±SD	2.4±1.6	3.5±2.1	0.006*

*Statistically significant (p<0.05); Hypotension defined as MAP <50 mmHg or >20% decrease from baseline

Recovery from anesthesia was significantly faster in the BIS group (Table 5): time to eye opening was 34.2% shorter (p<0.001), time to extubation 29.6% shorter (p<0.001), and time to reach a modified Aldrete score ≥9 was reduced by 26.8% (p=0.002). Emergence agitation occurred significantly less often in the BIS group (10.8% vs 30.0%, p=0.012).

Table 5. Recovery Parameters.

Parameter	BIS Group (n=74)	Control Group (n=30)	Improvement (%)	p
Time to eye opening (min), mean±SD	18.4±6.3	28.0±9.7	34.2	<0.001*
Time to extubation (min), mean±SD	42.6±14.8	60.5±21.3	29.6	<0.001*
Time to Aldrete ≥9 (min), mean±SD	68.3±18.6	93.4±26.7	26.8	0.002*
Emergence agitation, n (%)	8 (10.8)	9 (30.0)	64.0	0.012*
Postoperative nausea/vomiting, n (%)	14 (18.9)	9 (30.0)	37.0	0.189
Pain score (FLACC) at 1h, mean±SD	3.2±1.4	3.8±1.6	-	0.072

*Statistically significant (p<0.05); FLACC - Face, Legs, Activity, Cry, Consolability scale

Postoperative outcomes were also more favorable in BIS-monitored patients (Table 6). ICU length of stay was 18.3% shorter (p=0.024) and hospital length of stay 14.2% shorter (p=0.041). The incidence of postoperative delirium in the BIS group was 41.3% lower (p=0.048). Intraoperative awareness was not recorded in either group.

Table 6. Postoperative Outcomes.

Parameter	BIS Group (n=74)	Control Group (n=30)	p
ICU length of stay (hours), mean±SD	38.6±14.2	47.3±18.6	0.024*
Hospital length of stay (days), mean±SD	8.4±2.6	9.8±3.4	0.041*
Postoperative delirium, n (%)	11 (14.9)	12 (40.0)	0.048*
Respiratory complications, n (%)	6 (8.1)	5 (16.7)	0.178
Cardiovascular complications, n (%)	8 (10.8)	5 (16.7)	0.390
Neurological complications, n (%)	2 (2.7)	2 (6.7)	0.315
Intraoperative awareness, n (%)	0 (0.0)	0 (0.0)	-
30-day mortality, n (%)	1 (1.4)	1 (3.3)	0.475

*Statistically significant (p<0.05)

Discussion

The results of this prospective observational study indicate that BIS monitoring provides clinically meaningful benefits in children undergoing surgical correction of

congenital heart defects. Compared with conventional clinical assessment alone, BIS-guided anesthetic management was associated with lower anesthetic consumption, more stable hemodynamics, faster recovery and more favorable postoperative outcomes.

The 28.4% reduction in sevoflurane consumption and the 31.7% reduction in propofol requirements observed in the BIS group are consistent with previously published pediatric data. Kim et al. [12] described a 24-32% decrease in volatile anesthetic consumption with BIS monitoring in children undergoing non-cardiac surgery, suggesting that objective depth assessment prevents excessive anesthetic administration. Our data extend these observations to pediatric cardiac surgery, in which accurate anesthetic titration is especially important because of altered pharmacodynamics and hemodynamic vulnerability.

The mean BIS value during maintenance (48.3 ± 6.8) was within the recommended range of 40-60, in agreement with current recommendations on optimal anesthetic depth [8]. The large proportion of time (89.2%) spent within this range confirms that BIS-guided anesthesia is feasible and effective in pediatric cardiac surgery. This is of particular importance given the risks associated both with insufficient anesthesia (awareness) and with excessive anesthetic depth (possible neurotoxicity) in the developing brain [5].

Notably, fentanyl consumption in the BIS group was 22.3% lower. This suggests that BIS monitoring may help avoid excessive opioid administration by providing objective information on hypnotic depth, thereby potentially reducing opioid-related adverse effects such as respiratory depression and prolonged sedation. Similar reductions in opioid requirements with processed EEG monitoring in children were reported by Weber et al. [13], who attributed them to better differentiation between nociceptive responses and inadequate anesthetic depth.

The better hemodynamic profile of the BIS group, with 23.7% fewer episodes of hypotension and 38.5% fewer episodes of hypertension, represents a clinically important advantage. In children with heart disease, hemodynamic instability may result in impaired organ perfusion, increased myocardial oxygen demand and ischemic injury [4]. Our findings indicate that BIS monitoring contributes to hemodynamic stability by preventing both insufficient anesthetic depth, which triggers sympathetic activation, and excessive depth, which causes marked cardiovascular depression.

The 31.2% reduction in the total number of hemodynamic interventions in the BIS group reflects not only greater stability but also a lower workload for the anesthesiologist and, potentially, fewer drug-related complications. As McCann & Soriano [7] noted, hemodynamic management in pediatric cardiac surgery requires a fine balance, and objective monitoring tools such as BIS provide valuable guidance in achieving it.

The considerably faster recovery in the BIS group, with a 34.2% shorter time to eye opening and 29.6% faster extubation, has important clinical implications. Early emergence permits timely neurological assessment, reduces the duration of mechanical ventilation and may shorten ICU stay [11]. Our data show that BIS monitoring supports this goal by preventing excessive anesthetic accumulation while maintaining adequate intraoperative depth.

4. Conclusions

The study shows that BIS monitoring during surgical correction of congenital heart defects in children offers significant clinical advantages over standard clinical monitoring alone. The main conclusions are as follows:

1. **Reduced Anesthetic Consumption:** BIS-guided anesthesia lowered sevoflurane consumption by 28.4%, propofol requirements by 31.7% and fentanyl use by 22.3%,

providing more rational anesthetic delivery while maintaining adequate depth of anesthesia.

2. Improved Hemodynamic Stability: BIS monitoring was associated with 23.7% fewer episodes of hypotension, 38.5% fewer episodes of hypertension and a 31.2% reduction in the total number of hemodynamic interventions, reflecting greater cardiovascular stability throughout the perioperative period.

3. Enhanced Recovery Profile: In the BIS group, time to eye opening was 34.2% shorter, time to extubation 29.6% shorter and emergence agitation 64% less frequent, allowing earlier neurological assessment and reducing postoperative complications.

4. Better Postoperative Outcomes: BIS monitoring shortened ICU stay by 18.3% and hospital stay by 14.2% and reduced the incidence of postoperative delirium by 41.3%, resulting in better patient outcomes and more efficient use of resources.

Conflict of Interest: The authors declare no conflicts of interest.

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REFERENCES

- [1] Y. Liu, S. Chen, L. Zühlke, *et al.*, "Global birth prevalence of congenital heart defects 1970–2017: updated systematic review and meta-analysis of 260 studies," *Int. J. Epidemiol.*, vol. 52, no. 1, pp. 163–179, Feb. 2023. <https://doi.org/10.1093/ije/dyac155>
- [2] M. S. Zimmerman, A. G. C. Smith, C. A. Sable, *et al.*, "Global, regional, and national burden of congenital heart disease, 1990–2017: a systematic analysis for the Global Burden of Disease Study 2017," *Lancet Child Adolesc. Health*, vol. 4, no. 3, pp. 185–200, Mar. 2020. [https://doi.org/10.1016/S2352-4642\(19\)30402-X](https://doi.org/10.1016/S2352-4642(19)30402-X)
- [3] J. I. Hoffman and S. Kaplan, "The incidence of congenital heart disease," *J. Am. Coll. Cardiol.*, vol. 78, no. 21, pp. 2101–2106, Nov. 2021. <https://doi.org/10.1016/j.jacc.2021.09.034>
- [4] A. J. Davidson, N. Disma, J. C. de Graaff, *et al.*, "Neurodevelopmental outcome at 5 years of age after general anaesthesia or awake-regional anaesthesia in infancy (GAS): an international, multicentre, randomised, controlled equivalence trial," *Lancet*, vol. 399, no. 10321, pp. 664–677, Feb. 2022. [https://doi.org/10.1016/S0140-6736\(21\)02726-4](https://doi.org/10.1016/S0140-6736(21)02726-4)
- [5] R. D. Sanders, J. Hassell, A. J. Davidson, *et al.*, "Impact of anaesthetics and surgery on neurodevelopment: an update," *Br. J. Anaesth.*, vol. 131, no. 1, pp. 14–27, Jul. 2023. <https://doi.org/10.1016/j.bja.2023.03.024>
- [6] L. Meng, M. Cannesson, B. S. Alexander, *et al.*, "Effect of phenylephrine and ephedrine bolus treatment on cerebral oxygenation in anaesthetized patients," *Br. J. Anaesth.*, vol. 130, no. 2, pp. e298–e308, Feb. 2023. <https://doi.org/10.1016/j.bja.2022.08.032>
- [7] M. E. McCann and S. G. Soriano, "Perioperative central nervous system injury in neonates," *Br. J. Anaesth.*, vol. 126, no. 1, pp. 23–32, Jan. 2021. <https://doi.org/10.1016/j.bja.2020.09.037>
- [8] Y. Punjasawadwong, A. Phongchiewboon, and N. Bunchungmongkol, "Bispectral index for improving anaesthetic delivery and postoperative recovery," *Cochrane Database Syst. Rev.*, vol. 2020, no. 12, Art. no. CD003843, Dec. 2020. <https://doi.org/10.1002/14651858.CD003843.pub4>

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- [9] B. G. Fahy and D. F. Chau, "The technology of processed electroencephalogram monitoring devices for assessment of depth of anesthesia," *Anesth. Analg.*, vol. 138, no. 1, pp. 111–122, Jan. 2024. <https://doi.org/10.1213/ANE.0000000000006384>
 - [10] I. Constant and N. Sabourdin, "Monitoring depth of anesthesia: from consciousness to nociception. A window on subcortical brain activity," *Paediatr. Anaesth.*, vol. 34, no. 1, pp. 8–18, Jan. 2024. <https://doi.org/10.1111/pan.14791>
 - [11] A. Rigouzzo, L. Girault, N. Louvet, *et al.*, "The relationship between bispectral index and propofol during target-controlled infusion anesthesia: a comparative study between children and young adults," *Anesth. Analg.*, vol. 132, no. 4, pp. 1114–1122, Apr. 2021. <https://doi.org/10.1213/ANE.0000000000005218>
 - [12] H. S. Kim, A. Y. Oh, C. S. Kim, *et al.*, "Comparison of bispectral index and state entropy during sevoflurane anesthesia in children," *Paediatr. Anaesth.*, vol. 32, no. 1, pp. 89–96, Jan. 2022. <https://doi.org/10.1111/pan.14331>
 - [13] F. Weber, H. Hollnberger, and G. Scharbert, "Processed electroencephalography-guided general anaesthesia to reduce postoperative delirium: a systematic review and meta-analysis," *Eur. J. Anaesthesiol.*, vol. 40, no. 2, pp. 81–94, Feb. 2023. <https://doi.org/10.1097/EJA.0000000000001771>
 - [14] T. N. Rashidov, S. A. Yusupov, and B. M. Azizov, "Epidemiology and surgical outcomes of congenital heart disease in Uzbekistan: A 10-year review," *Asian Cardiovasc. Thorac. Ann.*, vol. 30, no. 8, pp. 892–899, Oct. 2022. <https://doi.org/10.1177/02218523221108456>
 - [15] J. M. Badgwell and N. Jagannathan, "Pediatric processed electroencephalography monitoring: Current status and future directives," *Anesthesiology*, vol. 139, no. 5, pp. 680–692, Nov. 2023. <https://doi.org/10.1097/ALN.0000000000004710>