ISSN: 1607-8322, e-ISSN: 2220-5799 **Anaesthesia, Pain & Intensive Care**

Vol 28(2); April 2024 DOI: 10.35975/apic.v28i2.2481

INVITED REVIEW MONITORING IN ANESTHESIA

Enhancing anesthesia precision: integration of BIS monitoring in anesthesia machines

Muhammad Arslan Zahid [1], Vinod Kumar [2], Jatendar Wadhwani [3], Ajeet Kumar [4], Muhammad Farhan Hasan [5], Muhammad Saleh [6]

Author affiliations:

1. Muhammad Arslan Zahid, Consultant Anesthetist, National Medical Center, Karachi, Pakistan; E-mail: dr.arslanzahid@gmail.com; ORCID:0009-0003-4707-0786
2. Vinod Kumar, The Indus Hospital & Health Network, Karachi, Pakistan; E-mail: vinodvankwani@gmail.com
3. Jatendar Wadhwani, Kings College Hospital London, Dubai; E-mail: jkwadhwani@hotmail.com
4. Ajeet Kumar, Anesthesia Resident, The Indus Hospital & Health Network, Karachi, Pakistan; E-mail: ajeetlarai33@gmail.com
5. Muhammad Farhan Hasan, Anesthesia Resident, The Indus Hospital & Health Network, Karachi, Pakistan; E-mail: hunny.hasan94@gmail.com
6. Muhammad Saleh, Senior Registrar Anesthesia, Jinnah Postgraduate Medical Center, Karachi, Pakistan; E-mail: salehbozdar@gmail.com

Correspondence: Muhammad Arslan Zahid, **E-mail:** dr.arslanzahid@gmail.com; **Phone:** +923345914326

Editor's note: In developed countries, BIS is an integral part of patient monitoring during intubation and ventilation in operating rooms (ORs), emergency rooms (ERs) and intensive care units (ICUs). BIS has been instrumental in saving lives in case of accidental extubation, and there have been multiple incidents of patient deaths due to unrecognized esophageal intubation. In our country, the importance of this modality is not adequately recognized, so most of the ORs and ICUs have basic monitoring, but not BIS. The dire need of creating awareness about BIS, prompted 'Anaesthesia, Pain & Intensive Care' to invite scholars around the world to write a narrative review. The editorial team of the journal is thankful to Dr. Muhammad Arslan Zahid and his colleagues for sharing this review. [Editor-in-Chief]

ABSTRACT

The review examines the integration of Bispectral Index (BIS) monitoring into anesthesia machines, focusing on its fundamental principles, clinical applications, and technical nuances. BIS, a parameter derived from electroencephalogram (EEG) analysis, quantifies the hypnotic effects of anesthesia, providing an objective measure of the patient's neurological state. The integration enhances perioperative outcomes, improve patient safety, and optimize the administration of anesthetic drugs. This review highlights the challenges posed by variations in patient reactions to anesthetics and the limited effectiveness of traditional monitoring methods. BIS monitoring offers real-time evaluation and precise titration of anesthesia, reducing risks of over-sedation and insufficient anesthesia. Thereby reducing the risk of oversedation and insufficient anesthesia. It also mitigates anesthesia awareness, which is a rare but serious phenomenon. This review discusses the implementation and practice guidelines for BIS monitoring, emphasizing the need for thorough training of anesthesia practitioners. It also discusses the economic implications and cost-effectiveness of BIS monitoring, with potential benefits in optimizing anesthesia management. The ethical and legal considerations associated with BIS monitoring are also discussed, emphasizing its role in providing impartial evidence in disputes. The article concludes by positioning BIS monitoring as a standard of care in anesthesia and critical care settings, highlighting its pivotal development in anesthesia machines, including wireless connectivity.

Keywords: Anesthesia Machines; Anesthesia Precision; Awareness, Intraoperative; BIS Monitoring; Bispectral Index (BIS); Depth of Anesthesia; EEG Analysis; Perioperative Outcomes; Patient Safety; Surgical Precision

Citation: Zahid MA, Kumar V, Wadhwani J, Kumar A, Hasan MF, Saleh M. Enhancing anesthesia precision: integration of BIS monitoring in anesthesia machines. Anaesth. pain intensive care 2024;28(3):558−565; **DOI:** 10.35975/apic.v28i2.2481

Received: January 20, 2024; **Reviewed:** February 23, 2024; **Accepted** February 23, 2024

1. INTRODUCTION

The constant evolution of contemporary anesthetic practices has been driven by the employment of cutting-edge technology that enhances precision, patient safety, and clinical outcomes. The incorporation of Bispectral Index (BIS) monitoring into the anesthetic machinery is a major innovation that will help achieve these goals. The ever-evolving nature of anesthetic care necessitates research on the impact, benefits, and challenges of this integration, and its possible future repercussions. In this review, we have highlighted the fundamental concepts, clinical applications and the technical know-how. We have also discussed how BIS monitoring might completely change the face of anesthesia care.

BIS is a newly processed electroencephalogram parameter that was specifically designed expressly to quantify the hypnotic effects of anesthesia. The findings of investigations conducted on volunteers show that BIS corresponds very well with clinical evaluation of the level of sleepiness caused by sedatives and hypnotics. Studies on the clinical value of BIS monitoring have demonstrated that it enables better management of the desired anesthetic depth, which leads to less hypnotic and narcotic consumption and improved recovery.[1]

2. BACKGROUND

Administration of anesthesia is a complex art that necessitates a careful balance between preserving the patient's comfort and maintaining their physiological homeostasis. Because of the wide range of reactions that patients have to anesthetic medications and surgical stimuli, striking a delicate balance may not always be very easy. Monitoring the depth of anesthesia in the past often consisted of subjective clinical evaluation and monitoring of vital signs. This method is not adequate to capture the complexities of the patient's neurological status under anesthesia.

Awareness under anesthesia, often referred to as unplanned intraoperative consciousness, is the conscious recollection of sensory sensations that occur when a patient is under general anesthesia (GA). It is not very common, and the occurrence rate may exceed 1% in people who are at high risk.[2, 3] The great majority of people who receive GA each year in the United States inhale an anesthetic gas. This number is estimated to be 21 million individuals.[4] It is common practice to monitor the concentration of breathed anesthetic gases by analyzing the absorption of infrared light, which enables the exact identification and quantification of the gases that have been expired.[5]

The concentration of anesthetic gas known as the minimum alveolar concentration (MAC) is the amount of gas that must be present in order to keep 50% of test participants from moving in response to painful stimuli. Keeping the ETAG concentration at a level higher than 0.7 MAC may reduce the risk of awareness.[6, 7] The use of BIS monitoring fills the crucial need by offering a quantitative and objective measurement of the patient's degree of awareness as well as the extent to which they are under the influence of anesthesia. The BIS Index is a composite index that is produced from analysis of an electroencephalogram (EEG) of the patient. This index ranges from zero, which indicates complete unconsciousness; to 100, which indicates a completely alert patient. This index acts as a strong tool that aids anesthesia physicians in adapting medication administration to each patient's individual needs, therefore limiting the dangers of over-sedation or under-sedation during anesthesia.[8, 9]

The integration of BIS monitoring into the anesthesia machine was motivated by the need to enhance perioperative outcomes, improve patient safety, and maximize the effectiveness of the administration of anesthetic drugs. BIS monitoring can provide exact titration of anesthetic agents because it provides a real-time evaluation of the patient's neurological state. This leads to smoother transitions between various depths of anesthesia and a faster awakening from anesthesia. In addition, the capability to reduce intraoperative consciousness as well as postoperative cognitive impairment highlights the significance of BIS monitoring in the provision of patient care.

The integration of BIS monitoring in anesthesia is a promising frontier for advancements beyond conventional practices. This review explores its fundamental principles, clinical applications, technical aspects, and broader implications for anesthesia practice. This study illuminates the benefits and challenges of this integration, ultimately paving the way for refined and patient-centric anesthesia care.

3. BIS: FUNDAMENTALS

Anesthesiologists employ some landmarks to accurately administer anesthesia drugs, thus mitigating the danger of excessive depth of anesthesia, which has been associated with postoperative cognitive impairments, morbidity, and an increased likelihood of intraoperative awareness.[10, 11]

EEG was first described in 1875 by Caton at al. at Liverpool Royal Infirmary.[12] Berger at al. later extended the work to humans.[13] The effect of certain drugs on EEG was noted approximately 10 y later.[14] In a study, Brown et al. revealed the effects of anesthesia on brain electrical activity, resulting in distinct EEG patterns. As the GA level deepens, the low frequency and high-amplitude activity increases. EEG patterns can be described in three distinct periods: induction, maintenance, and emergence.[15]

The raw EEG has limited use in measuring depth of anesthesia, as clinicians often lack the time and skill to interpret the complexity of raw data. Therefore, efforts have been made to compress and simplify the analysis. Sigl and Chamoun introduced the BIS technology for brain monitoring in 1994, which includes a noninvasive adhesive sensor, patient interface cable, digital signal converter, BIS engine, and monitor. The technology is also available as a module for integration into other manufacturers' monitoring systems.[16]

In EEG, both a power spectrum and a phase spectrum are produced by rapid Fourier transformation. Only the power spectrum is used to determine EEG variables like median frequency and spectral edge frequency. Historically, the phase spectrum has been disregarded as being unimportant. In contrast, bispectral analysis measures the connection of phase angles between various frequencies and is based on the power spectrum and phase spectrum. The BIS synthesizes a combination that corresponds with behavioral measures of drowsiness and hypnosis by combining different EEG characteristics into a single variable using a vast volume of clinical data. The bispectral analysis contribution is the SynchFastSlow subvariable. The ratio of the sum of all Bispectral peaks in the range from 0.5 to 47 Hz over the sum of the Bispectral peaks in the range from 40 to 47 Hz is known as SynchFastSlow. BIS is a term used to describe a proprietary combination of the SynchFastSlow algorithm with the sub-parameter "ratio" and the time domain sub-variable "burst suppression."[17]

BIS uses EEG data from a patient's forehead to create a 'BIS index', a dimensionless number indicating the level of GA with a low probability of consciousness. Other data include the BIS trend, signal quality index (SQI) bar, and suppression ratio (SR), which display the patient brain activity over time.[17]

The BIS is an EEG measure that has undergone extensive validation and clinical relevance. The derivation of the measures involves the use of a combination of techniques in EEG signal processing, including bispectral analysis, power spectral analysis, and temporal domain analysis. The aforementioned variables were integrated using an algorithm enhance the association between the EEG and the clinical outcomes of anesthesia. Quantification of this correlation was achieved by employing the BIS Index range.[18]

The monitoring of brain status under anesthesia uses BIS technology, including Bispectral Analysis, BIS Algorithm, and BIS Index. Bispectral analysis performs signal components and detects synchronization in EEG signals. Multivariate statistical models are used to determine the optimal combination of EEG variables correlated with sedation clinical endpoints.[19]

The BIS is a numerical scale ranging from 0 to 100 that is employed to assess the impact of anesthetic drugs on the EEG.[20] This observation denotes the extent of the anesthetic impact on the EEG. A value close to 100 signifies a state of wakefulness, whereas a value of 0 signifies the maximal effect on the EEG. A fall in the BIS Index value is associated with a reduction in the likelihood of explicit recall, but a value below 60 indicates diminished consciousness.[21] Ensuring that the BIS Index values are maintained within the range of 40-60 is crucial for achieving sufficient hypnotic effect during the administration of GA administration and enhancing the process of post-anesthetic recovery (Figure 1). Nevertheless, it should be noted that values over 70 during the sedative care administration have the potential to heighten levels of consciousness and enhance the ability to recall information.[22]

3.1. Depth of anesthesia monitoring techniques

Monitoring of anesthesia depth plays a critical role in contemporary healthcare by ensuring the maintenance of patient comfort, safety, and precision throughout medical procedures. The use of appropriate anesthesia levels is crucial in mitigating the occurrence of both under-anesthesia, which may induce distress, and over-anesthesia, which can result in problems and protracted recovery periods.[23]

3.2. Impact on patient outcomes

Maintaining optimal anesthesia levels is crucial for improving patient outcomes. Insufficient depth control management can lead to intraoperative awareness, a phenomenon in which patients recollect sensory perception postoperatively. This may occur in 1-2 per 1000 patients,[24] especially when depth of anesthesia monitoring is not used. This issue is prevalent in 0.2-3% of patients, but can reach over 40% in high-risk patients, posing significant medical liability and potentially causing postoperative psychosomatic dysfunction.

Anxiety, post-traumatic stress disorder and psychological trauma have the potential to adversely affect the patient's quality of life and overall surgical experience due to awareness.[25] On the other hand, an excessive level of anesthetic depth can potentially give rise to various issues, including delayed emergence, increased risk of postoperative nausea and vomiting, and increased duration of hospital stay.[26]

3.3. Surgical precision

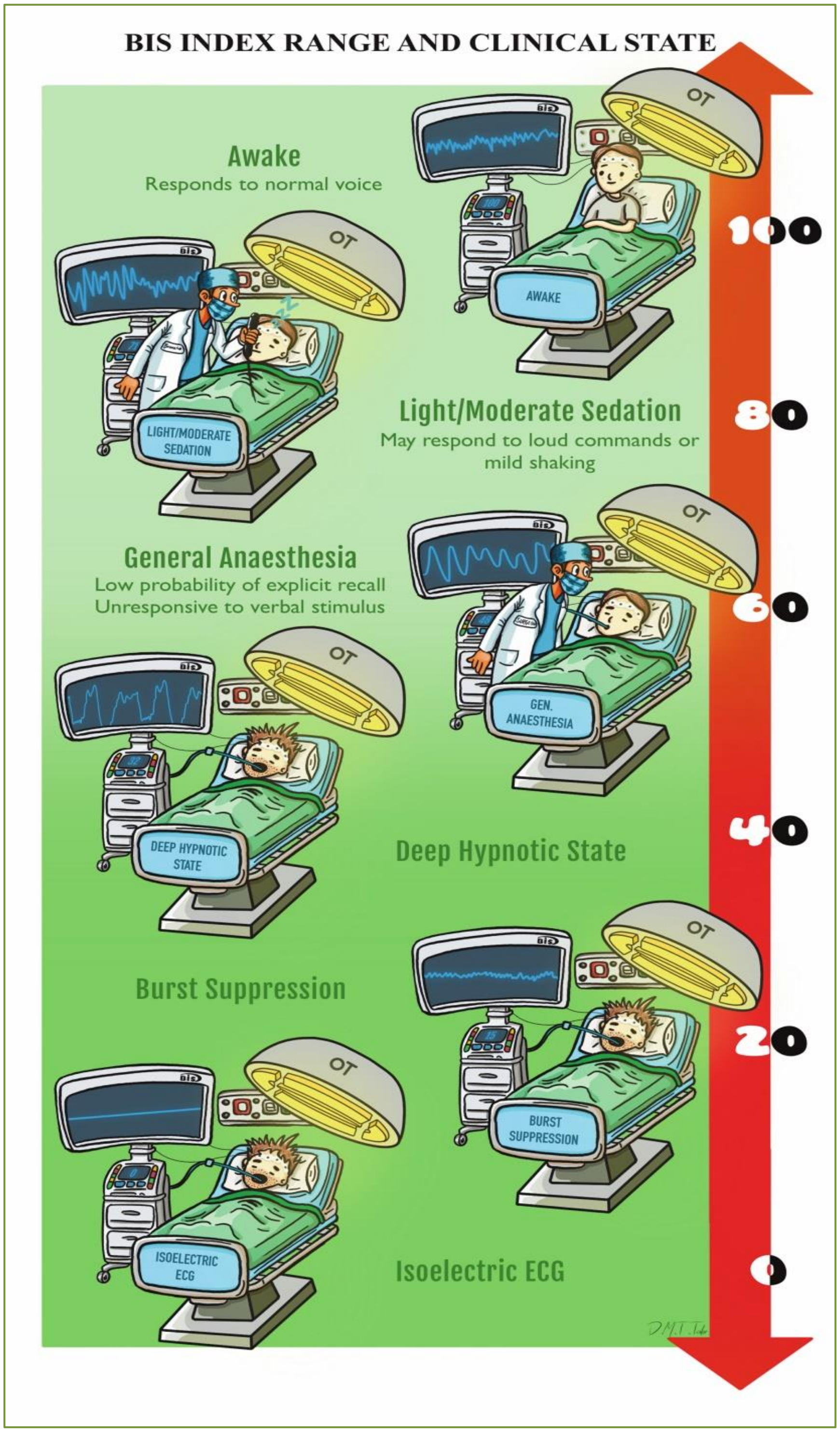

Figure 1: BIS Index range and general pattern of EEG changes in different depths of anesthesia (Animation credits to Dr. Muhammad Talha Tahir; insta: medicalcanvas)

Monitoring anesthesia depth plays a critical role in surgical operations that necessitate accurate patient placement and participation, such as neurosurgery, orthopedic interventions, and minimally invasive surgeries. Deviation from the intended level of anesthetic depth can undermine the success of the procedure and escalate the likelihood of problems.[27-30]

3.4. Variability in individuals

Anesthetic medication response varies among patients due to factors like age, weight, medical history, and metabolism. Anesthetic depth monitoring allows for dynamic adjustments to accommodate individual needs, thereby allowing for customization of anesthesia protocols. This not only improves patient safety but also facilitates a more seamless recovery process, thereby enhancing the overall patient experience.[31]

3.5. Improving patient outcomes

BIS-guided anesthesia, a strategy using the BIS, improves patient outcomes by enabling real-time adjustments in anesthesia depth, and reducing postoperative delirium, cognitive impairment, and nausea/vomiting. It also reduces hospital stays, mortality rates, and patient satisfaction by ensuring smoother emergence from anesthesia and aligning with recovery protocols.[30-34]

4. LIMITATIONS

Despite the advantages it offers, BIS (Bispectral Index) monitoring, a technology commonly employed in anesthesia and critical care, is not without its limits. A notable constraint is the reliance on quantitative EEG analysis to evaluate the degree of consciousness in a patient. The algorithm employed for the computation of the BIS score may exhibit some degree of inaccuracy when applied to different individuals, resulting in potential disparities between the BIS value and the cognitive condition of the patient.

Anesthetic agents, such as ketamine and nitrous oxide, can affect BIS values, making the BIS monitor unreliable. A 2017 study by Mishra et al. found that the BIS value increases with the addition of nitrous oxide, possibly because of its neuro-stimulant properties, which increase cerebral blood flow velocities and cerebral oxygen consumption (CMRO). This suggests that the use of anesthetic agents can affect patient sedation.[35]

In a study patient`s with hypothermia during cardiopulmonary bypass revealed significant fluctuations in BIS measurements. A drop in body temperature decreased in cerebral metabolic rate for oxygen, as seen in the electroencephalogram (EEG). Aortic cannulation was also associated with reduced EEG activity. The study also found a temporary decline in EEG activity during cardiopulmonary bypass, likely due to brain perfusion with a crystalloid primary solution. These findings underscore the complex relationship between temperature fluctuations, cerebral metabolism, and EEG patterns in hypothermia and cardiac treatments.[36]

Moreover, the accuracy of the BIS monitor may be affected by a range of circumstances, including patient movement, electrical interference, and signal artifacts. These factors can lead to inaccurate findings. The presence of medical devices can result in interference, leading to artifacts and compromising the BIS monitor's capacity to effectively evaluate alterations in the level of anesthesia. In their study, Chan et al. observed a drop in Surgical Quality Index (SQI) levels when electrosurgical cautery was employed.[37]

Although BIS monitoring unquestionably provides valuable insights, it is crucial to exercise caution when interpreting its data and to incorporate other clinical observations to obtain a comprehensive understanding of a patient's neurological condition.

4. IMPLEMENTATION / PRACTICE GUIDELINES

Monitoring of BIS plays a critical role in enhancing patient care and safety within the field of anesthesia. Integration of threshold values for various stages of anesthesia into anesthesia protocols is essential to mitigate the risks of excessive sedation or insufficient anesthesia. It is imperative that anesthesia practitioners undergo thorough training in the principles, operation, and interpretation of BIS, considering various parameters such as patient age, drugs, and medical conditions. Regular training sessions and workshops are essential for providers to be informed about the latest improvements in BIS monitoring. The recommendations should encompass suitable patient populations, effectively handle any restrictions, and provide standardized methods for reporting and recording. By incorporating BIS monitoring into anesthetic procedures, delivering comprehensive training, and delineating recommendations, healthcare facilities can optimize patient outcomes and guarantee the administration of anesthesia with increased safety.[38]

4.1. BIS in ambulatory surgery

Healthcare facilities can optimize patient outcomes and ensure safe anesthesia delivery by incorporating BIS monitoring into anesthetic procedures, providing comprehensive training, and recommending recommendations. The increasing importance of ambulatory surgery has led to the development of effective anesthetic procedures that prioritize quality and safety. Intravenous procedures, particularly propofol, offer safe, efficient, and cost-effective anesthesia. Novel administration techniques, such as TCI, monitored anesthesia care, and patient-controlled sedation, along with monitoring tools like BIS, can enhance intraoperative conditions and facilitate recovery, potentially leading to expedited discharge from the ambulatory setting.[39]

4.2. Economic implications / cost-effectiveness

To evaluate the cost-effectiveness of a physiological monitor, it is crucial to determine the desired outcome, such as preventing hypoxic episodes or myocardial infarction. Obtaining result data that show the occurrence of the selected endpoint with and without the monitor is essential for developing a cost-effectiveness model. The BIS monitor has been the focus of numerous studies examining its cost-effectiveness. Recent research has shown that the BIS monitor has yielded favorable outcomes in anesthetic management, such as reduced administration of hypnotic anesthetic medications, decreased extubation time, lower nausea and vomiting, and decreased intraoperative awareness. These advantages are at an additional cost of approximately $5 per anesthetic. The study concludes that the use of BIS is warranted in all instances of GA because of its minimal cost and established advantages.[40]

4.3. Ethical and legal considerations

BIS monitoring is crucial to anesthesia for resolving disagreements about anesthesia administration, patient outcomes, and decision-making processes. It can provide impartial proof for claims of insufficient anesthesia or incorrect dosage, and can help determine if the anesthetic was administered in accordance with the guidelines. Ethically, BIS monitoring can enhance openness and responsibility in anesthesia, thereby ensuring patient safety and well-being. However, it is important to recognize that BIS values alone may not provide a comprehensive view of the clinical setting, as factors like patient history, medical issues, and concurrent drugs can influence outcomes. Therefore, interpretation should be contextualized within the broader framework of clinical information and expert perspectives to achieve equitable and precise results in legal and ethical processes. The use of this technology encompasses various applications, including the monitoring of anesthetic depth, record maintenance, research endeavors, and medico-legal considerations.[41]

4.4. Global adoption and future perspectives

BIS monitoring has seen significant growth globally, improving patient safety and optimizing anesthesia administration. Technological advancements could enhance the precision and dependability of BIS monitors, potentially reducing artifact vulnerabilities. The integration of neuromuscular and advanced hemodynamic monitoring could provide a more comprehensive assessment of a patient's physiological condition during anesthesia. BIS monitoring can also be applied in critical care situations, such as monitoring sedated or unconscious individuals in the ICU, to enhance sedation management and promote prompt reawakening.[42] Collaboration between healthcare practitioners and researchers is crucial for algorithm refinement, validation, and prediction of patient outcomes. Ethical considerations must be addressed to ensure ethical integration into clinical practice.

4.5. BIS as a standard of care

BIS monitoring is increasingly recognized as a valuable benchmark in anesthesia and critical care settings, offering the potential to improve patient safety, optimize anesthesia administration, and improve clinical outcomes.[43] BIS allows for objective evaluation of a patient's anesthesia state through EEG data analysis, providing vital information for anesthesia providers to make informed decisions and customize interventions. It also helps in achieving an optimal balance between patient comfort and preventing excessive sedation, leading to shorter healing periods, reduced medication reliance, and reduced negative outcomes.[44] BIS monitoring is particularly valuable for vulnerable patient populations, such as the elderly and those with comorbidities, because of the variability in anesthesia response.[45] However, establishing BIS monitoring requires collaboration between healthcare practitioners, regulatory entities, and organizations, as well as the development of training and education programs to improve anesthesia practitioners' proficiency in interpreting BIS data and making informed clinical decisions.

An important development in modern anesthesia and patient care is the incorporation of Bispectral Index (BIS) monitoring into anesthesia machines, even though wireless connected monitors is available now a days.[46] Healthcare personnel are able to monitor the patient's BIS value and other vital indicators in real time by connecting EEG sensors to the machine's monitoring infrastructure. This makes it possible to decide on the anesthetic dose with knowledge, assuring optimal patient consciousness and lowering the likelihood of under- or overmedication.

5. Conflict of Interest

There are no conflicts of interest to disclose.

6. Acknowledgement

We would like to express our sincere gratitude to Dr. Muhammad Talha Tahir, Consultant Pulmonologist Sheikh Zayed Medical College and Hospital @Insta: medicalcanvas for their valuable contributions in preparing the animated graphics for this article.

7. Authors contribution

MAZ: Principle investigator, Concept and design of study

VK: Initial draft and finalizing

JW: Proof reading

AJ: Literature search

MFH: Manuscript editing

MS: Final review

All authors have read the final proof and approve it for publishing in the current state.

8. REFERENCES

1. Rosow C, Manberg PJ. Bispectral index monitoring. Anesthesiol Clin North Am. 2001;19(4):947-66. [PubMed] DOI: 10.1016/s0889-8537(01)80018-3
2. Ranta S, Jussila J, Hynynen M. Recall of awareness during cardiac anaesthesia: influence of feedback information to the anaesthesiologist. Acta Anaesthesiol Scand. 1996;40(5):554-60. [PubMed] DOI: 10.1111/j.1399-6576.1996.tb04487.x
3. Sebel PS, Bowdle TA, Ghoneim MM, Rampil IJ, Padilla RE, Gan TJ, et al. The incidence of awareness during anesthesia: a multicenter United States study. Anesth Analg. 2004;99(3):833-9. [PubMed] DOI: 10.1213/01.ANE.0000130261.90896.6C
4. Preventing, and managing the impact of, anesthesia awareness. Sentinel Event Alert. 2004 Oct 6;(32):1-3. [PubMed]

5. Walder B, Lauber R, Zbinden AM. Accuracy and cross-sensitivity of 10 different anesthetic gas monitors. J Clin Monit. 1993;9:364-73. [PubMed] DOI: 10.1007/BF01618679

6. Ghoneim MM. Awareness during anesthesia. Anesthesiology. 2000;92(2):597-602. [PubMed] DOI: 10.1097/00000542-200002000-00043

7. Gonsowski CT, Chortkoff B, Eger EI, Bennett HL, Weiskopf RB. Subanesthetic concentrations of desflurane and isoflurane suppress explicit and implicit learning. Anesth Analg. 1995;80(3):568-72. [PubMed] DOI: 10.1097/00000539-199503000-00024

8. Liu J, Singh H, White PF. Electroencephalographic bispectral index correlates with intraoperative recall and depth of propofol-induced sedation. Anesth Analg. 1997;84(1):185-9. [PubMed] DOI: 10.1097/00000539-199701000-00033

9. Jeleazcov C, Fechner J, Schwilden H. Electroencephalogram monitoring during anesthesia with propofol and alfentanil: the impact of second order spectral analysis. Anesth Analg. 2005;100(5):1365-9. [PubMed] DOI: 10.1213/01.ANE.0000148689.35951.BA

10. Frost EA. Differential diagnosis of delayed awakening from general anesthesia: a review. Middle East J Anaesthesiol. 2014;22(6):537-48. [PubMed]

11. Chung HS. Awareness and recall during general anesthesia. Korean J Anesthesiol. 2014;66(5):339-45. [PubMed] DOI: 10.4097/kjae.2014.66.5.339

12. Caton R. Electrical currents of the brain. J Nerv Ment Dis. 1875;2(4):610.

13. Berger H. Über das elektroenkephalogramm des menschen. Arch Psychiatr Nervenkr. 1929;87(1):527-70.

14. Gibbs FA, Gibbs E, Lennox W. Effect on the electro-encephalogram of certain drugs which influence nervous activity. Arch Intern Med. 1937;60(1):154-66.

15. Brown EN, Lydic R, Schiff ND. General anesthesia, sleep, and coma. N Engl J Med. 2010;363(27):2638-50. [PubMed] DOI: 10.1056/NEJMra0808281

16. Sigl JC, Chamoun NG. An introduction to bispectral analysis for the electroencephalogram. J Clin Monit. 1994;10(6):392-404. [PubMed] DOI: 10.1007/BF01618421

17. Rampil IJ. A primer for EEG signal processing in anesthesia. Anesthesiology. 1998;89(4):980-1002. [PubMed] DOI: 10.1097/00000542-199810000-00023

18. Senapathi TGA, Wiryana M, Aribawa I, Ryalino C. Bispectral index value correlates with Glasgow Coma Scale in traumatic brain injury patients. Open Access Emerg Med. 2017;9:43-6. [PubMed] DOI: 10.2147/OAEM.S130643

19. Yousefi-Banaem H, Goharani R, Hajiesmaeili M, Tafrishinejad A, Zangi M, Amirdosara M, et al. A Review of Bispectral Index Utility in Neurocritical Care Patients. Arch Neurosci. 2020;7(3):e96490. DOI: 10.5812/ans.96490

20. Rani DD, Harsoor S. Depth of general anaesthesia monitors. Indian J Anaesth. 2012;56(5):437-41. [PubMed] DOI: 10.4103/0019-5049.103956

21. Smajic J, Praso M, Hodzic M, Hodzic S, Srabovic-Okanovic A, Smajic N, et al. Assessment of depth of anesthesia: PRST score versus bispectral index. Med Arh. 2011;65(4):216-20. [PubMed] DOI: 10.5455/medarh.2011.65.216-220

22. Bibian S, Ries CR, Huzmezan M, Dumont G. Introduction to automated drug delivery in clinical anesthesia. Eur J Control. 2005;11(6):535-57.

23. Musizza B, Ribaric S. Monitoring the depth of anaesthesia. Sensors (Basel). 2010;10(12):10896-935. [PubMed] DOI: 10.3390/s101210896

24. Sandhu K, Dash H. Awareness during anaesthesia. Indian J Anaesth. 2009;53(2):148-57. [PubMed]

25. Mashour GA, Esaki RK, Tremper KK, Glick DB, O'Connor M, Avidan MS. A novel classification instrument for intraoperative awareness events. Anesth Analg. 2010;110(3):813-5. [PubMed] DOI: 10.1213/ANE.0b013e3181b6267d

26. Petsiti A, Tassoudis V, Vretzakis G, Zacharoulis D, Tepetes K, Ganeli G, et al. Depth of Anesthesia as a Risk Factor for Perioperative Morbidity. Anesthesiol Res Pract. 2015;2015:829151. [PubMed] DOI: 10.1155/2015/829151

27. Boztug N, Bigat Z, Akyuz M, Demir S, Ertok E. Does using the bispectral index (BIS) during craniotomy affect the quality of recovery? J Neurosurg Anesthesiol. 2006;18(1):1-4. [PubMed] DOI: 10.1097/01.ana.0000188028.80960.dd

28. Akcali DT, Özköse Z, Yardim Ş. Do we need bispectral index monitoring during total intravenous anesthesia for lumbar discectomies? Turk Neurosurg. 2008;18(2):125. [PubMed]

29. Kerssens C, Gaither JR, Sebel PS. Preserved memory function during bispectral index–guided anesthesia with sevoflurane for major orthopedic surgery. J Am Soc Anesthesiol. 2009;111(3):518-24. [PubMed] DOI: 10.1097/ALN.0b013e3181b05f0b

30. Poon YY, Chang HC, Chiang MH, Hung KC, Lu HF, Wang CH, et al. "A real-world evidence" in reduction of volatile anesthetics by BIS-guided anesthesia. Sci Rep. 2020;10(1):11245. [PubMed] DOI: 10.1038/s41598-020-68193-x

31. Anderson BJ. My child is unique; the pharmacokinetics are universal. Paediatr Anaesth. 2012;22(6):530-8. [PubMed] DOI: 10.1111/j.1460-9592.2011.03788.x

32. Chan MT, Cheng BC, Lee TM, Gin T, Group CT. BIS-guided anesthesia decreases postoperative delirium and cognitive decline. J Neurosurg Anesthesiol. 2013;25(1):33-42. [PubMed] DOI: 10.1097/ANA.0b013e3182712fba

33. Quan C, Chen J, Luo Y, Zhou L, He X, Liao Y, et al. BIS-guided deep anesthesia decreases short-term postoperative cognitive dysfunction and peripheral inflammation in elderly patients undergoing abdominal surgery. Brain Behav. 2019;9(4):e01238. [PubMed] DOI: 10.1002/brb3.1238

34. Ahmad S, Yilmaz M, Marcus RJ, Glisson S, Kinsella A. Impact of bispectral index monitoring on fast tracking of gynecologic patients undergoing laparoscopic surgery. Anesthesiology. 2003;98(4):849-52. [PubMed] DOI: 10.1097/00000542-200304000-00010

35. Mishra RK, Mahajan C, Prabhakar H, Kapoor I, Bithal PK. Effect of nitrous oxide on bispectral index values at equi-minimum alveolar concentrations of sevoflurane and desflurane. Indian J Anaesth. 2017;61(6):482-5. [PubMed] DOI: 10.4103/ija.IJA_363_16

36. Doi M, Gajraj RJ, Mantzaridis H, Kenny GN. Effects of cardiopulmonary bypass and hypothermia on electroencephalographic variables. Anaesthesia. 1997;52(11):1048-55. [PubMed] DOI: 10.1111/j.1365-2044.1997.229-az0364.x

37. Chan MT, Ho SS, Gin T. Performance of the bispectral index during electrocautery. J Neurosurg Anesthesiol. 2012;24(1):9-13. [PubMed] DOI: 10.1097/ANA.0b013e31823058bf

38. Shepherd J, Jones J, Frampton G, Bryant J, Baxter L, Cooper K. Clinical effectiveness and cost-effectiveness of depth of anaesthesia monitoring (E-Entropy, Bispectral Index and Narcotrend): a systematic review and economic evaluation. Health Technol Assess. 2013;17(34):1-264. [PubMed] DOI: 10.3310/hta17340

39. Tesniere A, Servin F. Intravenous techniques in ambulatory anesthesia. Anesthesiol Clin North Am. 2003;21(2):273-88. [PubMed] DOI: 10.1016/s0889-8537(02)00081-0

40. Klopman MA, Sebel PS. Cost-effectiveness of bispectral index monitoring. Curr Opin Anaesthesiol. 2011;24(2):177-81. [PubMed] DOI: 10.1097/ACO.0b013e328343eb19

41. Arya S, Asthana V, Sharma JP. Clinical vs. bispectral index-guided propofol induction of anesthesia: A comparative study. Saudi J Anaesth. 2013;7(1):75-9. [PubMed] DOI: 10.4103/1658-354X.109819

42. Shetty RM, Bellini A, Wijayatilake DS, Hamilton MA, Jain R, Karanth S, et al. BIS monitoring versus clinical assessment for sedation in mechanically ventilated adults in the intensive care unit and its impact on clinical outcomes and resource utilization. Cochrane Database Syst Rev. 2018;2(2):Cd011240. [PubMed] DOI: 10.1002/14651858.CD011240.pub2

43. Jospin M, Caminal P, Jensen EW, Litvan H, Vallverdú M, Struys MM, et al. Detrended fluctuation analysis of EEG as a measure of depth of anesthesia. IEEE Trans Biomed Eng. 2007;54(5):840-6. [PubMed] DOI: 10.1109/TBME.2007.893453

44. Chew WZ, Teoh WY, Sivanesan N, Loh PS, Shariffuddin II, Ti LK, et al. Bispectral Index (BIS) Monitoring and Postoperative Delirium in Elderly Patients Undergoing Surgery: A Systematic Review and Meta-Analysis With Trial Sequential Analysis. J Cardiothorac Vasc Anesth. 2022;36(12):4449-59. [PubMed] DOI: 10.1053/j.jvca.2022.07.004

45. Pybus DA. Expanding the role of mobile devices in the operating room: direct wireless connection to the anesthesia monitor. J Cardiothorac Vasc Anesth. 2015;29(3):785-90. [PubMed] DOI: 10.1053/j.jvca.2014.10.009

