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DEPTH OF GENERAL ANESTHESIA: CLINICAL SIGNIFICANCE, MONITORING STRATEGIES, AND CURRENT CONTROVERSIES

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ABSTRACT

Research Objectives: The depth of general anesthesia is a critical yet incompletely defined component of modern anesthetic practice. Both insufficient and excessively deep anesthesia have been associated with adverse intraoperative and postoperative outcomes, particularly in vulnerable patient populations. This narrative review aims to summarize current evidence on the clinical significance of anesthetic depth, discuss available monitoring strategies, and explore major limitations and controversies related to depth-of-anesthesia assessment, with particular emphasis on electroencephalography (EEG)-based monitoring.
Methods: A narrative review of experimental, observational, and clinical studies was conducted using the PubMed/MEDLINE and PubMed Central databases. Publications published between 2005 and 2025 were included, supplemented by selected foundational studies addressing the neurophysiological mechanisms of consciousness and anesthesia. In total, 40 peer-reviewed publications were analyzed. The review focused on the dynamic nature of general anesthesia, the risks associated with excessive anesthetic depth, and the performance, benefits, and limitations of EEG-based monitoring techniques, including the bispectral index and entropy.
Conclusions: General anesthesia represents a dynamic and multidimensional neurophysiological process rather than a binary loss of consciousness. Evidence suggests that excessively deep anesthesia is associated with cardiovascular depression, intraoperative hypotension, pathological EEG patterns, and an increased risk of postoperative delirium and cognitive dysfunction. EEG-based depth-of-anesthesia monitoring provides indirect insight into cerebral activity and may support anesthetic titration, reduction of excessive dosing, and improved hemodynamic stability. However, inter-device variability, susceptibility to artifacts, population-specific responses, and the absence of universally accepted cutoff values limit its use as a standalone tool. Depth-of-anesthesia monitoring should therefore complement comprehensive clinical assessment. Future research should focus on methodological standardization, multimodal monitoring, and individualized anesthetic strategies to improve perioperative safety.

KEYWORDS

General Anesthesia, Depth of Anesthesia, Electroencephalography, Bispectral Index, Intraoperative Hypotension, Postoperative Delirium

CITATION

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1. Introduction

General anesthesia constitutes the foundation of modern anesthesiology and enables the performance of surgical procedures through the reversible suppression of consciousness, pain perception, and protective physiological responses. One of the key yet most complex components of general anesthesia is its depth, understood as the degree of inhibition of central nervous system activity induced by anesthetic agents [1]. Maintaining an appropriate depth of anesthesia is of fundamental clinical importance, as both insufficient and excessively deep anesthetic states are associated with significant consequences for patient safety.

Insufficient depth of anesthesia may result in intraoperative awareness, autonomic responses, and surgical stress, whereas excessive anesthetic depth is associated with cardiovascular depression, intraoperative hypotension, and a potential increase in the risk of postoperative complications. These risks are particularly pronounced in vulnerable patient populations, such as older adults and individuals undergoing cardiac surgery [2,3]. Clinical studies have also suggested a possible association between anesthetic depth and the occurrence of postoperative cognitive dysfunction and delirium, although these relationships remain incompletely defined and are not entirely consistent across studies [4,5].

Despite decades of research and the development of advanced monitoring techniques, there is no universally accepted operational definition of an “optimal” depth of anesthesia. Although the concept is well established at a theoretical level, no single universal parameter or cutoff value can be applied independently of patient population, type of surgical procedure, anesthetic regimen, or monitoring modality [1,6]. Comparative analyses have demonstrated that different commercially available electroencephalography (EEG)-based monitors may provide divergent clinical information, even when analyzing the same underlying bioelectrical brain signals, further complicating the interpretation of monitoring data [6].

From a neuroscientific perspective, general anesthesia is not a homogeneous state but rather a dynamic process involving complex alterations in neuronal network function, modulated by the type and dose of anesthetic agents as well as individual patient characteristics [7,8]. This neurophysiological variability provides an important explanation for why attempts to define a single "ideal" depth of anesthesia encounter substantial limitations and often yield conflicting clinical results [6].

In recent years, there has been rapid development of EEG-based monitoring technologies aimed at achieving a more precise assessment of brain state during anesthesia and optimizing anesthetic dosing [2]. Nevertheless, findings from studies evaluating the impact of depth-of-anesthesia monitoring on clinical outcomes remain inconsistent, and consensus regarding their routine use has not yet been established [2,6].

The aim of this narrative review is to summarize current knowledge on the clinical significance of anesthetic depth in general anesthesia, to discuss available methods for its monitoring, and to identify the main controversies and directions for future research in this field.

2. Methodology

This study was conducted as a narrative review aimed at providing a concise synthesis of the current state of knowledge regarding the clinical significance of the depth of general anesthesia, methods used for its monitoring, and the associated controversies and practical implications. Given the complex and interdisciplinary nature of the topic—encompassing both clinical and neurophysiological aspects—a narrative review format was selected, as it allows for the integration of evidence derived from studies with heterogeneous methodologies.

The literature search was performed using the PubMed/MEDLINE and PubMed Central (PMC) databases, supplemented by selected publications from leading journals in the fields of anesthesiology and neuroscience. In total, 40 peer-reviewed publications were included in the final analysis. The search primarily covered articles published between 2005 and 2025; however, this time frame was intentionally expanded to include classical and foundational works addressing consciousness, mechanisms of anesthetic action, and the fundamentals of electroencephalography. These earlier studies remain conceptually relevant and continue to underpin contemporary approaches to monitoring anesthetic depth.

The review incorporated original research articles, randomized and observational clinical studies, narrative and systematic reviews, and meta-analyses involving both adult and pediatric populations. Case reports lacking broader clinical relevance and publications not directly related to the assessment of anesthetic depth were excluded. Owing to the narrative nature of the review, no formal risk-of-bias assessment or quantitative synthesis was undertaken. Instead, the analysis was qualitative and interpretative, focusing on the identification of key concepts, inconsistencies among study findings, and their clinical implications.

3. Results of Literature Review

3.1. General anesthesia as a dynamic process

General anesthesia is not a uniform state of "switched-off consciousness," but rather a process composed of multiple components and transitional stages that together lead to loss of consciousness, amnesia, analgesia, and akinesia. It is primarily a pharmacologically induced state in which both external and internal stimuli are suppressed, and the patient loses the capacity for conscious perception and purposeful responses to stimuli [9,10].

The key features of general anesthesia include:

- loss of conscious awareness of the environment,
- absence of explicit memory formation,
- impairment of nociceptive and motor responses.

Importantly, these elements do not occur simultaneously but instead evolve along a continuum that depends on the dose of the anesthetic agent and individual patient characteristics [8] (neurophysiological description of consciousness).

From a neurophysiological perspective, anesthesia can be understood as a pharmacologically mediated disconnection of different aspects of brain function, including information integration, sensory awareness, and communication between cortical regions. Anesthetic agents act on multiple neuronal systems by modulating synaptic transmission and large-scale network connectivity, leading to a gradual suppression of cognitive functions. This process is dependent on drug concentration as well as the receptor profiles through which individual anesthetics exert their effects [10].

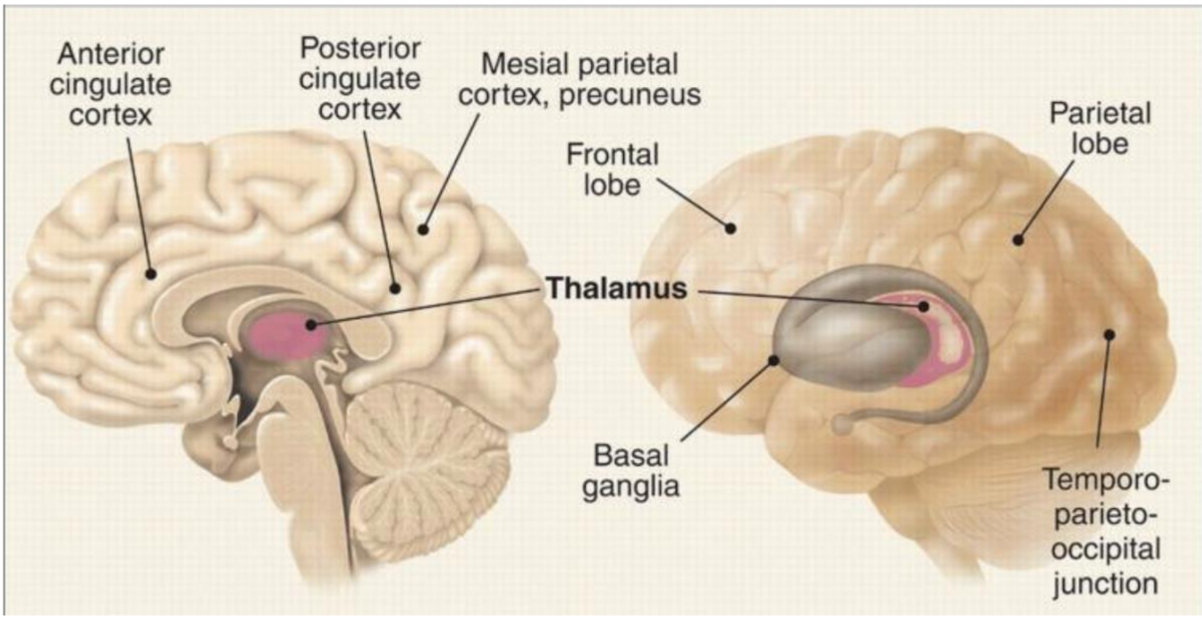

Fig. 1. *Brain regions involved in the mechanisms of loss of consciousness during general anesthesia.*

General anesthesia disrupts the integration of neuronal networks involving, among others, the thalamus, the cingulate cortex, and fronto-parietal regions, which play a key role in the generation and maintenance of consciousness. Based on [9].

Interindividual variability in responses to anesthetic agents is substantial and reflects differences related to age, comorbid conditions, genetic background, as well as pharmacokinetic and pharmacodynamic factors. For example, in elderly patients or those with significant comorbidities, the same anesthetic concentration may result in a much deeper depression of the central nervous system than in younger, otherwise healthy individuals [11]. Such variability also affects the speed of induction and emergence from anesthesia, as well as postoperative cognitive function.

These considerations give rise to the concept of “optimal” versus “excessively deep” anesthesia. An ideal depth of anesthesia should reliably ensure unconsciousness and amnesia for surgical events while avoiding excessive depression of physiological functions and minimizing the risk of adverse outcomes. However, the boundary between an adequate and an excessively deep anesthetic state is not clearly defined and depends on the dynamic interaction between the administered drug and the individual patient. Available evidence indicates that deepening anesthesia beyond the minimum required for clinical effectiveness does not necessarily confer additional benefits and may instead increase the risk of adverse effects [10].

Consequently, general anesthesia should be regarded as a dynamic process in which consciousness, perception, and behavioral responsiveness change continuously under the influence of anesthetic agents and patient-specific characteristics. Understanding this dynamic nature forms the foundation for appropriate monitoring of anesthetic depth and for the optimization of anesthetic management in clinical practice.

3.2. Excessively Deep Anesthesia and Associated Risks

Although the primary goal of general anesthesia is to ensure unconsciousness and the absence of responses to surgical stimuli, exceeding the optimal depth of anesthesia may lead to clinically significant consequences that extend beyond the intraoperative period. One of the most frequently described effects of excessive anesthetic depth is cardiovascular depression. General anesthetics exert inhibitory effects on the myocardium and the autonomic nervous system, resulting in reduced myocardial contractility, decreased cardiac output, and peripheral vasodilation. Consequently, intraoperative hypotension is commonly observed and constitutes an independent risk factor for organ ischemia and postoperative complications [12].

Intraoperative hypotension associated with excessive hemodynamic depression may directly impair cerebral and visceral organ perfusion. Epidemiological data indicate that prolonged episodes of low arterial blood pressure correlate with an increased risk of acute kidney injury, myocardial infarction, and neurological complications. Although the mechanisms underlying these associations are multifactorial—encompassing both direct ischemia and disturbances of vascular autoregulation—clinical observations consistently emphasize the importance of maintaining arterial pressure above critical perfusion thresholds as a key component of safe anesthetic management [12,13].

Increasing attention has also been directed toward the long-term consequences of excessively deep anesthesia. In particular, the relationship between anesthetic depth and the occurrence of postoperative delirium and cognitive dysfunction has been widely investigated. Retrospective and observational studies have shown that patients experiencing periods of deep anesthesia are at higher risk of postoperative delirium. Although this relationship is not unequivocally causal, it has been suggested that prolonged central nervous system depression, combined with reduced cerebral perfusion and disturbances in metabolic homeostasis, may predispose patients to transient or persistent postoperative neurological dysfunction [13,14].

Recent analyses further highlight the role of individual susceptibility of the brain to anesthetic agents in this context. Literature reviews indicate that in elderly individuals, patients with neurodegenerative disorders, or those with pre-existing cognitive impairment, excessive anesthetic depth may result in more pronounced and longer-lasting neurological sequelae. This phenomenon has been linked to a reduced neuronal reserve and increased vulnerability of brain networks to pharmacological suppression of synaptic activity [15].

Analyses of cerebral electrical activity during anesthesia provide additional support for the concept of risk associated with excessive anesthetic depth. Excessively deep anesthesia has been associated with pathological EEG patterns, such as periods of burst suppression or irregular low-amplitude activity, which correlate with prolonged emergence times and an increased risk of postoperative neurological complications. Although interpretation of EEG recordings requires specialized expertise, the presence of such patterns during anesthesia constitutes an important warning signal, prompting reassessment of anesthetic dosing and the overall clinical condition of the patient [15,16].

In summary, excessive anesthetic depth may be viewed as the starting point of a cascade of clinical events in which profound central nervous system depression leads to impaired hemodynamic regulation, reduced organ perfusion, and an increased risk of postoperative complications, including neurological disorders and delirium. This conceptual framework underscores that control of anesthetic depth is a critical component of perioperative safety, extending far beyond the mere prevention of intraoperative awareness.

3.3. Methods for Monitoring the Depth of Anesthesia

Monitoring the depth of anesthesia aims to assess whether the patient is in a state appropriate for performing a surgical procedure without the risk of intraoperative awareness and without complications resulting from either excessive or insufficient suppression of central nervous system activity. In clinical practice, no single parameter can unequivocally reflect a patient's level of consciousness. Therefore, the methods used encompass both traditional clinical indicators and biophysical techniques based on the analysis of brain activity—primarily electroencephalography (EEG)—as well as EEG-derived indices such as the Bispectral Index (BIS) and entropy.

3.3.1. Traditional Clinical Parameters and Their Limitations

Traditionally, the depth of anesthesia has been assessed on the basis of hemodynamic parameters and behavioral responses, such as heart rate, arterial blood pressure, respiratory rate, responses to surgical stimuli, and the presence of motor reflexes. These parameters are readily available and constitute the foundation of routine monitoring in most operating rooms [17,18]. Their main advantages include simplicity and the possibility of continuous observation without the need for additional equipment.

However, numerous studies have demonstrated that traditional clinical parameters have limited specificity as indicators of the actual depth of anesthesia. Hemodynamic responses may be influenced by many factors not directly related to the patient's level of consciousness, including concomitant medications, cardiovascular disease, hypovolemia, or stress-related nociceptive responses [17]. In addition, changes in these parameters often occur with a delay, appearing only after a significant deepening or lightening of anesthesia, which limits their usefulness for precise titration of anesthetic doses.

Another important limitation is the pharmacological blunting of hemodynamic responses, for example through the use of opioids or β-adrenergic blockers. Such interventions may mask the true state of the central nervous system and lead to an inaccurate assessment of anesthetic depth [18]. As a result, traditional clinical parameters only indirectly reflect cerebral activity and do not always correlate with the patient’s level of consciousness, which has been one of the main drivers for the development of EEG-based monitoring methods.

3.3.2. EEG-Based Monitoring

Electroencephalography (EEG) records the electrical activity of the brain and represents a direct physiological indicator of changes occurring in the central nervous system under the influence of anesthetic agents. With increasing anesthetic depth, characteristic alterations in EEG frequency, amplitude, and waveform organization can be observed, reflecting modulation of neuronal activity and synchronization of brain networks [19,20].

A major advantage of EEG-based monitoring is the potential for earlier detection of changes in cerebral state compared with traditional clinical parameters, which may allow more precise adjustment of anesthetic dosing. In recent years, increasing attention has been paid to the analysis of raw EEG signals, which can provide information on specific patterns of brain activity—such as burst suppression or changes in cortical rhythms—that are clinically relevant from a patient safety perspective [21].

At the same time, interpretation of raw EEG signals is complex and requires specialized expertise. EEG recordings are susceptible to artifacts, including facial muscle activity, patient movement, and electrical interference, which limits their direct applicability in routine clinical practice. Consequently, the development of signal-processing algorithms and numerical indices has been a key step in facilitating the widespread use of EEG as a tool for monitoring anesthetic depth [19,21].

3.3.3. BIS, Entropy, and Other EEG-Based Technologies

One of the most commonly used tools in clinical practice is the Bispectral Index (BIS). This method is based on mathematical analysis of the EEG signal, transforming complex bioelectrical data into a numerical scale ranging from 0 to 100. Lower index values indicate deeper levels of anesthesia, while values between 40 and 60 are widely considered appropriate for the maintenance of general anesthesia [22,23]. Bispectral analysis incorporates both frequency and phase relationships within the EEG signal, enabling a more comprehensive assessment of cerebral activity [24].

The main advantages of BIS include a standardized and easily interpretable scale, seamless integration with anesthesia monitors, and the ability to track trends in real time. However, its limitations include susceptibility to electromyographic artifacts, incomplete specificity for different states of neurological unconsciousness, and dependence on the type of anesthetic agent used as well as individual patient variability [1,22,23].

Entropy represents an alternative approach, describing the degree of irregularity in the EEG signal. State Entropy (SE) primarily reflects cortical EEG activity, whereas Response Entropy (RE) also incorporates higher-frequency components that partly originate from muscle activity [22,23]. This method may be more sensitive to early changes in patient state; however, similar to BIS, it remains susceptible to artifacts and lacks clearly defined universal cutoff values.

The literature also describes other EEG-based monitoring technologies, including advanced algorithms for raw EEG signal analysis and systems that integrate EEG data with hemodynamic parameters. Although these approaches may offer deeper insight into brain state, their routine clinical use remains limited due to the complexity of interpretation and the lack of full standardization [19-21].

It should be emphasized that all EEG-derived indices represent indirect markers of neuronal activity rather than direct measurements of patient consciousness. Their interpretation must always take into account the clinical context, hemodynamic parameters, and the pharmacological properties of the anesthetic agents being used [19,20,25].

Table 1. Comparison of Methods for Monitoring Depth of Anesthesia

Method	Physiological Parameter Assessed	Main Advantages	Key Limitations
Classical clinical parameters	Hemodynamic responses, motor reflexes	Widely available; simple to use; no additional equipment required	Low specificity; delayed response; easily influenced by drugs and comorbidities
Raw EEG	Electrical activity of the brain	Direct assessment of central nervous system activity	Susceptible to artifacts; complex interpretation; requires expert knowledge
Bispectral Index (BIS)	Processed EEG-derived numerical index	Standardized scale; easy interpretation; real-time trend monitoring	EMG interference; context-dependent; limited specificity for consciousness
Entropy (RE/SE)	EEG signal irregularity (cortical and EMG components)	Sensitive to early changes in anesthetic state	Artifact susceptibility; lack of universally accepted cutoff values
Other EEG-based algorithms	Advanced EEG signal analysis	Potentially greater neurophysiological insight	Limited clinical availability; lack of standardization

3.4. Clinical Significance of Monitoring Depth of Anesthesia

Monitoring the depth of anesthesia has potentially important implications for clinical practice, primarily through its influence on anesthetic dosing, hemodynamic stability, and the incidence of perioperative complications. Systematic use of monitors such as the Bispectral Index (BIS) and other EEG-derived indices allows for a more direct assessment of central nervous system activity than traditional clinical parameters, which in theory should translate into more precise anesthetic management.

3.4.1. Impact of Monitoring on Anesthetic Dosing

Evidence suggests that the use of depth-of-anesthesia monitors may lead to more efficient and reduced dosing of general anesthetics. In particular, BIS-guided anesthesia allows avoidance of unnecessarily high anesthetic concentrations that do not improve patient comfort but may contribute to hemodynamic depression and delayed recovery of consciousness. A review of data in patients with multiple traumatic injuries demonstrated that the use of depth-of-anesthesia indices was associated with reduced anesthetic requirements without an increased risk of intraoperative awareness, indicating the potential for dose optimization in a challenging clinical population [26].

In pediatric patients, depth-of-anesthesia monitoring may also have a measurable impact on anesthetic dosing. Pediatric studies indicate that the use of EEG-based indices can reduce variability in anesthetic administration and promote more stable levels of sedation, which is particularly relevant in a population characterized by marked pharmacokinetic variability [27].

3.4.2. Potential Impact on Hemodynamic Stability

One of the major clinical challenges during anesthesia is the frequent occurrence of intraoperative hypotension and hemodynamic instability, which may result from both insufficient and excessively deep anesthesia. EEG-based monitoring, by enabling earlier detection of progressive deepening of the anesthetic state, may help prevent excessive anesthetic administration that contributes to cardiovascular depression. Although not all studies have demonstrated a clear improvement in hemodynamic stability with BIS monitoring, retrospective analyses suggest smaller deviations in blood pressure and heart rate when anesthesia is guided by depth indices rather than by hemodynamic parameters alone [18,28].

3.4.3. Association Between Monitoring and Perioperative Complications

The literature also suggests that monitoring the depth of anesthesia may reduce the incidence of certain perioperative complications, particularly postoperative cognitive dysfunction and delirium. Cohort and retrospective studies have shown that patients monitored using EEG-based indices exhibited a lower risk of neurological complications compared with those managed using traditional monitoring alone [29,30]. Although these associations have not yet been conclusively confirmed in large randomized controlled trials, observational data indicate that more precise monitoring may limit episodes of excessive anesthesia, which are potentially linked to subsequent cognitive impairment.

Despite some inconsistency across studies, findings from several randomized trials, systematic reviews, and meta-analyses indicate that EEG-based depth-of-anesthesia monitoring may:

- reduce overall anesthetic consumption,
- limit periods of excessively deep anesthesia,
- shorten emergence and recovery times,
- potentially decrease the risk of neurological complications.

A clinical review published in the British Journal of Anaesthesia emphasizes that although the impact of depth-of-anesthesia monitoring on hard clinical endpoints such as mortality remains insufficiently documented, there is general agreement regarding its value in optimizing anesthetic management and its potential contribution to patient safety [29].

Table 2. Impact of Depth-of-Anesthesia Monitoring on Clinical Parameters and Perioperative Complications

Study / Population	Monitoring Method	Primary Outcome	Clinical Implications
Multitrauma patients	EEG / BIS	Reduced anesthetic consumption	Dose optimization without increased risk of intraoperative awareness [26]
Pediatric population	EEG / BIS	More stable anesthetic dosing	Improved dose adjustment in pharmacokinetically variable patients [27]
Mixed adult populations	EEG / BIS	Reduced incidence of neurological complications	Suggested reduction in delirium and postoperative cognitive dysfunction [29,30]
Adult surgical patients	EEG-based monitoring	Reduced hemodynamic variability	Indirect improvement in intraoperative cardiovascular stability [18,28]

Depth of anesthesia monitoring in clinical practice offers tangible benefits: it may enable more precise titration of anesthetic agents, contribute to a reduction in hemodynamic fluctuations, and lower the risk of selected perioperative complications. Although data from randomized controlled trials still do not provide definitive answers to all clinical questions—particularly with regard to hard endpoints—evidence from cohort studies, retrospective analyses, and selected controlled trials suggests clinically meaningful advantages of EEG-based monitoring. In light of these findings, integrating depth of anesthesia monitoring with other clinical parameters may represent an important component of advanced anesthetic care.

Nevertheless, more recent analyses emphasize that the impact of depth of anesthesia monitoring on clinical outcomes is highly dependent on patient population, type of surgical procedure, and the manner in which EEG-derived indices are interpreted. This context dependence significantly limits the formulation of universal recommendations and underscores the need for individualized clinical application [31].

Despite the potential clinical benefits described above, interpretation of studies evaluating depth of anesthesia monitoring remains burdened by substantial methodological limitations and marked heterogeneity among available technologies, which constitutes the subject of further discussion.

3.5. Limitations and controversies

Despite growing interest in depth of anesthesia monitoring and the increasingly widespread use of EEG-based indices, their application in routine clinical practice remains associated with significant limitations and controversies. One of the principal challenges is the absence of clearly defined cutoff values that could be universally applied as indicators of "optimal" anesthetic depth. Commonly accepted ranges—such as BIS values between 40 and 60—are inherently approximate and do not account for differences related to patient age, anesthetic agent used, type of surgical procedure, or individual sensitivity of the central nervous system. Consequently, identical index values may correspond to different states of consciousness in different patients, limiting their utility as standalone decision-making tools [5].

An additional source of controversy lies in the substantial variability among commercially available depth-of-anesthesia monitors. Individual technologies rely on distinct EEG signal-processing algorithms, different frequency ranges, and varying approaches to integrating cerebral and muscular signals. Comparative studies have demonstrated that indices such as BIS and entropy may respond differently to the same anesthetic concentrations, and their temporal dynamics are not always parallel. For example, State Entropy and BIS may differ in their sensitivity to changes in anesthetic state, complicating direct comparisons between technologies and limiting the generalizability of clinical research findings [4,32].

A further important limitation of EEG-based methods is their susceptibility to artifacts and the risk of misinterpretation. Facial muscle activity, electromyographic signals, patient movement, and electrical interference from operating room equipment may substantially affect signal quality and result in spurious changes in index values. In such circumstances, monitors may suggest either deepening or lightening of anesthesia that does not reflect the true state of the central nervous system. For this reason, the literature consistently emphasizes that interpretation of EEG monitoring requires clinical experience and careful consideration of hemodynamic and pharmacological context, rather than reliance on isolated numerical values alone [4].

Moreover, it has been highlighted that simplified numerical indices do not always capture the true complexity of EEG patterns observed during anesthesia. Failure to consider raw EEG signals may lead to overinterpretation of index fluctuations that lack direct clinical significance, further complicating decision-making processes [33].

Inconsistencies in study outcomes assessing the effectiveness of depth of anesthesia monitoring represent another major source of controversy. Differences in study design, patient populations, anesthetic regimens, and endpoint definitions hinder direct comparisons and the formulation of unequivocal conclusions. While some studies suggest potential clinical benefits associated with EEG-based monitoring, others fail to demonstrate significant differences in complication rates or long-term outcomes. Review analyses emphasize that these discrepancies largely stem from methodological heterogeneity and the absence of standardized research protocols [8].

As a result, although depth of anesthesia monitoring provides valuable insights into cerebral state during anesthesia, current tools are not free from limitations. The lack of definitive cutoff values, variability between technologies, susceptibility to artifacts, and inconsistency of research findings indicate that these methods should be regarded as supportive rather than substitutive to comprehensive clinical assessment. This highlights the need for further research and continued efforts toward greater standardization of depth of anesthesia monitoring methodologies in the future [5].

3.6. Implications for clinical practice

Depth of anesthesia monitoring should not be considered an autonomous tool, but rather a component of comprehensive anesthetic care. Although techniques such as the bispectral index (BIS) and other EEG-based indices do not replace clinical judgment, they provide valuable insight into the state of the central nervous system that may be leveraged in selected clinical scenarios to optimize therapy and reduce the risk of complications.

Monitoring is particularly valuable in clinical contexts where standard physiological parameters are insufficient or potentially misleading for assessing anesthetic depth. This primarily applies to patients with altered pharmacological responses—such as elderly individuals, patients with significant comorbidities, central nervous system disorders, or hypometabolic states—in whom traditional indicators (blood pressure, heart rate, reflexes) may correlate poorly with the level of consciousness suppression. In such cases, EEG-based monitoring may facilitate more accurate titration of anesthetic dosing, helping to avoid both insufficient and excessively deep anesthesia [18,34].

Depth of anesthesia monitoring may also be especially relevant in patients at high risk of perioperative complications, including those undergoing complex cardiac, multiorgan, or trauma-related surgeries, where hemodynamic variables are profoundly influenced by underlying pathology and surgical intervention. In these situations, the use of EEG-based indices as an adjunctive assessment tool may help reduce episodes of excessive cardiovascular depression and intraoperative hypotension, thereby lowering the risk of organ ischemia and neurological complications [18,23].

Importantly, depth of anesthesia monitoring should not be applied reflexively or used as the sole determinant of clinical decisions. EEG-based indices provide complementary information rather than a replacement for clinical evaluation. Overreliance on these technologies—such as mechanically targeting a specific numerical index without accounting for clinical, pharmacological, and hemodynamic context—may lead to inappropriate therapeutic decisions, including unnecessary escalation of anesthetic dosing or failure to address alternative causes of physiological instability [34].

In routine clinical practice, the optimal approach involves integrating EEG-based monitoring with traditional parameters and clinical judgment, enabling a more holistic assessment of the patient's condition. Particularly in situations characterized by substantial variability in anesthetic responsiveness, EEG-derived indices may support informed dose adjustments, reduce episodes of excessive central nervous system depression, and potentially improve hemodynamic stability and perioperative outcomes.

4. Discussion

Despite the dynamic development of depth of anesthesia monitoring technologies and the growing body of clinical research, this field remains characterized by substantial inconsistencies and controversies. The results of available studies are frequently divergent, and attempts to define an unequivocal "optimal" depth of anesthesia have not yet led to a broadly accepted consensus. A key source of these discrepancies lies in the fact that general anesthesia does not represent a homogeneous, binary state of "consciousness versus unconsciousness," but rather a dynamic process in which individual components of brain function are suppressed to varying degrees and at different time points.

From a neuroscientific perspective, consciousness is not a single function amenable to direct measurement, but an emergent property of complex neuronal networks involving information integration, interregional communication, and sensory processing. Research on the nature of consciousness indicates that its loss during anesthesia does not occur in a linear or uniform manner, but through the gradual disconnection of distinct functional elements of the brain [35]. Importantly, an increasing body of evidence suggests that changes in EEG activity do not always translate directly into the clinical state of consciousness, and that observed neurophysiological patterns may reflect different levels of information processing that are not necessarily linked to the patient's subjective experience [36]. Consequently, identical anesthetic concentrations or similar EEG index values may correspond to different neurophysiological states across individual patients.

Differences among depth of anesthesia monitors further amplify interpretative challenges. Individual technologies rely on distinct EEG signal-processing algorithms, selectively emphasizing different frequency bands, phase relationships, or electromyographic components. In practice, this means that these monitors do not measure a single, common biological phenomenon, but rather different aspects of brain activity that do not necessarily evolve in parallel during anesthesia. As a result, comparisons between studies employing different monitoring technologies may yield seemingly contradictory conclusions, even though the observed phenomena remain consistent with current neurobiological knowledge.

The absence of a universal cutoff value for anesthetic depth should therefore be interpreted not as a deficiency of existing technologies, but as a consequence of the inherent complexity of the phenomenon itself. Data derived from experimental studies, including comparative analyses across different species, demonstrate that mechanisms of consciousness loss and cerebral responses to anesthetics exhibit substantial interindividual and interspecies variability [37]. Attempts to reduce this process to a single numerical index thus appear to represent an oversimplification that fails to capture the true neurobiological complexity of anesthesia.

Population-related differences constitute another important factor contributing to inconsistent research findings. Patient age, comorbidities, baseline central nervous system status, and variability in pharmacokinetics and pharmacodynamics significantly modulate anesthetic responses and EEG patterns observed during anesthesia. As a result, monitoring strategies that prove effective in one patient group may not be directly transferable to other clinical populations. Consequently, generalizing research findings without adequate consideration of clinical context leads to divergent conclusions and limits their practical applicability.

From a clinical standpoint, these observations underscore that depth of anesthesia monitoring should be regarded as a supportive rather than a decisive tool. EEG-based indices provide valuable information about cerebral activity, but their interpretation requires integration with clinical assessment, hemodynamic parameters, and an understanding of the pharmacological properties of anesthetic agents. As emphasized by contemporary neurophysiological analyses, mechanically equating changes in EEG indices with the patient's level of consciousness may result in oversimplifications that are not aligned with the realities of anesthetic practice [36].

In summary, the inconsistency of findings in studies on depth of anesthesia monitoring arises from fundamental characteristics of the phenomenon itself—namely, the complex nature of consciousness, the diversity of neurophysiological mechanisms involved, and the heterogeneity of patient populations. Recognizing these limitations allows for a more appropriate interpretation of available data and suggests that future research should focus not on identifying a single universal marker, but on developing more integrated and context-sensitive monitoring strategies that more accurately reflect the true cerebral state during general anesthesia.

5. Conclusion

The depth of general anesthesia represents a crucial yet still incompletely defined component of modern anesthesiology. As demonstrated in this narrative review, general anesthesia should be understood as a dynamic process characterized by substantial interindividual variability in patient responses and complex interactions between anesthetic dosing, central nervous system activity, and clinical parameters.

Available evidence indicates that both excessively shallow and excessively deep anesthesia are associated with significant clinical risks, including hemodynamic instability, intraoperative hypotension, and an increased incidence of selected postoperative complications, particularly neurological disturbances. In this context, EEG-based depth of anesthesia monitoring provides valuable insight into cerebral state and may support clinical decision-making.

At the same time, analysis of the literature confirms that currently available monitoring methods do not allow for the determination of a universal cutoff value defining an "optimal" depth of anesthesia. Differences between technologies, susceptibility to artifacts, and population-related variability limit their applicability as standalone decision-making tools. EEG-based monitoring should therefore be considered an adjunct rather than a replacement for comprehensive clinical assessment.

In light of the presented evidence, future research should focus on improved standardization of monitoring methodologies, greater consideration of population-specific differences, and integration of EEG signals with other physiological parameters. Such an approach may ultimately contribute to more precise and safer management of general anesthesia and improved perioperative outcomes.

Disclosures

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