



Advancing Trends in Electroencephalography Monitoring in Anesthesia: A Bibliometric Analysis from 1980 to 2024

Anesteziye Elektroensefalografi Monitörizasyonunda Gelişen Trendler: 1980'den 2024'e Bibliyometrik Analiz

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Advancing Trends in Electroencephalography Monitoring in Anesthesia: A Bibliometric Analysis from 1980 to 2024

ABSTRACT

This study examines research trends, productivity, and global academic collaborations related to electroencephalography (EEG) monitoring in anesthesia management. Articles published between 1980 and 2024 were analyzed using bibliometric methods in the Web of Science database. A total of 3,371 articles were identified, with anesthesiology, neuroscience, and clinical neurology being the most active areas. The United States (865 articles) and Germany (433 articles) were the leading contributors. The number of articles strongly correlated with economic indicators such as Gross Domestic Product-Purchasing Power Parity (GDP-PPP) ($r=0.885$, $p<0.001$). EEG monitoring has become a multidisciplinary field with high citation rates in anesthesiology and neuroscience journals. Key research topics include the bispectral index (BIS), Narcotrend index, entropy-based EEG analyses, and personalized anesthesia management. Developed countries drive innovation in this field, while equipment costs, technological requirements, and data interpretation complexity remain major barriers to widespread adoption of EEG-based anesthesia monitoring.

Keywords: Anesthesia, Bibliometric analysis, Electroencephalogram, Electroencephalography.

ÖZET

Bu çalışma, anestezi yönetiminde elektroensefalografi (EEG) monitörizasyonu ile ilgili araştırma eğilimlerini, üretkenliği ve küresel akademik iş birliklerini incelemektedir. 1980-2024 yılları arasında yayımlanan makaleler, Web of Science veri tabanında bibliyometrik analiz yöntemiyle değerlendirilmiştir. Toplam 3.371 makale tespit edilmiş olup en aktif araştırma alanları anesteziyoloji, sinir bilimleri ve klinik nörolojidir. ABD (865 makale) ve Almanya (433 makale) en fazla katkı sağlayan ülkeler olarak öne çıkmıştır. Makale sayısı, Gayri Safi Yurtiçi Hasıla-Satın Alma Gücü Paritesi (GDP-PPP) gibi ekonomik göstergelerle güçlü bir ilişki göstermiştir ($r=0.885$, $p<0.001$). EEG izlemi, anesteziyoloji ve sinir bilimi dergilerinde yüksek atıf oranlarıyla çok disiplinli bir alan olarak öne çıkmaktadır. Öne çıkan araştırma konuları arasında Bispektral indeks (BIS), Narcotrend indeksi, entropi temelli EEG analizleri ve EEG verilerine dayalı kişiselleştirilmiş anestezi yönetimi yer almaktadır. Gelişmiş ülkeler bu alanda yeniliklerin öncüsü konumundadır. Ancak ekipman maliyetleri, teknolojik gereksinimler ve veri yorumlamanın karmaşıklığı, EEG tabanlı anestezi izleminin yaygınlaşmasını kısıtlayan temel engeller arasında yer almaktadır.

Anahtar Sözcükler: Anestezi, Bibliyometrik analiz, Elektroensefalogram, Elektroensefalografi.

Introduction

The application of electroencephalographic (EEG) monitoring in anesthesia has gained increasing prominence in recent years due to the demand for a more accurate and objective assessment of anesthesia depth (1,2). Traditional monitoring methods, which rely on physiological markers such as heart rate and blood pressure, as well as objective parameters like minimum alveolar concentration (MAC) or target-controlled anesthesia (TCA), are often indirect and may not fully capture the complex effects of anesthetic agents on the brain (3). In contrast, EEG monitoring directly measures electrical brain activity, providing a real-time view of the patient's cerebral status. This allows for more precise titration of anesthetic dosage, reducing the risk of intraoperative awareness or oversedation (4,5).

Various indices derived from EEG signals attempt to quantify anesthetic depth numerically. In this context, commercial systems such as the bispectral index (BIS) and Narcotrend have become increasingly widespread. However, these indices tend to reduce complex brain activity to a single numerical value, which imposes certain limitations (5,6). EEG signals can vary depending on the anesthetic agents used and the individual's unique brain structure (5-7). Advanced methods such as the density spectral array (DSA) reflect this trend (7,8). As a result, recent years have seen a growing emphasis on the direct analysis of raw EEG data and its integration into clinical decision-making (5,7).

EEG monitoring not only enhances intraoperative safety but also has the potential to promote faster postoperative cognitive recovery, facilitate early extubation, and reduce complications (4,5,8,9). In neuroanesthesia, it is indispensable for real-time monitoring of cerebral function during procedures such as epilepsy surgery, tumor resections, and awake craniotomies (10,11).

As EEG monitoring techniques become more refined and widely adopted, they are expected to enhance the standards of perioperative care and improve overall patient outcomes (5). Despite these benefits, several limitations must be considered. A primary challenge is the interpretation of raw EEG data, which is inherently complex and requires a high level of expertise, as signals can vary significantly

depending on the anesthetic agent used and the patient's individual cerebral characteristics. Additionally, EEG-derived indices such as BIS can oversimplify the brain's dynamic activity by reducing the raw data to a single number, which may result in less accurate assessments of anesthesia depth (1). Another limitation is the high sensitivity of EEG signals to artifacts from muscle activity, electrical interference, and patient movements.

Given these challenges and considering the potential of EEG monitoring to provide a more accurate reflection of the brain's response to anesthesia, a bibliometric analysis of research in this area is warranted. This study aims to systematically analyze the literature published between 1980 and 2024 in order to evaluate the role of EEG in anesthesiology practice, identify research trends, and map scientific collaborations.

Material and Method

The literature review was conducted using the WoS (Clarivate Analytics, Jersey, USA) database, accessed on 26 September 2024. A bibliometric analysis was conducted on all articles in the WoS database published between 1980 and 2024 that contain the specified search keywords. The search employed the following keywords: 'Electroencephalography' OR 'Electrocorticography' OR 'Electroencephalogram' OR 'Electrocorticogram' OR 'Electroencephalographic' OR 'Electrocorticographic' OR 'EEG' OR 'ECoG' OR 'Alpha Wave' OR 'Alpha Band' OR 'Alpha Activity' OR 'Beta Wave' OR 'Beta Band' OR 'Beta Activity' OR 'Theta Wave' OR 'Theta Band' OR 'Theta Activity' OR 'Delta Wave' OR 'Delta Band' OR 'Delta Activity' OR 'Slow Wave' OR 'Slow Activity' OR 'High Frequency' OR 'Low Frequency' OR 'Suppression Ratio' OR 'Burst Suppression' OR 'Brain Wave' OR 'Frequency Band' OR 'Bispectral index' OR 'Patient State Index' OR 'Narcotrend Index' OR 'Density Spectral Array' OR 'Power Spectral Density' OR 'Spectral Edge Frequency' OR 'Local Field Potential' OR 'Oscillatory' OR 'Oscillation' OR 'Spike' OR 'Amplitude' OR 'Event-Related Potential' OR 'Depth of Anesthesia' OR 'Anesthesia Depth' OR 'Anesthetic depth' (Title) and 'Anesthesia' OR 'Anaesthesia' (Topic); Timespan: 1980-2024. Indexes: A&HCI, BKCI-SSH, BKCI-S, ESCI, CPCI-SSH, CPCI-S, SCI-EXPANDED, SSCI. VOSviewer

(version 1.6.20) software was used to visualize the bibliometric network.

Statistical analyses were conducted using SPSS version 24.0 (IBM Corp, Armonk, NY, USA). Data normality was assessed with the Shapiro–Wilk test. Pearson correlation analysis was used to evaluate the relationship between the number of articles produced by countries and economic and developmental indicators, including gross domestic product (GDP), gross domestic product purchasing power parity (GDP-PPP), and the human development index (HDI). A *p*-value of less than 0.05 was considered statistically significant.

Results

The literature screening identified a total of 4,358 published items. Among these, 3,371 were articles, 366 were proceedings papers, 321 were meeting abstracts, 180 were letters, and 141 were reviews. The remaining 116 items include editorial materials, early access publications, corrections, notes, book chapters, retracted publications, and news items. Only 3,371 articles were included in the bibliometric analysis. The 3,371 articles received a total of 44,956 citations, of which 42,210 citations excluded self-citations. The *h*-index of these articles was 124, and an average of 27.28 citations was received per article. Of these, 96% (*n* = 3,233) were published in English. The remaining 4% were in other languages: German (*n* = 76), French (19), Spanish (16), Portuguese (9), Russian (7), Turkish (4), Polish (2), Chinese (1), Japanese (1), Korean (1), Italian (1), and Unspecified (1).

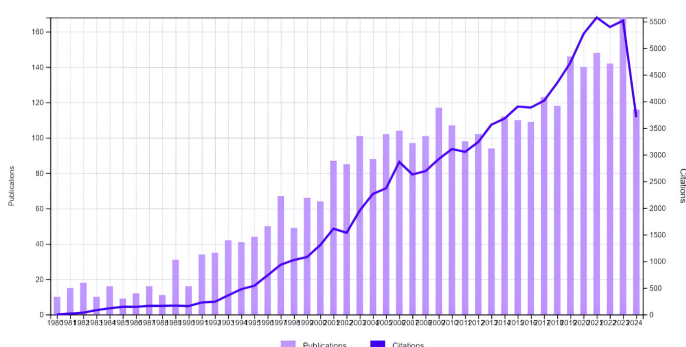


Figure I. Number of Publications and Citations by Years on EEG Studies in Anesthesiology

Research fields: The leading 10 research fields for the published articles were anesthesiology

(1,468, 43.5%), neurosciences (578, 17.1%), clinical neurology (329, 9.8%), veterinary sciences (160, 4.7%), engineering biomedical (157, 4.7%), surgery (156, 4.6%), medicine general internal (131, 3.9%), physiology (127, 3.8%), critical care medicine (110, 3.3%), multidisciplinary sciences (108, 3.2%).

Table I. Correlation Analysis

	Record Count			
	n	df	r	p
HDI	73	71	0.279	0.017
GDP (million dollar)	73	71	0.884	0.000
GDP PPP (million dollar)	71*	69	0.736	0.000

GDP: Gross Domestic Product; GDP-PPP: Gross Domestic Product Purchasing Power Parity; HDI: Human Development Index; *r*: Pearson Correlation coefficient; *df*: degrees of freedom
* Cuba and Taiwan were excluded from the analysis due to the unavailability of their GDP-PPP data on the official source

As shown in Figure I, the number of publications per year remained low during the 1980s but began to increase significantly starting in the 2000s. The number of publications peaked between 2021 and 2023, with a slight decline observed in 2024.

The number of citations, on the other hand, has increased cumulatively over the years. This trend indicates that EEG monitoring is not only a popular topic but also a field of research that generates high-impact contributions.

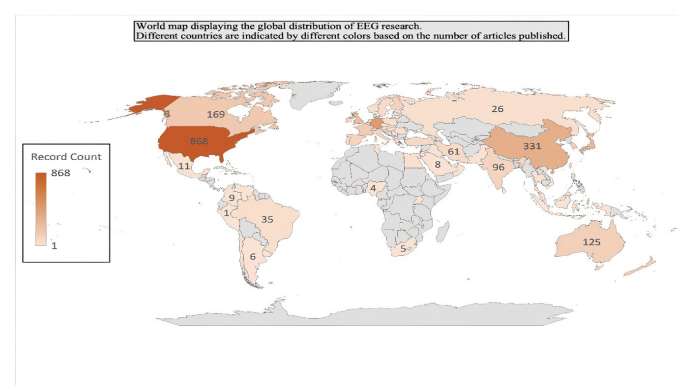


Figure II. World Map for The Publication Productivity of Worldwide Countries on EEG Studies in Anesthesiology

Top countries

Figure II presents the distribution of articles across various countries. The active countries contributing more than 100 articles were the United States of America (USA) (865), Germany (433), China (330),

Japan (274), England (199), Canada (169), France (149), New Zealand (137), Australia (124), South Korea (123), Netherlands (114), Finland (110), Belgium (104), Switzerland (102). A total of 93 countries produced 3,371 articles. Figure III presents the network map illustrating international cooperation among the 38 countries that had published at least 10 articles. Publications originating from the United States show strong collaboration with Germany, Canada, the United Kingdom, and China. Similarly, Germany maintains close ties with Japan, the Netherlands, and the Scandinavian countries. This indicates that both transatlantic and intra-continental collaborations play a prominent role in EEG research (Figure III).

Table II. Active Journals on EEG Studies in Anesthesiology

Journals	RC	C	AC
Anesthesia and Analgesia	246	1,304	5.3
British Journal of Anaesthesia	231	1,159	5.0
Anesthesiology	194	1,179	6.1
Journal Of Clinical Monitoring and Computing	72	281	3.9
Acta Anaesthesiologica Scandinavica	69	373	5.4
European Journal of Anaesthesiology	68	346	5.1
Clinical Neurophysiology	57	471	8.3
Journal of Neurosurgical Anesthesiology	52	268	5.2
Anaesthesia	51	376	7.4
Journal of Neurophysiology	50	618	12.4
Journal of Clinical Anesthesia	44	248	5.7
Pediatric Anesthesia	40	294	7.4
Plos One	38	500	13.2
BMC Anesthesiology	37	215	5.9
Frontiers In System Neuroscience	33	155	4.7
Anaesthesist	32	195	6.1
Anaesthesia and Intensive Care	29	149	5.1
Scientific Reports	29	445	15.3
Neuroscience	28	401	14.3
Journal of Neuroscience	27	808	29.9
IEEE Transactions on Biomedical Engineering	25	180	7.2
Canadian Journal of Anaesthesia Journal Canadien D'Anesthesie	23	146	6.3
Veterinary Anaesthesia and Analgesia	22	128	5.8
Journal of Cardiothoracic and Vascular Anesthesia	21	263	12.5
Korean Journal of Anesthesiology	21	112	5.3
Neuroimage	21	458	21.8

RC: Record Count, C: Number of Citation, AC: Average Citation Per Document.

Correlation analysis

The normality of the data distribution was assessed using the Shapiro-Wilk test (WRC=0.491,

WGDP=0.891, WGDP-PPP=0.331, WHDI=0.410). GDP and GDP-PPP data were obtained from the official website of the World Bank using 2023 data, while HDI data were sourced from the official website of the United Nations Development Programme (<https://data.worldbank.org/indicator/NY.GDP.MKTP.CD?locations=>, <https://data.worldbank.org/indicator/NY.GDP.MKTP.PP.KD?locations=>, <https://hdr.undp.org/data-center/country-insights#/ranks>). Statistically significant correlations were observed between the number of articles published by countries on EEG studies in anesthesiology and GDP, GDP-PPP, and HDI, with corresponding *p-values* of $p<0.001$, $p<0.001$, and $p=0.017$, respectively (Table I). These findings indicate that countries with a high level of economic development are more active in producing publications related to EEG.

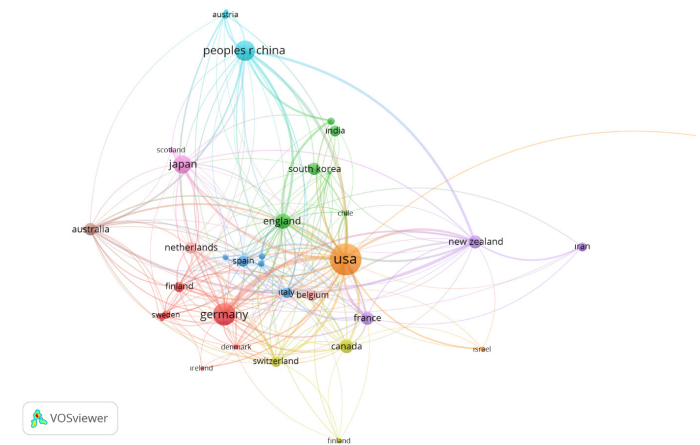


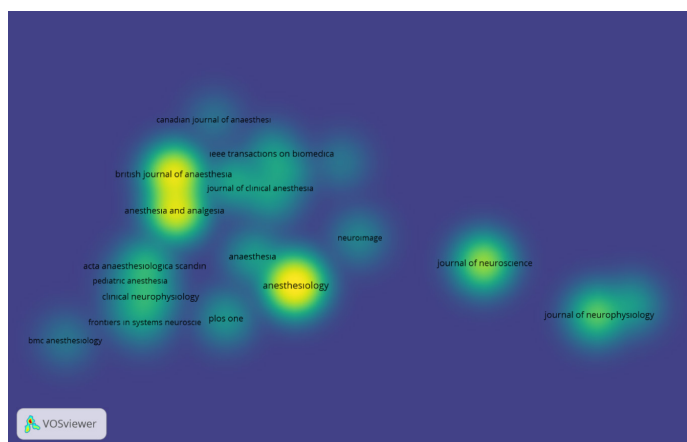
Figure III. Network Visualization Map for International Collaboration of Worldwide Countries on EEG Studies in Anesthesiology

Top journals

The 3,371 articles were published in a total of 1,081 journals. Among these, 26 journals published at least 20 articles on the topic. Table II presents the top 26 journals, which collectively contributed the majority of the articles. The last column of the table displays the total citation count for each journal, along with the average citation number per article. Notably, neuroscience journals such as Journal of Neuroscience and NeuroImage have achieved high average citation counts. The high average citation counts in neuroscience journals, in particular, highlight the multidisciplinary impact of EEG research.

Figure IV presents the journal-based citation density of publications in the field of EEG monitoring.

Sleigh (or James W.) (combined total: 77), Gerhard Schneider (51), Matthias Kreuzer (40), Patrick L. Purdon (39), Emery N. Brown (39), Craig B. Johnson (37), Michel R. F. Struys (31), Arvi M. Yli-Hankala (31), Mircea Steriade (27), Jörgen Bruhn (25), Shouzen Fan (25), Michael S. Avidan (24), Darren Hight (24), and Xiaoli Li (24) in descending order.



The network graph displays a wide range of medical concepts and their interrelationships. Key clusters include:

- Anesthesia and Sedation:** Nodes like 'anesthesia', 'general anesthesia', 'sedation', 'consciousness', and 'depth of anesthesia' are highly interconnected.
- Monitoring and Assessment:** Nodes such as 'monitoring', 'bispectral index', 'depth of anesthesia', and 'consciousness monitors' are linked together.
- Pharmacology:** Various drugs and substances are represented, including 'ketamine', 'propofol', 'isoflurane', 'sevoflurane', 'desflurane', 'nitrous oxide', and 'dexamethomidine'.
- Neurological and Pain Management:** Nodes like 'epilepsy', 'pain', 'burst suppression', and 'nociception' are also present.

The graph uses a color-coded system to group related terms, with colors like blue, green, red, and purple used to distinguish different clusters of concepts.

Figure V. Network Visualization Cluster Map for Keyword Analysis on EEG Studies in Anesthesiology

Citation analysis

Table IV presents the 15 most cited articles in the field of anesthesiology, selected by choosing ‘anesthesiology’ in the citation topic meso category of WoS (13-27). The last column of the table includes the annual citation count for each article. The majority of these articles appear to focus on BIS and the loss and recovery of consciousness. This underscores the dominant position of the BIS index in the scientific literature and the central role of concerns related to intraoperative awareness.

Affiliations	RC	Affiliations	RC
Harvard University	139	Berlin Institute of Health	44
Harvard Medical School	102	Charite Universitatsmedizin Berlin	44
Massachusetts General Hospital	85	Massachusetts Institute of Technology Mit	44
University of California System	83	University of Bonn	41
Technical University of Munich	74	Institut National De La Sante Et De La Recherche Medicale Inserm	40
University of Auckland	57	Laval University	39
Hannover Medical School	53	Ghent University	38
Waikato Hospital	52	University of Pennsylvania	38
Capital Medical University	51	University of London	35
Tampere University	51	University of Michigan	35
Humboldt University of Berlin	47	University of Michigan System	35
Free University of Berlin	46	University of Texas System	35
Washington University Wustl	46		

Figure VI. Network Visualization

Figure VI. Network Visualization

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Table IV. The 15 Most Cited Manuscripts on EEG Studies in Anesthesiology

No.	Article	Author	Journal	PY	TC	AC
1	Bispectral index monitoring to prevent awareness during anaesthesia: the B-Aware randomised controlled trial (13)	Myles PS et al.	Lancet	2004	792	37.71
2	Anesthesia awareness and the bispectral index (14)	Avidan MS et al.	New England Journal of Medicine	2008	564	33.18
3	Electroencephalogram signatures of loss and recovery of consciousness from propofol (15)	Purdon PL et al.	Proceedings of The National Academy of Sciences of The United States of America	2013	541	45.08
4	Bispectral index monitoring allows faster emergence and improved recovery from propofol, alfentanil, and nitrous oxide anesthesia (16)	Gan TJ et al.	Anesthesiology	1997	464	16.57
5	Measuring the performance of anesthetic depth indicators (17)	Smith WD et al.	Anesthesiology	1996	355	12.24
6	Electroencephalographic bispectral index correlates with intraoperative recall and depth of propofol-induced sedation (18)	Liu J et al.	Anesthesia and Analgesia	1997	330	11.79
7	Hospital Stay and Mortality Are Increased in Patients Having a "Triple Low" of Low Blood Pressure, Low Bispectral Index, and Low Minimum Alveolar Concentration of Volatile Anesthesia (19)	Sessler DI et al.	Anesthesiology	2012	318	24.46
8	A multicenter study of bispectral electroencephalogram analysis for monitoring anesthetic effect (20)	Sebel PS et al.	Anesthesia and Analgesia	1997	305	10.89
9	Propofol Anesthesia and Sleep: A High-Density EEG Study (21)	Murphy M et al.	Sleep	2011	279	19.93
10	Titration of volatile anesthetics using bispectral index facilitates recovery after ambulatory anesthesia (22)	Song DJ et al.	Anesthesiology	1997	278	9.93
11	Approximate entropy as an electroencephalographic measure of anesthetic drug effect during desflurane anesthesia (23)	Bruhn J et al.	Anesthesiology	2000	274	10.96
12	Cortical and thalamic cellular correlates of electroencephalographic burst-suppression (24)	Steriade M et al.	Electroencephalography and Clinical Neurophysiology	1994	248	8.00
13	Electroencephalographic derivatives as a tool for predicting the depth of sedation and anesthesia induced by sevoflurane (25)	Katoh T et al.	Anesthesiology	1998	247	9.15
14	Electroencephalographic quantitation of opioid effect-comparative pharmacodynamics of fentanyl and sufentanil (26)	Scott JS et al.	Anesthesiology	1991	243	7.15
15	The Ageing Brain: Age-dependent changes in the electroencephalogram during propofol and sevoflurane general anaesthesia (27)	Purdon PL et al.	British Journal of Anaesthesia	2015	241	24.10

No: Number; PY: Publication Year; TC: Total Citation; AC: Average Citations Per Year

Co-citation analysis

The 3,371 articles referenced a total of 57,724 publications. Among these, 10 publications received more than 150 citations. These publications receiving most citations are, in order, Rampil Ij et al. (1998) (Number of citations: 479), Glass Ps et al. (1997) (338), Myles Ps et al. (2004) (205), Purdon Pl et al. (2015) (203), Gan Tj et al. (1997) (192), Sigl Jc et al. (1994) (189), Johansen Jw et al. (2000) (177), Purdon Pl et al. (2013) (175), Smith Wd et al. (1996) (155) and Brown En et al. (2010) (155) (13, 15-17, 28-33).

Keywords

A total of 5,234 different keywords were identified in the 3,371 articles. The clustering of 53 keywords that appeared in at least 20 publications is presented

in Figure V, while their temporal trends are shown in Figure VI. Table V lists the most frequently used terms. Figure V illustrates the clustering of 53 keywords that appeared in at least 20 different publications. In this analysis, core concepts such as EEG, bispectral index, depth of anesthesia, propofol, burst suppression, and consciousness are positioned at the center.

Figure VI presents the temporal trend of these keywords over the years. Terms such as bispectral index and depth of anesthesia show a marked increase after 2005, while in recent years, concepts like propofol, dexmedetomidine, and consciousness monitors have gained prominence. The concepts of Narcotrend and entropy appeared within the same cluster, and this group has shown an increase over

Table V. The Trend Keywords on EEG Studies in Anesthesiology

Keywords	O	Keywords	O	Keywords	O
Bispectral Index	339	Monitoring, Bispectral Index	50	Hippocampus	27
Propofol	292	Remifentanyl	49	Nociception	26
Anesthesia	266	Sleep	48	Postoperative Delirium	26
Electroencephalography	252	Epilepsy	46	Midazolam	24
EEG	238	Ketamine	43	Fentanyl	23
Electroencephalogram	209	Depth of Anaesthesia	42	Cardiac Surgery	23
Sevoflurane	139	Entropy	41	Isoflurane	23
Monitoring	117	Monitoring, Electroencephalography	39	Surgery	23
Depth Of Anesthesia	101	Children	37	Bispectral Index Monitoring	22
Anaesthesia	98	Anaesthesia, Depth	36	Narcotrend	21
General Anesthesia	91	Electroencephalogram (EEG)	35	Desflurane	21
Sedation	89	Consciousness Monitors	32	Halothane	21
Burst Suppression	69	Awareness	30	Spectral Analysis	21
Dexmedetomidine	57	Bispectral Index	29	Anesthesia	21
Consciousness	53	Cardiopulmonary Bypass	29	Seizure	20
BIS	53	General Anaesthesia	29	Electrocorticography	20
Rat	52	Pain	28	EEG Monitoring	20
Isoflurane	51	Anaesthetics I.V., Propofol	28		

O: number of occurrences.

the past five years.

Discussion

This bibliometric analysis aims to provide a comprehensive overview of publication trends, scientific productivity, and international collaborations in the field of EEG monitoring in anesthesia. Our findings reveal an increasing number of publications focused on the use of EEG to optimize the depth of anesthesia, alongside a shift towards more advanced and sensitive monitoring techniques in perioperative care. In this context, the current literature demonstrates a clear trend away from traditional physiological markers towards real-time brain activity monitoring using EEG-derived indices such as the BIS and the Narcotrend index (2). Despite the limitations associated with BIS, it remains the most frequently cited topic in EEG-related anesthesia research (9,34). In contrast, other EEG-derived indices, such as the Narcotrend index and density spectral array (DSA), receive less attention, despite new evidence suggesting their potential advantages in specific clinical context (35-37). Despite the availability of alternative techniques, the continued preference for BIS monitoring suggests a conservative approach to the adoption of newer methods.

The United States of America and Germany

are recognized as leaders in the number of active research centers. This leadership can be attributed to the critical role of substantial economic resources, advanced research institutions, and technological capabilities in generating high-impact research. As demonstrated in previous studies, economically advanced countries with strong financial foundations and higher human development indices tend to contribute more significantly to the global scientific output (38, 39). Our findings align with this trend, showing that nations with higher GDP and GDP-PPP are more productive in EEG-related research, particularly in the field of anesthesia. It can be concluded that economically developed countries with higher GDP and HDI levels make greater academic contributions, particularly in specialized areas such as anesthesia and neuroscience. Similarly, while the United States, Germany, and China lead in terms of publication volume, countries such as Japan and the United Kingdom also produce a substantial number of publications. This further highlights that contributions to specialized academic fields are significant in countries with strong economic foundations. Moreover, it is not surprising that research from these nations also ranks highly in terms of citation counts.

In terms of publication impact, it is evident that

leading journals in the field of anesthesia are also the most significant contributors to the literature on this topic. However, the high citation rates observed in neuroscience journals suggest that EEG monitoring research extends beyond perioperative anesthesia and provides broader insights into brain function. Additionally, our findings point to a growing interest in integrating EEG data with patient-specific cerebral characteristics to develop more personalized anesthesia management systems (40-42). In the future, the use of algorithms with high temporal and spatial resolution to analyze EEG signals may facilitate the development of patient-specific anesthesia protocols. Moreover, the integration of EEG data with other physiological markers—such as hemodynamic parameters, pupillometry, and cerebral oximetry—within multimodal monitoring systems could allow for a more comprehensive assessment of the patient's neurophysiological state during anesthesia. Especially in elderly patients, EEG-guided individualized anesthetic titration may become central to perioperative care strategies aimed at preventing postoperative cognitive dysfunction. Despite these advancements, several challenges continue to hinder the widespread adoption of EEG monitoring, including high equipment costs, limited accessibility, the need for specialized training, and the complexity of interpreting raw EEG data (43,44). Overcoming these barriers is crucial for maximizing the clinical utility of EEG monitoring and improving anesthesia management.

Future research should focus on the development of artificial intelligence-driven clinical decision support tools capable of real-time interpretation of EEG data, and randomized controlled trials should be conducted to evaluate their impact on patient outcomes. Furthermore, studies examining whether EEG-derived indices vary according to age, neurological status, and type of surgery will be essential to inform more refined clinical guidelines. Ultimately, the role of EEG in anesthesia may evolve beyond depth monitoring to become a core component of personalized and goal-directed anesthesia care.

In addition, our study has certain limitations. The analysis was based on data from the WoS database, which may have excluded relevant studies indexed in

other databases such as PubMed or Scopus, potentially limiting the scope of this analysis. Furthermore, the study primarily focused on quantitative metrics, such as publication counts and citation rates, without assessing the clinical significance of the findings. Future analyses should incorporate clinical relevance metrics to provide a more comprehensive understanding of the field.

Conclusion

The increasing trend in publications on EEG monitoring in anesthesia highlights the growing interest and use of EEG as a critical tool for enhancing patient safety and optimizing anesthesia practice. These findings indicate that the most productive countries in this field are those with higher levels of economic development. Therefore, low-cost EEG solutions should be encouraged for developing countries.

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