Perioperative Medicine

REVIEW

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Global trends in artificial intelligence research in anesthesia from 2000 to 2023: a bibliometric analysis

Yi Ou[1], Xiaoyi Hu[2*], Cong Luo[1] and Yajun Li[1]

Abstract

Background Interest in artificial intelligence (AI) research in anesthesia is growing rapidly. However, there is a lack of bibliometric analysis to measure and analyze global scientific publications in this field. The aim of this study was to identify the hotspots and trends in AI research in anesthesia through bibliometric analysis.

Methods English articles and reviews published from 2000 to 2023 were retrieved from the Web of Science Core Collection (WoSCC) database. The extracted data were summarized and analyzed using Microsoft Excel, and bibliometric analysis were conducted with VOSviewer software.

Results AI research literature in anesthesia has exhibited rapid growth in recent years. The United States leads in the number of publications and citations, with Stanford University as the most prolific institution. Hyung-Chul Lee is the author with the highest number of publications. The journal *Anesthesiology* is highly recognized and authoritative in this field. Recent keywords include "musculoskeletal pain", "precision medicine", "stratification", "images", "mean arterial pressure", " enhanced recovery after surgery", "frailty", "telehealth", "postoperative delirium" and "postoperative mortality" indicating hot topics in AI research in anesthesia.

Conclusions Publications on AI research in the field of anesthesia have experienced rapid growth over the past two decades and are likely to continue increasing. Research areas such as depth of anesthesia (DOA) and drug infusion (including electroencephalography and deep learning), perioperative risk assessment and prediction (covering mean arterial pressure, frailty, postoperative delirium, and mortality), image classification and recognition (for applications such as ultrasound-guided nerve blocks, vascular access, and difficult airway assessment), and perioperative pain management (particularly musculoskeletal pain) have garnered significant attention. Additionally, topics such as precision medicine, enhanced recovery after surgery, and telehealth are emerging as new hotspots and future directions in this field.

Keywords Artificial intelligence, Anesthesia, Bibliometrics, VOSviewer

Introduction

Artificial intelligence (AI) is a broad field that represents technologies capable of reasoning and performing tasks such as classification, problem solving, decision making and predicting future states (Hashimoto et al. 2020). Machine learning, deep learning, natural language processing, and the ability to visualize and recognize objects (computer vision) are all commonly used AI techniques (Greco et al. 2021). Currently, AI has

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become an integral part of modern healthcare, with a wide range of applications encompassing disease prevention, diagnosis, treatment, patient management, and medical data analysis (Bindra and Jain 2024; Varghese et al. 2024; Yu et al. 2018).

Anesthesiology, as a field, encompasses multiple aspects of perioperative management, including preoperative risk assessment and prediction, intraoperative drug infusion and monitoring, and postoperative complications and pain management (Hashimoto et al. 2020). With the aging population and the increasing volume of anesthetic procedures, the rising demand for anesthesia has led to a significant increase in the workload for anesthesiologists. This increased workload can easily lead to a decrease in the quality of anesthesia, thereby increasing perioperative risks for patients.

AI can enhance preoperative risk stratification, optimize intraoperative drug dosages, and predict postoperative complications, thereby improving patient prognosis and reducing adverse events (Chen et al. 2023a, 2022; Xue et al. 2021). Additionally, AI can enable more personalized and precise anesthetic management by analyzing individual patient data (Alexander and Joshi 2018). This not only improves the safety and efficacy of anesthesia but also promotes faster recovery and a better overall patient experience. In conclusion, the integration of AI in anesthesiology research is critical for advancing the field. It is expected to transform traditional anesthesia practice, drive innovation in patient care, and usher in a new era of intelligent, data-driven anesthesia management.

VOSviewer is a free-to-use, user-friendly, and versatile software tool designed for constructing and visualizing bibliometric maps. It offers multiple visualization options, each highlighting distinct aspects of the bibliometric data. Notably, VOSviewer excels in presenting large-scale bibliometric maps in a clear and comprehensible manner, making it particularly valuable for complex analyses. The software has been effectively utilized in numerous research projects conducted by the Center for Science and Technology Studies, demonstrating its reliability and applicability in bibliometric research. This study utilizes VOSviewer bibliometric analysis software to analyze research literature on AI in the field of anesthesiology. Bibliometric analysis was conducted on research articles published from 2000 to 2023 in the Web of Science Core Collection (WoSCC) database. This analysis aims to assist new researchers in identifying current topics of interest from a global perspective and to predict future trends in AI research within the field of anesthesiology.

Methods

Data sources and search strategy

The Science Citation Index Expanded of the WoSCC database was used as the data source for this paper, which was searched on 17 April 2024. The search formula is: TS =("artificial intelligence"OR"computational intelligence"OR"deep learning"OR"machine learning"OR"machine intelligence "OR"neural network"OR"artificial neural network"OR" convolutional neural network"OR"natural language processing"OR"feature learning"OR"feature extraction "OR"reinforcement learning"OR"image segmentation "OR"hybrid intelligent system"OR"hybrid intelligent system"OR"recurrent neural network"OR"data learning "OR"big data"OR"support vector machine"OR"random forest"OR"bayesian network"OR"bayesian learning"OR" evolutionary algorithms"OR"multiagent system") AND TS =(perioperative OR peri-operative OR anesthesia OR anaesthesia OR anesthetic OR anesthesiology OR"perioperative management"OR"perioperative care"OR"anesthetic management"OR"anesthesia care "OR"pain management"OR"pain care"). A total of 1581 publications were initially retrieved. After limiting the time span to 2000–2023, 1481 publications remained. Only reviews and articles were included, resulting in 1371 publications after screening. Finally, applying a language restriction to English, a total of 1355 publications were analyzed (Fig. 1).

Data extraction and visualization

The retrieved publications were compiled and exported as"plain text"files. The output records included"full record and references."Extracted data encompassed publication year, country, institution, author, journal, and H-index. Microsoft Excel 2019 and VOSviewer (version 1.6.20) were employed for data analysis. Microsoft Excel 2019 was used to assemble and sort each publication's characteristics. Each record from the WoSCC database was imported into VOSviewer for co-authorship, co-citation, and co-occurrence analysis.

VOSviewer is a software tool for constructing and visualizing bibliometric networks, widely used to build and visualize networks based on scientific publications, journals, authors, institutions, countries, or keywords (Perianes-Rodriguez et al. 2016). Co-authorship analysis is employed to connect two elements that co-authored articles, revealing the specific context of collaboration networks. Co-citation analysis examines the relationship between two documents by determining how frequently they are cited together by other documents (Kumar 2015). Co-occurrence analysis calculates each keyword to identify high-frequency terms

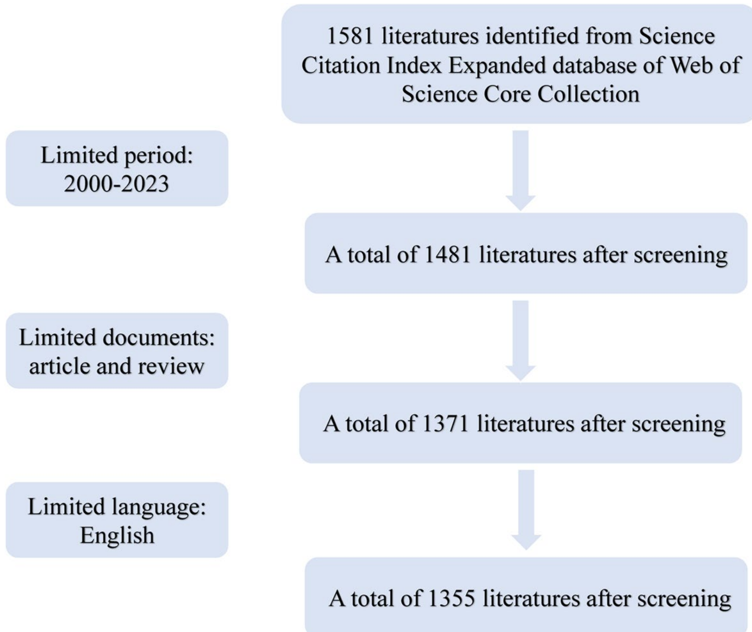

Fig. 1 Flow chart of literature screening

and research directions (Kleminski et al. 2022). In the networks generated by VOSviewer, the size of a node represents the number of publications, with larger nodes indicating a higher number of publications. Links between nodes represent correlations between parameters, and the thickness of the links indicates their strength. The importance of a node in the network is quantitatively determined by its total link strength (TLS) with other nodes.

Results

Number of publications and trends

Figure 2A illustrates the number of publications related to AI in the field of anesthesia from 2000 to 2023. It is evident that significant interest in AI in anesthesia began in 2019, with an annual growth rate of 75%. Since then, the number of publications has increased sharply each year, reaching 326 in 2023. The number of papers published between 2019 and 2023 surged dramatically, accounting for 80.81% (1095/1355) of all included publications. In addition, Fig. 2A shows the growth trend in the number of publications per year. The number of published documents is positively correlated with the publication year, with a correlation coefficient (R^2) of 0.9812, indicating a significant upward trend in AI research in anesthesia. Figure 2B compares the annual number of publications from the top ten countries. The United States and China contributed approximately 62.66% (849/1355) of the publications, with a notable rapid increase in the number of publications post- 2019.

Countries analysis

Table 1 lists the top 10 countries with the highest number of publications on AI research in anesthesia. The United States (USA) has the most publications ($n = 485$), accounting for 35.8% of the total, followed by China ($n = 364$) and England ($n = 100$). The USA also has the highest H-index (44), followed by China (23) and England (23). Additionally, the USA has the highest number of citations (8764), followed by China (2539) and England (1985). Italy has the highest average number of citations per publication (19.24), followed by the Netherlands (18.64) and the USA (18.07), while China ranks lower in average citations per publication. Co-authorship analysis visualized using VOSviewer shows that 40 countries have at least five publications. The top five countries with the highest TLS are the USA (276), England (163), Italy (129), Germany (121), and China (103) (Fig. 3A, B). Figure 3C illustrates the geographical distribution of these publications. The most prolific countries include those in North America, Europe, and several in Asia, predominantly located in the Northern Hemisphere.

Institutions analysis

Table 2 lists the top 10 institutions with the highest number of publications. This includes 4 research

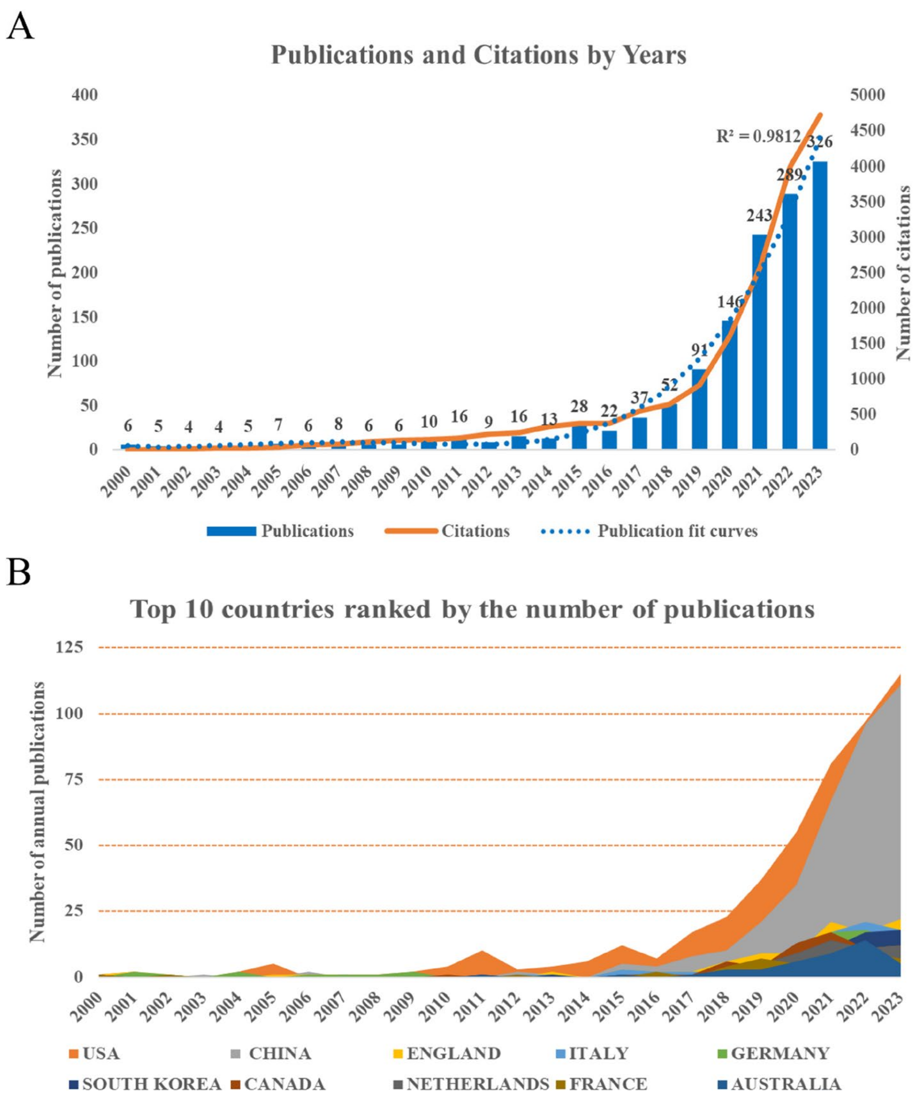

Fig. 2 **A** The number of publications and citations in the field per year, incluing publication fit curves; **B** Top 10 countries ranked by the number of publications

Table 1 Top 10 most prolific countries

Countries	Number of publications (%)	H-index	Number of citations	Mean Citations/ Publication
USA	485(35.8)	44	8764	18.07
China	364(26.9)	23	2539	6.98
England	100(7.4)	23	1985	16.85
Italy	80(5.9)	20	1539	19.24
Germany	74(5.5)	18	1903	14.77
South Korea	69(5.1)	16	1908	15.91
Canada	68(5.0)	19	880	12.94
Netherlands	55(4.1)	15	1205	18.64
Australia	46(3.4)	15	489	10.63
France	43(3.2)	12	677	15.74

institutions each from the USA and China, and one each from Canada and South Korea. The institution with the highest number of publications is Stanford University ($n=$ 35), followed by Harvard Medical School ($n=$ 33) and the University of Toronto ($n=$ 25). The five institutions with the highest H-indices are Stanford University ($n=$ 14), Harvard Medical School ($n=$ 11), University of California Los Angeles ($n=$ 11), Seoul National University ($n=$ 11), and University of Michigan ($n=$ 11). We visualized 139 institutions based on at least 5 publications each and constructed a collaboration network according to the number of publications and their relationships. The 5 institutions with the highest TLS are University of Toronto (52), Chinese

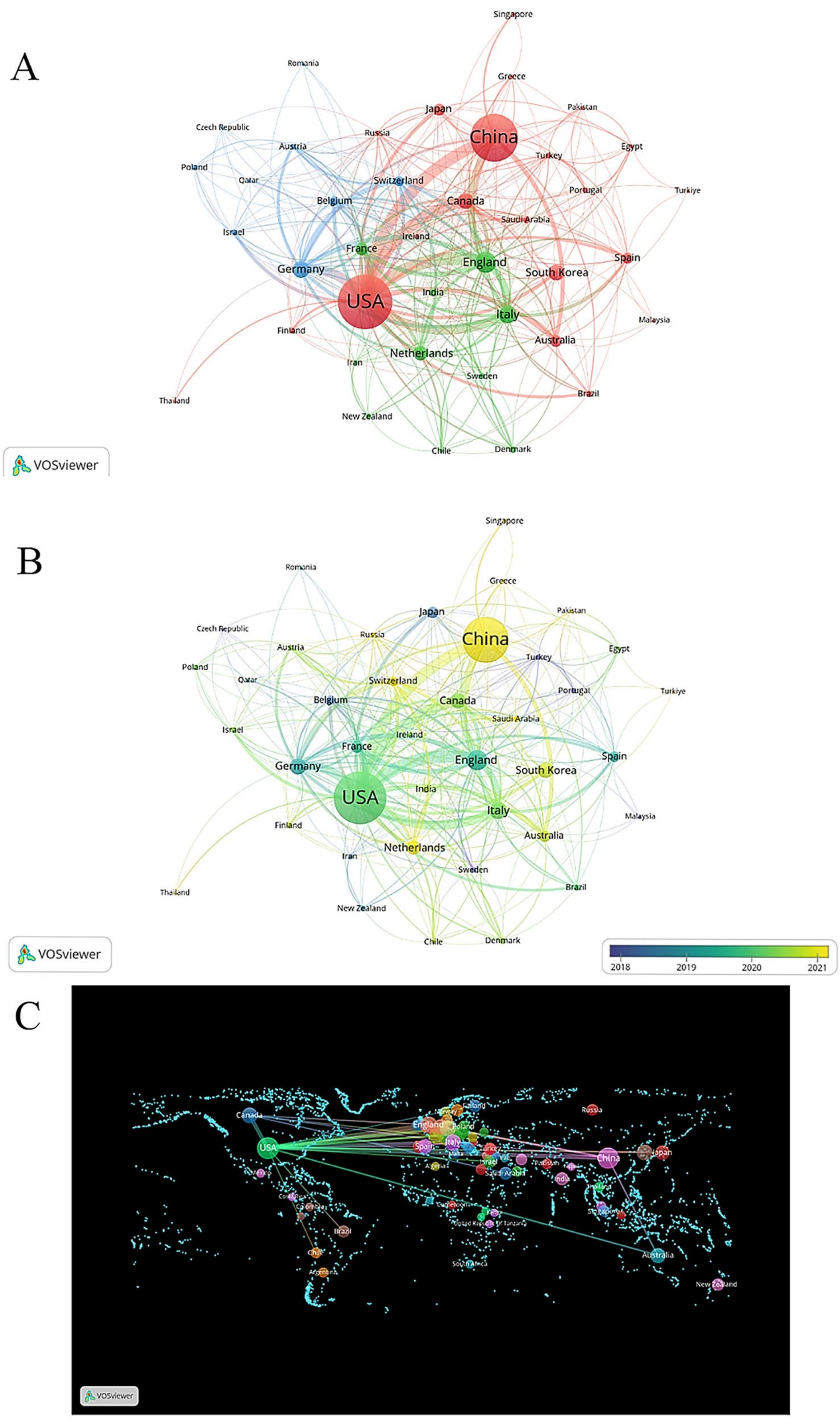

Fig. 3 Analysis of country co-authorship. **A** Network visualization; **B** Overlay visualization; **C**Geographical view

Table 2 Top 10 most prolific institutions

Institutions	Country	Number of publications (%)	H-index	Number of citations	Mean Citations/ Publication
Stanford University	USA	35 (2.6)	14	669	19.11
Harvard Medical School	USA	33 (2.4)	11	386	11.70
University Of Toronto	Canada	25 (1.8)	10	305	12.20
University Of California Los Angeles	USA	23 (1.7)	11	363	15.78
Seoul National University	South Korea	22 (1.6)	11	609	27.68
University Of Michigan	USA	21 (1.5)	11	286	13.62
Zhejiang University	China	21 (1.5)	5	79	3.76
Capital Medical University	China	20 (1.5)	8	199	9.95
Shanghai Jiao Tong University	China	20 (1.5)	7	131	6.55
Chinese Academy of Sciences	China	19 (1.4)	8	381	20.05

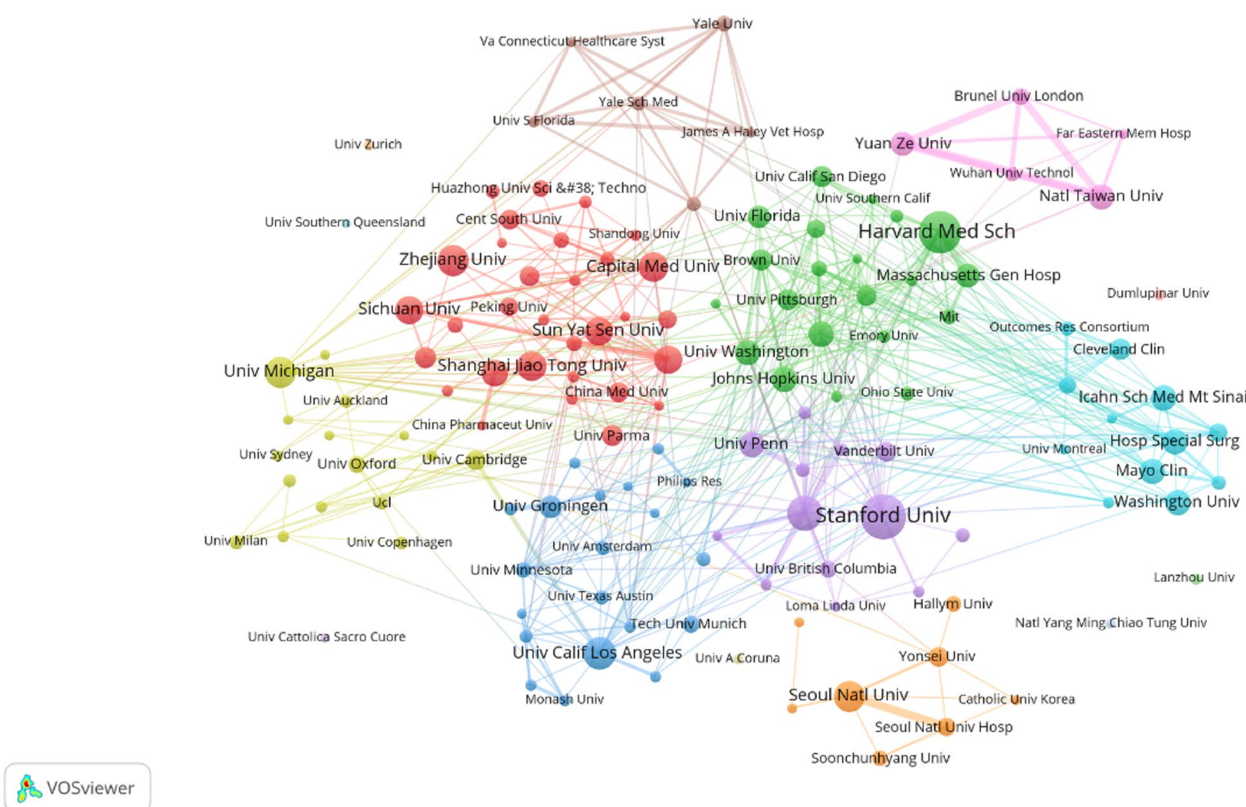

Fig. 4 Analysis of institutional co-authorship

Academy of Sciences (38), National Taiwan University (36), Yuan Ze University (35), and University of California San Francisco (34) (Fig. 4).

Analysis of authors

Table 3 lists the top 10 most prolific authors. These authors have published 99 papers, accounting for 7.3% of the total. The most published author is Lee, Hyung-Chul from University College London with 14 papers, followed by Abbod, Maysam F (n= 12), Fan, Shou-Zen (n= 12), and Shieh, Jiann-Shing (n= 12). Among these 10 authors, Shieh, Jiann-Shing has the highest H-index (10) and the highest average citations per paper (n= 56.49). Additionally, the majority of the top 10 authors are from China. The authors'collaboration network indicates several potential collaborative teams. Nevertheless,

Table 3 Top 10 most prolific authors

Author	Country	Institution	Number of publications (%)	H-index	Number of citations	Mean Citations/ Publication
Lee, Hyung-Chul	England	University College London	14 (1.0)	8	510	36.43
Abbod, Maysam F	England	Brunel University	12 (0.9)	9	284	23.67
Fan, Shou-Zen	China	National Taiwan University	12 (0.9)	9	284	23.67
Shieh, Jiann-Shing	China	Yuan Ze University	12 (0.9)	10	284	23.67
Bellini, Valentina	Italy	University of Parma	9 (0.7)	5	58	6.44
Jung, Chul-Woo	South Korea	Seoul National University College of Medicine	9 (0.7)	5	363	40.33
Lu, Yining	China	Hebei Medical University	9 (0.7)	4	80	8.89
Liu, Quan	China	Wuhan University of Technology	8 (0.6)	6	159	19.88
Bignami, Elena	Italy	University of Parma	7 (0.5)	4	71	10.14
Cannesson, Maxime	USA	University of California Los Angeles	7 (0.5)	4	117	16.71

the network is relatively dispersed, suggesting that cross-border collaboration needs to be strengthened. A visualization was created for 42 authors with at least 5 publications. The top 3 authors in terms of TLS are Abbod, Maysam F (31), Fan, Shou-Zen (31), and Shieh, Jiann-Shing (31) (Fig. 5).

Analysis of journals

Table 4 lists the top 10 journals that have published the most articles on AI research in anesthesia. *Scientific Reports* has published the highest number of articles (n = 35), followed by *PLOS ONE* (n = 33) and Anesthesia & Analgesia (n = 29). The *British Journal of Anaesthesia* has the most citations (n = 773), followed by *PLOS ONE* (n = 498) and *Scientific Reports* (n = 396). According to the 2023 Journal Citation Reports, the *British Journal of Anaesthesia* has the highest impact factor (9.1), followed by *Anesthesia & Analgesia* (4.6) and *Scientific Reports* (3.8) (Table 4). We selected 347 journals that were cited at least 30 times. The top 3 journals by TLS are: *Anesthesiology* (65,044), *Anesthesia & Analgesia* (58,658), and *British Journal of Anaesthesia* (42,756) (Fig. 6).

Analyses on cited references

Among the 51,257 references retrieved, the minimum number of references was set to 10, and 176 references

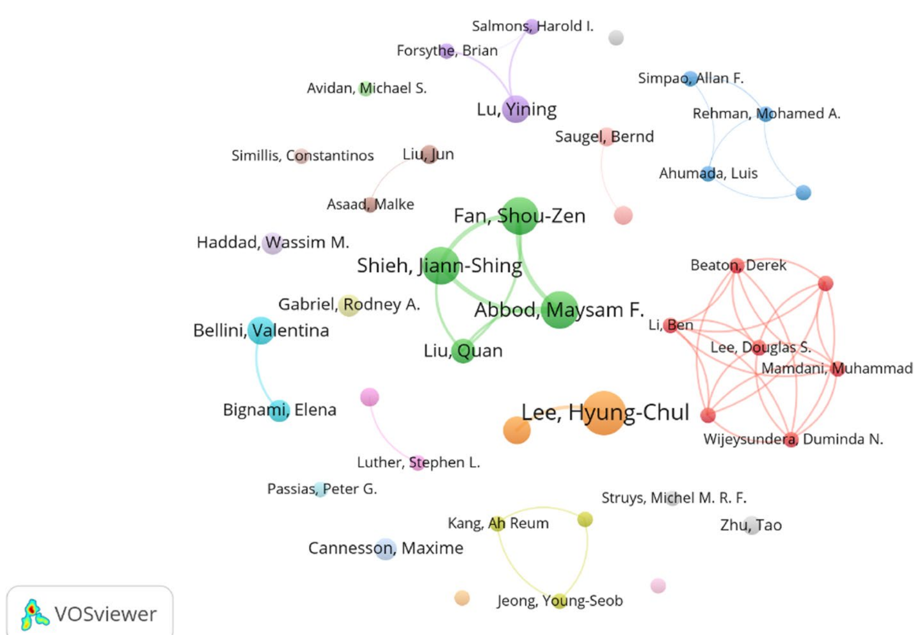

Fig. 5 Analysis of authors'co-authorship

Table 4 Top 10 most prolific journals

Journal	Number of publications (%)	H-index	Number of citations	Mean Citations/ Publication	IF (2023)
Scientific Reports	35 (2.6)	10	396	11.31	3.8
PLOS ONE	33 (2.4)	11	498	15.09	2.9
Anesthesia & Analgesia	29 (2.1)	13	390	13.45	4.6
British Journal of Anaesthesia	27 (2.0)	15	773	28.63	9.1
Journal of Clinical Medicine	25 (1.8)	7	315	12.60	3.0
Journal of Clinical Monitoring and Computing	24 (1.8)	9	280	11.67	2.0
BMC Anesthesiology	22 (1.6)	6	98	4.45	2.3
Sensors	18 (1.3)	7	144	8.00	3.4
Current Opinion in Anesthesiology	15 (1.1)	8	136	9.07	2.3
Frontiers in Medicine	15 (1.1)	5	59	3.93	3.1

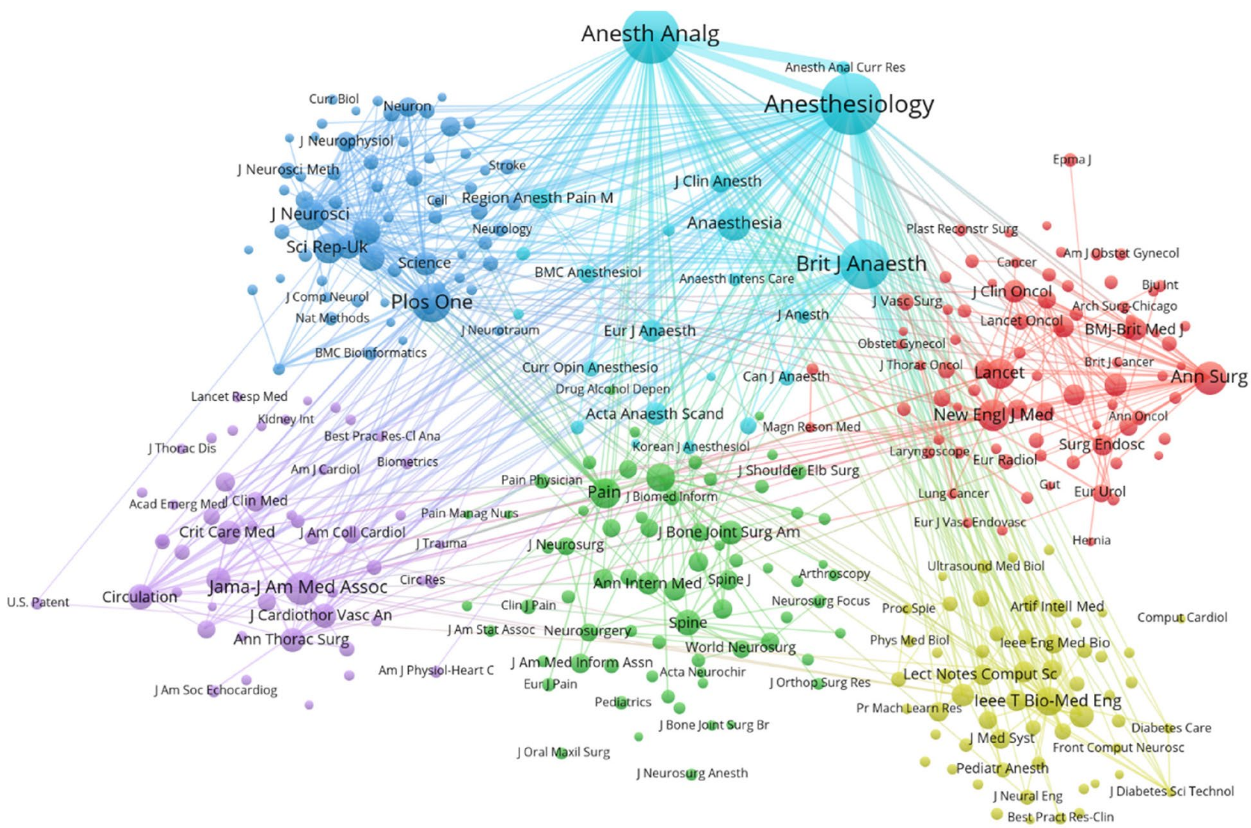

Fig. 6 Journal co-citation analysis

were selected for co-citation analysis (Fig. 7). The lines between nodes indicate that the two items were cited together in publications, with shorter and thicker lines indicating a closer relationship between the two items. The size of the nodes represents the total number of citations for the item. Additionally, nodes of different colors divide the articles into distinct clusters. *Cluster I* (red), consisting of 66 references, focuses on the prediction of perioperative complications and mortality using AI; *ClusterII* (green), with 43 references, centers on research related to monitoring the depth of anesthesia (DOA); *Cluster III* (blue), containing 27 references, emphasizes studies on images and neural networks in anesthesia; *Cluster IV* (yellow), with 22 references, is concerned with perioperative hypotension; and *ClusterV* (purple), including 18 references, focuses

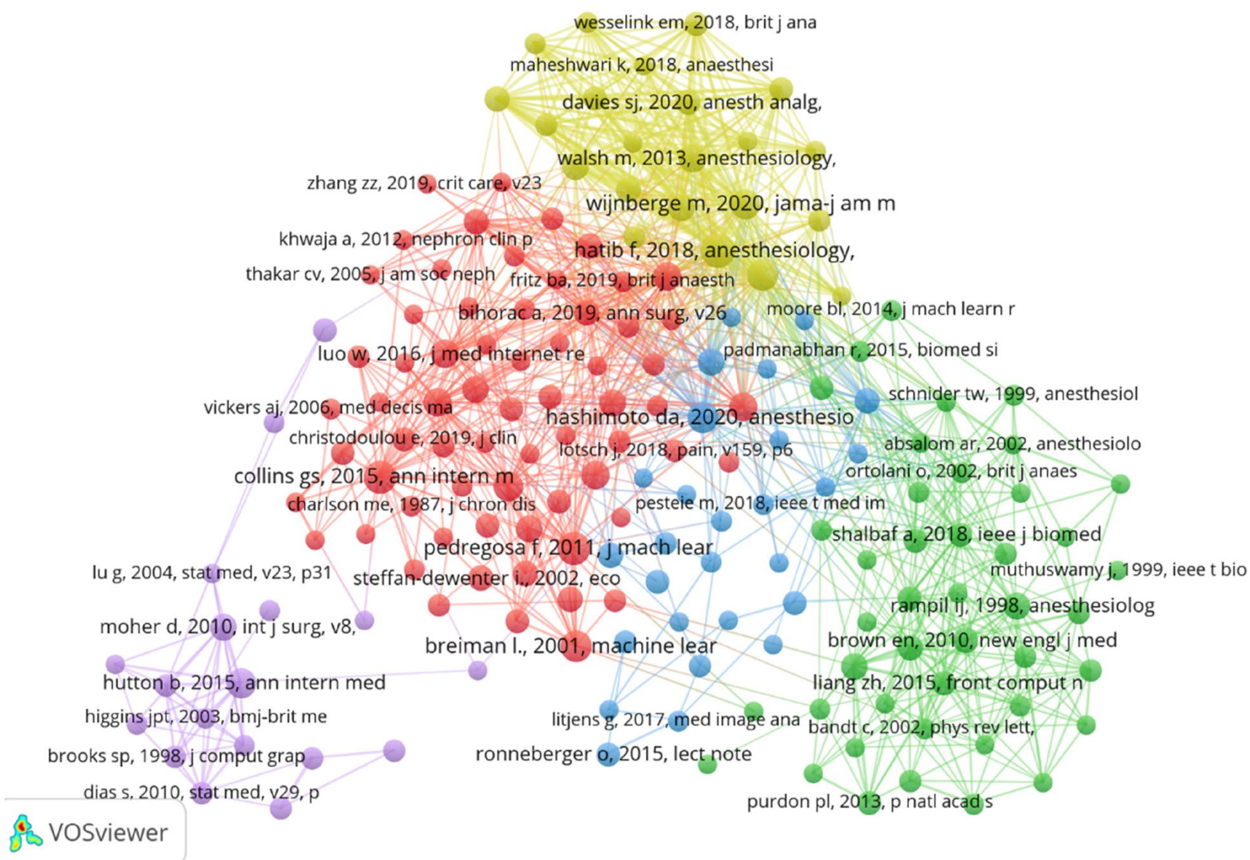

Fig. 7 Analysis of co- citation references

on perioperative pain management and systematic reviews.

Keyword analysis

Table 5 lists the 20 most frequently occurring keywords in AI research literature in the field of anesthesia. The top 5 co-occurring keywords are machine learning (n= 350), anesthesia (n= 207), risk prediction (n= 194), artificial intelligence (n= 192), and surgery (n= 158). Co-occurrence analysis was used to explore recent research hotspots. Among the 5,999 keywords in the 1,355 included studies, a minimum co-occurrence threshold of 5 was set, and 245 keywords were selected for the co-occurrence analysis (Fig. 8). Figure 8A shows that the 245 keywords are divided into 5 clusters. *Cluster I* (red) primarily focuses on topics related to anesthetic drugs and DOA monitoring and regulation; *ClusterII* (green) centers on perioperative risk assessment and prediction; *Cluster III* (blue) involves pain management and postoperative complications; *Cluster IV* (yellow) highlights AI applications in surgery; and *ClusterV* (purple) pertains to AI applications in image classification and recognition. Figure 8B visualizes the keywords by average publication year

Table 5 Top 20 keywords

Keyword	Number of occurrences	APY
Machine learning	350	2021.5
Anesthesia	207	2018.8
Risk prediction	194	2021.2
Artificial intelligence	192	2021.8
Surgery	158	2020.4
Mortality	117	2020.8
Outcomes	109	2021.9
Prediction	106	2021
EEG	101	2017.3
Models	86	2020.6
Classifications	81	2019
Complications	79	2020.8
Propofol	75	2017.7
General anesthesia	66	2019.1
Neural networks	64	2014.1
Deep learning	62	2021.7
Bispectral index	61	2016.8
Association	61	2021.3
Mate-analysis	61	2021.3
Pain	60	2020

(APY) using VOSviewer. The recent keywords identified in the overlapping visualization include"musculoskeletal pain"(APY: 2022.8),"precision medicine"(APY: 2022.6), "stratification"(APY: 2022.6),"images"(APY: 2022.5),"mean arterial pressure"(APY: 2022.4),"enhanced recovery after surgery"(APY: 2022.3),"frailty"(APY: 2022.2),"telehealth" (APY: 2022.2),"postoperative delirium"(APY: 2022.1), and"postoperative mortality"(APY: 2022). Figure 8C shows the density, visualization, and hotspots of co-occurring keywords. High-frequency keywords such as machine learning, anesthesia, artificial intelligence, risk prediction, mortality, electroencephalography, classification, and pain remain prevalent.

Discussion

Global trends

In this study, bibliometric methods were used to conduct a statistical analysis of 1,355 articles from the WoSCC database, and VOSviewer software was utilized for visualization. The analysis aimed to explore the research hotspots and development trends of AI in the field of anesthesia. Curve fitting revealed a rapid growth in the number of publications in this field over the past two decades, with a marked increase observed after 2019, reaching 326 articles by 2023. This trend indicates that AI in anesthesia is a hot research topic. The increase in publications may be attributed to the widespread application of AI in anesthesia, particularly in precision medicine and rapid postoperative recovery. The growing demands on anesthesiologists highlight the importance of comprehensive and in-depth research on AI in anesthesia, suggesting that such research will continue to expand.

Countries

The H-index and total citation count are fundamental indicators for measuring the academic impact and quality of publications (Bastian et al. 2017). According to the network visualization map, the top 10 countries with the most publications include 5 European countries (England, Italy, Germany, the Netherlands, and France), two Asian countries (China and South Korea), two North American countries (the USA and Canada), and one Oceanian country (Australia). The USA leads the field with the highest number of citations ($n = 8764$) and the highest H-index (44). Although China ranks second in total citations, its average annual citation count is significantly lower than that of other countries. Italy, while accounting for only 5.9% of the total publications, boasts the highest average annual citation count and an outstanding H-index of 20. Based on the publication trends of each country (Fig. 2B) and the overlay visualization of co-authorship analysis (Fig. 3B), China shows the fastest growth in the number of publications and has strengthened its academic collaborations with other countries. However, its relatively low average citation count per publication ($n = 6.98$) indicates that there is room for improvement in the quality of its research.

Institutions and authors

Stanford University, Harvard Medical School, and the University of Toronto are the three most prolific institutions in AI-related publications in anesthesia. Among the top ten institutions, 4 are from the USA and 4 from China. Based on co-authorship analysis, we observe that institutions from the USA are at the center of the collaboration network. Institutions in North America and Europe exhibit close cooperation; however, most institutions in Asian countries have predominantly internal collaborations (Fig. 4).

Lee, Hyung-Chul, Abbod, Maysam F, and Shieh, Jiann-Shing are the most prolific researchers in AI research in the field of anesthesia. 4 of the top 10 most prolific authors are from China. According to co-authorship analysis, authors from the same country often collaborate closely, but connections between authors from different countries remain low (Fig. 5). Therefore, it is recommended that scholars worldwide overcome academic barriers and strengthen collaboration to advance AI research in anesthesia.

Journals

Journals and co-citation analysis provide researchers with critical insights to guide them in selecting appropriate journals for publication. The co-citation network reveals that *Anesthesiology* (IF =9.1, 2023) holds the highest recognition and authority in AI research in the field of anesthesia. Following closely are *Anesthesia & Analgesia* (IF =4.6, 2023) and the *British Journal of*

(See figure on next page.)

Fig. 8 Analysis of keyword co-occurrence. **A** 245 keywords were divided into 5 clusters by different colors (cluster I: red, cluster II: green, cluster III: blue, cluster IV: yellow, cluster V: purple) with the minimum co-occurrence times of 5. The size of the node represents the co-occurrence frequency and the closeness of the co-occurrence relationship with other keywords. **B** Visual network map of keywords according to the APY. The more yellow the node is, the later the keyword occurrences. **C** Density visualization map for 245 keywords. Each keyword in the density map shows the frequency of its occurrence in related research fields. Red represents the high-frequency keyword, and the position of the keyword is related to the degree of correlation between it and other keywords. The position in the center indicates the stronger correlation with the others

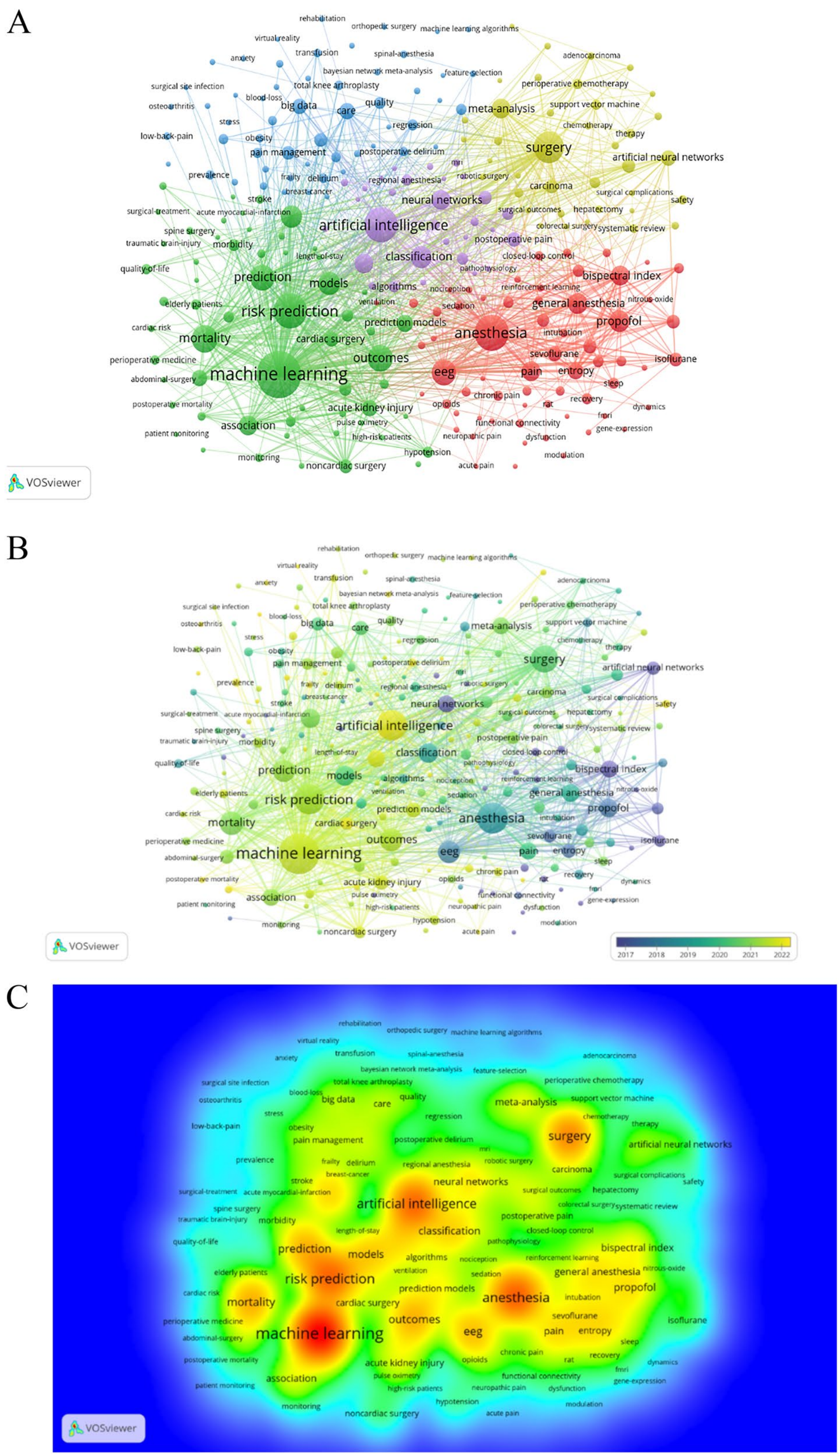

Fig. 8 (See legend on previous page.)

Anaesthesia (IF =9.1, 2023), both of which rank among the top three in terms of the number of papers published and have notably high TLS in the co-citation visualization network. The top 10 most prolific journals account for 17.9% of the total publications, with only the *British Journal of Anaesthesia* having an impact factor exceeding 5. These findings suggest that most research in this domain still requires greater recognition by high-impact medical journals.

Current knowledge and hot topics

DOA monitoring and regulation

Numerous studies have found that electroencephalogram (EEG) signals can reflect the effects of drugs on the central nervous system of patients, thereby indicating the patient's state of consciousness. EEG has thus become a mainstream method for monitoring the DOA, with the bispectral index (BIS) being the most widely used. However, BIS has limitations such as lag and susceptibility to interference from electrocautery, which can affect its monitoring efficacy. Researchers have used machine learning techniques to analyze EEG data to more accurately assess DOA and improve real-time monitoring and accuracy. Nguyen-Ky T et al. (2011) proposed a method for constructing a wavelet-based DOA index, using adaptive thresholds to denoise low-frequency and spike noise. Gu Y et al. (2019) combined various EEG features, including frequency domain and entropy features, with neural networks to estimate DOA. Their experimental results showed that this method could effectively distinguish between awake and other anesthesia states. Afshar S et al. (2021) introduced a new hybrid deep learning structure, which includes convolutional neural networks (inspired by the inception module), bidirectional long short-term memory, and an attention layer. This model continuously predicts BIS using EEG signals. Madanu R et al. (2021) combined ensemble empirical mode decomposition with power spectral analysis and a convolutional neural network classifier to predict DOA. This method offers the potential for safer surgical procedures by establishing simpler devices for DOA prediction.

Closed-loop target-controlled delivery system

Closed-loop control of anesthesia delivery can be defined as set-point tracking, where the controller adjusts one or more inputs (manipulated variables) of the system based on feedback from one or more outputs (controlled variables) of the system (Ghita et al. 2020). In 1950, Mayo CW et al. (1950) used cortical activity to automatically titrate ether delivery during abdominal surgery. Since then, various signals have been used to guide the automatic titration of different anesthetic agents in various surgical settings (Mayo et al. 1950). In recent years, the rapid development of machine learning and AI has led to the creation of new anesthesia prediction models. Padmanabhan R et al. (2015) applied reinforcement learning to develop a closed-loop anesthesia controller. Lee HC et al. (Lee et al. 2018) demonstrated that deep learning models outperform traditional models in predicting BIS during target-controlled infusion of drugs in surgical patients. With the advancement of AI, automated feedback control is expected to mitigate the impact of variability among individual patients, optimize anesthesiologists'workload, increase the time spent in more optimal clinical states, and ultimately enhance the safety and quality of anesthesia care (LE Guen et al 2016).

Constructing prediction models

Based on machine learning methods and incorporating multimodal patient data, predictive models for critical adverse events such as hypotension, hypoxemia, postoperative acute kidney injury, and postoperative mortality can be developed. Hatib F et al. (2018) demonstrated that machine learning algorithms trained on high-fidelity arterial pressure waveform datasets can predict arterial hypotension events in surgical patients'physiological data. Lundberg SM et al. (2018) developed a machine learning model that more accurately predicts impending hypoxemia than anesthesiologists and identifies the causes of hypoxemia. Tseng P et al. (2020) utilized machine learning to predict acute kidney injury after cardiac surgery, aiding in postoperative risk assessment. Fritz BA et al. (2019) proposed a novel deep learning algorithm that incorporates preoperative and intraoperative dynamic data to predict 30-day mortality. Additionally, researchers have used AI to predict postoperative cognitive dysfunction (Xie et al. 2023), postoperative nausea and vomiting (Shim et al. 2022), intraoperative hypothermia (Dibiasi et al. 2023), perioperative blood transfusion requirements (Stehrer et al. 2019), and postoperative infections (Chen et al. 2023b). The efficient computational power of AI to process complex data allows for the early prediction of adverse events and timely intervention, ensuring perioperative safety for patients.

Image classification and recognition

Due to its low cost, portability, and real-time imaging capabilities, ultrasound has garnered significant attention from anesthesiologists. Ultrasound-guided nerve blocks, vascular access, and epidural analgesia are now widely used in clinical practice (Bowness et al. 2021; Pesteie et al. 2018; Tian et al. 2022; Viderman et al. 2022). AI-guided solutions can enhance the optimization and interpretation of ultrasound images, as well as visualize needle advancement and local anesthetic injection (Viderman et al. 2022). This assistive technology can be used to facilitate target recognition (e.g., peripheral nerves and fascial planes) and to identify optimal block sites by displaying relevant landmarks and guiding structures (e.g., bones and muscles) (Bowness et al. 2021). Additionally, AI can rapidly assess cardiac function (Chen et al. 2021), identify and classify difficult airways (Hayasaka et al. 2021; Tavolara et al. 2021), and recognize and classify pain (Bargshady et al. 2020). AI in medical image analysis is currently a hot research topic. AI technologies can successfully interpret anatomical structures in real-time ultrasound imaging and assist young anesthesiologists in practicing ultrasound-guided nerve blocks and puncture techniques.

Pain management

Postoperative pain is challenging to predict due to the multitude of influencing factors. Patient-related factors (such as age, gender, genetic characteristics, comorbid medical and psychological conditions) and surgical factors (such as surgeon, surgery type, surgical site, and anesthetic techniques) can all lead to severe acute or chronic postoperative pain (Rashidi et al. 2019). In acute pain research, big data is utilized to evaluate postoperative pain outcomes, opioid use, and the effectiveness of multimodal pain management strategies (Muller-Wirtz and Volk 2021). Shi G et al. (2023) developed a machine learning model to predict moderate to severe acute postoperative pain in orthopedic patients under general anesthesia by identifying risk factors. Nair AA et al. (2020) demonstrated that machine learning models could predict postoperative opioid needs in outpatient surgery patients, potentially improving the management of their acute postoperative pain. Another common application of AI in pain medicine is predicting the progression of chronic pain (Abd-Elsayed et al. 2024). Sun C et al. (2023) utilized machine learning methods to establish a predictive model for chronic postoperative pain in breast cancer patients, aiding in identifying high-risk individuals and improving postoperative management. Zhao Y et al. (2020) evaluated a deep learning framework for chronic pain assessment, using a large number of sensors on patients to evaluate chronic pain. The application of machine learning in telemedicine pain management enables physicians to make effective, real-time, data-driven decisions (Cascella et al. 2022).

Limitations

Through bibliometric analysis and literature visualization, this study provides insights into the development trends and research hotspots in the field, serving as a reference for researchers and clinicians in related fields. However, there are some limitations to this study. First, the bibliometric analysis is based on data retrieved from the WoSCC database, which only includes English publications. These factors result in selection bias by overlooking other databases, such as PubMed and Scopus, and potentially excluding important publications published in other languages. Therefore, future research should address this limitation by expanding the range of literature databases and language restrictions included in the search. Second, several biases may affect the results, such as publication bias. In addition, in the early years, AI manuscripts were often more easily accepted and published if the topic was novel. Lastly, the evaluation of an article's impact relies solely on citation counts. In reality, a more comprehensive evaluation should incorporate time factors due to differences in publication years. The earlier an article is published, the more citations it may receive. And more recent publications tend to be cited less frequently, so their impact may be underestimated.

Conclusions

This study provides a comprehensive summary and visual mapping of AI research in the field of anesthesia over the past two decades, illustrating the current status, hotspots, and development trends. Increasing attention has been drawn to studies on DOA and drug infusion (e.g., electroencephalogram, deep learning), perioperative risk assessment and prediction (e.g., mean arterial pressure, frailty, postoperative delirium, and mortality), image classification and recognition (e.g., ultrasound-guided nerve blocks, vascular access, and difficult airway assessment), and perioperative pain management (e.g., musculoskeletal pain). Additionally, topics such as precision medicine, enhanced recovery after surgery, and telehealth are emerging as new research hotspots and future directions in the field.

Abbreviations

TLS	Total link strength
AI	Artificial intelligence
USA	The United States
DOA	Depth of anesthesia
EEG	Electroencephalogram
WoSCC	Web of Science Core Collection
APY	Average Publication Year

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Not applicable.

Authors' contributions

Yi Ou: Methodology, Validation, Investigation, Writing—Original Draft, Visualization. Xiaoyi Hu: Conceptualization, Methodology, Validation, Investigation, Writing—Original Draft, Visualization. Cong Luo: Writing—Review & Editing. Yajun Li: Writing—Review & Editing, Supervision.

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Data availability
No datasets were generated or analysed during the current study.

Declarations

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The authors declare no competing interests.

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