# Artificial Intelligence in Anesthesiology over the Past Decade: A Comprehensive Bibliometric Study

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**Abstract**

**Background**: With artificial intelligence (AI) transforming healthcare, its application in anesthesiology has seen substantial growth aimed at improving patient care and clinical decision-making. A bibliometric analysis was needed to assess the state of AI research within anesthesiology, recognizing influential trends, contributors, and future research directions.

**Methods**: A comprehensive literature search of the Scopus database was conducted to collate relevant AI in anesthesiology publications from 2013 to 2023. Using bibliometrix and Latent Dirichlet Allocation in R and Python, we analyzed annual publication trends, institutional and regional activity, author contributions, journal dissemination, keyword frequencies, topics, and citation impact.

**Results**: Our decade-long survey uncovered a thirteen-fold increase in publications, with significant growth in the last three years, emphasizing a heightened focus on AI in anesthesiology. The United States and China were pivotal, contributing the most to the field's academic output. Leading institutions like Harvard University fostered extensive collaborative networks. High-impact research focused on preoperative to postoperative AI applications, with pain management, anesthesia monitoring, and predictive modeling identified as key areas through keyword and topic analyses. Citation analysis highlighted seminal works influencing the field.

**Conclusion**: The rapid expansion of AI research in anesthesiology is evident, with increasing contributions from key global regions and a focus on collaborative efforts. With a shift toward AI integration, future directions include enhancing patient safety, decision-making, and resource optimization in anesthesiology practices. Challenges remain in data quality, interpretability, and ethical considerations. This bibliometric overview serves as a foundation for clinicians and researchers to advance AI applications and improve patient care in anesthesiology.

Keywords: Artificial Intelligence, Anesthesiology, Bibliometric Analysis, Publication Trends, Collaboration Networks

**Introduction**

In recent years, artificial intelligence (AI) has emerged as a transformative force across various domains, including healthcare1. The field of anesthesiology has witnessed a surge in AI applications aimed at enhancing patient care, optimizing clinical decision-making, and improving overall outcomes 2,3. As the volume of research on AI in anesthesiology continues to grow, it is crucial to assess the current landscape and identify trends, key contributors, and potential areas for future exploration.

Bibliometric analysis has proven to be a valuable tool for evaluating the impact and progress of research within a specific field4,5. By examining various metrics such as publication count, citation analysis, and collaboration patterns, researchers can gain insights into the development and dissemination of knowledge6. Previous bibliometric studies have investigated the application of AI in various medical specialties, such as radiology7, ophthalmology8, and oncology9. However, to date, no comprehensive bibliometric analysis has been conducted to assess the state of AI research in anesthesiology.

This study aims to bridge this gap by providing a comprehensive bibliometric overview of AI research in anesthesiology over the past decade. By analyzing publication trends, identifying key research themes, and evaluating the contributions of leading authors, institutions, and countries, we seek to present a holistic view of the current landscape and highlight potential future directions for AI applications in anesthesiology.

The findings of this study will be of interest to anesthesiologists, researchers, and policymakers seeking to understand the impact of AI on the field and identify opportunities for further research and collaboration. Moreover, by providing a systematic assessment of the current state of AI in anesthesiology, this study will serve as a valuable resource for those looking to harness the potential of AI to improve patient care and advance the practice of anesthesiology in the coming years10,11.

**Methods**

***Literature Search and Selection***

A comprehensive literature search was conducted in the Scopus database using the following query: (TITLE-ABS-KEY("Artificial Intelligence") OR TITLE-ABS-KEY("Machine Learning") OR TITLE-ABS-KEY("Deep Learning") OR TITLE-ABS-KEY("AI")) AND (TITLE-ABS-KEY("Anesthesiology") OR TITLE-ABS-KEY("Anesthesia") OR TITLE-ABS-KEY("Pain Management") OR TITLE-ABS-KEY("Perioperative Care") OR TITLE-ABS-KEY("Sedation") OR TITLE-ABS-KEY("Anesthetic Monitoring")) AND (PUBYEAR > 2012 AND PUBYEAR < 2024). The search results were limited to articles and reviews, yielding a total of 1,248 publications. (Figure 1)

***Bibliometric Analysis***

Bibliometric analysis was performed using the bibliometrix package (4.1.4) in R (4.2.2) 12 to examine the following aspects of the selected literature: a. Annual publication trends b. Most active research institutions and regions c. Most active researchers d. Publication and journal analysis e. Keyword and topic analysis f. Citation analysis

***Topic Modeling***

Latent Dirichlet Allocation (LDA), a topic modeling technique, was applied using scikit-learn (1.0.2) in Python (3.8.16) 13 to discover the main research themes within the selected literature. The LDA model was used to identify and categorize the publications into eight primary research topics.

***Algorithm Application Analysis***

The frequency of various artificial intelligence and machine learning algorithms mentioned in the included publications was analyzed and quantified.

***Data Visualization***

Data visualization techniques were employed to present the findings of the bibliometric analysis, topic modeling, and algorithm application analysis. Graphs, charts, and tables were created by R (4.2.2) to facilitate the understanding and interpretation of the results.

This comprehensive approach, combining literature search and selection, bibliometric analysis, topic modeling, algorithm application analysis, and data visualization, allowed for a thorough examination of the current state and trends of artificial intelligence research in the fields of anesthesiology, pain management, and related areas.

**Results**

***Annual Publication Trends***

The analysis of the annual publication trends revealed a steady increase in the number of research articles published in this field over recent years (Figure 2). The number of publications grew from 26 in 2013 to over 350 in 2023, representing a 13-fold increase within a decade. This upward trend, with an average annual growth rate of around 30%, indicates a rapidly growing research interest in the application of artificial intelligence in anesthesiology. The steepest increase in publication volume occurred between 2019 and 2021, suggesting a surge in research activity during this period14 .

The evolution of citation impact in AI anesthesiology research reveals significant fluctuations that correspond with key developments in the field. Initially, modest citation counts reflect the nascency of AI applications within anesthesiology. However, a discernible escalation occurs, reaching a peak around 2017. This peak potentially denotes a watershed moment where certain studies or advancements resonated deeply within the academic milieu, prompting a concentrated burst of scholarly dialogue15. Post-peak, a retraction in average citation counts is noted, aligning with the broadening of the research base and the typical dilution effect seen as fields mature. The decline observed post-2017, while indicative of a distribution in scholarly focus, should not detract from the ongoing research vigor but rather be viewed in light of the diversifying interests and the integration of emerging AI research. (Figure 3)

Mirroring this trend, individual articles saw their citation zenith in the same timeframe, emphasizing the period's significance in delivering impactful research. This alignment of total and average citations underscores a congruence in the field's research milestones. (Figure 4)

***Most Active Research Institutions and Regions***

The most active research institutions in this field are primarily located in the United States and China (Figure 5). Harvard University leads the list with over 1200 publications, followed by the University of California, with around 70 publications. Other notable institutions include the University of Washington, Stanford University, each contributing more than 50 publications. These institutions have established collaborative networks to advance research in this area (Figure 6), fostering knowledge exchange and accelerating scientific progress16. Geographically, the United States is the most active country in this research field, with over 300 publications, followed by China (approximately 215 publications), Germany (around 60 publications), and Korea (over 50 publications) (Figure 7). This geographic distribution highlights the global nature of research efforts in this field, with major contributions from North America, Europe, and Asia17.

As observed in the preceding analysis, the United States and China lead in the number of published papers, reflecting their dominant positions in the field. In the collaboration network, these two countries are represented by the largest nodes and the most extensive connections, signifying that they are the most active participants in international collaborations. (Figure 8) This indicates not only a high level of domestic research activity but also their centrality in the global exchange of knowledge and expertise.

***Most Active Researchers***

Several researchers have made significant contributions to this field, with Wang Y, Zhang J, and Li Y being among the most active (Figure 9). Wang Y have authored 20 publications, while Zhang J, Li Y, Liu J has contributed to more than 15 articles. Other prominent researchers include Chen X, Chen Y, Wang X, Lee H.C., Lu Y, and Zhang X, each with 10 or more publications. The consistent research output from these individuals demonstrates their expertise and dedication to advancing the field of AI in anesthesiology18.

The data reveals a trend where prolific authors have predominantly published the majority of their work in the most recent three-year period (2021-2023), with a noticeable increase in publication numbers over time (Figure 10).

***Publication and Journal Analysis***

The primary journals publishing research in this field include Anesthesia and Analgesia, Journal of Clinical Monitoring and Computing, PLOS ONE, and Scientific Reports, each with 23 or more publications (Table 1). Other important journals include BMC Anesthesiology, Journal of Clinical Medicine, British Journal of Anaesthesia, and Anesthesiology, collectively accounting for over 80 publications. These journals are known for their impact and academic standing in their respective fields, ensuring the dissemination of high-quality research findings to the scientific community. (Figure 11)

***Keyword and Topic Analysis***

Keyword co-occurrence analysis revealed research hotspots in the field, such as machine learning, deep learning, and neural networks, and their applications in anesthesiology (Figure 12). The prominence of these keywords underscores the central role of AI techniques in driving research advancements. The word cloud visualization offers a striking representation of the frequency with which certain keywords appear in the literature. (Figure 13)

Topic modeling analysis further identified eight main research topics (Figure 14), providing a comprehensive overview of the key areas of investigation:

Topic 0: AI clinical applications (242 documents)

Topic 1: Patient risk assessment and surgery (87 documents)

Topic 2: Anesthesiology, deep learning, and neural networks (196 documents)

Topic 3: Ultrasound and imaging techniques (104 documents)

Topic 4: Research groups, sedation, and control groups (144 documents)

Topic 5: Pain management and patient care (176 documents)

Topic 6: Postoperative care, hypotension, and intraoperative monitoring (102 documents)

Topic 7: Model learning, machine learning, and predictive models (197 documents)

The diverse range of topics highlights the multifaceted nature of AI applications in anesthesiology, spanning from preoperative risk assessment to intraoperative monitoring and postoperative care. The substantial number of documents associated with each topic indicates the depth and breadth of research efforts in these areas.

Our analysis highlights the prominence of deep learning techniques in the field, as evidenced by their frequent occurrence in the literature. Deep learning algorithms, such as Convolutional Neural Networks (CNNs) and Recurrent Neural Networks (RNNs), have gained significant popularity in recent years. These powerful models are particularly well-suited for handling complex, high-dimensional data and have been extensively applied in various domains, including image classification, natural language processing, and speech recognition.

In addition to deep learning, our findings also underscore the enduring relevance of classic machine learning algorithms. Logistic Regression, a fundamental technique for binary classification tasks, remains widely used due to its simplicity and interpretability. Random Forest, an ensemble learning method that combines multiple decision trees, is another prevalent algorithm. Its ability to handle high-dimensional data and capture complex interactions among features makes it a popular choice for researchers. Furthermore, Support Vector Machines (SVMs) maintain their position as a go-to algorithm for classification tasks, especially when dealing with smaller datasets or when the focus is on achieving high accuracy with limited computational resources.Notably, the study also reveals the frequent application of unsupervised learning methods, such as K-means clustering and Principal Component Analysis (PCA). These techniques play a crucial role in exploratory data analysis, enabling researchers to uncover hidden patterns, identify underlying structures, and reduce the dimensionality of their datasets. (Figure 15)

***Citation Analysis***

Citation analysis identified the most highly cited articles in the field (Table 2), with the top-cited article by Lundberg et al. (2018) published in Nature Biomedical Engineering accumulating an impressive 940 citations19 . This article, focusing on explainable AI for healthcare, has an annual citation rate of 134.29 and a normalized citation score of 24.59, underlining its significant impact on the field. Other highly cited articles include Wijnberge et al. (2020) in JAMA (238 citations)20 , Hashimoto et al. (2020) in Anesthesiology (209 citations)16, and Kendale et al. (2018) in Anesthesiology (148 citations)21. These articles, addressing topics such as hypotension prediction, intraoperative adverse event prediction, and machine learning for anesthesia depth monitoring, respectively, have shaped the research landscape and inspired further investigations.

The citation network analysis revealed the academic impact and knowledge flow within the research community, highlighting the interconnectedness of research efforts and the building of scientific knowledge over time22 (Figure 16).

In summary, the results demonstrate the rapid development of this research field in recent years, with a 13-fold increase in publication volume over the past decade and an average annual growth rate of 30%. Artificial intelligence techniques are being extensively explored and applied in various aspects of anesthesiology, ranging from preoperative risk assessment to intraoperative monitoring and postoperative care. Research institutions and scholars from the United States, China, and other countries are at the forefront of this field, with Harvard University, the University of California, and other leading institutions driving research progress through collaborative networks. The field's most highly cited articles, published in prestigious journals, have significantly influenced the research direction and sparked further investigations. Future research may focus on further advancements in AI applications for anesthesia risk assessment, intraoperative monitoring, and postoperative management, building upon the solid foundation established by the current body of work. As the field continues to evolve, it is expected that AI will play an increasingly pivotal role in enhancing anesthesia practice, ultimately improving patient outcomes and care quality.

**Discussion**

Artificial intelligence (AI) has been transforming various fields of medicine, and anesthesiology is no exception. This study aimed to investigate the trends and developments of AI applications in anesthesiology over the past decade using bibliometric analysis. The findings provide valuable insights into the current state and future directions of AI research in this domain.

One of the key strengths of this study lies in its comprehensive approach to examining AI-related publications in anesthesiology. By utilizing bibliometric methods, we were able to quantitatively analyze a large volume of research outputs and identify significant patterns and trends. This approach allowed us to objectively assess the growth of AI research in anesthesiology, the most active countries and institutions, and the prominent research themes12 .

Our findings revealed a substantial increase in the number of AI-related publications in anesthesiology over the past decade, with a particularly rapid growth observed in recent years. This trend highlights the growing interest and recognition of AI's potential in enhancing anesthesia practice and patient care16. The United States and China emerged as the leading contributors to AI research in anesthesiology, which is consistent with their overall dominance in AI research across various domains23.

The identification of the most frequently occurring keywords provided valuable insights into the main research themes and applications of AI in anesthesiology. Pain management, depth of anesthesia monitoring, and predictive modeling for complications were among the prominent topics. These findings suggest that AI techniques, such as machine learning and deep learning, are being increasingly explored to improve pain assessment, optimize anesthesia dosing, and predict patient outcomes14,24,25.

Furthermore, our analysis revealed the most prolific authors, institutions, and journals in AI research within anesthesiology. This information can facilitate collaborations, knowledge sharing, and targeted dissemination of research findings. It also helps researchers and clinicians identify the key players and sources of knowledge in this field26.

The study's findings have important implications for anesthesiology practice and research. The increasing adoption of AI techniques in anesthesiology has the potential to enhance patient safety, improve decision-making, and optimize resource utilization27. AI-assisted tools can aid anesthesiologists in various tasks, such as preoperative risk assessment, intraoperative monitoring, and postoperative pain management28. However, the successful integration of AI in anesthesiology practice requires addressing challenges related to data quality, interpretability, and ethical considerations17.

Despite its strengths, this study has some limitations that should be acknowledged. First, the analysis relied on a single database (Scopus), which may not have captured all relevant publications. Future studies could consider including other databases to ensure a more comprehensive coverage. Second, the bibliometric analysis focused on quantitative aspects of research outputs and did not assess the quality or impact of individual studies. Complementary approaches, such as systematic reviews and meta-analyses, could provide more in-depth evaluations of specific AI applications in anesthesiology29.

Additionally, the study did not explore the practical implementation and adoption of AI tools in clinical settings. Future research could investigate the barriers, facilitators, and outcomes of integrating AI technologies into anesthesiology practice. This could involve conducting surveys, interviews, or observational studies to gather insights from anesthesiologists and other healthcare professionals30,31.

**Conclusion**

This study provides a comprehensive overview of the trends and developments of AI research in anesthesiology over the past decade. The findings highlight the rapid growth of AI applications in this field, the leading contributors, and the main research themes. The study's strengths lie in its quantitative approach and the identification of key patterns and trends. However, limitations include the reliance on a single database and the lack of quality assessment of individual studies. Future research should focus on addressing these limitations, exploring the practical implementation of AI in anesthesiology, and assessing the impact of AI-assisted tools on patient outcomes and healthcare efficiency. As AI continues to advance, it holds great promise for revolutionizing anesthesiology practice and improving patient care.

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**Figure legends**

Figure 1. Workflow for article collection and analysis

Figure 2. Annual scientific publication output

Figure 3. Average total citations per publication per year

Figure 4. Average citations per article per year

Figure 5. Total articles published by institution

Figure 6. Institutional collaboration network

Figure 7. Article production by country

Figure 8. International collaboration network

Figure 9. Most prolific authors in the field

Figure 10. Authors' publication trends over time

Figure 11. Journal impact analysis

Figure 12. Keyword co-occurrence analysis

Figure 13. Word cloud visualization of key terms

Figure 14. Heatmap of document topics

Figure 15. Frequency of machine learning terminology

Figure 16. Co-citation network analysis

Table 1. Number of papers published per journal

Table 2. Articles with the highest citation counts

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