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Trends in Research on Artificial Intelligence in Anesthesia: A VOSviewer -Based Bibliometric Analysis

Marco Cascella[1*], Francesco Perri[2], Alessandro Ottaiano[3], Arturo Cuomo[1], Stefan Wirz[4], Sergio Coluccia[5]

[1] Division of Anesthesia and Pain Medicine, Istituto Nazionale Tumori - IRCCS - Fondazione Pascale, Napoli, Italy
[2] Medical and Experimental Head and Neck Oncology Unit, Istituto Nazionale Tumori - IRCCS Fondazione G. Pascale, Naples, Italy
[3] SSD-Innovative Therapies for Abdominal Metastases, Istituto Nazionale Tumori di Napoli, IRCCS "G. Pascale", via M. Semmola, Naples 80131, Italy.
[4] Abteilung für Anästhesie, Interdisziplinäre Intensivmedizin, Schmerzmedizin/Palliativmedizin - Zentrum für Schmerzmedizin, Weaningzentrum, Cura Krankenhaus - eine Betriebsstätte der GFO Kliniken Bonn, Schülgenstr. 15, 53604, Bad Honnef, Deutschland
[5] Epidemiology and Biostatistics Unit, Istituto Nazionale Tumori, IRCCS Fondazione G. Pascale, 80100 Naples, Italy.

*Corresponding Author: Marco Cascella: m.cascella@istitutotumori.na.it

Abstract Background: The scientific literature on Artificial Intelligence (AI) in anesthesia is rapidly growing. Considering that applications of AI strategies can offer paramount support in clinical decision processes, it is crucial to delineate the research features. Bibliometric analyses can provide an overview of research tendencies useful for supplementary investigations in a research field. Methods: The comprehensive literature about AI in anesthesia was checked in the Web of Science (WOS) core collection. Year of publication, journal metrics including impact factor and quartile, title, document type, topic, and article metric (citations) were extracted. The software tool VOSviewer (version 1.6.17) was implemented for the co-occurrence of keywords and the co-citation analyses, and for evaluating research networks (countries and institutions). Results: Altogether, 288 documents were retrieved from the WOS and 154 articles were included in the analysis. The number of articles increased from 4 articles in 2017 to 37 in 2021. Only 34 were observational investigations and 7 RCTs. The most relevant topic is “anesthesia management”. The research network for countries and institutions shows severe gaps. Conclusion: Research on AI in anesthesia is rapidly developing. Further clinical studies are needed. Although different topics are addressed, scientific collaborations must be implemented.

Keywords: Artificial Intelligence; Anesthesia; Bibliometric analysis; Machine Learning; Deep Learning; Network analysis

1 Introduction

Artificial Intelligence (AI) is a computer science discipline that through the combination of hardware and software systems allows machines to express certain properties that are generally recognized in humans. Such properties include, for example, visual and vocal recognition, space-time perceptions, and decision-making processes with problem-solving tasks. Notably, this kind of intelligence is not confined to the ability to compute or acquire abstract data but may include all those different forms of intelligence that are recognized by Gardner's theory of multiple intelligences and ranging from spatial to social, kinesthetic to introspective intelligence [1]. In these terms, AI can mimic human cognitive functions and (natural) intelligence. Machine learning (ML) and deep learning (DL) are disciplines within

AI that are used to analyze large data sets for developing classification or predictive models [2]. Briefly, ML uses data (usually thousands of data points) to train and find accurate results through selected automated algorithms. These algorithms allow supervised, unsupervised, and reinforcement learning models. DL is an evolution of ML, suitable for operating on big data (millions of data points). In DL, more levels of algorithms are implemented, and data are processed through a series of layers each containing different elements or neurons; each layer interprets data features and relations and operates a specific mathematical operation on the input. This complex network is called artificial neural network.

The application of AI methods toward clinical decision support has been demonstrated to be effective in many fields of medicine [3,4], including clinical anesthesia [5]. In particular, AI has been investigated for stratification of the risks of anesthesia and event prediction, depth of anesthesia monitoring, anesthesia management (e.g., closed-loop anesthesia), ultrasound-based procedures (nerve blocks and vascular access), pain management, operating room logistics, and other aims [6,7]. As Alexander et al. [8] highlighted, in the field of anesthesia, AI can help in decision-making but can mainly enable anesthesiologists to address clinical issues through a proactive, rather than reactive, approach.

Bibliometrics is a computable approach that analyzes the emerging tendencies and the insight architecture within a given field to obtain computable, reproducible, and objective information. This type of analysis describes extensively the knowledge of the research area [9]. Furthermore, it is particularly effective for promoting multidisciplinary collaboration [10].

On these premises, this bibliometric investigation is aimed at dissecting the available research on the argument. It could provide profitable data for designing future investigations, suggesting corrective strategies, implementing research networks, and favoring efficacious translational research processes.

2 Methods

2.1 Data Collection

The study methodology refers to the approach previously implemented for conducting other bibliometric analyses [11,12]. The comprehensive literature on AI in anesthesia was checked in the Web of Science (WOS) online database. The search terms and the string we adopted to intercept the closest matching articles included the terms “Artificial Intelligence” and “anesthesia” (both in “All Fields”). No language restrictions were established. All data were acquired on April 30, 2022. We downloaded the original data from WOS, selected the full record, and cited references. Data were exported as a Microsoft Excel (.xlsx) file [13].

2.2 Research Methods

Titles and abstracts were independently screened by two authors (A.O. and F.P.). Both independent researchers reviewed full-text versions of the articles and not pertinent papers were excluded. Crosschecking was performed, and any disagreements were resolved after discussion with the first author (M.C.). The features of the articles that met the prerequisites were extracted. Information collected included the year of publication, journal name and metrics (impact factor and quartile, Q), article title, document type, count of citations, and topics. We identified 9 topics: ultrasound-guided anesthesia and regional anesthesia, pediatric anesthesia, neuroanesthesia, cardiac anesthesia, perspectives, anesthesia management, monitoring, anesthesia research, and risk assessment and outcomes. For journal metrics, the source was Journal Citation Reports™ 2020 (Clarivate Analytics).

The literature analysis and knowledge visualization software VOSviewer (version 1.6.17, Leiden University, Leiden, The Netherlands) was adopted. This software instrument provides clusterization of closely related elements and graphical visualization of bibliometric features such as journals, countries, and institutions. The tool can be also implemented to obtain text extraction (e.g., keywords or full-text analysis) for finally structuring networks of linguistic elements mined from a set of scientific articles. Standard weight attributes including “Links” and “Total link strength” attributes are provided [14]. In this bibliometric investigation, VOSviewer was implemented to investigate the following features:

- Co-occurrence of keywords. A co-occurrence network or semantic network analyzes potential links between terms (interconnection). Normalization was obtained through the strength association method [15].
- Co-citation analysis for sources (journals). It is also indicated as bibliographic coupling and indicates the frequency with which two documents are cited together by other documents [16].

- Co-authorship analysis (by countries). It expresses the research network among countries.
- Collaborations between institutions. For analyzing links among organizations.

3 Results

3.1 Literature output

From the WOS core database, the search strategies yielded 288 documents on AI in anesthesia. Of those, 134 were excluded as not pertinent to the topic of AI (n=134) or not addressing AI in anesthesia (n=38). One hundred and fifty-four articles were included in the bibliometric analysis (Figure 1).

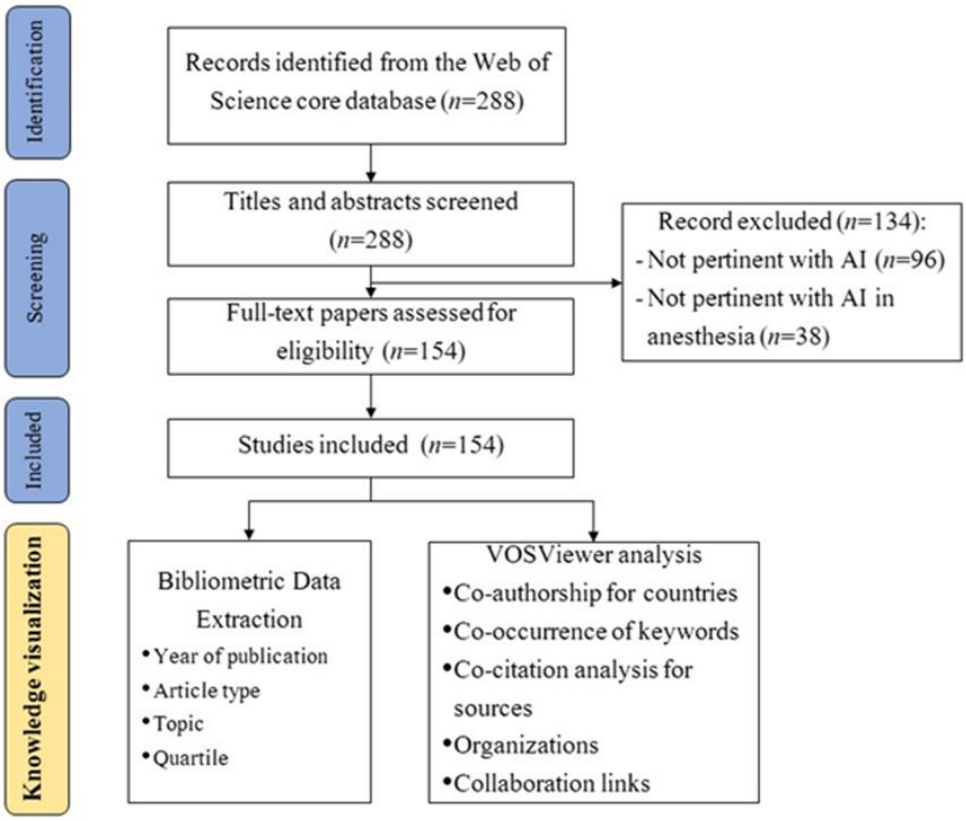

Figure 1. Flowchart of the study

A considerable increase in the number of articles has occurred mainly in recent years. The annual research output demonstrated that the number of articles increased from 4 articles in 2017 to 10 articles in 2018, 15 in 2019, 27 in 2020, and 37 in 2021. From January to April 2022, the search yielded 15 articles (Figure 2).

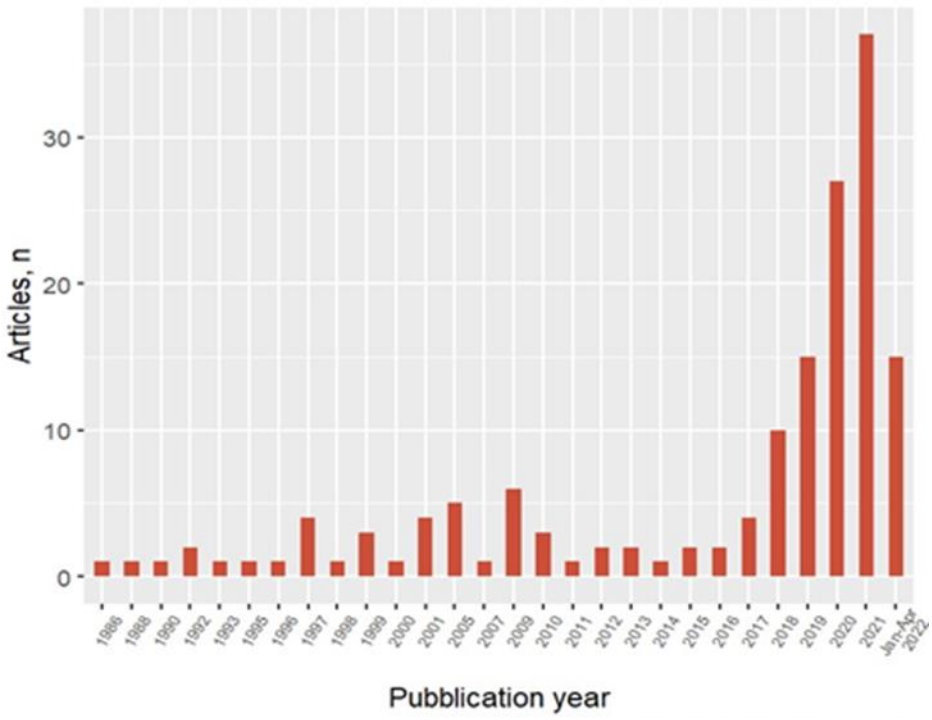

Figure 2. Number of articles on Artificial Intelligence in anesthesia, by year (up to April 30, 2022). Source Web of Science core database (n=154).

Of the extracted 154 articles, 34 (22%) were observational investigations, 29 reviews (18.8%) (28 narratives, 1 systematic), 16 editorial articles (10.4), 7 RCTs (4.5%), 5 (3.2%) preclinical research, 6 opinions (3.9), 2 letters (1%), and 1 case report. Fifty-seven articles concerned math analysis, algorithm validation processes, simulation studies, surveys, meeting reports, book chapters, corrections, abstracts, and other types of study mostly derived from meeting abstracts or proceeding papers (n=42) (Figure 3).

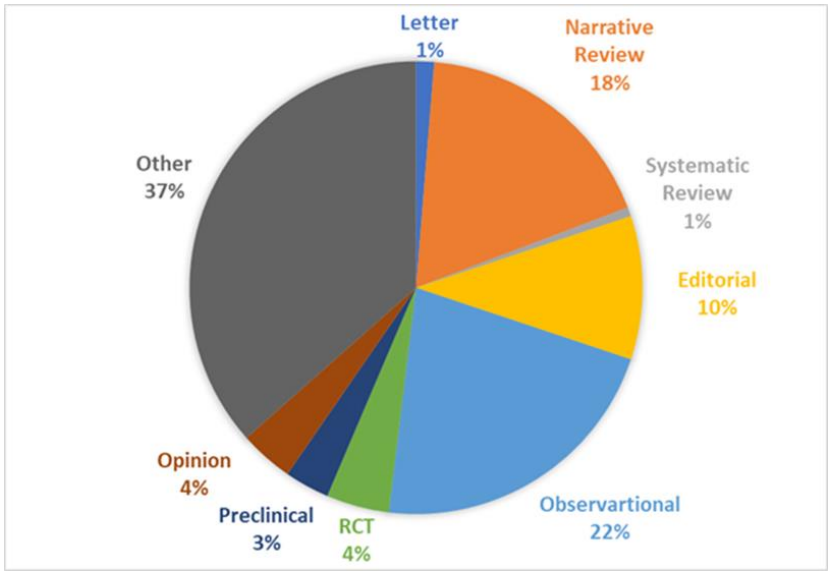

Figure 3. Articles on Artificial Intelligence in anesthesia, by article category. From 154 articles, 157 types were identified and grouped into 9 categories.

According to the Quartile analysis, 51% of papers were published in Q1, 13% in Q2, 21% in Q3, and 15% in Q4 (Figure 4).

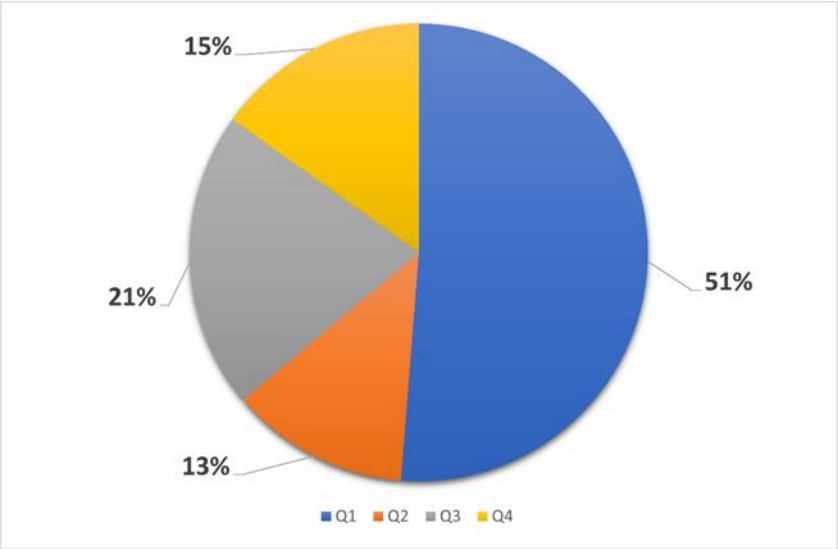

Figure 4. Quartile analysis.

Articles were cited 909 times with a mean of 9.6 (SD 14) citations per article and a median of 5 (IQR 2; 11.2) citations per article. One article was cited 99 times, 24 articles (15.6%) were uncited, and 41 articles (26.6%) were cited once or twice. Overall, most of the papers (98%) reached less than 25 citations (Figure 5).

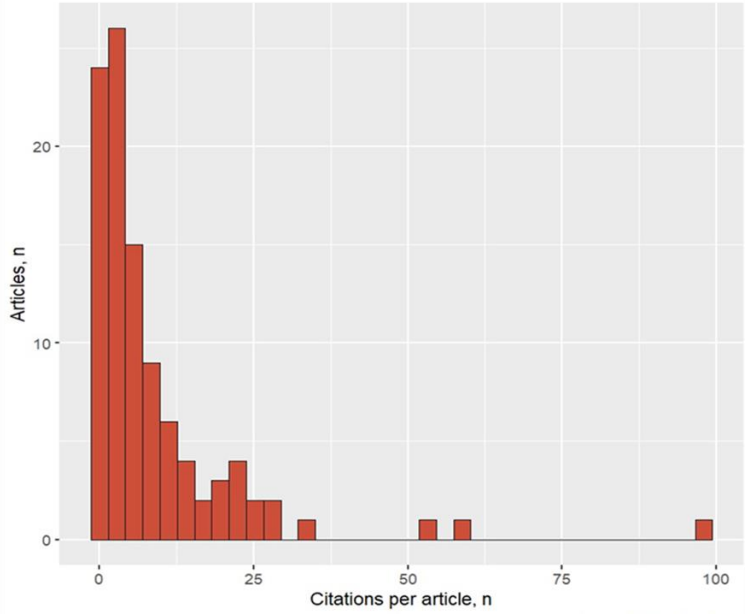

Figure 5. Number of citations per article

The total IF was 486.73 with a mean of 3.9 (SD 2.34) for article (median 4; IQR 2.5, 5.3). About journals and the number of publications on the topic, ARTIFICIAL INTELLIGENCE IN MEDICINE (Q1) published 17 articles, and ANESTHESIA & ANALGESIA (Q1) 15 (Table 1).

Table 1. Journals with more publications

JOURNAL	Impact Factor*	Quartile*	Articles (*n*)
ARTIFICIAL INTELLIGENCE IN MEDICINE	5.32	1	17
ANESTHESIA & ANALGESIA	5.17	1	15
LECTURE NOTES IN ARTIFICIAL INTELLIGENCE	0.3	4	11
JOURNAL OF CARDIOTHORACIC AND VASCULAR ANESTHESIA	2.62	3	9
CURRENT OPINION IN ANESTHESIOLOGY	2.7	3	5
JOURNAL OF CLINICAL MONITORING AND COMPUTING	2.5	3	4
ANESTHESIOLOGY	7.89	1	4
SCIENTIFIC PROGRAMMING	1	4	3
REGIONAL ANESTHESIA AND PAIN MEDICINE	6.28	1	3
JOURNAL OF MEDICAL SYSTEMS	4.46	1	3

** Based on Clarivate Analytics Journal Citation Reports 2020*

The most relevant topics of the papers selected by this bibliometric analysis were “anesthesia management” (n=60) “perspectives” (n=31), and “monitoring” (n=21) (Figure 6)

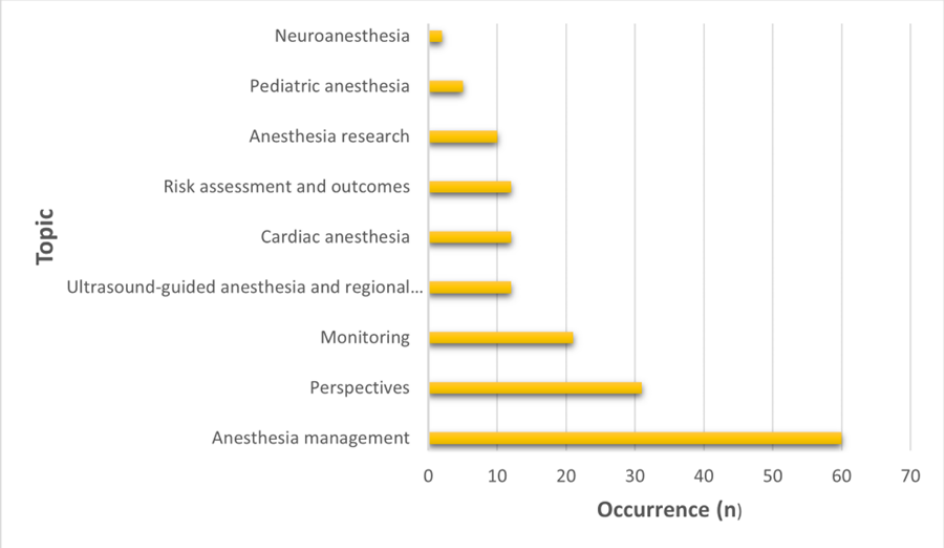

Figure 6. Most relevant topics

3.2 Knowledge visualization

3.2.1 Bibliometric Analysis of the Keywords

The analysis focused on the keywords that occurred more than 2 times in the database. Of the 323 keywords, 45 reached the cut-off. Six clusters were identified. The most used keywords were

ARTIFICIAL INTELLIGENCE (occurrence 27; total link strength 80); ANESTHESIA (7/42), and BISPECTRAL INDEX (4/32) (Figure 7).

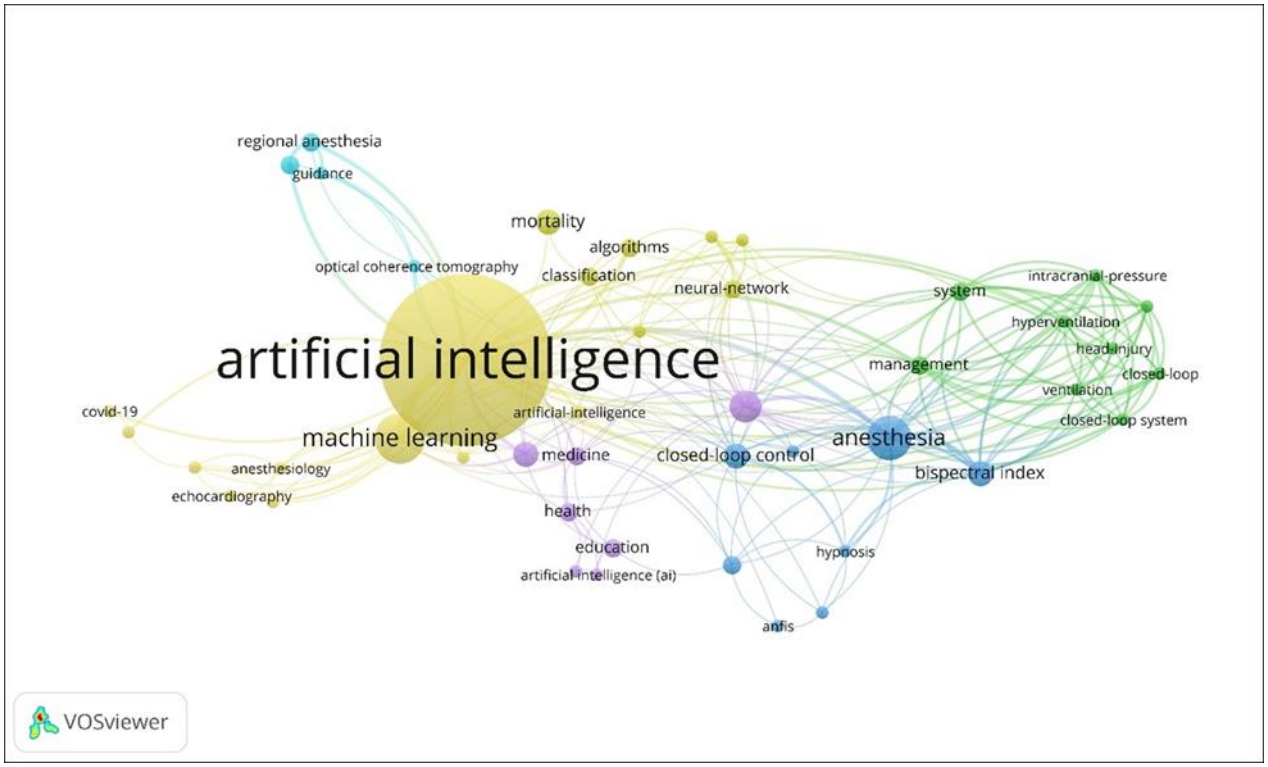

Figure. 7. Co-occurrence of keywords. The volume of nodes illustrates the rate of occurrence. The curves between the nodes illustrate their co-occurrence in the same document. The shorter the space between the 2 nodes, the larger extent of co-occurrence of the 2 keywords. The analysis provided 323 keywords; of those, 45 reached the cut-off (2 times) and 6 clusters were collected (distinct colors).

3.2.2 Co-citation Analysis

For the co-citation analysis, we selected cited sources (journals) as a unit of analysis. The minimum number of citations of a source was 5. In this way, of 1019 sources, 84 met the threshold and were grouped into 3 clusters. For each of the 84 sources, the cumulative strength of the co-citation links with other sources was measured. The journal ANESTHESIA & ANALGESIA obtained 60 citations and 1911 links; IEEE TRANSACTIONS ON BIOMEDICAL ENGINEERING 27 citations and 1766 links; ANESTHESIOLOGY 62 citations and 1660 links (Figure 8).

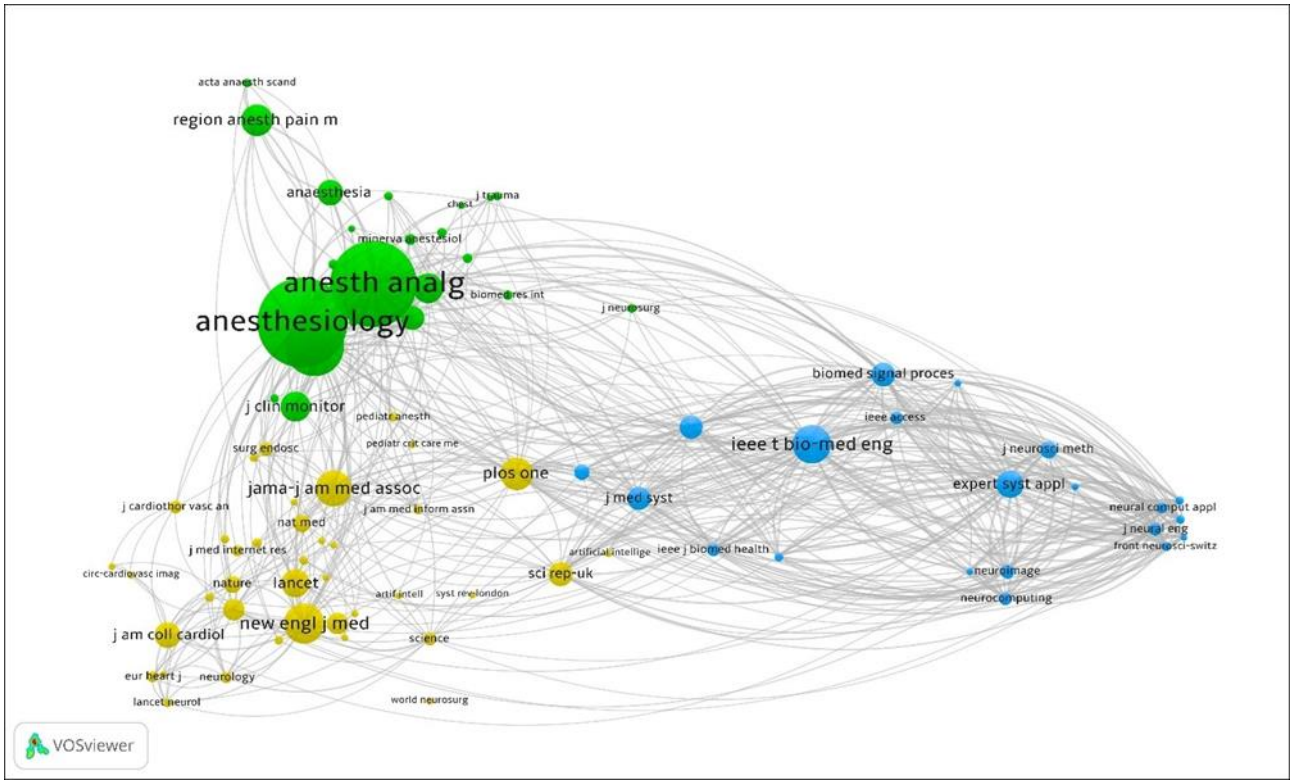

Figure 8. Co-citation analysis for sources. Of 1,019 sources (journals), 84 met the threshold (n=5) and were grouped into 3 clusters.

3.2.3 Co-authorship Analysis (Countries)

The lowest number of documents (threshold) per country was 2. Therefore, 12 countries met the threshold. For each of the 12 countries, the overall strength of the co-authorship links with other countries was measured. Two countries were not joined to each other, and the largest set consisted of 10 items (countries). Most partnerships involved the United States, China, and Australia. In the United States, 21 documents with 8 links were listed; in China, 12 documents and 5 links; in Australia, 5 documents and 5 links (Figure 9).

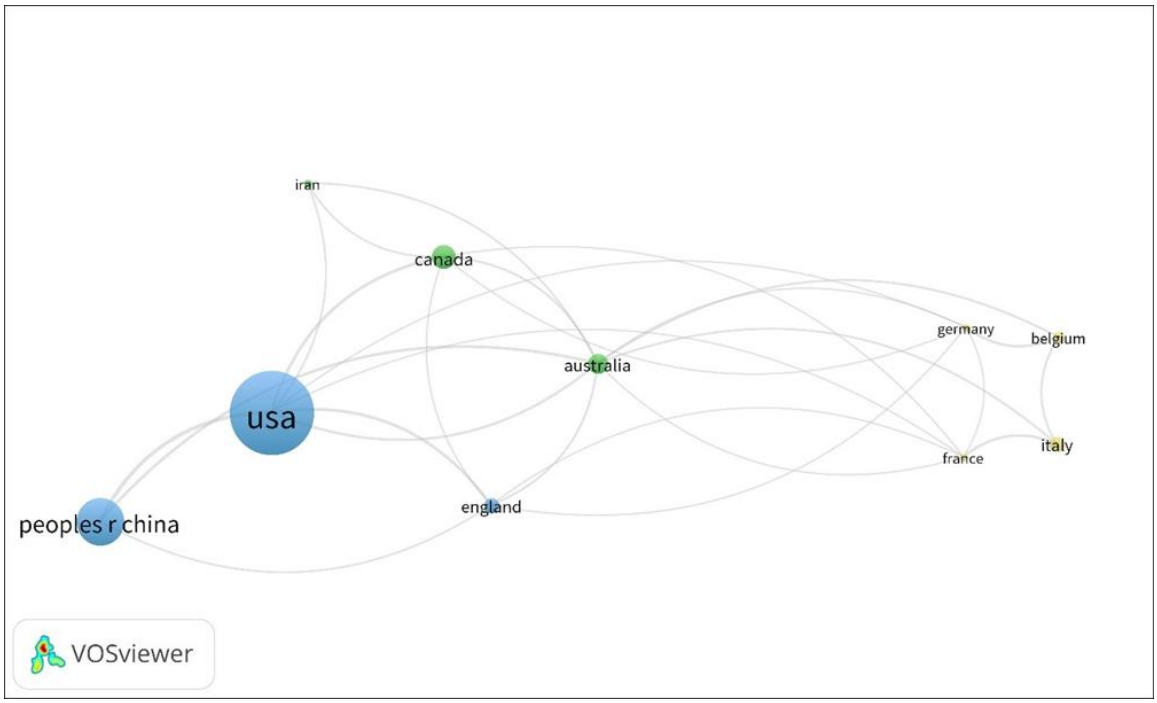

Figure 9. Co-authorship analysis for countries. Ten countries met the cut-off of 2 documents (3 clusters).

3.2.4 Collaborations between institutions

The analysis of the networks among institutions was carried out by assuming the cut-off number of 2 as the lowest number of documents of an organization, and 1 as the lowest number of citations. Out of 142 institutions, 85 met both thresholds. For each of these 85 institutions, the total strength of the citation links with other organizations was measured. The largest set of connected institutions was composed of 48 items. The HARVARD UNIVERSITY (links, n=27), the UNIVERSITY OF SAN FRANCISCO (n=22) in the United States, and the UNIVERSITY of OXFORD (n=19) in the United Kingdom produced stronger links with other organizations (Figure 10).

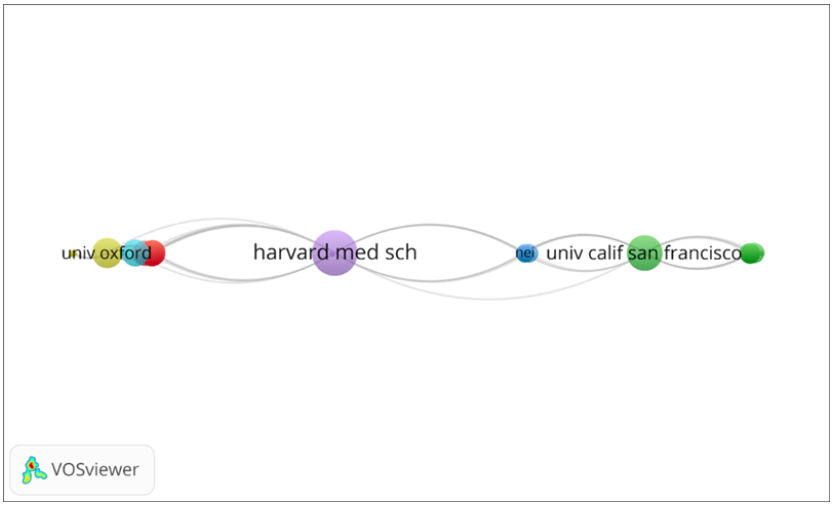

Figure 10. Collaborations between institutions for articles on Artificial Intelligence in anesthesia. The analysis found 6 clusters.

4. Discussion

To our knowledge, this is the first bibliometric analysis of publications on AI in anesthesia. The results of this analysis offer interesting elements to be discussed. For example, although the number of articles on the subject is growing rapidly, many scientific gaps must necessarily be filled. Many articles are narrative reviews, editorials, opinions, and letters. Moreover, more than a quarter of the included manuscripts are dataset analyzes, algorithm validation studies, and other research included in conference proceedings, especially as abstracts. Clinical studies (observational studies and RCTs) account for approximately a quarter of the papers.

The quality of the studies highlights the poor translation into clinical studies of evaluable research proposed by computer scientists. Many editorials and perspective articles suggest that although clinicians seem fascinated by this discipline, they struggle to carry out solid research projects. As shown by the network analysis, this data translates into a scarce international collaboration between the different research centers. Nevertheless, multidisciplinary processes aimed at researching the application of AI in anesthesia seem to be extremely complex. They presuppose that the clinician should acquire adequate baggage of statistical and IT knowledge; on the other hand, computer scientists must be able to adequately answer the clinician's research queries. This interdisciplinary collaboration process needs to be implemented as AI-based models must be clinically validated to confirm their postulated utility [6].

Since AI works by approaching big data, a key aspect of this translational pathway is the capability of computer scientists to work on well-structured datasets. Considering that a lot of data are usually produced from perioperative situations, anesthesia offers an incredible opportunity to build predictive models useful in multiple clinical contexts. Consequently, standardizing the collection of perioperative information is mandatory, and as Glance et al. [17] suggested, it is time to build bridges across clinical registries.

The relevance of the topic and the applicative potentialities of AI in anesthesia are demonstrated by the high value of the journals that have published the articles. Nearly two-thirds of the papers were published by journals in the top two Qs. This finding is reinforced by the high average IF of the documents (mean of 4 for article). Furthermore, articles are published in computer journals, but anesthesia journals are also interested in their publication (Table 1). On the other hand, these papers commonly receive a scarce number of citations (Figure 5). Probably, as the number of articles has only recently increased, the extent of citations will tend to progressively increase over time.

About topics addressed, anesthesia management seems to be the major interest of researchers. Methods for automatic anesthetic administration (closed-loop anesthesia) are deeply investigated [18,19]. Postoperative complications such as postoperative delirium [20], perioperative transfusion medicine, and prediction of bleeding risk [21] as well as models to perform accurate estimation of the depth of anesthesia [22], automatic prediction of difficult endotracheal intubation [23], and perioperative hypotension [24] are hot research topics. These aspects underline that the main interest of the study of AI in anesthesia is the improvement of clinical management, accurately predicting possible complications, and suggesting optimal therapeutic strategies in real-time [25]. Among research topics, anesthesia research is also addressed. For instance, Lee et al. [26] adopted a DL process for developing a metric (i.e., the explainable consciousness indicator) to simultaneously compute the two elements of consciousness (arousal and awareness).

An important weakness that emerged from the analysis is the poor collaboration between different countries and institutions. In both analyzes, to achieve clustering, we had to minimize the threshold of documents to be compared. Regarding collaborations between institutions, only two academic centers in the United States and one in the United Kingdom have produced an appreciable link of collaborations.

4.1 Limitations

Several limitations of this study require consideration. Firstly, we performed the analysis from the WOS dataset, without considering other datasets. However, we followed the methodology that is commonly adopted in VOSviewer-based bibliometric studies [16]. Secondly, this analysis is limited to anesthesia. Thus, articles relating to the study of pain if not of anesthesia relevance (e.g., cancer pain) and articles on the intensive care unit (ICU) were deliberately excluded [27]. Even if the sample was consequently reduced, this strategy allows focusing attention on anesthesia topics. In addition, some

articles on ICU were still included if related to anesthesia (e.g., postoperative ICU admission). This research strategy excluded important topics such as ethical aspects in anesthesia. Probably, the relevant articles (and keywords) on ethics are not enough to be included in the clusters. Research must necessarily address the issue of ethical issues in anesthesia and related clinical branches. Finally, some findings would have required a necessary analytical study. For example, the analysis of citations had to include the correction of the temporal bias by normalizing citations of individual publications. For this purpose, for example, the Category Normalized Citation Index (CNCI) can help to normalize an article regardless of its age [28]. Nevertheless, this paper was aimed at offering a broad overview of the phenomenon and more in-depth analyses could be the subject of further publications.

5. Conclusions

A rapidly growing number of articles and the high quality of the journals that publish them are strengths of the scientific literature on the application of AI in anesthesia. Nevertheless, robust clinical investigations are required to validate the proposed AI-based models. A positive aspect of the research is that it addresses different topics with the aim of implementing decision-making processes during anesthesia and preventing postoperative complications. Finally, the analysis highlights that collaborations between clinicians and scientists from different research centers need to be strengthened.

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