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ORIGINAL ARTICLE

Thirty years in anesthesiology: A bibliometric analysis*

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* In whole or in part, this article has not been published elsewhere and is not being evaluated by any other journal. The study data were presented as a poster at Euroanaesthesia on June 4–6th, 2022.

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Received: 31 July 2023, Accepted: 30 August 2023,
Published online: 30 December 2023

ABSTRACT

Background: The number of publications on anesthesiology continues to increase. Although there are studies conducted about this increase, they are insufficient to show the direction and structure of the changes. This study aimed to investigate the conceptual structure and thematic evolution in publications about anesthesiology over the last 30 years.

Methods: In this study we made a systematic reviews and bibliometric analyses of observational and Randomized Controlled Trial (RCT) studies. Bibliometric analysis was used to reveal thematic clusters by associating keywords and relationship patterns in three periods. Thematic clusters were revealed using a science mapping analysis based on co-word networks and strategic diagrams created according to centrality. Density values were used to determine the positions of the clusters. A total of 119,842 articles published between 1990 and 2022 in the anesthesiology category of the Web of Science (WOS) Core Collection were analyzed. Articles published before 1990 and/or not in the WOS Collection were excluded from the study.

Results: Seven thematic areas were identified over three time periods: Pain, Medications, Regional Anesthesia, Cardiovascular Anesthesia, Pediatric Anesthesia, Critical Care, and Airway Management. Over the years, motor themes have been shaped by new anesthetic agents and techniques. Pain and Regional Anesthesia have been the most researched topics. Patient Safety, Elderly Patients, and Palliative Care were the emerging themes in the last years. Critical Care thematic area moved to Mortality, Mechanical Ventilation, and COVID-19.

Conclusion: Pain is the most popular topic over the last 30 years. Increasing of themes like Patient Safety and Palliative Care in the last years may be related to the increasing quality management awareness and the older population. The fact that the COVID-19 thematic area has a large place in last period shows the effect of the pandemic in the field of anesthesiology.

Keywords Anesthesia, bibliometrics, science mapping.

INTRODUCTION

Since the first written document on anesthesiology in 1847 [1], the number of publications on anesthesiology has increased. Currently, there are more than 250,000 scientific studies on this topic in the literature. Along with technological developments in medicine and medical engineering, the agendas and interests of anesthesiologists have constantly changed over the last 50 years. Although various studies have shown this change in anesthesiology literature, the number and content of these changes remain insufficient to show the direction and structure of these changes. It is possible to trace the transformation of conceptual and thematic flows in the literature using bibliometric analysis.

Bibliometrics is the application of mathematical and statistical methods in scientific communication environments [2]. It is an important tool for the discovery of tacit knowledge among scientific publications and offers methods and metrics for explaining the complex structure of scientific communication [3]. Bibliometrics examine different bibliographic elements, such as keywords [4,5], citations [6,7], authors, and institutions of publications [8-10] in a scope that differs according to the purpose of the studies [11]. One of the main approaches in bibliometric literature addresses the field of science [12].

This study aimed to understand the conceptual structure and thematic evolution of anesthesiology over the last 30 years through detailed bibliometric techniques. We hope to guide readers on their scientific paths by showing how trends and topics change in anesthesiology.

MATERIALS AND METHODS

The type of this study is a bibliometric data analysis. Hence, no ethical approval or waiver document was required. The methodology of this study was based on two basic approaches to bibliometrics: performance analysis and science mapping [13-15]. A performance analysis was conducted to measure the contribution and impact of the analysis elements in the research field, and science mapping was performed to reveal the cognitive structure of the research field and determine research themes based on data visualization [14]. Both methods were adopted in our study to examine the conceptual structure and thematic evolution of research themes in the anesthesiology field. The workflow of this study is illustrated in Figure 1.

Data

In the first stage, it was necessary to retrieve publications from the anesthesiology field. Academic publications are the primary source of data for bibliometric studies. For this reason, bibliographic databases were used as data sources in the bibliometric analysis. Currently, there are many bibliographic databases in which academic journals are systematically indexed. We used Web of Science (WoS) in our study, the main reason for this is that the anesthesiology research field is defined categorically in WoS. Keywords are one of the most significant tools for the presentation of academic publications in the digital environment [16]. Efficient use of keywords is one of the main tools for readers to access articles. Keywords are determined by the author of the article to include the outline, subject, interesting aspects and sub-

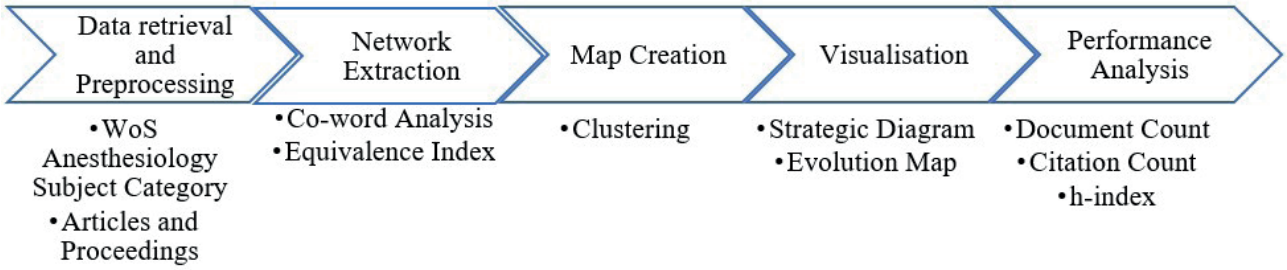


Figure 1. Analysis workflow.

fields of the article [17]. In this respect, it has the aspect of representing an article in its most concentrated form.

Bibliometric analyses were conducted using the keywords of publications in the anesthesiology research field. To analyze publications using keywords, the search was limited to two main publication types: articles and proceedings. Articles and proceedings are main academic products. While preliminary findings of the on-going researches and contemporary academic activities of the field are discussed through proceedings at the conferences, a more comprehensive and long term production period is in question with articles [18]. Both types of studies are at the center of academic communication in terms of representing academic performance in a field [19-21]. Therefore, these two publication types are frequently used in bibliometric studies examining the performance in a field [20,22,23].

Another limitation is the year range. The starting point was taken as 1990, when keywords were regularly indexed in publications.

Bibliometric analyses are conducted by examining academic publications in a certain period. In this context, the choice of periodization can be shaped according to the purpose of the study. There are studies to monitor the reflection of certain events affecting a field in the literature [24,25] and studies that monitor the transformation of a field in the process in periods [26,27]. In our study, since we wanted to follow the conceptual structure and thematic evolution of anesthesiology over the scientific publications, 30 years of academic production was considered in 3 periods of 10 years each.

Analyses were performed for three periods to observe the periodic evolution:1990-1999, 2000-2009, and 2010-2021. Data preprocessing is the most important step in bibliometrics to obtain accurate results. Therefore, it is necessary to combine the same concepts and eliminate typographic errors in analysis elements. Data preprocessing was conducted by field experts using distance algorithms [28].For this purpose, 80252 keywords were reviewed by experts. A systematic approach was followed at this stage and firstly similar keywords were brought together with distance algorithms. Then, by using a thesaurus approach the keywords were viewed as broader and narrower terms [29] and only similar keywords were brought together to maintain the balance between levels and to maintain this level for different terms [30]. The SciMAT [28], bibliometric analysis tool and Openrefine [31] data cleaning tool were used to prepare the data and perform the analyses.

Methodology

In our study, keywords were used as analysis items. Co-word analysis was used to reveal thematic clusters in the field. Co-word analysis is a method for exploring topics in a related scientific field by matching keywords that are frequently used together. The co-word analysis technique uses the association of keywords according to their co-occurrence in a publication to identify relationship patterns among study subjects [4,32].

In this method, all keywords in a set of publications are matched, and keywords that are used more frequently with each other, form certain densities within this relationship network. These densities are used to identify the thematic clusters studied in the field.

After the links between the analysis elements are established, the links within the created network must be normalized to derive similarities [33]. Normalization is a process of arranging data to establish stable data structures, reduce data anomalies, and construct a consistent data framework. [34,35]. In co-word analysis, keyword links are weighted by normalization according to their co-occurrence in the publications. In our study, normalization was performed with the equivalence index, which is proportional to the ratio between the co-occurrence of two keywords in the same document and the number of documents in which these keywords appear [4,13,32,33,36]. After the normalization of links between keywords, intensely related concepts emerged as research themes in the field (Figure 2-a).

After the thematic densities emerge in the keyword network created for the co-word analysis, the clustering and visualization of these themes is started. Thematic clusters are formed by bringing together the keywords that are most frequently used together. Each thematic cluster consists of the keywords that are most frequently used together in the keyword network. The representation of the clusters is provided by the most central keyword within this thematic density (Figure 2-a).

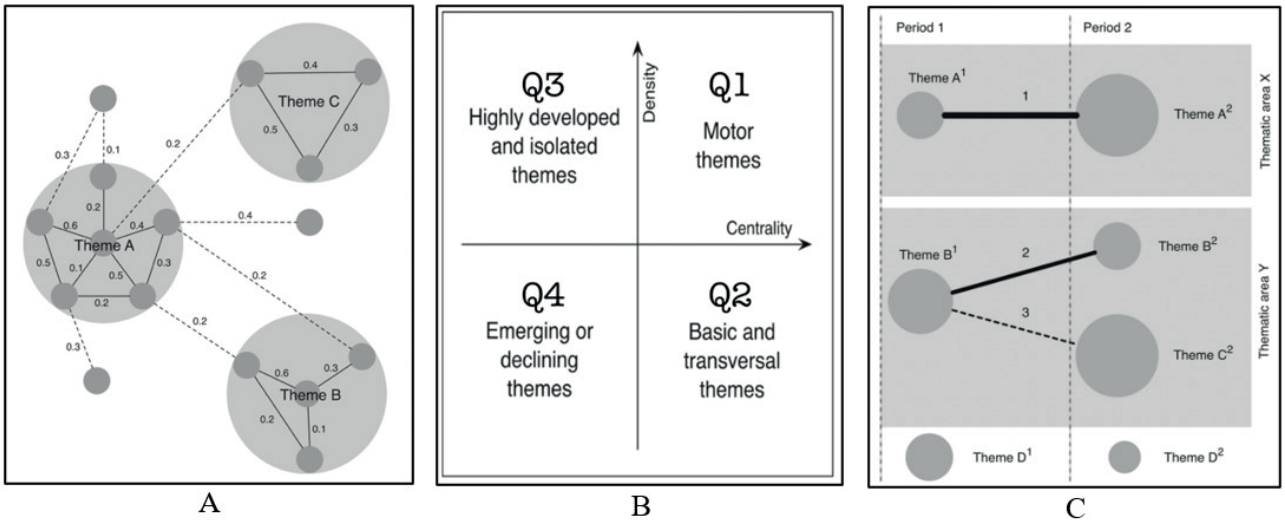


Figure 2. A) Clusters, B) Strategic diagram, C) Evolution map.

Strategic diagrams and an evolution map were used to determine the positions of the thematic clusters in the research field. A strategic diagram is a two-dimensional map with centrality on the x axis and density values on the y axis. The map was obtained by calculating the centrality and density values of the thematic clusters determined over the keywords using co-word analysis and placing them in this coordinate system. The two main measures calculated after identifying thematic clusters within the keyword network are centrality and density. The centrality value indicates the position of a cluster in the research field based on the strength of its communication with other clusters. Conversely, the density value indicates how well the links of keywords in the cluster are developed [28,32]. A cluster with a high centrality value has more network relationships with all other clusters. Density indicates the relational density of keywords within these clusters. A cluster with a high-density value indicates that the keywords within it are used much more frequently with each other.

The centrality value was calculated according to the strength of the links of a given cluster with other clusters, and the density value was calculated based on the strength of the links among the keywords within the cluster [28, 31, 32]. Strategic diagrams were used to determine the positions of thematic clusters within the research field. Strategic diagrams have quadrants that allow clusters to be interpreted differently according to their centrality and density values. An example strategic diagram is shown in Figure 2-b.

Clusters in the upper-right quadrant (Q1) of the strategic diagram have both high-density and high-centrality values. These clusters have intensely developed inner links and strong communications with other clusters. The clusters in the upper left quadrant (Q3) show clusters that are highly developed but relatively isolated. Although these clusters had highly developed inner links between keywords, they had relatively weak communications with other clusters. The clusters in the lower-right quadrant (Q2) show the basic clusters in areas with low and high centrality values. The bottom left quadrant (Q4) had both low and low-density values. The clusters in this quadrant indicate emerging or declining research areas [13,28,32,37].

After analyzing the thematic clusters in the research field, an evolution map was used to show the periodic development and transformation of these thematic clusters (Figure 2-c). The evolution map consisted of columns with thematic clusters. Each column represents the analysis period. The thematic research areas in anesthesiology were monitored, with connections established between thematic clusters over time. These links indicate that the clusters share common keywords. Solid lines indicate that the connected clusters share one of their central keywords, and dotted lines indicate connected cluster shares other than central keywords. In addition, the size of the lines was proportional to the number of common keywords in the two clusters. Monitoring the connections between clusters allows us to understand the periodic conceptual transformation and communication in different clusters.

At all stages of the study, thematic clusters were evaluated using performance values calculated over the number of publications, citations, and Hirsch index (h-index) [38,39]. Two values are used to indicate the number of publications in the performance analysis. The first value is the number of core publications, which represents the number of publications with at least two keywords in the cluster. The values in parentheses indicate all publications with at least one keyword in the cluster. Performance analysis enables quantitative evaluation and comparison of the effectiveness of thematic clusters in the research field.

RESULTS

Bibliometric analyses were performed on 119,842 articles and proceedings papers in the anesthesiology category of the WoS Core Collection. Three strategic diagrams (Figure 3-5) were created using SciMAT to analyze the notable themes in each sub-period. In these representations, the sphere volume was proportional to the number of documents associated with each theme. The effect of these themes in each subperiod is shown in Tables (Table 1-3) containing information on performance values (number of documents, h-index, and number of citations).

First Period (1990-1999)

The results for this period are shown in the strategic diagram in Figure 3, and the performance indicators in Table 1. During Period 1, 22 themes with 29,208 publications were identified. Among the themes with 150 or more publications, which can be considered as the most productive themes according to performance indicators, the motor themes in the first quadrant are "MORPHINE," "BUPIVACAINE," "ANAESTHETICS-LOCAL," "VECURONIUM," "NEUROPATHIC-PAIN," and "EQUIPMENT," and the basic and transversal themes in the second quadrant were "PROPOFOL," "HALOTHANE" and also "INTUBATION" and "CHRONIC-PAIN" themes from the fourth quadrant, which were placed in emerging or declining themes. Considering the performance indicators, the most significant themes in the first period were "NEUROPATHIC-PAIN," "CHRONIC-PAIN," "MORPHINE," "BUPIVACAINE," "PROPOFOL," and "SYMPATHETIC-NERVOUS-SYSTEM."

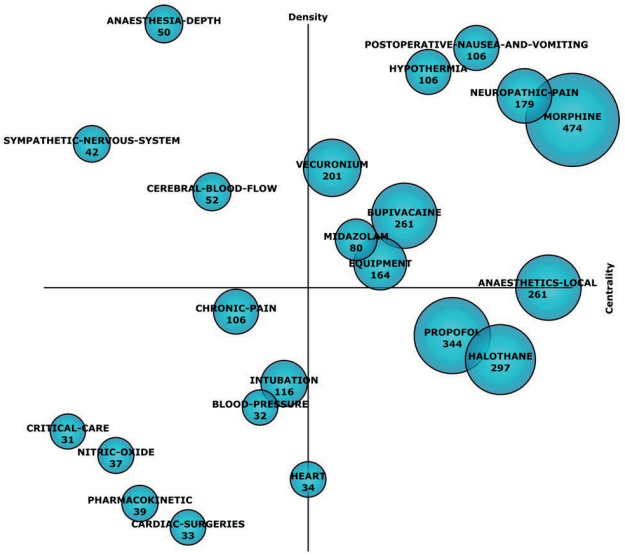


Figure 3. Period 1 (1990-1999).

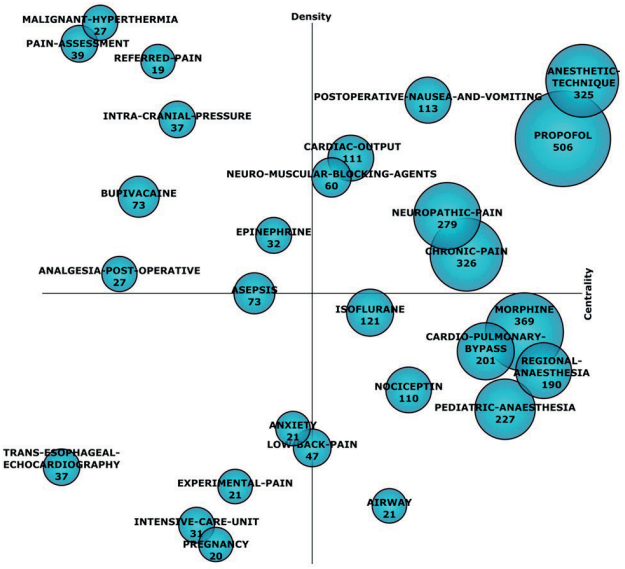


Figure 4. Period 2 (2000-2009).

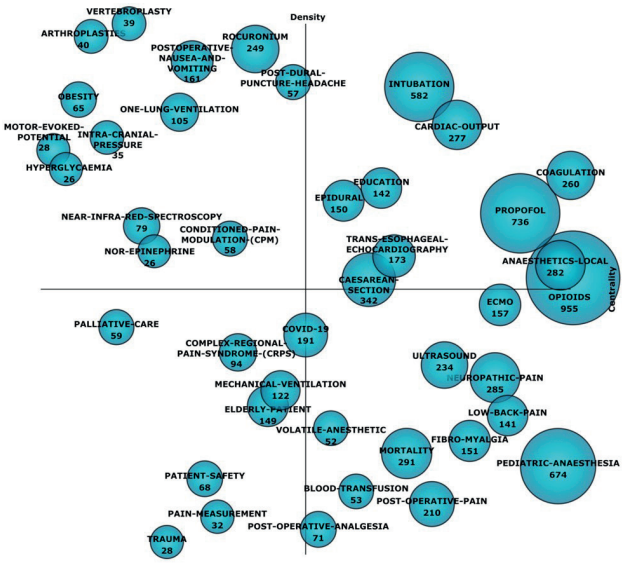


Figure 5. Period 3 (2010-2021).

Table 1. Themes Performance for the 1990-1999 Period

Themes	Quadrant	Core Documents (All Documents)	h-index	Average Citations
Morphine	Q1	474 (1761)	69	42,61
Propofol	Q2	344 (1713)	52	31,94
Halothane	Q2	297 (1703)	48	28,58
Bupivacaine	Q1	261 (1211)	56	40,81
Anesthetics-local	Q1	261 (1267)	42	27,77
Vecuronium	Q1	201 (648)	26	16,07
Neuropathic pain	Q1	179 (695)	74	107,53
Equipment	Q1	164 (1133)	33	22,82
Intubation	Q4	116 (604)	35	32,94
Chronic pain	Q4	106 (473)	57	108,45
Hypothermia	Q1	106 (678)	34	36,88
Postoperative-nausea-and-vomiting	Q1	106 (503)	32	30,75
Midazolam	Q1	80 (546)	25	22,98
Cerebral-blood-flow	Q3	52 (241)	20	23,77
Anesthesia-depth	Q3	50 (280)	24	38,88
Sympathetic-nervous-system	Q3	42 (267)	22	40,95
Pharmacokinetic	Q4	39 (340)	19	31,87
Nitric oxide	Q4	37 (284)	14	19,41
Heart	Q4	34 (283)	14	15,21
Cardiac surgeries	Q4	33 (327)	14	19,18
Blood-pressure	Q4	32 (227)	16	26,03
Critical care	Q4	31 (329)	4	1,71

Q1: Motor themes; Q2: Basic and transversal themes; Q3: Highly developed and isolated themes; Q4: Emerging or declining themes

The motor theme "MORPHINE" and the basic and transversal theme "PROPOFOL" had high publication counts. The theme "MORPHINE" focused on analgesia and pain management in the postoperative period or in cancer patients. The theme "PROPOFOL" was related to intravenous anesthetic techniques and the induction of general anesthesia. The basic and transversal theme "HALOTHANE" with the motor theme "BUPIVACAINE" and "ANESTHETICS-LOCAL" presented similar publication values, considered as highlighted themes. The theme "HALOTHANE" was related to other volatile anesthetics, such as malignant hyperthermia as a complication, and pediatric anesthesia. The theme "BUPIVACAINE" was composed of documents that enhanced the importance of obstetric surgeries under spinal and epidural anesthesia and post-operative pain.

The emerging theme "CHRONIC-PAIN" and motor theme "NEUROPATHIC-PAIN" had moderate publication counts, but the highest number of citations. "CHRONIC PAIN" is related to psychological (anxiety and depression) and socioeconomic (sex and social classes) characteristics. The "NEUROPATHIC-PAIN" theme had the highest h-index in this period related to experimental animal studies and hyperalgesia.

Second Period (2000-2009)

The results for this period are shown in the strategic diagram in Figure 4, and the performance indicators in Table 2. During Period 2, 28 themes were identified among 35,566 publications. The most productive themes according to performance indicators for which the themes had 150 or more core documents, were from the first quadrant "PROPOFOL," "CHRONIC-PAIN," "ANAESTHETIC-TECHNIQUE," and "NEUROPATHIC-PAIN," and from the second quadrant "MORPHINE," "PEDIATRIC-ANAESTHESIA," "CARDIO-PULMONARY-BYPASS." Considering the performance indicators, the most significant themes in the second period were "CHRONIC-PAIN," NEUROPATHIC-PAIN, "MORPHINE," NOCICEPTIN, "PROPOFOL," and "LOW-BACK-PAIN."

The theme "PROPOFOL," which became a motor theme during this period, had the highest number of publications. Studies on propofol have focused on target-controlled anesthesia techniques, anesthesia depth, and the comparison of propofol

Table 2. Themes Performance for the 2000-2009 Period

Themes	Quadrant	Core Documents (All Documents)	h-index	Average Citations
Propofol	Q1	506 (1793)	47	21,96
Morphine	Q2	369 (2363)	66	46,97
Chronic pain	Q1	326 (1511)	90	78,47
Anesthetic-technique	Q1	325 (1765)	48	28,39
Neuropathic pain	Q1	279 (1106)	76	67,49
Pediatric anesthesia	Q2	227 (1950)	42	25,40
Cardio-pulmonary-bypass	Q2	201 (1132)	28	18,36
Regional anesthesia	Q2	190 (1425)	35	24,14
Isoflurane	Q2	121 (851)	26	17,00
Postoperative-nausea-and-vomiting	Q1	113 (734)	24	19,33
Cardiac output	Q1	111 (733)	33	26,52
Nociceptin	Q2	110 (727)	47	55,86
Asepsis	Q3	73 (671)	25	21,53
Bupivacaine	Q3	73 (387)	26	21,85
Neuro-muscular-blocking-agents	Q1	60 (298)	17	15,50
Low-back-pain	Q4	47 (556)	32	81,91
Pain, -assessment	Q3	39 (247)	26	74,77
Trans-esophageal echocardiography	Q4	37 (369)	11	7,30
Intra-cranial pressure	Q3	37 (179)	13	14,70
Epinephrine	Q3	32 (322)	15	18,97
Intensive-care-unit	Q4	31 (404)	11	13,97
Malignant hyperthermia	Q3	27 (137)	7	7,41
Analgesia, -post-operative	Q3	27 (202)	20	33,19
Experimental pain	Q4	21 (252)	18	82,24
Airway	Q2	21 (277)	10	23,33
Anxiety	Q4	21 (228)	19	76,00
Pregnancy	Q4	20 (263)	10	14,50
Referred pain	Q3	19 (146)	15	46,74

Q1: Motor themes; Q2: Basic and transversal themes; Q3: Highly developed and isolated themes; Q4: Emerging or declining themes

with volatile anesthetics. "MORPHINE," which turned into a basic and transversal theme in this period, and the motor themes "ANAESTHETIC-TECHNIQUE" and "CHRONIC-PAIN" were highlighted themes with similar high publication counts. The "MORPHINE" theme was mostly related to postoperative pain and analgesia. However, the most cited articles from morphine-themed publications of this period were about the adverse effects of opioids, such as M Ricardo Buenaventura, M Rajive Adlaka and M Nalini Sehgal [40]. The "ANAESTHETIC-TECHNIQUE" theme focused on complications, central neuraxial blocks, and local anesthetics. The most cited articles on the theme of "ANAESTHETIC-TECHNIQUE" concerned the use of ultrasound in nerve blocks [41,42], complications, and local anesthetics [43,44]. The other highlighted theme in this period, "CHRONIC-PAIN," had the highest h-index. During this period, the "CHRONIC-PAIN" theme was related to the management of opioid treatment and psychological factors of patients. It was remarkable that "LOW-BACK-PAIN" and "EXPERIMENTAL-PAIN" themes, which were in the emerging and declining themes quadrant, had the highest average citation numbers, although the number of publications was low. Another pain-related theme, "NEUROPATHIC-PAIN," had the second highest h-index value during this period. The motor theme "NEUROPATHIC-PAIN" is related to sensory testing, hyperalgesia treatment, and complex regional pain syndrome.

Third Period (2010-2021)

The results for this period are shown in the strategic diagram in Figure 5, and the performance indicators in Table 3. During Period 3, 42 themes in the field, with 54,469 publications, were identified. Among

Table 3. Themes Performance for the 2010-2021 Period

Themes	Quadrant	Core Documents (All Documents)	h-index	Average Citations
Opioids	Q1	955 (5361)	53	13,85
Propofol	Q1	736 (2740)	30	6,93
Pediatric anesthesia	Q2	674 (4471)	33	8,21
Intubation	Q1	581 (1718)	35	9,82
Caesarean-section	Q1	342 (1561)	18	5,09
Mortality	Q2	291 (2104)	25	9,47
Neuropathic pain	Q2	285 (1499)	42	20,82
Anesthetics-local	Q1	282 (1699)	31	12,47
Cardiac output	Q1	277 (1232)	27	9,82
Coagulation	Q1	260 (1344)	26	11,45
Rocuronium	Q3	249 (596)	22	7,82
Ultrasound	Q2	234 (1359)	15	4,67
Post-operative-pain	Q2	210 (1788)	24	9,67
COVID-19	Q4	191 (1599)	17	7,61
Trans-esophageal echocardiography	Q1	173 (1521)	13	3,94
Postoperative-nausea-and-vomiting	Q3	161 (866)	17	7,76
ECMO	Q2	157 (988)	15	5,15
Fibromyalgia	Q2	151 (1343)	28	21,56
Epidural	Q1	150 (875)	19	11,29
Elderly-patient	Q4	149 (1308)	23	12,21
Education	Q1	142 (1563)	14	5,7
Low-back-pain	Q2	141 (976)	25	15,84
Mechanical ventilation	Q4	122 (1074)	13	4,85
One-lung-ventilation	Q3	105 (488)	12	5,17
Complex-regional-pain-syndrome	Q4	94 (865)	26	24,38
Near-infra-red-spectroscopy	Q3	79 (441)	11	8,33
Post-operative-analgesia	Q2	71 (914)	11	7,54
Patient-safety	Q4	68 (765)	11	9,84
Obesity	Q3	65 (308)	12	6,92
Palliative-care	Q4	59 (616)	11	7,98
Conditioned-pain-modulation	Q3	58 (469)	20	23,88
Post-dural-puncture-headache	Q3	57 (458)	10	5,18
Blood-transfusion	Q2	53 (636)	11	15,45
Volatile anesthetic	Q2	52 (537)	15	11,46
Arthroplasties	Q3	40 (119)	12	19,4
Vertebroplasty	Q3	39 (147)	11	8,54
Intra-cranial pressure	Q3	35 (226)	9	6,69
Pain-measurement	Q4	32 (544)	10	15,91
Motor-evoked-potential	Q3	28 (205)	6	2,89
Trauma	Q4	28 (417)	7	5,54
Hyperglycemia	Q3	26 (192)	6	5,27
Nor-epinephrine	Q3	26 (336)	7	5,96

Q1: Motor themes; Q2: Basic and transversal themes; Q3: Highly developed and isolated themes; Q4: Emerging or declining themes

the themes with 150 or more core publications according to the performance indicators, the motor themes in the first quadrant were "OPIOIDS," "PROPOFOL," "INTUBATION," "CAESAREAN-SECTION," "ANAESTHETICS-LOCAL," "CARDIAC-OUTPUT," "COAGULATION," "TRANS-ESOPHAGEAL-ECHOCARDIOGRAPHY," and "EPIDURAL," the second and third quadrants were "PEDIATRIC-ANAESTHESIA," "MORTALITY," "NEUROPATHIC-PAIN," "ROCURONIUM,""ULTRASOUND,""POST-OPERATIVE-PAIN," "POSTOPERATIVE-NAUSEA-AND-VOMITING," "ECMO," and "FIBRO-MYALGIA," and finally, the "COVID-19" theme from the fourth quadrant, which was in the emerging or declining themes. Although the third period's values were lower compared with other periods due to citation lag, significant themes in the third period with h-indexes and average citation values were "OPIOIDS," "NEUROPATHIC-PAIN," "INTUBATION," "PEDIATRIC-ANAESTHESIA," "PROPOFOL," "ANAESTHETICS-LOCAL," and "FIBRO-MYALGIA."

The motor theme "OPIOIDS" had the best performance results, with the highest publication counts and h-indexes. The "OPIOIDS" theme was related to chronic pain, analgesia, and the adverse effects of opioids. The basic and transversal theme "PEDIATRIC-ANAESTHESIA" and motor themes "PROPOFOL" and "INTUBATION" were the highlighted themes after opioids. They had similar h-index and average citation numbers. The theme of "PEDIATRIC ANESTHESIA" has been studied in many different subjects. Some of the most frequently mentioned were general anesthesia, complications, premedication, postoperative delirium, and pain management. The "PROPOFOL" theme was related to anesthesia depth, sedation, and other sedatives such as dexmedetomidine and ketamine. The other motor theme, "INTUBATION," was related to airway management, air management devices (e.g., laryngoscope and video laryngoscope), and difficult intubation. The most cited article on the "INTUBATION" theme after C Frerk, VS Mitchell, AF McNarry, C Mendonca, R Bhagrath, A Patel, EP O'Sullivan, NM Woodall and I Ahmad [45] guideline for the management of unanticipated difficult intubation in adults was the T Cook, K El-Boghdadly, B McGuire, A McNarry, A Patel and A Higgs [46] consensus guideline for airway management in patients with COVID-19.

Although it had a lower publication count than "PROPOFOL" and "PEDIATRIC-ANAESTHESIA" themes, the basic and transversal theme "NEUROPATHIC-PAIN" had the higher number of average citations and h-index. During this period, the "NEUROPATHIC-PAIN" theme was related to testing sensory signs and modeling the mechanism and treatment of pain. The FIBROMYALGIA," "COMPLEX REGIONAL PAIN SYNDROME," and" "CONDITIONED-PAIN-MODULATION" themes, which were related to pain, were also highly cited, although they had a lower number of publications.

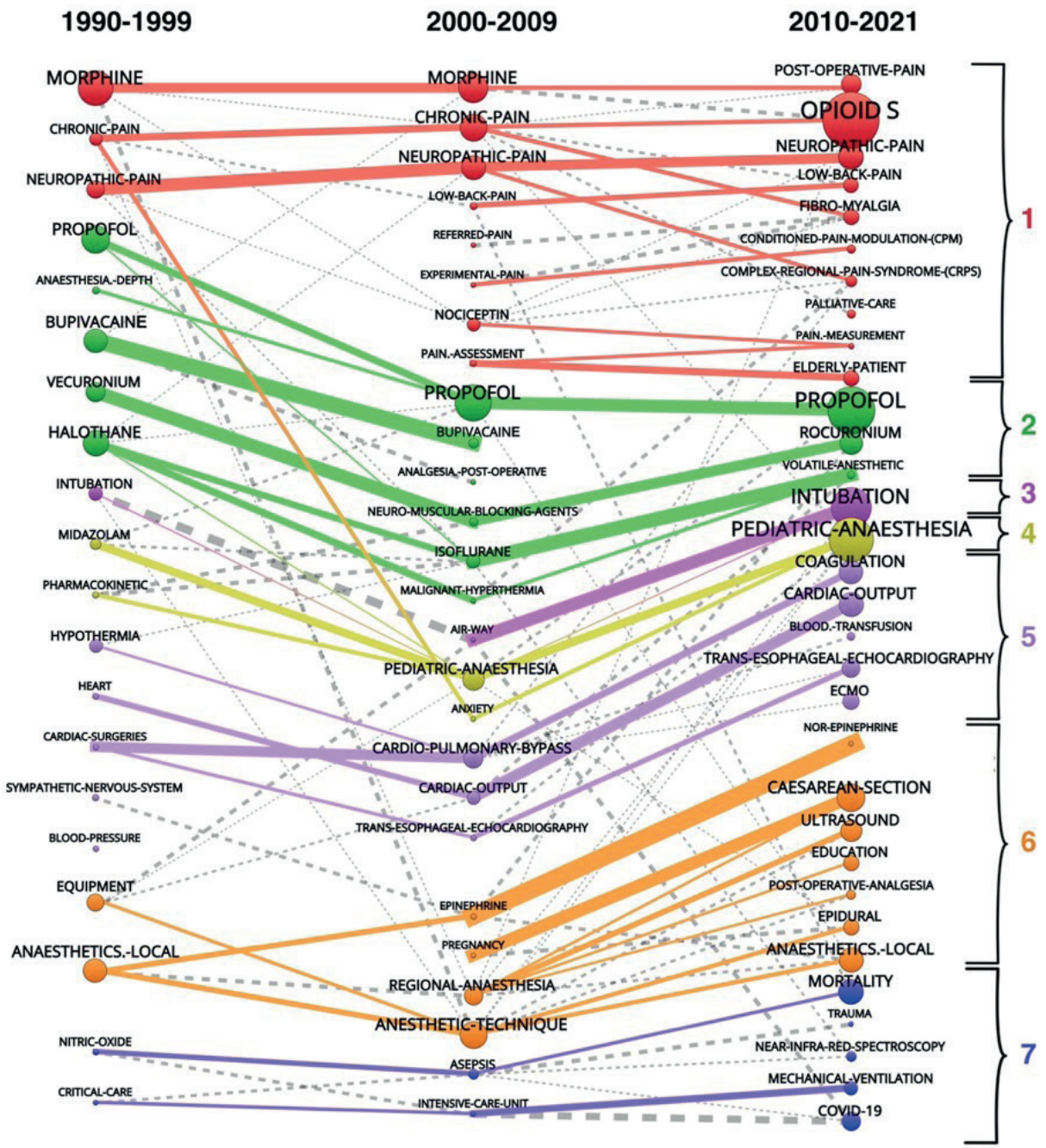
The emerging or declining themes regarding pain in the last 10 years were "PAIN MEASUREMENT" and "POST-OPERATIVE ANALGESIA." Other emerging or declining themes were "PATIENT SAFETY," "ELDERLY PATIENTS," and "PALLIATIVE-CARE.

Finally, the "COVID-19" theme, which has become the most popular topic in recent years, emerged as a basic and transversal theme during the 2010-2021 period. The "COVID-19" theme was above the middle rank in terms of both the number of publications and citations. Some topics related to COVID-19 include airway management, personal protective equipment, intensive care units, and prone positioning. T Cook, K El-Boghdadly, B McGuire, A McNarry, A Patel and A Higgs [46], J Begley, K Lavery, C Nickson and D Brewster [47], M Sorbello, K El-Boghdadly, I Di Giacinto, R Cataldo, C Esposito, S Falcetta, G Merli, G Cortese, R Corso and F Bressan [48] and W Yao, T Wang, B Jiang, F Gao, L Wang, H Zheng, W Xiao, S Yao, W Mei and X Chen [49] were the most cited publications on the "COVID-19" theme.

Thematic Evolution in Thirty Years

Seven thematic areas were identified over three time periods: pain, medications, regional anesthesia, cardiovascular anesthesia, pediatric anesthesia, critical care, and airway management. The thematic areas and conceptual evolutions are shown in Figure 6. The performance measures for these thematic areas are presented in Table 4.

Pain was the largest thematic area and the best performance indicators were obtained. In the last period of anesthesiology literature, the number of core articles and average citations on the topic of pain continued to increase exponentially. Pain had twice



1= Pain, 2= Medications, 3= Airway Management, 4= Pediatric Anesthesia, 5= Cardiovascular Anesthesia, 6= Regional Anesthesia, 7= Critical Care

Figure 6. Evolution map.

Table 4. Thematic Areas in Evolution Map

Thematic areas	Core Documents	Sum Citations	Average Citations
Pain (1)	4103	161363	39,33
Medications (2)	2954	57790	19,56
Airway Management (3)	718	10017	13,95
Pediatric Anesthesia (4)	1041	15976	15,35
Cardiovascular Anesthesia (5)	1566	24467	15,62
Regional Anesthesia (6)	2239	35243	15,74
Critical Care (7)	883	8391	9,5

the average number of citations as a medication, which was the closest thematic field. Regarding the structure and theme composition, the number of themes related to pain increased during the second period. "NEUROPATHIC PAIN," "MORPHINE," and "CHRONIC-PAIN" were the highlighted themes in pain research. "NEUROPATHIC PAIN," which is seen in all periods, became the basic theme from the motor theme in the last period. "MORPHINE," which was a motor theme in the first period, continued as a basic theme in the second period. In the last period, morphine transformed into two themes as a basic theme "POSTOPERATIVE-ANALGESIA," and a motor theme, "OPIOIDS". "CHRONIC PAIN," which was an emerging theme in the first period, turned into a basic theme in the second period. In the last period, "CHRONIC-PAIN" turned into two themes as another motor theme "OPIOIDS," and the basic theme "FIBRO-MYALGIA." Pain was comprised of motor and emerging/declining themes during the first period. Motor and basic themes comprised most themes in the second period. Although basic and emerging/declining themes were the major themes in the last period, the motor theme "OPIOIDS" had the highest core document values in the third period. The pain thematic area covered topics related to pain measurement, opioid medication, and types of pain. In the last period, there was an increase in interest in pain research on the theme of "PALLIATIVE CARE" and "ELDERLY PATIENTS."

Medications, the second-largest thematic area in anesthesiology, is a thematic area of anesthetics (intravenous, inhalers, and some local anesthetics) and neuromuscular blockers. In each period, the themes in this area were scattered as motor, basic, or isolated. "PROPOFOL," the largest theme in this area, became a motor theme from a basic theme after the first period. The motor theme, "VECURONIUM," which is a neuromuscular blocker, transformed into another motor theme "NEURO-MUSCULAR-BLOCKER-AGENTS" in the second period. In the last period, "NEURO-MUSCULAR-BLOCKER-AGENTS" became an isolated theme "ROCURONIUM," also a neuromuscular blocker. "VOLATILE ANESTHETIC" agents were basic themes in each period. "HALOTHANE" transformed into the basic theme "ISOFLURANE" and the isolated theme "MALIGNANT HYPERTHERMIA" in the second period. These two themes then turned into the basic theme "VOLATILE-ANESTHETIC" in the last period.

Regional anesthesia started with a motor theme, "ANESTHETICS-LOCAL." In the second period, the basic themes "REGIONAL ANESTHESIA" and motor theme "ANESTHETIC TECHNIQUE" were highlighted. In the last period, most of the themes related to regional anesthesia were motor themes. The theme of this thematic area has increased during each period. From the second period, "PREGNANCY" and "CESAREAN-SECTION" themes entered "REGIONAL ANESTHESIA." The motor theme, "EDUCATION," and basic theme, "ULTRASOUND," were among the notable themes in the thematic area of regional anesthesia in the last period.

Cardiovascular anesthesia and pediatric anesthesia had similar average citation numbers. However, cardiovascular anesthesia had more core document numbers and themes than pediatric anesthesia. "PEDIATRIC-ANESTHESIA" became a basic theme after the second period and continued as one of the largest themes in the third period.

Critical care was a thematic area with emerging and declining themes until the last period. In the last period, this area had one isolated theme, "NIRS," one basic theme "MORTALITY," and three emerging/declining themes, "TRAUMA," MECHANICAL VENTILATION," and "COVID-19."

Airway management has emerged as an emerging and declining theme. In the second period, it evolved into a basic theme. During the last period, this area continued to have a motor theme. The last period had the largest number of themes. Advanced and difficult airway devices, such as fiber-optic bronchoscopes, video laryngoscopes, and difficult airway algorithms, have been mentioned more frequently.

DISCUSSION

The objective of this study is to comprehend the conceptual framework and thematic progression of anesthesiology over the past three decades, employing comprehensive bibliometric methodologies. Seven thematic areas have been identified in anesthesiology literature over the last 30 years. Among them, pain was the largest thematic area. Most of the pain-related themes were motor themes during the three periods. The morphine theme has been replaced with the opioid theme over the years. In the last period, the

number of articles on the adverse effects of opioids increased. After the second period, the association of pain with the postoperative period, chronic pain, and older age emphasized that pain treatment was an acute and important phenomenon that required continuity. In this context, the theme of pain will maintain its importance in the field of anesthesiology literature in the coming decades.

Medications, the second thematic area, comprised three important daily anesthetic agents: propofol, volatile anesthetics, and neuromuscular blockers. Propofol, together with opioids, was the two most popular theme in each period. Although propofol was the only subgroup of medications that did not change in any of the three periods, volatile anesthetics and neuromuscular blocking drugs were updated over the years.

The third thematic area, regional anesthesia, started with the themes of local anesthetic and anesthesia equipment and increased the diversity of sub-groups over the years. The education and ultrasound subthemes of this thematic area in the last period could be an indication of the popularity and growing trend of regional anesthesia in anesthesia practice.

Cardiovascular and pediatric anesthesia were the fourth and fifth largest thematic areas, respectively. The cardiovascular area has many more subthemes than the pediatric area. In this context, it is possible that pediatric anesthesia is growing.

During the last period under examination, a discernible uptick was observed in the proliferation of subthemes within the critical care domain. This escalation could be attributed to the emergence of sub-themes centered around mortality, mechanical ventilation, and COVID-19. Although the COVID-19 sub-theme materialized only within the final two years, it appears to have assumed a prominent position within the annals of anesthesiology history over the last decade. It is of particular note that the critical care thematic sphere exhibited a lower average citation count compared to its thematic counterparts. The clusters scrutinized within the ambit of critical care generally encompassed a substantial number of recent investigations. Notably, the inclusion of "COVID-19" substantially contributed to the body of work within this cluster. As a consequence, our assessment posits that the relatively diminished average citation count within the critical care thematic purview may be attributed to the necessity for a certain temporal window for citations to accumulate.

CONCLUSION

In conclusion, this study has provided a comprehensive and insightful exploration of the evolving landscape of anesthesiology through the lens of bibliometric analysis. By investigating the thematic trajectory and conceptual shifts within the field over the past three decades, this research contributes valuable insights to the existing body of knowledge.

The findings of this study underscore the dynamic nature of anesthesiology research, as evidenced by the shifting thematic domains and emerging subthemes. The identification of key thematic areas such as pain, medications, regional anesthesia, cardiovascular and pediatric anesthesia, and critical care serves as a foundation for researchers, practitioners, and policymakers to navigate the diverse landscape of anesthesiology research.

Moreover, the study's inclusion of the COVID-19 sub-theme within the critical care domain demonstrates the relevance and adaptability of bibliometric analysis in capturing contemporary issues and their impact on research trends.

While this study offers a comprehensive overview, it is important to acknowledge its limitations, including potential database biases, subjectivity in data preprocessing, and the constraints of citation-based metrics. However, these limitations open avenues for future research to refine methodologies and expand the scope of analysis.

In sum, this study's multidimensional approach sheds light on the past, present, and potential future directions of anesthesiology research. It enriches our understanding of the thematic evolution within the field, presents opportunities for targeted investigations, and invites scholars to explore novel methodologies that can enhance our comprehension of this evolving domain. As the field of anesthesiology continues to evolve, this study serves as a steppingstone for further inquiry, collaboration, and advancement in the pursuit of enhanced patient care and medical knowledge.

Author contribution

Study conception and design: MT, TÖ, and HY; data collection: MT, TÖ, and Mİ; analysis and interpretation of results: MT and TÖ; draft manuscript preparation: MT, TÖ. All authors reviewed the results and approved the final version of the manuscript.

Ethical approval

Due to the nature of our study as a literature review, ethical approval has not been sought.

Funding

The authors declare that the study received no funding.

Conflict of interest

The authors declare that there is no conflict of interest.

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