Original Article

Visual analysis of the research literature on extracorporeal membrane oxygenation-assisted support for respiratory failure based on CiteSpace and VOSviewer: a 20-year study

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Background: This study aims to visually assess the bibliometric status, current hotspots, and development trends in the field of extracorporeal membrane oxygenation (ECMO)-assisted support for respiratory failure through an examination of articles pertaining to ECMO-assisted support for respiratory failure.

Methods: A search was conducted on pertinent literature in the domain of ECMO-assisted support for respiratory failure published from 2003 to 2023, utilizing the Web of Science Core Collection (WOSCC) database. A bibliometric analysis was conducted using CiteSpace and VOSviewer visualization software to identify and assess associations between keywords, countries, institutions, authors, journals, and references.

Results: The present study incorporated a compilation of 1,901 pertinent articles. The United States published the maximum number of research articles in this field, and was closely followed by Germany and China. Furthermore, the University of Michigan was the leading institution in ECMO research. In this context, Daniel Brodie, an American expert, significantly contributed to this field and had published 107 related articles on the subject. Concurrently, active collaboration among ECMO researchers was also observed. *Asaio Journal* was the most prolific contributor, and Giles J. Peek, 2009, published in *Lancet*, comprised the most cited article in the field. Additionally, the analysis of keywords could be divided into three categories: (I) neonatal ECMO; (II) complications of ECMO; (III) ECMO application in coronavirus disease 2019 (COVID-19); (IV) application of point-of-care ultra sound in ECMO.

Conclusions: This study employed CiteSpace and VOSviewer to conduct a systematic literature review on ECMO-assisted support for respiratory failure from 2003 to 2023 in the Web of Science core database. The research outcomes in this domain were presented, offering researchers references for them to gain an accurate understanding of the current state of research and emerging trends in this field.

Keywords: Extracorporeal membrane oxygenation (ECMO); respiratory failure; Web of Science; bibliometrics; visual analysis

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Introduction

Extracorporeal membrane oxygenation (ECMO), also referred to as cardiopulmonary bypass in the intensive care unit (ICU), has been the subject of ongoing technological and equipment advancements since the initial successful implementation of the heart-lung machine by John Gibbon in 1953 (1). ECMO uses classic single-circuit cardiac bypass techniques to support circulation (2). Correspondingly, it facilitates extracorporeal oxygenation and provides a continuous, nonpulsatile cardiac output (3). In patients exhibiting severe yet potentially reversible cardiac or respiratory deterioration, veno-venous ECMO (V-V ECMO) provides respiratory support, whereas veno-arterial ECMO (V-A ECMO) provides cardiopulmonary support (4). In addition, ECMO assists patients during the course of treatment for an underlying disease, injury, transplant-related crisis (e.g., infection), or until the donor organ is available. Presently, ECMO technology has benefited patients suffering from acute respiratory distress syndrome, severe pneumonia, cardiogenic shock, heart failure, as well as those undergoing treatments for various acute and critical diseases (5-8), and intraoperative and perioperative circulatory replacement in heart transplantation and lung transplantation (9-11). Additionally, for critically ill patients afflicted with severe respiratory infections such as H7N9, coronavirus disease 2019 (COVID-19), and severe acute respiratory syndrome (SARS), ECMO is a vital auxiliary treatment technology (12-14).

Bibliometrics, first reported in the 20th century, comprises an approach that employs quantitative analysis to examine and assess the existing body of literature within specialized disciplines (15). During the analysis, detailed information including but not limited to authors, keywords, journals, countries, institutions, and references, etc. can be obtained. Additionally, the literature analysis is rendered more lucid through the utilization of computer technology and visual outcomes, including images (16). Furthermore, through the utilization of visual analysis, one can discern the interrelationships that exist among this information, such as the same research topics by different authors, the research priorities of various institutions, novel theories originating from established institutions, and future research directions in this field (17). Based on the aforementioned visual analysis technology, the present study performed bibliometric analysis on the pertinent literature concerning global ECMO-assisted support for respiratory failure, encompassing the core database of Web of Science over the past two decades, to provide scientific and technological practitioners with an up-to-date understanding of the research landscape and current areas of interest within this domain. Correspondingly, the analysis of the global competitive landscape in this particular domain is likely to provide valuable insights into the trajectory of advancements in ECMO technology.

Highlight box

Main findings

- In this study, CiteSpace and VOSviewer were used to systematically review the literatures on extracorporeal membrane oxygenation (ECMO) as an adjunct to respiratory failure from 2003 to 2023 in the Web of Science core database.

What is known and what is new?

- As we all know, bibliometrics has been paid more and more attention in recent years, but there is no bibliometric study on ECMO in the treatment of respiratory failure.
- Compared with traditional literature statistical research, bibliometrics presents the authors, publishing countries or institutions, journals, references, keywords, etc. of important articles related to ECMO assisted support for respiratory failure in more characteristic graphical and tabular forms, which is helpful to summarize research interests and reveal emerging trends.

What is the implication, what should change now?

- In the bibliometric analysis, the first step is to collect the complete and comprehensive literature related data from the core database of Web of Science for further statistical analysis.

Methods

Data collection and screening

The information utilized in this study was obtained from the Web of Science Core Collection (WOSCC) database, which has been recognized by researchers as the most suitable digital literature resource database for bibliometric analysis (18). The following parameters were considered—search strategy: #1 (((TI = (Extracorporeal Membrane Oxygenation)) OR TI = (ECMO)) AND TS = (respiratory failure)) AND PY = (2003–2023); time span: January 2003 to June 2023, with a cut-off date of 15 June 2023; document type: articles and review articles; language: English; index: SCI-Expanded; a total of 2,273 literatures were retrieved, 446 non-articles and review articles were excluded, and 44 non-English articles were excluded. The exported documents contained comprehensive records of the final screened literatures and the cited references in

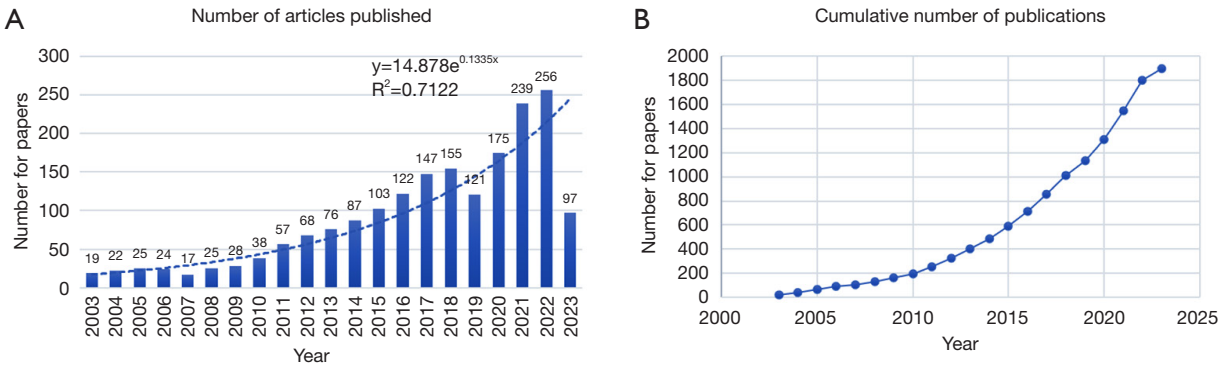

Figure 1 Observed trends in articles published per year.

plain text format. CiteSpace (version 1.6.18) was employed to eliminate duplicate entries in the Web of Science format prior to data analysis. Following the de-duplication process, 1,901 literatures remained. Since all of the information in this study was obtained from publicly accessible databases, no ethical approval was required.

Statistical analysis

The data in this study were visualized using CiteSpace (version 5.8.r 3) and VOSviewer (version 1.6.18) (19). Depending on VOSviewer, researchers can utilize a computer program to map the network data. Concurrently, the co-authorship of institutions and authors, the co-authorship of references and periodicals, as well as the co-citation of authors were discussed (20). A dual map of journals was generated using CiteSpace to examine the distribution of academic journals by subject and to generate explosive words for keywords and references. Additionally, the research hotspots that emerged unexpectedly in a particular year within this field were discussed (21). The annual and cumulative numbers of publications were graphed using Excel (version 2021). There are no controlled studies in this study, so no statistical analysis is involved.

Results

Annual publication trends

The present study retrieved 1,901 papers that met the specified criteria. Among them were 24,584 citations from 4,245 journals and were authored by 9,507 individuals representing 2,052 institutions across 65 countries. The papers were published in 398 journals. With an average of 23 articles published annually from 2003 to 2009, research on ECMO-assisted support for respiratory failure followed a steady trend. However, there was a gradual increase in the number of articles published during the subsequent eight years, from 2010 to 2018. This was followed by a substantial surge in scholarly investigations within this field between 2020 and 2022, peaking at 256 studies in 2022 (*Figure 1*). Trends that are predicted to persist indicate that future research in this area will be even more extensive.

Analysis of authors with the highest number of publications

In the last two decades, research on ECMO-assisted support for respiratory failure has involved the participation of 9,507 authors (*Figure 2A*, *Table 1*). Among these authors, 72 had authored a minimum of ten publications. The author with the highest number of publications was Daniel Brodie [59] from the US, followed by Alaine Combes [46] from France and Eddy Fan [35] from France. Furthermore, Daniel Brodie [5,373] received the greatest number of total citations, with Alaine Combes [5,094] following closely behind. Additionally, the highest average citation rate was for Alaine Combes (110.7), which was closely followed by Matthieu Schmidt (96.5). The collaboration between the subjects was evaluated based on total link strength (TLS), with Alaine Combes [177] exhibiting the highest TLS followed by Daniel Brodie [158] and Thomas Mueller. The remainder were American authors, with Europe contributing 70% of the top 10 authors.

Analysis of the highest co-cited authors

Out of 17,307 co-cited authors, 43 authors had a co-citation threshold exceeding 100. *Figure 2B* illustrates the co-citation network in the journal, which consists of three

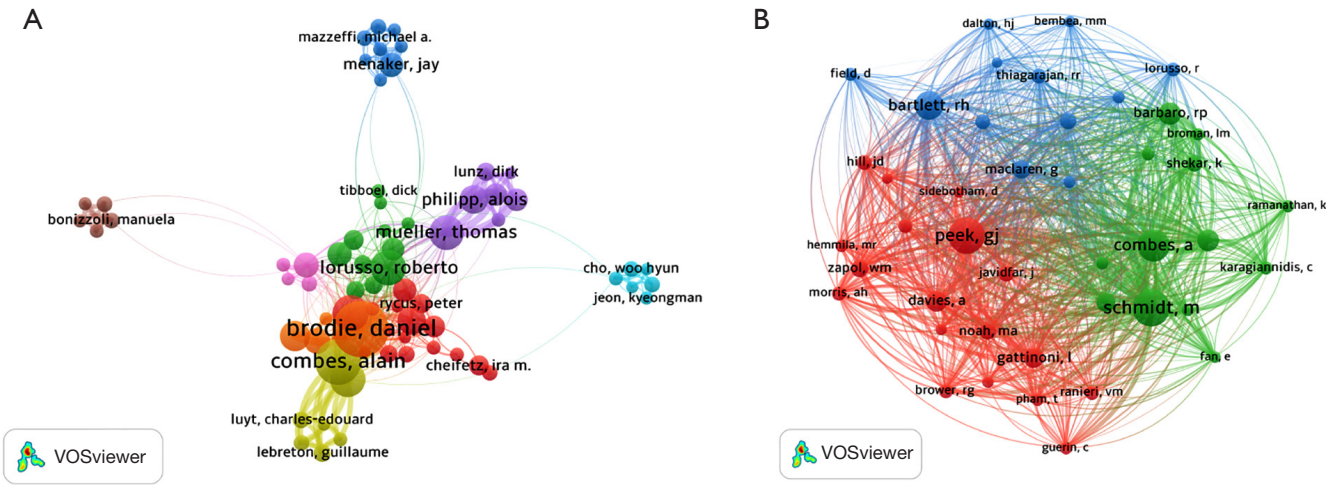

Figure 2 Visual maps of authors generated by VOSviewer. (A) Authors (authors with ≥10 total publications); (B) co-cited authors (co-citation threshold ≥200 times).

Table 1 Top 10 authors in terms of number of articles published

Rank	Author	Country	Documents	Citation	AAC	TLS
1	Daniel Brodie	USA	59	5,373	91.1	158
2	Alain Combes	France	46	5,094	110.7	177
3	Eddy Fan	France	35	2,108	60.2	58
4	Matthieu Schmidt	Germany	34	3,282	96.5	139
5	Roberto Lorusso	Czech	34	1,648	48.5	80
6	Thomas Mueller	Germany	33	2,238	67.8	146
7	Matthew Bacchetta	USA	29	1,648	56.8	38
8	Alois Philipp	Germany	27	1,305	48.3	101
9	Graeme Maclaren	Germany	27	2,103	77.9	64
10	Darrvl Abrams	USA	24	1,312	54.7	61

AAC, average article citations; TLS, total link strength.

clusters representing the three colors in the graph: Matthieu Schmidt, Giles J. Peek, and Robert H. Bartlett comprised the most cited colors, with Matthieu Schmidt, having the highest total citations. In addition, Giles J. Peek, received the second-most citations, amassing 826 total citations and a TLS of 6,118, while Alain Combes, ranked third with 683 total citations and a TLS of 6,259 (Table S1).

Analysis of the countries with the highest number of publications

The research on ECMO-assisted respiratory failure benefited from the contributions of 65 countries in total. Correspondingly, countries with five or more publications were screened using VOSviewer to generate a country network map. A total of 36 countries complied with the criteria (*Figure 3A*, *Table 2*). As observed, the country with the highest number of publications was the US (778 articles), followed by Germany (205 articles) and China (190 articles). In addition, the United States recorded the highest overall count of citations [23,629], followed by France [8,737] and third with Australia [7,925]. Furthermore, France (67.7) exhibited the highest mean citation rate, and was closely followed by Australia (61.4). Accordingly, the top three

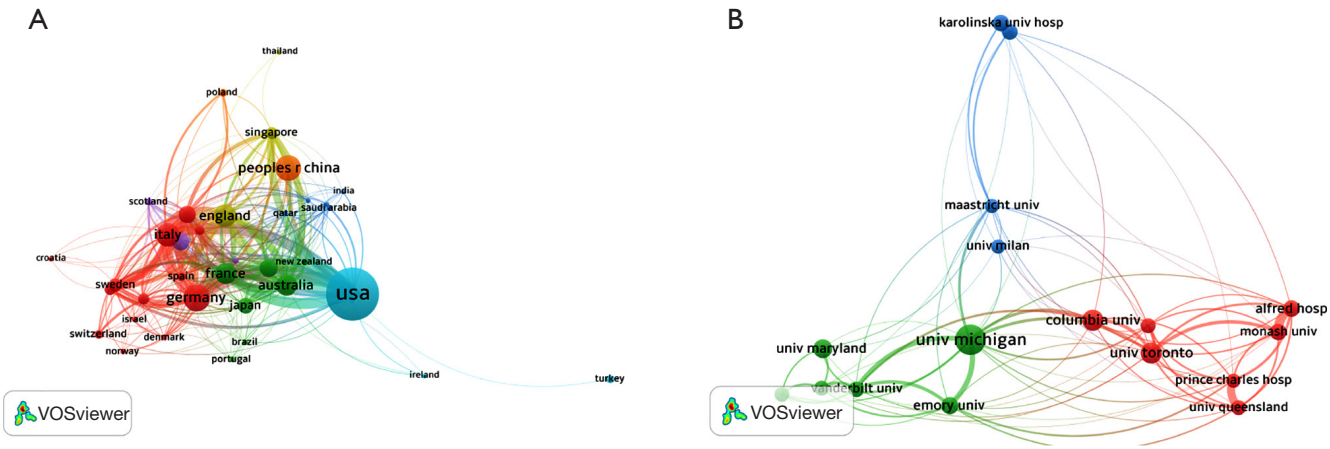

Figure 3 Visual maps of co-cited countries and institutions generated by VOSviewer. (A) Co-cited countries (number of articles published ≥5 countries); (B) co-cited institutions (institutions with a publication threshold of ≥30 articles).

Table 2 Top 10 countries in terms of number of articles published

Rank	Country	Documents	TC	AAC	TLS
1	USA	778	23,629	30.4	381
2	Germany	205	6,436	31.4	266
3	China	190	2,289	12.0	53
4	Italy	157	4,527	28.8	277
5	England	147	6,620	45.0	241
6	Australia	129	7,925	61.4	231
7	France	129	8,737	67.7	221
8	Canada	98	5,114	52.2	175
9	South Korea	96	1,028	10.7	26
10	Netherlands	86	2,899	33.7	223

TC, total citations; AAC, average article citations; TLS, total link strength.

TLS rankings were in the US, Italy and Germany.

Analysis of institutions with the highest number of articles

Institutions with a publication threshold of ≥30 articles between 2003 and 2023 were included using VOSviewer to construct a network map of institutions. Out of a total of 2,052 institutions, 17 were selected for the map (*Figure 3B*, *Table 3*). University of Michigan (75 publications) and Columbia University (50 publications) ranked first and second, respectively, with the University of Toronto (49 publications) serving as the primary monitor. In addition, the University of Toronto [3,832] was the institution that accumulated the subsequent-most citations [4,077] after the University of Michigan. Alfred Hospital achieved the highest mean citation rate of 103.1, while Monash University ranked second with 38.6. Canada accounted for the remaining 10% of the top ten publishing institutions, with the United States, Australia and Sweden contributing 50%, 20%, and 20%, respectively. Moreover, University of Michigan achieved the highest TLS [77], followed by the University of Toronto [59] and Alfred Hospital [56].

Analysis of the most-published journals

The VOSviewer analysis uncovered 38 out of 398 journals

Table 3 Top 10 institutions in terms of number of articles published

Organization	Country	Documents	TC	AAC	TLS
Univ Michigan	USA	75	4,077	54. 4	77
Columbia Univ	USA	50	3,067	61.3	46
Univ Toronto	Canada	49	3,832	78.2	59
Univ Maryland	USA	43	567	13.2	18
Emory Univ	USA	38	2,418	63.6	49
Alfred Hosp	Australia	37	3,815	103.1	56
Monash Univ	Australia	36	3,588	99. 7	55
Karolinska Univ Hosp	Sweden	36	772	21.4	32
Vanderbilt Univ	USA	34	764	22.5	51
Karolinska Inst	Sweden	34	662	19.5	37

TC, total citations; AAC, average article citations; TLS, total link strength.

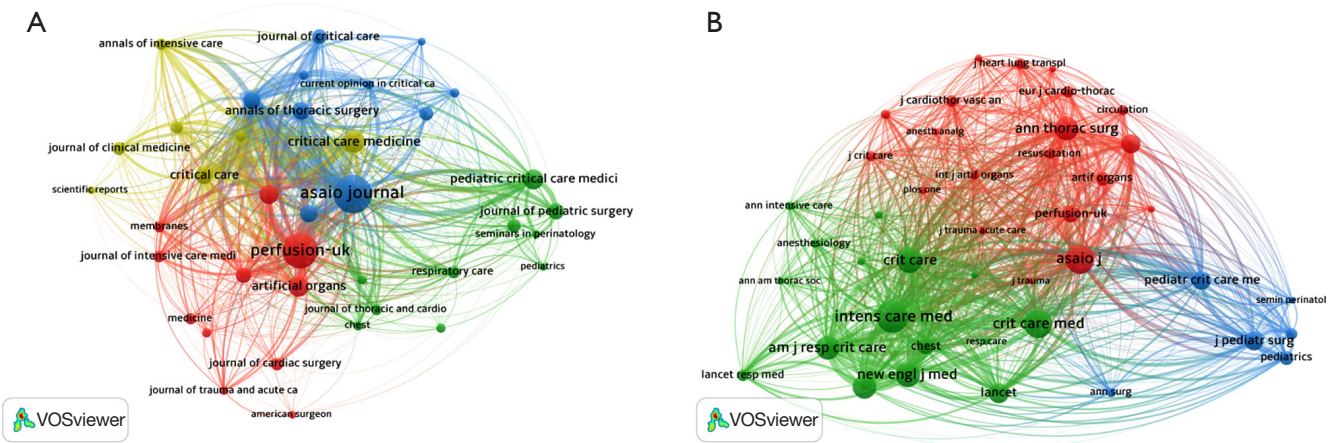

Figure 4 Visual maps of journals generated by VOSviewer. (A) Journals (journals with ≥10 publications); (B) co-cited journals (co-citation count ≥200).

with ≥10 publications between 2003 and 2023 (*Figure 4A*, *Table 4*). The *Asaio Journal* [153] exhibited the highest quantity of publications among the journals examined, followed by *Perfusion-Uk* [131], and *Critical Care Medicine* [59]. *Intensive Care Medicine* received the greatest number of intended citations [3,611], followed by *Asaio Journal* [2,796] and *Critical Care Medicine* [2,293]. Furthermore, *Intensive Care Medicine* received the highest average number of citations (95.0) followed by *Critical Care* (46.8). Four of the ten highest volume journals were published in Journal Citation Reports (JCR), with *Intensive Care Medicine* having the highest impact factor (IF) at 41.787, followed by *Critical Care* at 19.334. Seven of the top ten journals were published in the United States, two in the United Kingdom, and one in Italy.

Analysis of the highest co-cited journals

Further investigation into the co-cited journals revealed three clusters of co-citation networks in the journals, which corresponded to the three colors in *Figure 4B*. Accordingly, *Intensive Care Medicine* (3,298 citations), *Asaio Journal* (2,786 citations), and *Critical Care Medicine* (2,679 citations) comprised the top three journals cited (Table S2). The journals in the red cluster were predominantly in the field of cardiothoracic surgery. In the present study, the

Table 4 Top 10 journals in terms of number of articles published

Rank	Journal	Country	IF [2022]	JCR [2022]	Documents	Citations	AAC	TLS
1	*Asaio Journal*	USA	3.826	Q3	153	2,796	18.3	978
2	*Perfusion-UK*	England	1.581	Q4	131	1,060	8.1	604
3	*Critical Care Medicine*	USA	9.296	Q1	59	2,293	38.9	612
4	*Artificial Organs*	USA	2.663	Q4	51	759	14.9	330
5	*Pediatric Critical Care Medicine*	USA	3.971	Q1	49	1,268	25.9	296
6	*Journal of Cardiothoracic and Vascular Anesthesia*	USA	2.894	Q4	46	703	15.3	367
7	*Critical Care*	England	19.334	Q1	40	1,872	46.8	534
8	*Annals of Thoracic Surgery*	USA	5.102	Q4	40	1,442	36.1	352
9	*International Journal of Artificial Organs*	Italy	1.631	Q4	39	492	12.6	222
10	*Intensive Care Medicine*	USA	41.787	Q1	38	3,611	95.0	890

IF, impact factor; JCR, Journal Citation Reports; AAC, average article citations; TLS, total link strength.

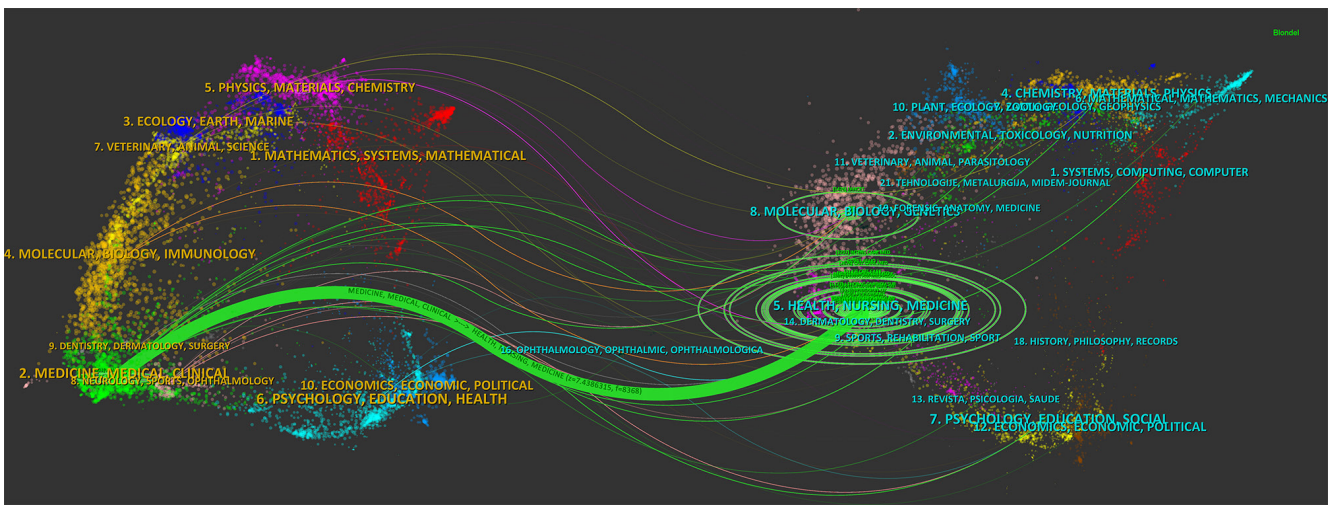

Figure 5 Dual map of CiteSpace generated journals showing the thematic distribution of journals. Citing journals are located on the left-hand side of the map, while cited journals are located on the right-hand side of the map. The labels represent the disciplines covered by the journals.

primary focus was on the complementary and supportive role of ECMO in the field of cardiothoracic surgery, as these journals were likely to have more case collections and technical studies, and the purpose of citing these journals was to provide technical support for the study. In addition, the journals in the green and blue clusters predominantly comprised journals covering intensive care medicine, which focused on basic and clinical research in intensive care medicine, and were cited for the purpose of reviewing existing research and providing existing theoretical and empirical support for their own research.

Figure 5 illustrates the citation path, which consisted of a single citation path arranged in a colored line from left to right. As observed, research from medicine/medical/clinical journals frequently cited studies from health/nursing/medical journals, as indicated by the citation paths.

Analysis of the highest co-cited references

To facilitate additional co-citation analysis of references, a summary of the ten most-cited references in the field from 2003 to 2023 was generated using VOSviewer (*Figure 6A*,

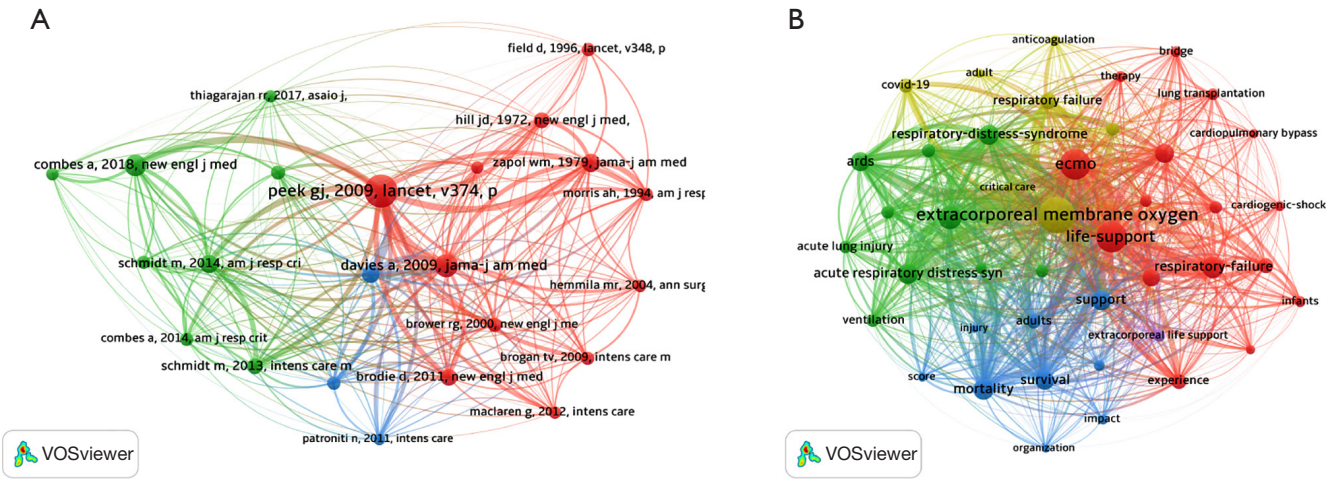

Figure 6 Visual maps of co-cited references and keywords generated by VOSviewer. (A) Co-cited references (co-citations ≥100); (B) co-cited keywords (frequency of occurrence ≥50 times).

Table 5 Top 10 keywords in terms of number of articles issued

Rank	Keywords	Occurrences	TLS
1	Extracorporeal membrane oxygenation	901	3,448
2	ECMO	647	2,544
3	Life-support	639	2,768
4	Failure	382	1,792
5	Respiratory failure	322	1,194
6	Mortality	297	1,523
7	Support	282	1,187
8	Respirator-distress-syndrome	271	1,271
9	Acute respiratory distress syndrome	265	1,249
10	Survival	254	1,286

TLS, total link strength.

Table S3). The most cited paper was "Efficacy and economic assessment of conventional ventilator support versus extracorporeal membrane oxygenation for severe adult respiratory disease", published in the Lancet by Giles J. Peek, in 2009, with a TLS of 2,084. Furthermore, this article was cited 585 times. The second resource was "Extracorporeal Membrane Oxygenation for 2009 Influenza A (H1N1) Acute Respiratory Distress Syndrome", a publication by Andrew R. Davies, that was featured 315 times in JAMA 2009 and had a TLS of 1,420. With a TLS of 815, "Extracorporeal Membrane Oxygenation for Severe Acute Respiratory Distress Syndrome" ranked third (277 times). This article was published in The New England Journal of Medicine in 2018 by Alain Combes.

Analysis of the most frequently occurring keywords

The keyword co-occurrence network view of 4,022 documents was created using VOSviewer, and 43 keywords with a frequency of ≥50 were selected for visual analysis (*Figure 6B*). In the keyword co-occurrence network view, extracorporeal membrane oxygen was categorized into four clusters, with the term itself serving as the central keyword. To enhance the clarity of the keyword specifics, the high

Keywords	Year	Strength	Begin	End	2013–2023
Lung transplantation	2013	11.29	2013	2015	
2009 influenza a (h1n1)	2013	7.12	2013	2018	
Acute lung injury	2013	6.02	2013	2015	
Bridge	2013	5.95	2013	2014	
CO_2 removal	2013	4.90	2013	2015	
Catheter	2013	4.35	2013	2015	
Influenza	2013	4.17	2013	2015	
Randomized controlled trial	2013	3.13	2013	2015	
Experience	2013	3.07	2013	2015	
Distress syndrome	2013	3.71	2014	2015	
Protective ventilation	2014	3.39	2014	2016	
Lung	2014	3.25	2014	2017	
Cardiopulmonary resuscitation	2014	4.99	2015	2016	
Resuscitation	2015	4.02	2015	2018	
Adult patients	2013	3.43	2015	2018	
Epidemiology	2019	4.47	2019	2023	
Position paper	2019	3.93	2019	2020	
Organization	2016	3.45	2019	2020	
Coronavirus disease 2019	2020	9.99	2021	2023	
Covid 19	2020	7.30	2021	2023	
Case report	2020	4.85	2021	2023	
Document	2021	4.50	2021	2023	
Cohort	2014	4.14	2021	2023	
Veno-venous extracorporeal membrane oxygenation	2017	3.50	2021	2023	
Risk factors	2013	3.30	2021	2023	

Figure 7 Key burst words generated by CiteSpace.

frequency keywords (>50) are shown in *Table 5*. The data from *Figure 6B* and *Table 5* indicate that ECMO was the most prevalent, appearing 901 times with a TLS of 3,448. ECMO ranked second with 647 occurrences and a TLS of 2,544, with a higher frequency of occurrences of the terms life-support, failure, respiratory failure, mortality, support, respirator-distress syndrome, and others that occurred frequently were representative of the field and rank next in terms of frequency.

Analysis of burst test of keywords

In order to investigate the most influential surge in keyword citations, we acquired the burst words via Citespace analysis (*Figure 7*). Pre-study hotspots included infants, children, persistent pulmonary hypertension, and life support in that order; mid-study hotspots included adult patients, CO2 elimination, bridges, acute lung injury, influenza 2009 (H1Z1), lung transplantation, and cardiopulmonary resuscitation; and most recent research frontiers were devoted to case reports, thrombosis, guidelines, and VV ECMO, etc.

Discussion

Bibliometric analysis is a crucial approach for investigating the temporal trends and knowledge structure of scientific inquiry (22,23). In addition, its involvement in numerous

biomedical domains, such as inflammation, immunity, and cancer, has been well demonstrated (24,25). Moreover, bibliometric analysis has made significant contributions to the advancement of clinical guidelines and disease treatment (26). Its functions include summarizing research interests, identifying emerging trends, and uncovering collaborative patterns within published literature. Additionally, bibliometric analysis can be used to identify unexplored areas of research topics, providing institutions and researchers with valuable guidance and insights.

The present study employed a combination of VOSviewer and CiteSpace software to visualize and analyze the literature pertaining to ECMO-assisted support for respiratory failure in the WOSCC database, in order to discern prevailing trends in ECMO research and to examine the collaboration and influence among various research institutions and countries. To achieve this, an analysis of the countries and institutions from which the articles originated was also conducted (27). The analysis focused on determining the prevailing hot research directions in the field through the utilization of keyword clustering and outbreak keyword analysis, as well as the strength of association of co-cited keywords. When it comes to constructing knowledge graphs, CiteSpace and VOSviewer each have their individual advantages that can complement each other. CiteSpace, an application built on the Java programming language, employs cluster analysis, co-occurrence analysis, and metrology to summarize and visually represent research frontiers and hot spots in the scientific literature of a particular field of study (28). Utilizing a probability-based data standardization method, VOSviewer offers a variety of visualization views in the domains of co-authors, co-institutions, and keywords, among others (e.g., overlay visualization, density, and network visualization). Notable attributes of these views include intuitive drawing capabilities and aesthetically pleasing presentations (29).

From 2003 to 2023, a cumulative sum of 1,901 articles were published pertaining to research concerning ECMO-assisted support for respiratory failure, according to literature data imported into the WOSCC database as of 15 June 2023. Commencing from 2003, the volume of research literature published in this field exhibited an annual upward trend. Moreover, a dramatic increase in the number of patients requiring ECMO-assisted support for respiratory failure was a direct consequence of the worldwide dissemination of COVID-19 between 2020 and 2022, which contributed significantly to the literature explosion in this field (30).

During the two decades of swift advancements in ECMO technology, the United States and France emerged as the frontrunner nations in terms of publication count, total citations, and TLS. Moreover, they maintained the most extensive and substantial international collaborations, which contributed significantly to the body of knowledge concerning ECMO-assisted support for respiratory failure. Geographically, European nations were actively conducive to academic exchange in this field; consequently, these nations occupied a preeminent position in research within this domain. China ranked third in terms of article publication volume; however, its comparatively modest total citations, average citation rate, and TLS suggested inadequate and superficial international relations. Consequently, there is a critical requirement to enhance article quality, communication, and collaborative research with other nations.

In terms of producing institutions, the University of Michigan held the distinction of being the scholarly establisher with the most publications, citations, and TLS. University of Michigan, a preeminent institution globally, maintains an exceptionally high academic reputation. Simultaneously, this establishment engages in close academic exchanges with other establishments and contributes to scholarly journals of superior value, demonstrating a robust integration of external collaboration. Moreover, the United States was home to five of the elite ten producing institutions. This finding supports the notion that the United States allocates adequate resources to research in ECMO-related domains, aligning with the results of the national power distribution. However, close academic exchange between institutions provides a wealth of valuable experience for excellent multi-center and extensive data research, and the analysis of institutional publications and TLS can assist researchers from various institutions in each country in identifying knowledge gaps and locating suitable collaboration and exchange partners.

With 59 publications and the highest total citations, Daniel Brodie of the United States of America ranked first among the ten authors in terms of authorship. Alain Combes of France ranked second in terms of average citations and TLS. Furthermore, when co-cited authors were considered, the researchers who had made the most substantial contributions to the field of ECMO-assisted support for respiratory failure were among the top 10 authors with a minimum of 144 co-citations. Schmidt M, (1,404 citations) ranked first in the overall analysis, with Alain Combes, and Giles J. Peek ranking close after. Furthermore, Matthieu

Schmidt, Alain Combes, and Giles J. Peek, whose research had made substantial contributions to this field and whose team of scholars made even more fruitful potential collaborators, were at the top of our comprehensive analysis. They are all highly cited authors with a solid academic collaboration network, and their contributions to this field are substantial.

With a grand total of 2,798 citations, *Asaio Journal* ranked first among journals in terms of the quantity of articles published [526]. Research and development of artificial organs, the most recent developments in the design of artificial organ devices, and the outcomes of preliminary tests comprised the majority of the articles in *Asaio Journal*. To promote the standardization of clinical application and research of ECMO technology, it is critical to investigate the distribution of major research efforts and the development process in this field, as well as to stay abreast of the latest research frontiers and development trends. In addition, these high quality journals provide a reference journal for original article submissions among scholars working on the future of ECMO research.

Extracorporeal life support was first used for extracorporeal circulation during cardiac surgery and has been used as long-term cardiopulmonary support for neonates since the first implementation of extracorporeal membrane lung technology (31,32). Although meconium aspiration syndrome affects only 3% to 9% of newborns, it is the most prevalent indication for ECMO. The present study recommends ECMO support for patients with meconium aspiration syndrome who have failed to respond to conventional conservative treatment (33). Additional indications for ECMO support in neonates include persistent pulmonary hypertension. Furthermore, timely evaluation and early ECMO-assisted support can yield favorable results in cases where conservative treatment has proven ineffective (34). Specifically, ECMO has been utilized in young and elderly populations since the 2009 influenza A (H1N1) pandemic as a bridge to recovery or transplantation (35). According to a 2017 study by Hoetzenecker *et al.*, the implementation of ECMO-assisted support for transplantation may increase survival rates and decrease the incidence of primary graft dysfunction (36). Gradually, individuals are coming to recognize the potential utility of ECMO technology in the treatment of severe cardiopulmonary failure, as its development has been substantial. The status of ECMO has been established through landmark studies including the multicenter randomized controlled trial (CESAR) of ECMO versus conventional mechanical ventilation for severe adult respiratory failure (COVID-19) in adults with severe acute respiratory failure and the study of ECMO in the treatment of severe ARDS (EOLIA) (37,38). The worldwide COVID-19 pandemic has further contributed to the increased popularity of ECMO. Accordingly, an increasing number of respiratory failure case reports caused by COVID-19 were supported by ECMO during this time period. While ECMO was crucial in ensuring the survival and stability of critically ill patients with COVID-19, its impact on reducing the mortality rate associated with severe acute respiratory distress syndrome caused by the virus was limited (39).

As ECMO research has advanced at an accelerated rate, scholars have begun to investigate its benefits before gradually shifting their focus to the potential complications associated with ECMO procedures, including bleeding and thrombosis (40). Hence, ECMO adjunct support places significant emphasis on the prevention of thrombosis and effective management of bleeding in these seemingly contradictory scenarios (41). However, due to the complexity of ECMO management and nursing, it is critical that all aspects of ECMO implementation are closely monitored and managed. The implementation of conventional monitoring techniques, including thermal dilution, is hindered by the alteration in physiological circulation mode brought about by ECMO (42). Additionally, certain imaging modalities, including computed tomography (CT) and magnetic resonance imaging (MRI), cannot be routinely examined on ECMO patients due to their critical condition and transportation challenges (43). There is an immediate demand for technologically advanced methods to precisely assess and monitor critically ill patients undergoing ECMO at their bedside. Point-of-care ultrasound (POCUS) has emerged as an indispensable technology in the domain of critical medicine due to its non-invasive nature and user-friendly operation, rendering it a crucial instrument for visual diagnosis and monitoring of critically ill patients (44). During the management of ECMO complications and at various stages of ECMO (prior to its establishment, during the establishment of the peripheral vascular pathway of ECMO, during its operation, and upon its withdrawal), POCUS can provide real-time assessments of cardiac structure and function, pulmonary lesion, volume state and responsiveness, vascular structure, and more. This capability facilitates the prompt and precise diagnosis and treatment of patients. POCUS can additionally provide clinicians with guidance during invasive procedures, including

catheterization and vascular puncture, which significantly enhances the procedure's precision and safety (45). In general, these scholarly articles showcased the advancements and refinement of ECMO technology, the investigation and progression of ECMO as a continuous support system for patients with respiratory failure, and the efficacy and safety of ECMO in clinical settings. Simultaneously, it can furnish researchers with valuable information aplenty to enhance their comprehension of the progression of knowledge structure pertaining to ECMO support.

Bibliometric analysis has the capability to furnish a broad spectrum of research hotspots within a given field and offer guidance for the subsequent progression of that field (46). Jointly conducted by CiteSpace and VOSviewer, our study is the first bibliometric visualization of ECMO-assisted respiratory failure-related research published in the Web of Science database over the past two decades. Its purpose is to provide a more precise, succinct, and comprehensible summary of research findings in this field over the past two decades. Moreover, a comprehension of the research trajectory, historical developments, and prospective orientations of ECMO-assisted support-related research in the past few years is achievable. Scientific progress must be accompanied by an evaluation of previous investigations in order to gain knowledge from the knowledge and insights of those who have come before. Consequently, clinical and biomedical bibliometrics research would be advantageous to the field of ECMO. An illustration of this would be clinical bibliometric analysis identifying research hotspots concerning ECMO as an adjunctive support for respiratory failure. Moreover, biomedical bibliometric analyses provide insights into the fluctuations of diverse indicators, including organismal immune mechanisms and metabolic mechanisms, that occur during ECMO operation. This information directs researchers' attention towards these particular facets. Enhancing the quality of life and increasing survival rate are the overarching objectives for certain patients undergoing ECMO for respiratory failure. In summary, these studies are of paramount importance in furthering the domain of ECMO research and providing ECMO assistance to patients afflicted with respiratory failure.

Despite its contribution to the advancement of ECMO in the future, this study is not without its limitations. To begin with, the Web of Science database failed to encompass certain outstanding articles in the field, including those sourced from PubMed and Embase. Consequently, we were unable to verify whether these articles were incorporated into the search strategy employed for this study, potentially introducing biased outcomes. Conversely, the reference publication requirement for this study was in English, thus certain articles written in languages other than English were temporarily excluded from consideration. Furthermore, the present investigation primarily incorporated scholarly articles published from 2003 to 2023; studies that were most recently published subsequent to the deadline for the literature search were temporarily excluded.

Conclusions

This study, in collaboration with CiteSpace and VOSviewer, conducted a systematic literature review on ECMO-assisted support for respiratory failure in the Web of Science core database. The results of research on ECMO-assisted support for respiratory failure from 2003 to 2023 were presented, enabling researchers to gain an accurate understanding of the current state of research and emerging trends in this domain.

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Footnote

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Conflicts of Interest: All authors have completed the ICMJE uniform disclosure form (available at https://jtd.amegroups.com/article/view/10.21037/jtd-23-1184/coif). The authors have no conflicts of interest to declare.

Ethical Statement: The authors are accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are

appropriately investigated and resolved.

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Supplementary

Table S1 Top 10 co-cited authors

Rank	Co-cited author	TC	TLS
1	Matthieu Schmidt	876	7,525
2	Giles J. Peek	826	6,118
3	Alain Combes	683	6,259
4	Robert H. Bartlett	538	3,559
5	Ryan P. Barbaro	361	2,973
6	Darrvl Abrams	330	3,440
7	Andrew R. Davies	323	2,987
8	Luciano Gattinoni	287	3,077
9	Daniel Brodie	279	2,682
10	Graeme MacLaren	253	2,334

TC, total citations; TLS, total link strength.

Table S2 Top 10 co-cited journals in terms of number of articles issued

Journal	Country	IF (2022)	JCR (2022)	Citations	TLS
Intens Care Med	USA	41.787	Q1	3,298	89,137
Asaio J	USA	3.826	Q3	2,786	79,176
Crit Care Med	USA	9.296	Q1	2,679	73,434
Crit Care	ENGLAND	19.334	Q1	2,142	60,550
New Engl J Med	USA	176.079	Q1	2,023	52,568
Am J Resp Crit Care	USA	30.528	Q1	1,980	56,348
Ann Thorac Surg	USA	5.102	Q2	1,947	53,505
Jama	USA	157.355	Q1	1,902	48,906
Lancet	USA	202.731	Q1	1,432	36,080
J Thorac Cardiov Surg	USA	6.439	Q1	1,377	38,731

TLS, total link strength.

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Table S3 Top 10 co-cited references

Rank	Title	Journals	Authors	Year	Citations	TLS
1	Efficacy and economic assessment of conventional ventilatory support versus extracorporeal membrane oxygenation for severe adult respiratory failure (CESAR): a multicentre randomised controlled trial	*Lancet*	Peek GJ	2009	585	2,084
2	Extracorporeal Membrane Oxygenation for 2009 Influenza A(H1N1) Acute Respiratory Distress Syndrome	*JAMA*	Davies A	2009	315	1,420
3	Extracorporeal Membrane Oxygenation for Severe Acute Respiratory Distress Syndrome	*The New England Journal of Medicine*	Combes A	2018	277	815
4	Predicting survival after extracorporeal membrane oxygenation for severe acute respiratory failure. The Respiratory Extracorporeal Membrane Oxygenation Survival Prediction (RESP) score	*American Journal of Respiratory and Critical Care Medicine*	Schmidt M	2014	213	900
5	Extracorporeal membrane oxygenation in severe acute respiratory failure. A randomized prospective study	*JAMA*	Zapol WM	1979	205	992
6	Referral to an Extracorporeal Membrane Oxygenation Center and Mortality Among Patients With Severe 2009 Influenza A(H1N1)	*JAMA*	Noah MA	2011	201	1,073
7	Extracorporeal Membrane Oxygenation for ARDS in Adults	*The New England Journal of Medicine*	Brodie D	2011	185	759
8	The PRESERVE mortality risk score and analysis of long-term outcomes after extracorporeal membrane oxygenation for severe acute respiratory distress syndrome	*Intensive Care Medicine*	Schmidt M	2013	162	819
9	Complications of extracorporeal membrane oxygenation for treatment of cardiogenic shock and cardiac arrest: a meta-analysis of 1,866 adult patients	*The New England Journal of Medicine*	Hill JD	2012	160	623
10	Acute respiratory distress syndrome: the Berlin Definition	*JAMA*	Ranieri VM	2012	142	537

TLS, total link strength.

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