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ORIGINAL RESEARCH

Mapping a Decade (2014-2024) of Research on Extracorporeal Membrane Oxygenation for Acute Respiratory Distress Syndrome: A Visual Analysis with CiteSpace and VOSviewer

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Background: Acute Respiratory Distress Syndrome (ARDS) stands as a primary cause of mortality among critically ill patients. Extracorporeal Membrane Oxygenation (ECMO) is increasingly employed in the rescue therapy of ARDS patients. However, the current status of research in the field of ECMO-assisted ARDS remains unclear.

Objective: This research aims to categorize and evaluate the literature regarding Extracorporeal Membrane Oxygenation (ECMO) support for Acute Respiratory Distress Syndrome (ARDS), offering a comprehensive analysis of bibliometric properties, research hotspots, and developmental trends within the domain of ECMO-assisted ARDS.

Methods: A literature search was conducted for ECMO-assisted support for patients with ARDS in the Web of Science Core Collection (WoSCC) database from 2014 to 2024. We employed visualization tools such as CiteSpace and VOSviewer to explore and assess connections among nations, institutions, researchers, and co-cited journals, authors, references, and keywords.

Results: This study included 1739 publications. The United States leads in publication volume with Columbia University at the forefront of ECMO research. Intensive Care Medicine has been identified as the most cited journal in this field. Alain Combes from France stands out as a key contributor, particularly in his 2018 publication in the New England Journal of Medicine, which is the most cited work in the discipline. Furthermore, keyword analysis identified three distinct research phases: examining complications associated with ECMO therapy, exploring optimal strategies for mechanical ventilation under ECMO support, and compiling insights into the application of ECMO in treating COVID-19 patients and in the development of predictive models for patient outcomes.

Conclusion: Using bibliometric visualization techniques, this study revealed significant progress in the use of ECMO for treating ARDS respiratory support, evaluated the impact of these findings, and outlined potential areas for future studies.

Keywords: extracorporeal membrane oxygenation, ECMO, acute respiratory distress syndrome, ARDS, visual analysis, bibliometrics

Introduction

Acute Respiratory Distress Syndrome (ARDS) represents a complex spectrum of clinical conditions arising from diverse causes, and is characterized by shared clinical and pathological features. These include increased permeability of the alveolar-capillary barrier leading to inflammatory edema, significant reductions in lung compliance due to augmented non-ventilated areas, and elevated levels of pulmonary shunting and dead space ventilation, which contribute to severe impairment of gas exchange, such as hypoxemia and hypercapnia.[1] In the intensive care unit, ARDS accounts for approximately 10% of all admissions and affects approximately 23% of the patients requiring mechanical ventilation. The severity of this condition is highlighted by its high mortality rate, which can reach up to 45%.[2]

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Contemporary therapeutic approaches for ARDS emphasize the identification and management of infections, the use of protective mechanical ventilation, the practice of prone positioning, the control of sedation and muscle relaxation, fluid management strategies, and the application of extracorporeal membrane oxygenation (ECMO).[3] ECMO, which improves oxygenation and facilitates the removal of carbon dioxide, helps reduce dependence on mechanical ventilation, allowing the lungs to recuperate, thereby mitigating ventilation-induced lung injury (VILI), and is thus considered a rescue therapy for severe ARDS cases. Since the 2009 H1N1 influenza pandemic, followed by the 2013 outbreak of H7N9 avian influenza and the worldwide health emergency triggered by COVID-19 in 2020, the role of ECMO technology in managing ARDS has become increasingly critical. During these epidemic outbreaks, when traditional treatments fail to manage the condition, ECMO is frequently used as a life-saving intervention to sustain the vital functions of patients with severe ARDS.[4,5]

Bibliometric analysis is a crucial method for examining temporal developments and frameworks of knowledge in scientific studies.[6,7] This approach has been validated and is effective across several biomedical subfields including research on inflammation, immune responses, and cancer.[8,9] Tools such as CiteSpace and VOSviewer possess distinct advantages that enhance the construction of knowledge graphs when used together. CiteSpace, created by Chen et al, functions as a citation visualization tool.[6,10] It utilizes techniques such as co-occurrence, co-citation, and cluster analyses to graphically depict and summarize research frontiers and emerging hotspots in the scientific literature of a specific domain. Utilizing methods based on probability for data normalization, VOSviewer provides multiple visualization views (such as networks, overlay visualization, and density visualization) in areas such as national, regional, and institutional collaborations.[11]

This study used both CiteSpace and VOSviewer to visualize and analyze publications on ECMO-assisted support for ARDS within the Web of Science Core Collection (WoSCC) database. Our analysis explores collaboration networks and their contributions to the field from various nations, regions, research institutions, scholars, and journals. Through detailed co-citation analysis, we delineated the historical trajectory of knowledge development in this discipline. Furthermore, keyword cluster analysis and the examination of emerging keywords allowed us to identify major research hotspots and trends, providing crucial insights for future research directions in the domain.

Method

Data Collection and Screening

We selected the WoSCC database as our primary source of information because of its comprehensive academic resources and high data integrity, which are ideal for bibliometric analysis.[12] Our search strategy was defined by the following criteria: (TS=("Extracorporeal membrane oxygenation" OR "ECMO") AND TS=("Acute respiratory distress syndrome" OR "ARDS") and PY = (2014–2024)). The search covered the period from January 2014 to March 2024, up and to March 26, 2024. We limited the document types to articles and reviews, and restricted inclusion to works published in English. The databases searched included SCI-EXPANDED, SSCI, CCR-EXPANDED, and IC. Initially, 2243 documents were retrieved; after the exclusion of 454 non-research papers and reviews as well as 50 non-English documents, 1739 documents remained for inclusion in the analysis. To ensure the accuracy and reliability of our study, we employed the CiteSpace software (version 6.2. R4) for data preprocessing, which included the removal of potential duplicate entries (Figure 1). As all the data were sourced from publicly accessible databases, this study did not require ethical approval.

Statistical Analysis

In our bibliometric analysis, we primarily focused on two key areas: co-authorship and co-citation analyses. Co-authorship analysis assesses collaborative relationships among authors by examining the number of jointly authored papers, effectively revealing trends in scientific collaboration and identifying influential countries, institutions, and researchers within specific fields. Co-citation analysis, on the other hand, involves the examination of instances where two or more authors, journals, or references are cited together in subsequent publications.[13] The frequency of such co-citations provides insights into the interconnections and influences among different research topics or fields.

VOSviewer (version 1.6.20) was used to conduct a co-authorship analysis of nations, regions, and institutions. In addition, a multidimensional bibliometric evaluation was performed using CiteSpace. This includes co-authorship

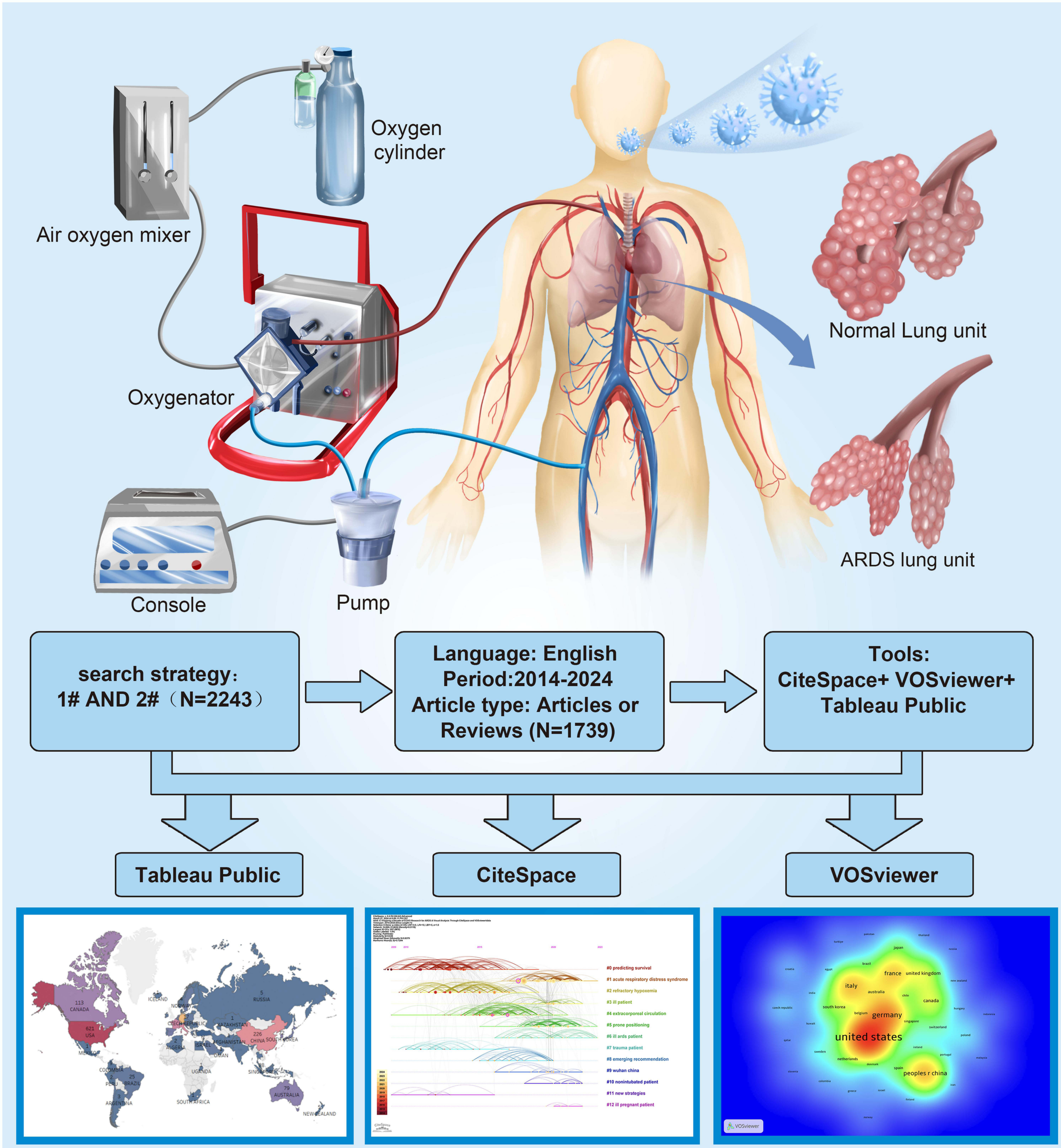

Figure 1 Schematic of the publication selection process and bibliometric tools for the study.
Abbreviations: ARDS, Acute Respiratory Distress Syndrome.

analysis of authors, co-citation analysis of authors, journals, and references, journal dual-map overlays, keyword co-occurrence, and citation bursts.

Results

Global Trends in Publication Output and Citation

After conducting a detailed analysis of data from the WoSCC database over the past decade, we compiled a dataset of 1739 academic papers that specifically focused on ECMO-assisted treatment for ARDS (Figure 1). These publications were distributed across 380 different journals and authored by 9983 researchers from 345 countries or regions, involving 7860 research institutions worldwide. Our analysis indicated a continuous increase in the number of studies published in this area over the past decade, exhibiting a significant exponential growth trend in cumulative publications ($R^2 = 0.9888$). In particular, at the end of 2019, coinciding with the global outbreak of COVID-19, there was a dramatic increase in the volume of publications, with 2021 marking a significant peak of 302 papers (Figure 2).

Country / Region Contribution

North America and Europe were leading contributors to research publications in this academic field (Figure 3A). Furthermore, Figure 3B shows the volume and trends of publications over the past decade for the top ten countries, ranked by publication volume. The United States stands out significantly, with 624 papers accounting for 35.88% of the total publications, which is more than double the number from Germany, contributing 304 papers (17.48%), as detailed in Table S1. The contributions from the United States are notable not only in volume but also in quality, with 17244 citations, far surpassing any other country and clearly demonstrating its leadership in this research domain. Other notable contributions came from Germany, China, and Italy, each surpassing 200 publications. Although France and Canada published fewer than 200 papers, with a total of 187 and 113, respectively, their high citation rates per paper - 66.3 and 85.8 respectively - highlight the impact and significance of their research.

The data presented in Figure 3C covers 45 countries/regions, with the United States (495), Italy (345), and France (338) leading in terms of Total Link Strength (TLS). A 3D density map based on the total cooperation scores among countries (Figure 3) revealed that collaborations are primarily among European and American countries. The highest

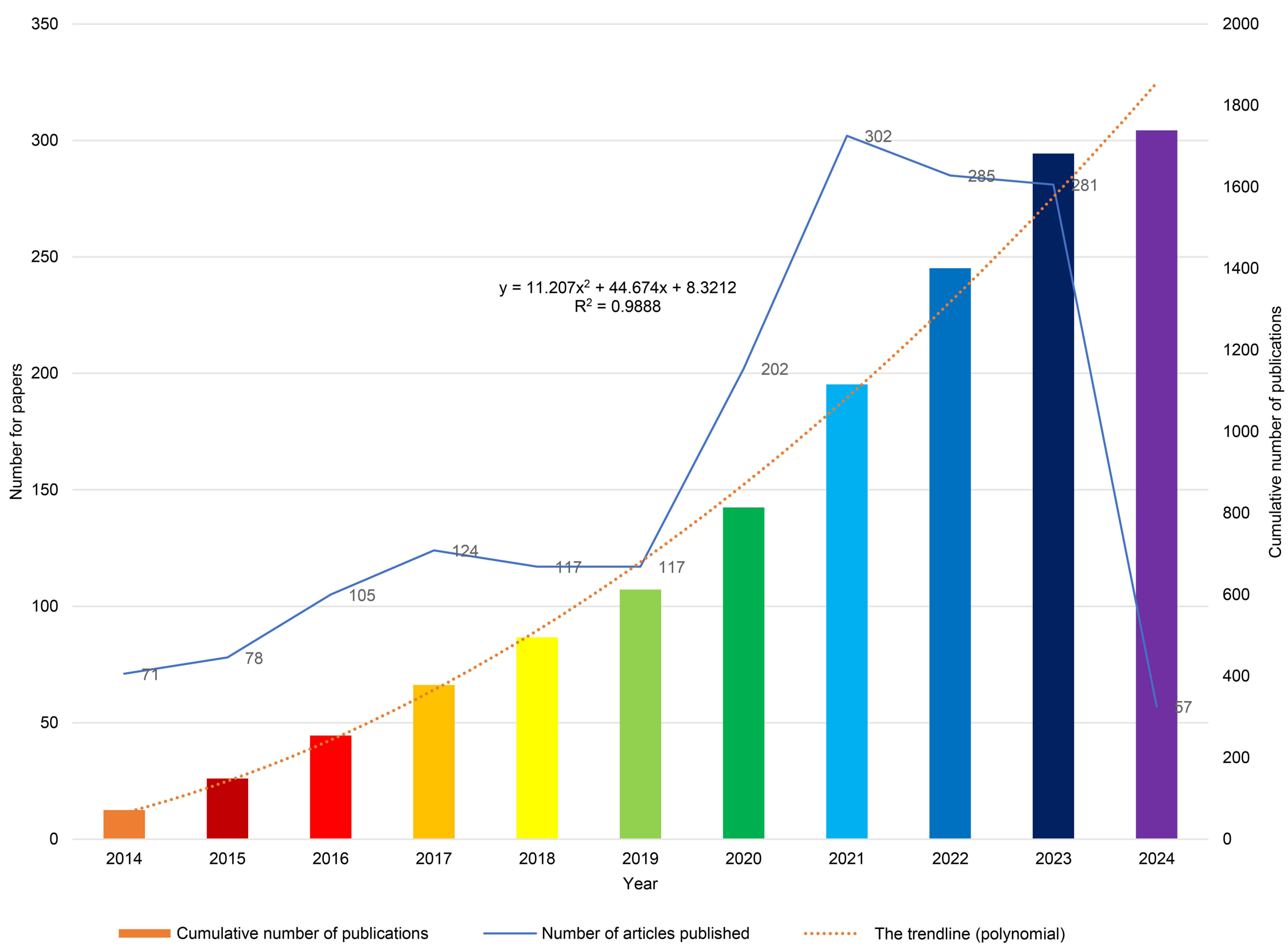

Figure 2 Observed Trends in Articles Published Per Year.

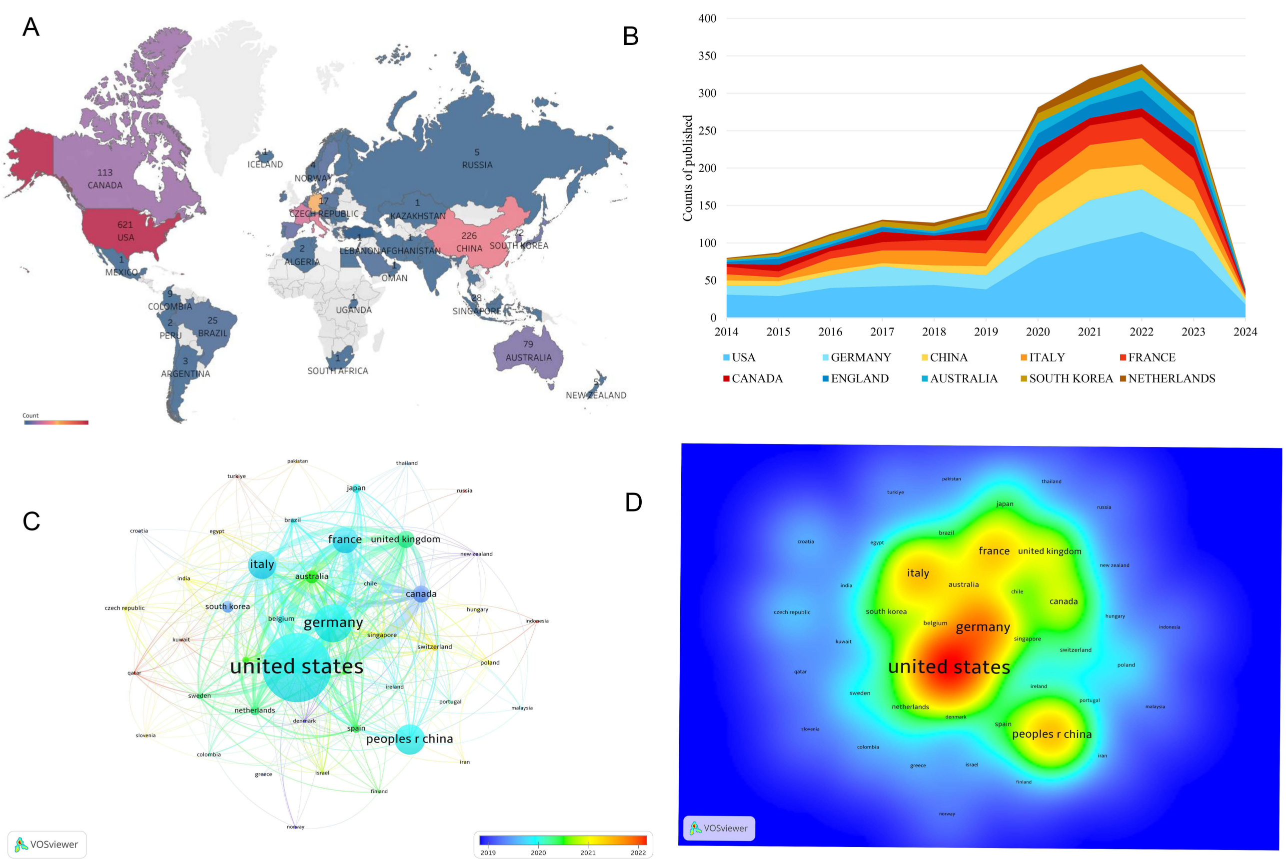

Figure 3 Visualizing ECMO-Assisted Support for ARDS in a Global Context.

Notes: Figure 3 provides a comprehensive visual representation of the global research landscape for ECMO-assisted support for ARDS. (**A**) illustrates the geographical distribution of scholarly articles, showing the total count by countries/regions. (**B**) details the variations in the annual publication counts from the top ten countries/regions over the past decade. (**C**) features an overlay visualization of international collaboration on ECMO-assisted support for ARDS, where the quantity of articles is represented by the size of the circles and the level of international cooperation is indicated by the line thickness. (**D**) presents a map that shows the density of international collaborations within the field, with the intensity of cooperation illustrated by a color gradient that transitions from blue to red (blue, green, yellow, red), indicating increasing intensity.

Abbreviations: ECMO, Extracorporeal Membrane Oxygenation; ARDS, Acute Respiratory Distress Syndrome.

degrees of cooperation were observed among the United States, Germany, Italy, Australia, France, and the United Kingdom. As the principal contributor, the United States not only leads to publication volume but also demonstrates its leadership in international collaboration, maintaining robust academic exchanges, and cooperative relationships with multiple countries, including Germany, the UK, Italy, France, and Canada.

Contribution of Top Institutions

The top 10 institutions in this domain are primarily based in North America and Europe, with four located in the United States and two in France (Table 1). Columbia University ranks first with 61 publications, followed closely by the University of Toronto and Sorbonne University. In terms of collaboration intensity, these institutions are ranked among the top three. Regarding citation impact, the leaders are Columbia University with 8003 citations, the University of Toronto with 7529, and Sorbonne University with 3970. Collectively, these metrics—publication volume, collaboration intensity, and total citation counts— highlight the significant academic influence of Columbia University, the University of Toronto, and Sorbonne University, with Columbia University leading in all categories.

According to the overlay views generated by VOSviewer (Figure 4), the top research institutions in North America and Europe, including Columbia University, the University of Toronto, and the Mayo Clinic, are recognized as pioneers in the domain of ECMO-assisted ARDS treatment.

Table 1 Top 10 Institutional Contributors to Publications

Rank	Organization	Country	Documents	TC	ACC	TLS
1	Columbia University	United States of America	83	8003	96.4	224
2	University of Toronto	Canadian	72	7529	104.6	187
3	Sorbonne University	French	56	3970	70.9	152
4	University of Michigan	United States of America	43	3692	85.8	116
5	University of Maryland	United States of America	42	476	11.3	27
6	Hôpital de la Pitié-Salpêtrière	French	40	3627	90.7	114
7	University of Milan	Italy	40	1441	36.0	86
8	The University of Queensland	Australia	36	1556	43.2	90
9	The University of Pennsylvania	United States of America	33	514	15.6	46
10	Albert Ludwig University of Freiburg	German	32	550	17.2	39

Abbreviations: TC: Total Citation Count; ACC: Average Article Citation Count; TLS: Total Link Strength.

Distribution of Co-Cited Journals and Journal Biplot Overlays

Figure 5 presents a comprehensive network diagram featuring 770 co-cited journals connected by 3355 collaborative links. Co-cited journals refer to those referenced together in other research, indicating a shared relevance or thematic connection within the field. Journal co-citation analysis enables mapping of essential knowledge sources across a

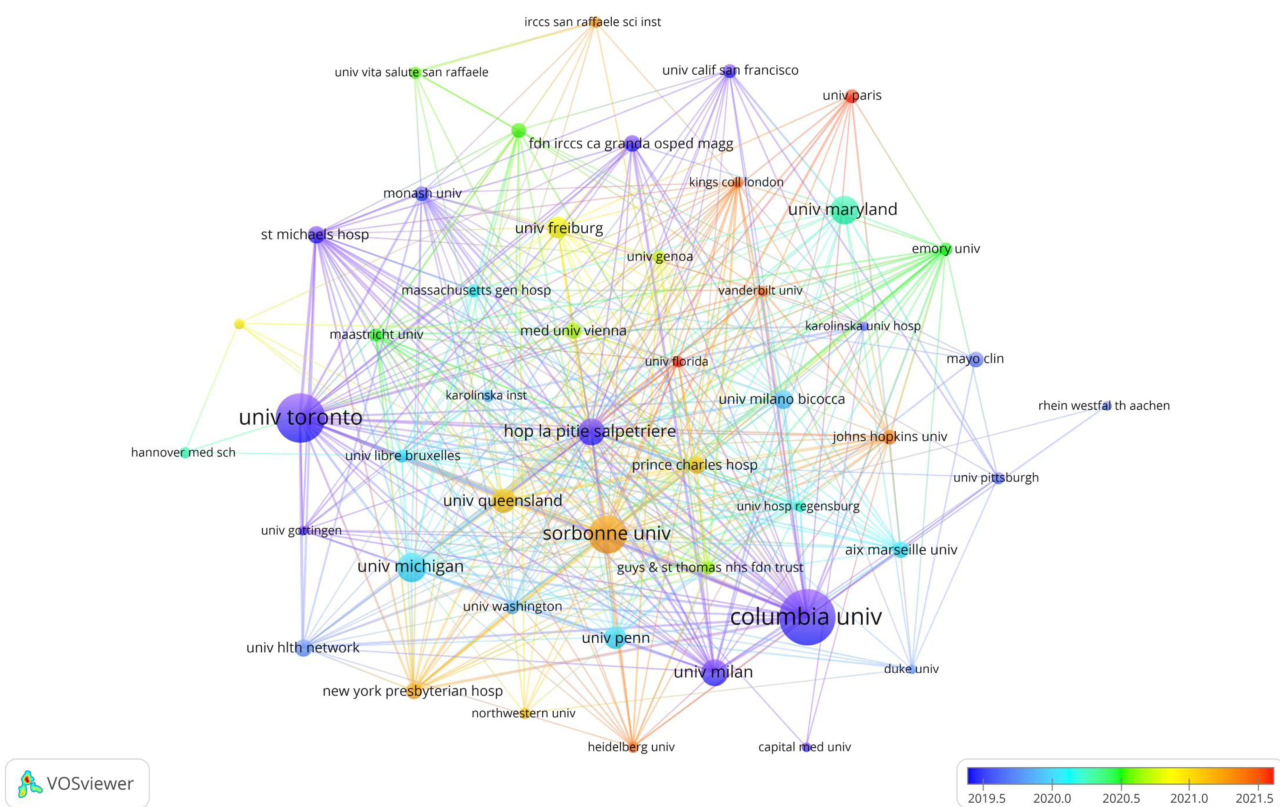

Figure 4 Institutional Visualization Diagram.
Notes: The color gradient from blue to red (blue, green, yellow, red) represents the chronological order in which institutions entered the research field.

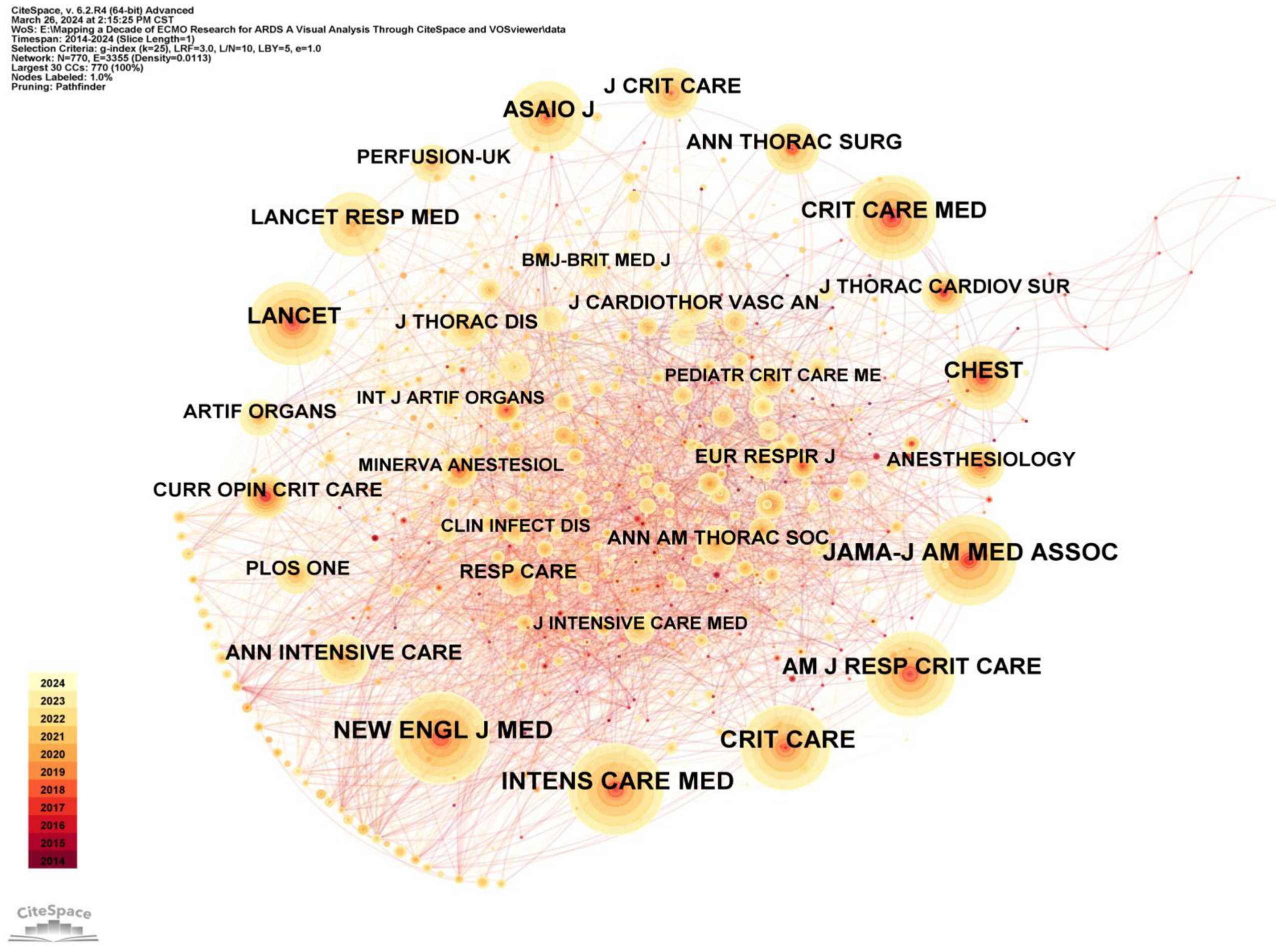

Figure 5 A Network Diagram of Co-cited Journals.
Notes: In Figure 5, each node in the network diagram represents a co-cited journal. The size of each node reflects its frequency of co-citation.

discipline,[14] highlighting how various journals contribute to the spread of essential research insights. Table 2 lists the ten journals most frequently co-cited in relation to ECMO-assisted ARDS research. Notable among these are Intensive Care Medicine with 1227 articles, the New England Journal of Medicine with 1184 articles, and Critical Care with 1123 articles. However, it is noteworthy that none of these journals exhibited betweenness centrality exceeding 0.1.

The dual overlay of the journal maps in Figure 6 demonstrates the citation connections between the citing and co-cited journals. The left panel displays a cluster of citing journals and the right panel shows a cluster of cited journals.[15] The green pathway highlighted in this Figure 6 represents the principal citation route, indicating that research articles from Medicine/Medical/Clinical journals primarily cite works from Molecular/Biology/Genetics and Health/Nursing/Medicine domains.

Distribution of Authors and Co-Cited Authors

In terms of publication volume, Alain Combes from France and Daniel Brodie from the USA each led to 62 papers, followed by Matthieu Schmidt from France (Figure 7, Table S2). Professors such as Alain Combes, Philipp M. Lepper, Konrad Hoetzenecker, and Aakash Shah exhibited high betweenness centrality in the author network map, reflecting their "bridging" role. Despite fewer frequent publications, these authors crucially connect diverse research themes and knowledge domains. However, the author network map revealed a low density (0.014), indicating that the research community was relatively dispersed. There is a significant need to strengthen collaboration, facilitate the sharing of research findings across various geographical and disciplinary boundaries, and encourage the ongoing progress in academic research.[14]

Table 2 Top 10 Co-Cited Journals for Publication Contribution

Rank	Co-cited Journal	Article counts	Centrality	IF (2022)	JCR (2022)
1	Intensive Care Medicine	1227	0.01	38.9	Q1
2	The New England Journal of Medicine	1184	0.00	158.5	Q1
3	Critical Care	1123	0.01	15.1	Q1
4	Journal of the American Medical Association	1123	0.00	47.7	Q1
5	American Journal of Respiratory and Critical Care Medicine	1060	0.00	24.7	Q1
6	Critical Care Medicine	1009	0.01	8.8	Q1
7	LANCET	984	0.01	168.9	Q1
8	ASAIO Journal	823	0.00	4.2	Q2
9	CHEST	699	0.00	10.1	Q1
10	LANCET RESP MED	635	0.01	76.2	Q1

Abbreviations: IF, Impact factor; JCR, Journal Citation Reports.

In the analysis of co-cited authors, Alain Combes had the highest co-citation count of 606, closely followed by Matthieu Schmidt (588), and Giles J. Peek (578) (Figure S1, Table S2). This examination allowed for rapid identification of researchers who have significantly influenced the field. The data indicate that Giles J. Peek had considerable early influence, Luciano Gattinoni had a significant impact during the mid-term, and Alain Combes emerged as the most influential co-cited author in recent times, demonstrating dynamic shifts in influence within the field.

Co-Citation Literature Analysis

As illustrated in Figure 8A, the co-citation network diagram contained 628 nodes and 720 links, showing intricate interconnections among highly referenced works. Table 3 lists the top 10 co-cited references within this domain, notably

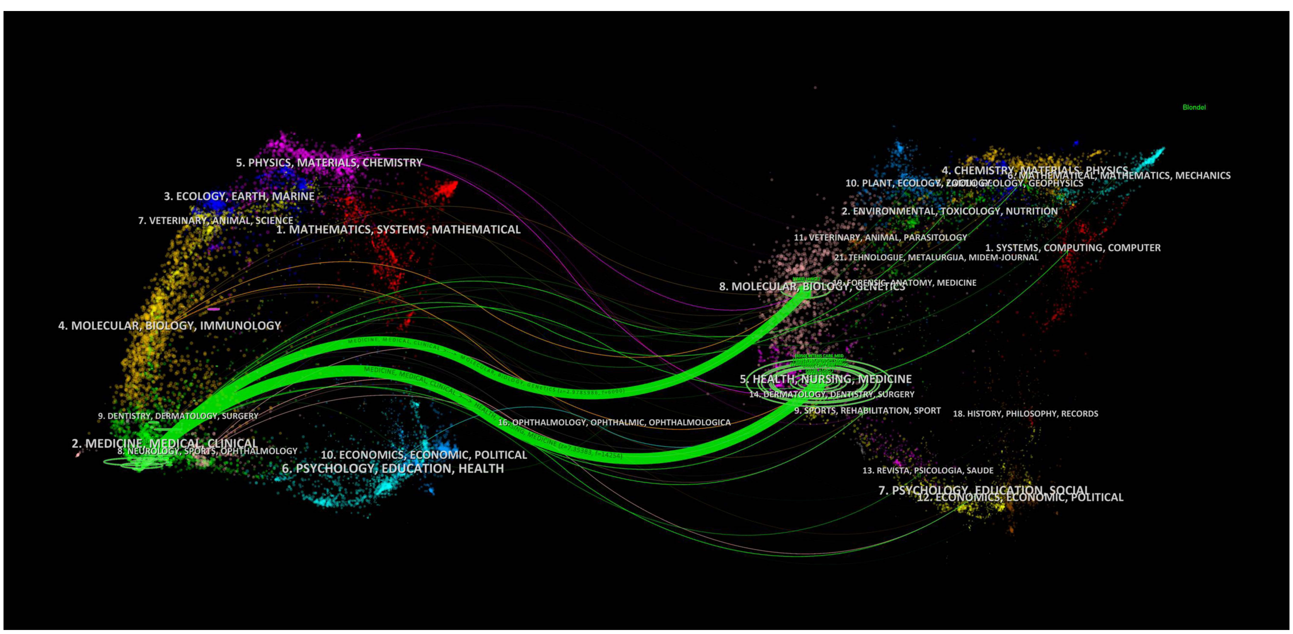

Figure 6 A dual-overlay created by CiteSpace, displaying the subject spread among the journals.
Notes: The labels on this diagram indicate the academic fields represented by the journals.

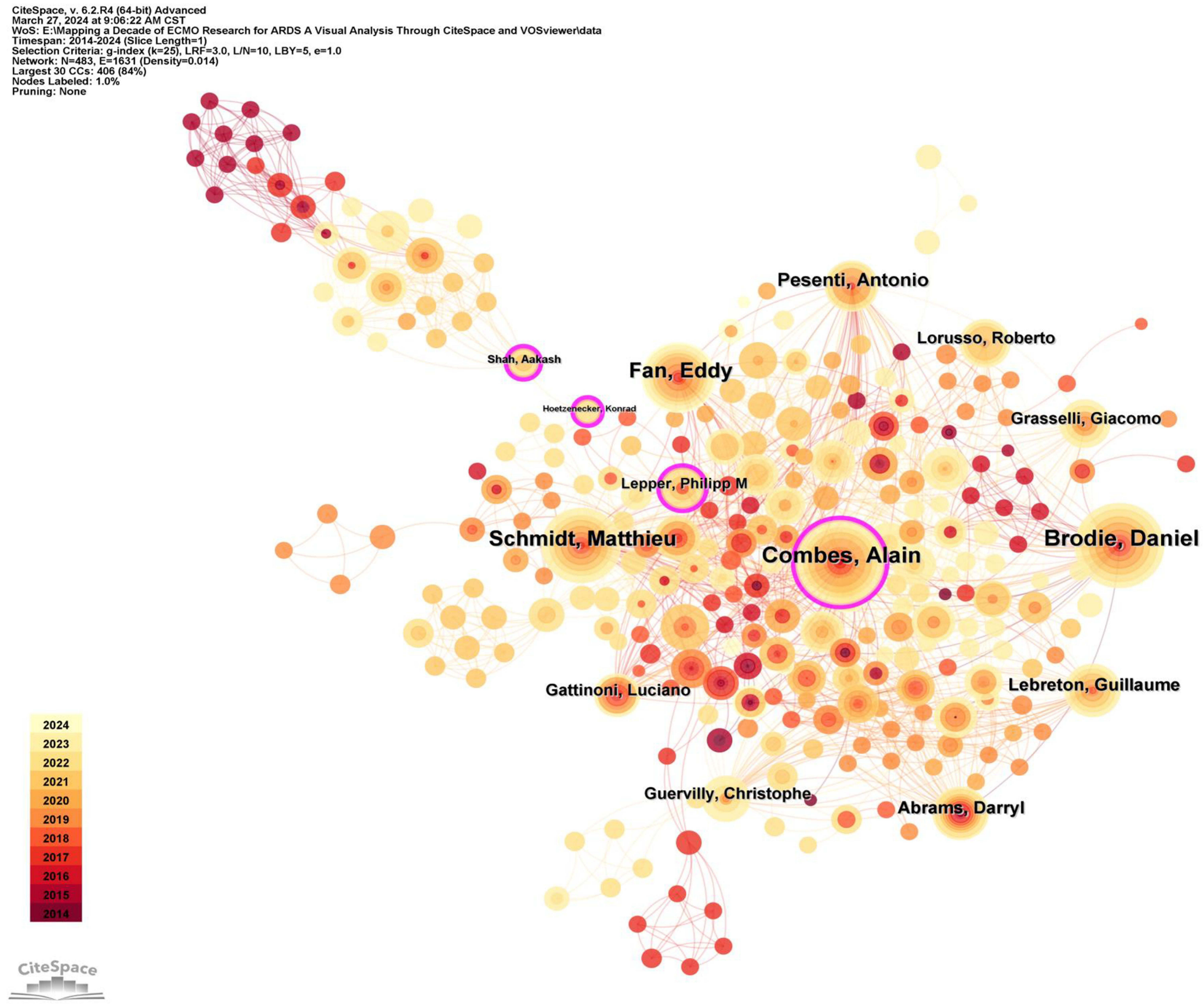

Figure 7 Author Collaboration Network.

Notes: The network graph in Figure 7 visually illustrates the collaborations among authors within the field of ECMO-assisted management for ARDS. Each node on the graph represents a single author, with the node size indicating the quantity of articles published by that author. Nodes outlined with purple edges highlight authors with higher betweenness centrality; the thicker the purple edges, the more significant their betweenness centrality. This graphical representation helps identify key contributors and central figures in the research network.

featuring publications in prestigious journals such as The Lancet (1), The New England Journal of Medicine (2), The Journal of the American Medical Association (3), and The Lancet Respiratory Medicine (2). Six of these references were cited more than 100 times each, indicating their foundational role in the field, while others had citation counts between 88 and 99. Notably, the works of Professors Ryan P. Barbaro and Matthieu Schmidt stand out with higher centralities at 0.06, compared with other articles, with centralities ranging from 0.00 to 0.05.

The analysis further identified 22 clusters, 13 of which were dominant and contained the most cited references. This cluster analysis yielded a modularity Q-value of 0.638, well above the threshold of 0.300, and a silhouette score of 0.8379, significantly exceeding the benchmark of 0.700, both of which demonstrate the robustness and reliability of the clustering outcomes (Figure 8B). Additionally, a timeline graph (Figure 8C) was constructed to trace the temporal evolution of research hotspots within this domain. Among these 13 clusters, clusters 0 and 2, which focused on improving ARDS patient survival rates and managing refractory hypoxemia through ECMO-assisted therapy, were identified as early research hotspots that have seen a decline in recent years. Currently, the most prominent research hotspot is cluster 5, which examines the integration of ECMO with prone position ventilation in the treatment of patients with severe ARDS.

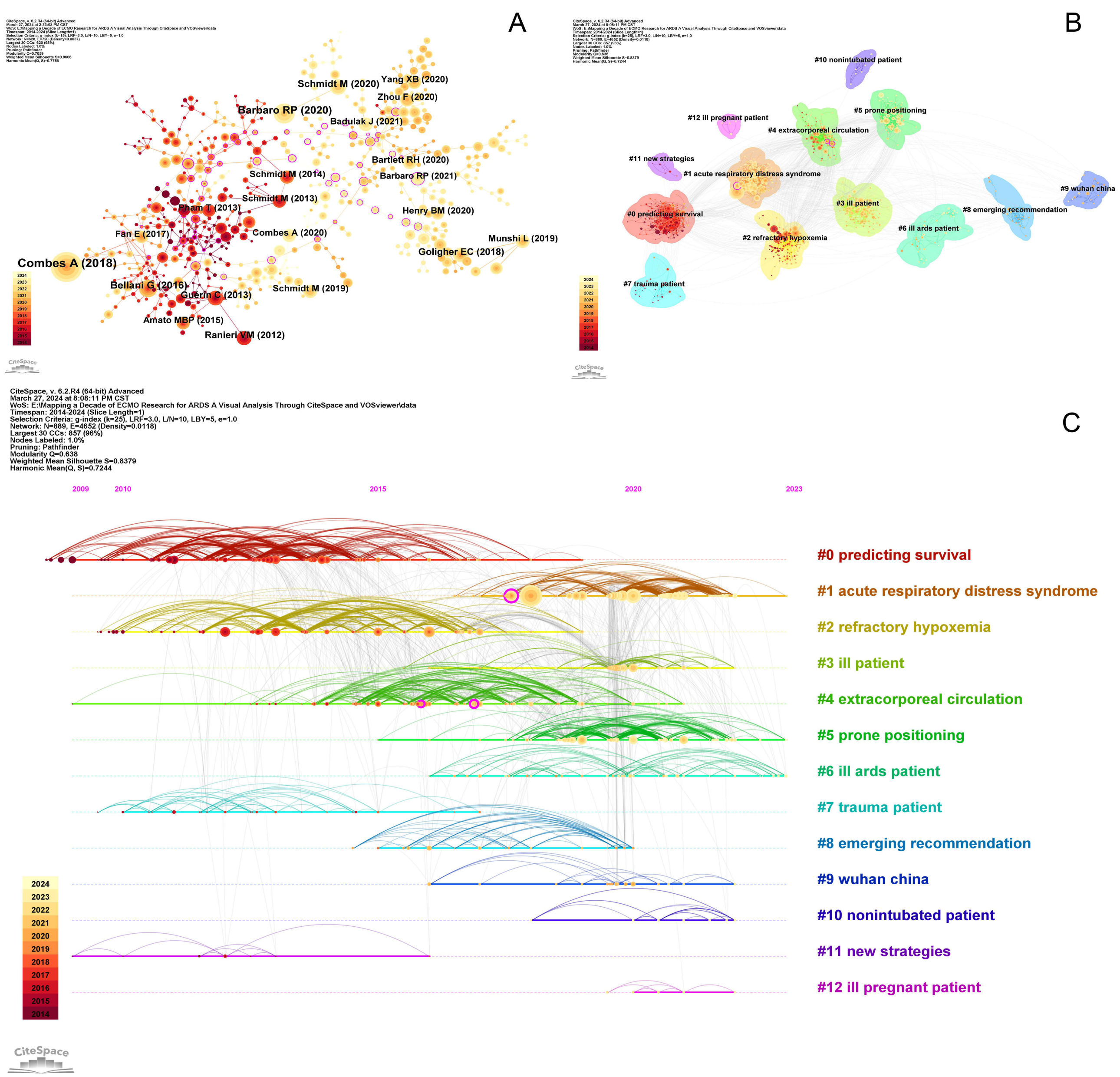

Figure 8 Co-citation Network Analysis.

Notes: Figure 8 presents detailed network diagrams illustrating the co-citation of references within the field. Each node in the diagram symbolizes a co-cited reference. (**A**) Literature co-citation network. The size of each nodes represents the frequency of co-citation, while the thickness of the connecting lines demonstrates the closeness of the relationship between the literature. Cooler colors represent older literature, while warmer colors indicate more recent publications. Nodes encircled by purple rings signify high betweenness centrality, marked at greater than 0.1. (**B**) Cluster diagram of reference co-citations. This diagram uses various colors to distinguish different groups of co-cited literature; (**C**) Timeline and cluster analysis of co-cited literature. The size of the literature nodes and the breadth of the connecting lines respectively illustrate the frequency of co-citations and the intimacy of the relationships between the documents.

Keywords Analysis

A total of 636 keywords were identified, 15 of which occurred more than 100 times. Table S3 lists the top 15 most frequently occurring keywords, with "extracorporeal membrane oxygenation" leading at 962 occurrences, followed by "acute respiratory distress syndrome" at 601, and "respiratory distress syndrome" at 349, which is consistent with our research theme. The frequencies of other keywords ranged from 113 to 281. A network density of 0.0278 observed in keyword co-occurrence maps is generally considered low, indicating that the literature covers a broad range of topics (Figure 9A). Twelve clusters were generated using the log-likelihood ratio (LLR) algorithm to index keyword terms, including diverse themes, such as #0 extracorporeal membrane oxygenation, #1 protective ventilation, #2 thrombosis, #3

Table 3 Top 10 Co-Cited Literature

Rank	Title	Journals	Authors	Year	Citations	Centrality	Research type
1	Extracorporeal Membrane Oxygenation for Severe Acute Respiratory Distress Syndrome	NEW ENGL J MED	Alain Combes	2018	422	0	Randomized Controlled Trial
2	Extracorporeal membrane oxygenation support in COVID-19: an international cohort study of the Extracorporeal Life Support Organization registry	LANCET	Ryan P Barbaro	2020	193	0.06	Cohort study
3	Epidemiology, Patterns of Care, and Mortality for Patients With Acute Respiratory Distress Syndrome in Intensive Care Units in 50 Countries	JAMA-J AM MED ASSOC	Giacomo Bellani	2016	148	0.01	Observational Study
4	Extracorporeal membrane oxygenation for severe acute respiratory distress syndrome associated with COVID-19: a retrospective cohort study	LANCET RESP MED	Matthieu Schmidt	2020	117	0.06	Retrospective cohort study
5	Prone positioning in severe acute respiratory distress syndrome	NEW ENGL J MED	Claude Guérin	2013	106	0.02	Randomized Controlled Trial
6	Acute respiratory distress syndrome: the Berlin Definition	JAMA-J AM MED ASSOC	V Marco Ranieri	2012	102	0	Guideline
7	Extracorporeal Membrane Oxygenation for Severe Acute Respiratory Distress Syndrome and Posterior Probability of Mortality Benefit in a Post Hoc Bayesian Analysis of a Randomized Clinical Trial	JAMA-J AM MED ASSOC	Ewan C Goligher	2018	99	0.02	Comparative Study
8	Extracorporeal Membrane Oxygenation for COVID-19: Updated 2021 Guidelines from the Extracorporeal Life Support Organization	ASAIO J	Jenelle Badulak	2021	90	0.03	Guideline
9	Venovenous extracorporeal membrane oxygenation for acute respiratory distress syndrome: a systematic review and meta-analysis	LANCET RESP MED	Laveena Munshi	2019	89	0.01	Meta-Analysis
10	Predicting survival after extracorporeal membrane oxygenation for severe acute respiratory failure. The Respiratory Extracorporeal Membrane Oxygenation Survival Prediction (RESP) score	AM J RESP CRIT CARE	Matthieu Schmidt	2014	88	0.05	Multicenter Study

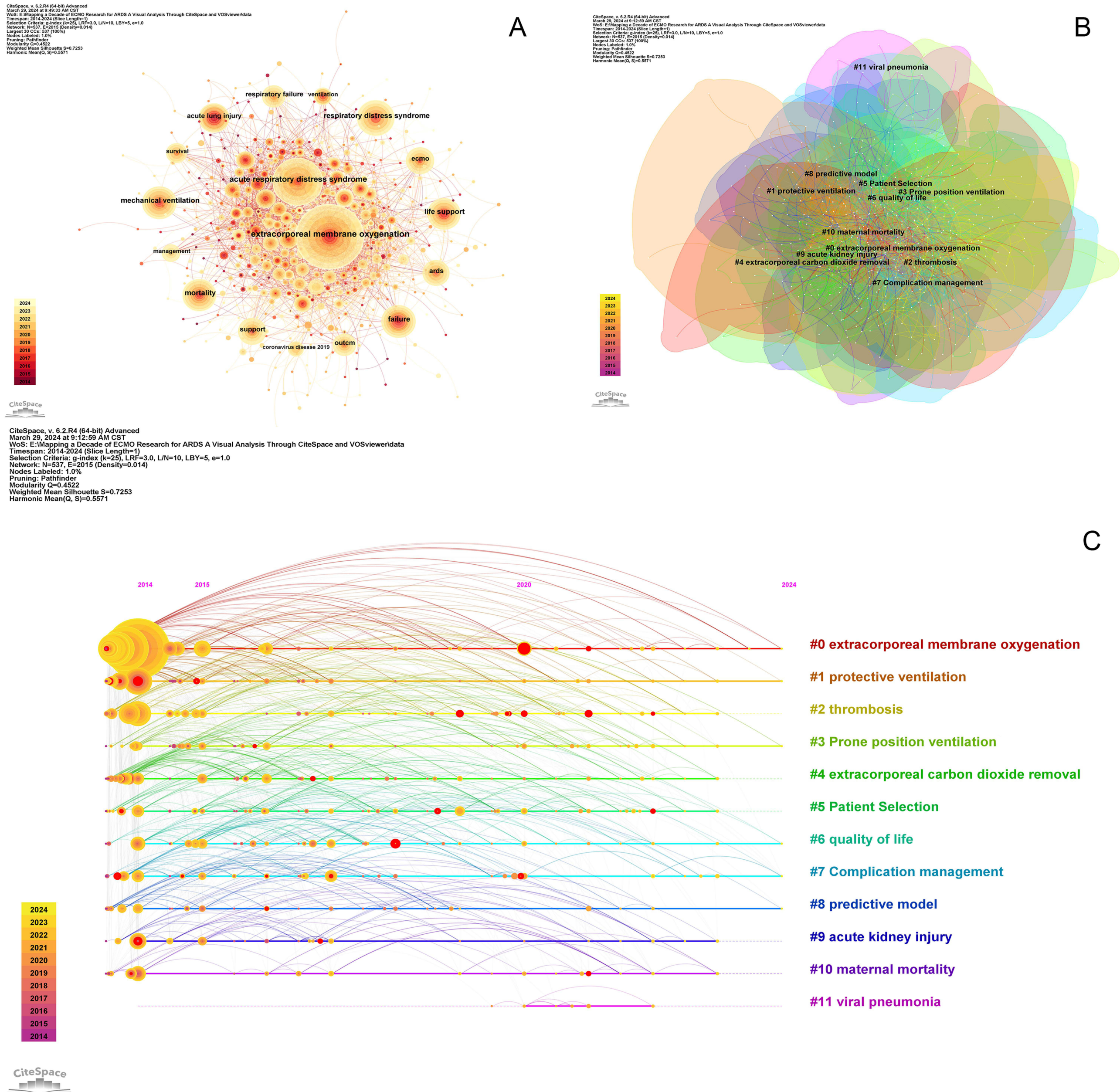

Figure 9 Keyword Visualization and Analysis.

Notes: Figure 9 shows a comprehensive visualization of the keyword network within the domain, where each node corresponds to a keyword. The connections between nodes illustrate the co-occurrence relationship among keywords. (**A**) In the keyword network, the size of each node reflects the frequency of keyword occurrences, and the thickness of the lines between nodes represents the closeness of the relationship between keywords. (**B**) Keyword clustering graph, which distinguishes clusters of keywords by different colors, each representing a distinct thematic group. (**C**) Keyword timeline and clustering view, where the sizes of the nodes are determined by keyword frequencies. The red ring around a node identifies a sudden increase in citations, showing emerging or hot topics within the field.

Abbreviations: ECMO, Extracorporeal Membrane Oxygenation; ards, Acute Respiratory Distress Syndrome; outcm, Outcome.

prone position, #4 extracorporeal carbon dioxide removal, #5 patient selection, #6 quality of life, #7 complication management, #8 predictive model, #9 acute kidney injury, #10 maternal mortality, and #11 viral pneumonia (Figure 9B). The average silhouette value of the 12 clusters exceeded 0.7, suggesting a high uniformity and reliable analytical results. Additionally, to examine the temporal characteristics within the research fields represented by each cluster, a keyword timeline graph was constructed (Figure 9C).

"Burst keywords" are terms that have been frequently cited over a defined period.[14] Figure 10 displays the 30 keywords that have exhibited the most significant surge in citations since 2014. The red bars represent the emergence and

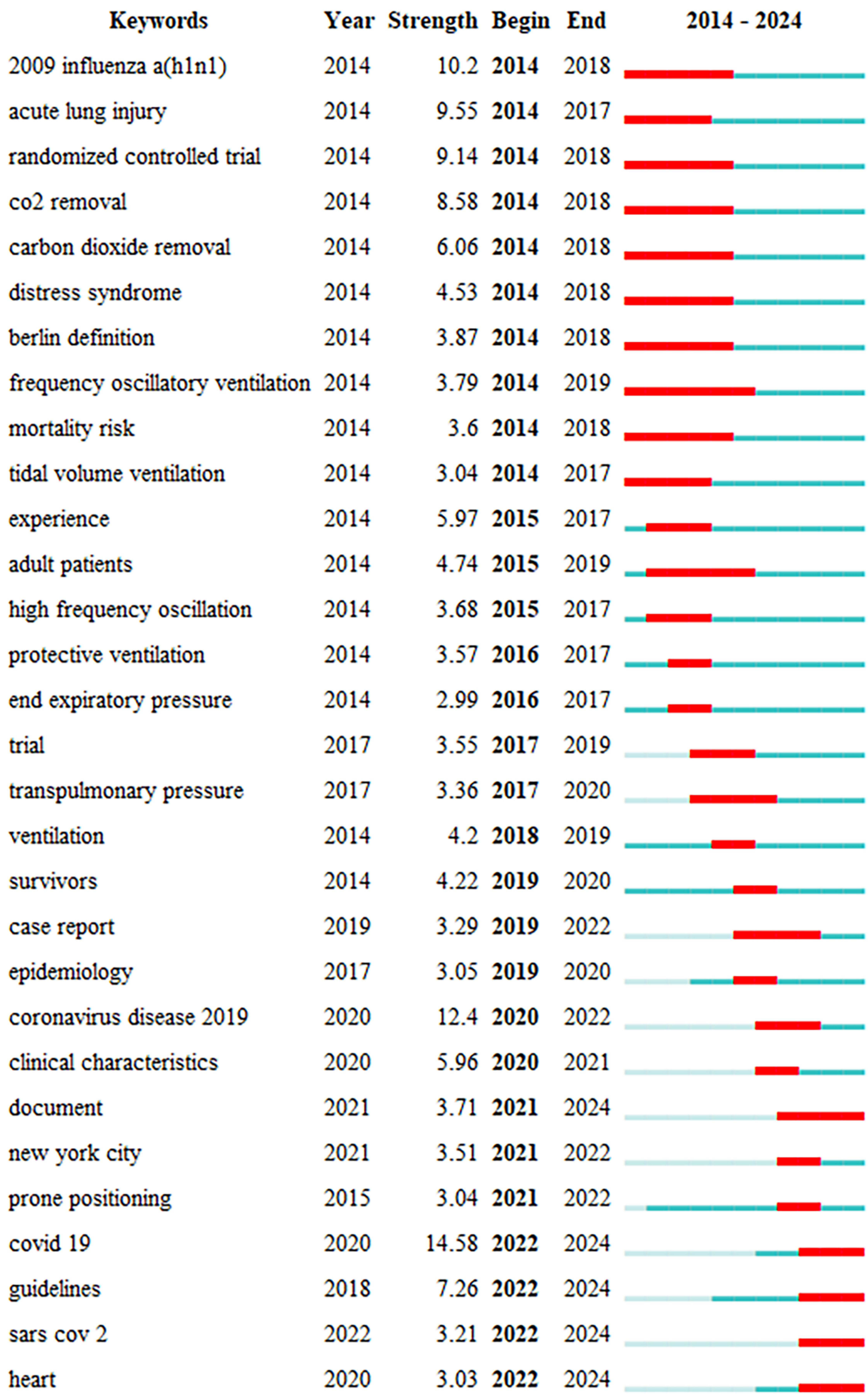

Figure 10 Analysis of Keywords Citation Bursts.

Notes: Figure 10 showcases the top 30 keywords that have experienced the most significant bursts in citations. The graph tracks the "start" to "end" timeframe for each keyword, illustrating the duration of heightened influence. Light blue years indicate years when the keyword had not been introduced; dark blue years reflect years with a more restricted impact of the keyword, and red years highlight times of substantial influence.

persistence of research hotspot,[16] with burst durations range from one to five years. Keywords such as "Randomized controlled trial" (2014–2018), "Berlin definition" (2014–2018) and "CO_2 removal" (2014–2018) received the most prolonged attention. Recently, keywords like "COVID-19", "SARS-CoV-2", and "Guidelines" have become prominent, indicating that they have received significant attention and may become hotspots in the future. The strongest citation burst was for "coronavirus" (14.58), followed by "H1N1" (10.2), "Acute lung injury" (9.55), "Randomized controlled trial" (9.14), "CO_2 removal" (8.58), and "Guidelines" (7.26), with other keywords having bursts between 3.03 and 6.06. These keywords were mainly focused on three categories.

1. Etiology of ARDS and indications for ECMO use This category includes discussions on the origins and triggers of ARDS along with the clinical criteria for employing ECMO, with a particular emphasis on conditions such as H1N1 and COVID-19.
2. Management of mechanical ventilation during ECMO for respiratory support. This includes a range of mechanical ventilation strategies used in conjunction with ECMO to optimize patient outcomes. The techniques discussed included small tidal volume ventilation, protective lung ventilation, positive end-expiratory pressure, transpulmonary pressure, and prone position ventilation.
3. Types and methods of research in this domain in recent years, such as randomized controlled trials (RCT), experiments, case reports, guidelines, and experiential studies.

Discussion

From January 2014 to March 2024, 1739 articles focusing on ECMO-assisted support for ARDS were analyzed. Notably, since 2019, there has been an annual increase in the volume of research in this domain, driven primarily by the global spread of COVID-19, which has significantly increased the need for ECMO-assisted treatment in ARDS patients.[17] This trend suggests that ECMO treatment will likely remain a central focus of interest in respiratory treatment support research for ARDS patients in the foreseeable future.

During the past decade, marked by rapid ECMO technology development, the United States has led globally not only in the volume of scientific publications and citations but also in forging substantial international collaboration networks. By contrast, while China ranks third globally in terms of publication volume, it has a lower citation frequency and total link strength in the international academic community. This highlights the challenges and opportunities China faces in enhancing research quality, strengthening international exchanges, and deepening cross-national cooperation to play a significant role in the global ECMO research field.

Examining institutional publications along with TLS enables researchers to pinpoint knowledge gaps and locate suitable collaborators and partners for communication, thus facilitating the advancement of high-quality multicenter research initiatives. The leading 10 institutions, predominantly located in North America and Europe, have exhibited exceptional performance across the main academic metrics of publication volume, collaboration intensity, and citation frequency. Notably, Columbia University, the University of Toronto, and Sorbonne University achieved remarkable outcomes, with Columbia University excelling in all the measured indicators.

By analyzing co-citation data from different journals, researchers can gain deeper insights into the interconnections among diverse research findings.[18] The top 10 journals, primarily found in the Q1 and Q2 categories, clarify the dominance and academic influence within the scope of the particular field. Intensive Care Medicine, The New England Journal of Medicine, and Critical Care, with their number of citations more than 1000 times are the most co-cited journals. This trend suggests that future research on ECMO respiratory support and the diagnosis and treatment of ARDS will likely reference research articles published in these journals. These findings emphasize the importance of focusing on these top journals, as they provide access to cutting-edge scientific knowledge crucial for research progress and enhance the scholarly impact of future scientific efforts in ECMO respiratory support and ARDS treatment.

In the co-authorship analysis, Alain Combes from France and Daniel Brodie from the USA had the highest number of publications, whereas Professors Alain Combes, Philipp M. Lepper, Konrad Hoetzenecker, and Aakash Shah had significant intermediary centrality. As advocated within this domain, their proposed new theories, methods, and technologies play a key role in advancing interdisciplinary research. For instance, Alain Combes made significant contributions to the evaluation of the role of ECMO in the treatment of patients with severe ARDS. Notably, during the COVID-19 pandemic, his research provided crucial evidence and guidance for the use of ECMO in the treatment of severe cases. Philipp M. Lepper focused on optimizing infection management during ECMO treatment, especially in preventing and managing secondary infections under ECMO support. Konrad Hoetzenecker pioneered the use of ECMO as a bridging tool in lung transplantation, particularly in managing patients with severe respiratory failure prior to surgery. Aakash Shah investigated the application of ECMO in special populations, such as children and patients with specific medical needs, and explored personalized ECMO treatment strategies.

In the co-citation analysis, Alain Combes, Matthieu Schmidt, and Giles J. Peek are the most frequently cited authors. Professor Alain Combes led the international multicentric large-scale RCT study known as "EOLIA", which provided crucial regarding the use of ECMO as a salvage treatment for ARDS patients. The protocols defined in this study will continue to serve as benchmarks for initiating ECMO treatment.[19] Matthieu Schmidt from Sorbonne University in Paris has focused on the management of patients with severe ARDS by identifying the optimal timing of ECMO use, implementing lung-protective ventilation strategies during ECMO support,[20] and integrating prone ventilation.[21] Giles J. Peek, an expert in cardiothoracic surgery and critical care medicine, has significantly contributed to the field of ECMO for both cardiac and respiratory support, ARDS, and congenital heart diseases with 90 publications.

The analysis of co-cited references reveals the core literature that has significantly influenced the evolution of the domain as well as shifting research priorities. Noteworthy studies have established the role of ECMO in seminal studies, such as the multicenter RCT comparing ECMO with traditional mechanical ventilation for severe acute respiratory distress in adults (CESAR) and EOLIA studies on ECMO for severe ARDS.[19,22] Notably, three of the top ten most co-cited references were related to COVID-19, reflecting the recent focus on the challenges of the pandemic. The study led by Ryan P Barbaro, involving 213 hospitals across 36 countries, reported a 37.4% in-hospital mortality rate at 90 days after initiating ECMO, supporting its use as a treatment option for refractory COVID-19-related respiratory failure in experienced medical centers.[4] Similarly, Matthieu Schmidtye et al found that the survival rates for patients with severe COVID-19 treated with ECMO were comparable to those for ECMO-supported severe ARDS. In the event of a similar COVID-19 surge, early ECMO intervention is recommended for patients experiencing severe respiratory failure despite optimized standard care such as prone ventilation.[23] Additionally, Jenelle Badulak, in collaboration with the ELSO COVID-19 Working Group, developed guidelines that provide critical advice for using ECMO during the pandemic, thereby enhancing the quality of patient care and facilitating global research and data collection efforts to treat COVID-19 patients with ECMO.[24]

Keywords are high-level summaries, and those with a high frequency and centrality often indicate popular research topics in a domain.[25] ECMO research has progressed through distinct phases according to an analysis that combines the timeline view (Figure 8) and keyword burst detection (Figure 9). The initial stage, from 2014 to 2016, focused on complications associated with ECMO treatment, particularly those associated with anticoagulation therapy. Although ECMO technology and management have advanced, optimizing anticoagulation therapy to prevent thrombosis and bleeding remains a significant challenge.[26,27] Additionally, patients with severe ARDS undergoing ECMO often present with severe comorbidities and complex pathophysiological disorders, leading to frequent bleeding and coagulation events. This has led to a shift in focus towards extracorporeal carbon dioxide removal devices, exploring their potential for treating severe ARDS patients with mechanical ventilation combined with extracorporeal carbon dioxide removal ($ECCO_2R$). $ECCO_2R$ offers advantages such as reduced vascular cannulation size, diminished blood flow rates ranging from 200 to 1500 mL/min, reduced costs, and simplified clinical management.[20,28,29] However, the application of $ECCO_2R$ in patients with ARDS has not achieved the expected outcome. A multicenter randomized clinical trial in the UK was prematurely terminated, as reductions in tidal volume facilitated by $ECCO_2R$ during invasive mechanical ventilation did not decrease the 90-day mortality rate compared with standard treatments.[30]

The second phase, from 2017 to 2019, focused on determining the optimal mechanical ventilation strategy under ECMO, with an increased emphasis on protective and ultra-protective lung ventilation techniques.[20] The primary objective was to optimize mechanical ventilation settings supported by ECMO to mitigate the damage inflicted by ventilators on the respiratory system (including the diaphragm), reduce systemic inflammatory responses and damage to extrapulmonary organs, accelerate healing of injured lung tissues, and improve long-term survival rates. This phase of the research explored various aspects of mechanical ventilation, including different ventilation modes, respiratory mechanical parameters, spontaneous breathing, and prone positioning. The Lifeguards study, the first prospective investigation explicitly aimed at detailing ventilation management in ARDS patients receiving ECMO therapy,[20] confirmed the widespread implementation of ultra-protective ventilation strategies following ECMO initiation. These strategies notably reduce tidal volume, respiratory rate, plateau pressure, driving pressure, and mechanical power. However, the multivariate analysis revealed no direct association between ventilatory settings and survival outcomes during ECMO. The current consensus within the academic community suggests that mechanical ventilation during ECMO in patients with ARDS should focus primarily on minimizing the intensity of VILI. Further research is essential to refine the adjustment of the ventilator parameters during treatment. Until further findings are available, the ventilator settings recommended by the EOLIA trial will serve as sensible interim standard.[31]

The third stage, from 2020 to the present, has precipitated an unprecedented increase in the number of ARDS patients requiring respiratory support owing to the emergence of the COVID-19 pandemic. This has led to a significant increase in ECMO use. Clinicians have leveraged their prior experiences with ECMO to treat various respiratory diseases and effectively manage severe COVID-19 cases, thereby saving lives, improving recovery rates, and reducing the risk of complications. Several observational studies[32–34] have validated that ECMO significantly enhances the short-term survival rate of critically ill COVID-19 patients. Research during this phase has primarily focused on exploring and documenting experiences with ECMO applications in the treatment of COVID-19 as well as developing predictive models for ECMO deployment,[35] including some that incorporate artificial intelligence to predict clinical outcomes.[36] Reliable prognostic tools for ARDS patients with ARDS who may require ECMO support are crucial for clinicians to make informed decisions, such as allocating ECMO to patients with a clear survival advantage. However, most existing predictive models, designed specifically for ECMO patients, exhibit a high risk of bias and have yet to be proven effective in individual patient decision-making.[37]

Limitations

Despite the meticulous and unbiased nature of the visualization analysis in this study, it is not without limitations. First, the dataset included only literature up to March 2024, thus excluding subsequent publications. Second, this analysis was limited to English-language literature, potentially omitting the significant research conducted in other languages. Third, owing to the specific format requirements of the CiteSpace tool, the study was restricted to articles indexed in the WoSCC database, which may have excluded pertinent studies available in alternative databases.

Conclusion

This research represents an inaugural systematic examination of ECMO-assisted treatment for ARDS through the lens of bibliometric visualization techniques aimed at delivering a thorough analysis of developments within this domain over the past decade. Employing this novel methodological approach, this study reveals the primary research dynamics of the field, assesses the impact of research findings, and indicates potential directions for future research. Future research should aim to identify ARDS patients who could benefit the most from ECMO, determine the optimal timing to initiate ECMO treatment, optimize daily management to further minimize complications, and improve strategies for mechanical ventilation under ECMO.

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