Bibliometric analysis of acute respiratory distress syndrome (ARDS) studies published between 1980 and 2020

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Abstract

Background. Acute respiratory distress syndrome (ARDS), an acute respiratory failure caused by noncardiogenic pulmonary edema, was first defined by Ashbaugh et al. in 1967. The number of publications increased enormously after the Berlin definition of ARDS was first described in 2012.

Objectives. This article intends to provide the physicians and the scientists with a reference guide to assess the most influential publications written about ARDS.

Materials and methods. We performed an exhaustive bibliometric analysis to identify publication trends by year, and the most influential research articles, authors, co-authors, journals, and countries. Articles on ARDS published in Science Citation Index (SCI) and Emerging Sources Citation Index (ESCI) journals between 1980 and 2020 were examined. On December 20, 2020, the keywords "ARDS" and "acute respiratory distress syndrome" were searched using the Web of Science Core Collection (WoSCC) database, and data including titles, author information, abstracts, journals, and references were analyzed.

Results. A total of 4564 articles related to ARDS published between 1980 and 2020 were identified. After excluding 192 proceedings papers, 19 early access papers, 1 book chapter, 1 research paper, and 1 retracted article, 4350 articles published in SCI and ESCI journals were analyzed. The largest number of articles (n = 557, 12.8%) appeared in 2020. The average citations per article was 38.21, and 4350 articles were cited 166,885 times altogether. The USA was at the top of the list of the most productive countries with 5025 articles. Harvard University was the most contributing institution with 244 articles. M.A. Matthay ranked as the most productive author in ARDS research with 87 published publications.

Conclusions. The present study provided a comprehensive, illustrative analysis of ARDS articles published in SCI and ESCI journals over the past 40 years.

Key words: intensive care, bibliometric analysis, acute respiratory distress syndrome

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Background

Acute respiratory distress syndrome (ARDS) is a progressive form of sudden respiratory failure characterized by severe hypoxemia and dyspnea. This condition, which involves refractory hypoxemia and diffuse bilateral infiltrates in lung radiology, was first described in 1967 by Ashbaugh et al.[1] After this definition was introduced in a case series with acute respiratory failure, it has been revised many times. In 1988, the definition of ARDS was expanded to include a 4-point lung injury score (0–4), the degree of hypoxemia and static lung compliance, the positive end-expiratory pressure level, and the extent of radiological infiltrations.[2] At the American-European Consensus Conference in 1994, a partial oxygen pressure/fraction of inspired oxygen (PaO_2/FiO_2) <300 mm Hg was defined as acute lung injury, and PaO_2/FiO_2 ratio <200 mm Hg was defined as ARDS.[3] The clinical criteria for ARDS have also changed over time, and the current diagnostic criteria and severity (classification) for ARDS are based on the Berlin definition.[4] Currently, the diagnostic criteria include bilateral opacities in chest imaging, an acute onset (within 1 week of a new clinical insult), arterial hypoxemia with a PaO_2/FiO_2 ratio <300 mm Hg, and noncardiogenic origin of pulmonary edema. The severity of ARDS is determined by the degree of hypoxemia, with mild ARDS defined as a PaO_2/FiO_2 ratio of 200–300 mm Hg, moderate as a PaO_2/FiO_2 ratio of 100–200 mm Hg, and severe as a PaO_2/FiO_2 ratio <100 mm Hg.

Since its first description, ARDS has become a major worldwide clinical problem, with a high morbidity, mortality and healthcare cost burden.[5] Studies from Europe have reported an ARDS incidence of between 5 and 7 cases per 100,000 individuals.[6] In a large observational study conducted in 2016 across 459 intensive care units (ICUs) in 50 countries, it was revealed that 23% of mechanically ventilated patients and 10% of critically ill patients met the diagnostic criteria for ARDS, and that ARDS represented 0.42 cases per ICU bed over 4 weeks. The investigators also found that the hospital mortality was 34.9% for patients with mild ARDS, 40.3% for those with moderate ARDS and 46.1% for those with severe ARDS.[7] Although there is a lack of epidemiological studies on ARDS in lower- and middle-income countries, a recent study from Vietnam reported a 57% ICU mortality rate for critically ill ARDS patients.[8]

Several risk factors triggering the onset of ARDS have been identified. The most common risk factors include pneumonia, non-pulmonary sepsis, pancreatitis, aspiration, shock, drug overdose, surgery, and trauma.[7,9] After exposure to these triggers, alveolar macrophages secrete mediators, neutrophils and alveolar epithelial cells activate, and proinflammatory mediators and chemokines are secreted, which cause impaired vascular permeability, gaps in the alveolar epithelial barrier and necrosis of alveolar cells. The intravascular coagulation cascade is also activated, and microthrombus formation occurs. These processes result in pulmonary edema, loss of surfactant, and debris deposition in the alveoli, in consequence decreasing pulmonary compliance and making gas exchange difficult.[10] Although this condition is severe and life-threatening, and several clinical studies have been carried out since its first description, there is no effective pharmacotherapy for ARDS apart from supportive therapies, such as lung-protective ventilation and conservative volume strategies.[11]

To quantify the impact of scientific articles, citation data have been used as indicators. Academic effectiveness is understood as authorship of highly cited articles. Bibliometric analysis can identify influential articles, journals and authors, and can guide future research.[12,13] In medicine, bibliometric methods estimate how much impact a selected article has on future research or how much impact an author's published article will have on the number of citations of a given issue of a journal. This method usually quantifies the number of times an article or author is cited after publication, and it has been used more and more often to determine the influence of articles, books or journals.[14] In some medical fields, such as oncology,[15] cardiology[16] and gynecology,[13] bibliometric analyses are widely used. Although they have been performed in some areas of intensive care medicine like sepsis, acute kidney injury and neurocritical care,[17–20] very few studies on ARDS were undertaken.[21,22]

Thus, in the present study, an exhaustive bibliometric analysis was carried out to identify publication trends by year, and the most influential research articles, authors, co-authors, journals, and countries associated with ARDS research between 1980 and 2020.

Objectives

Materials and methods

Web of Science (WoS) is one of the most commonly used databases among academics. It provides current and detailed information on many leading journals, including publications with worldwide impact.[23] On December 30, 2020, the keywords "ARDS" and "acute respiratory distress syndrome" were searched using the WoS Core Collection (WoSCC) database. As stated above, the definition of ARDS used within the year of publication of each article was accepted. The publication period was between 1980 and 2020. Original research articles published in Science Citation Index (SCI) and Emerging Sources Citation Index (ESCI) journals were included, and WoSCC data, including titles, author information, abstracts, journals, and references, were downloaded in plain TXT format.

A bibliometric analysis of the raw data was performed, and the specific analyses carried out are presented in Table 1. An online bibliometric analysis platform and Microsoft Excel 2016 (Microsoft Corp., Redmond, USA) were used to generate the figures. Authors from different

Table 1. Software and analysis

Software	Analysis
Bibliometrix Biblioshiny	annual production of articles in the years 1980–2020 top 15 institutions productive authors most-cited articles in ARDS research top 25 countries contributing to ARDS papers top 10 journals
VOSviewer	citation visualization map of the countries

ARDS – acute respiratory distress syndrome.

countries and the countries of publication were analyzed separately for each article. For articles with more than 2 authors affiliated with 2 different countries, the article was accounted for both countries.

Results

A total of 4564 articles related to ARDS published between 1980 and 2020 were identified. After excluding 192 proceedings papers, 19 early access papers, 1 book chapter, 1 research paper, and 1 retracted article, 4350 articles published in SCI and ESCI journals were analyzed. The largest number of articles (n = 557, 12.8%) appeared in 2020. The trend for the number of the articles published by year is shown in Fig. 1. The average citations per article was 38.21, and 4350 articles were cited 166,885 times altogether.

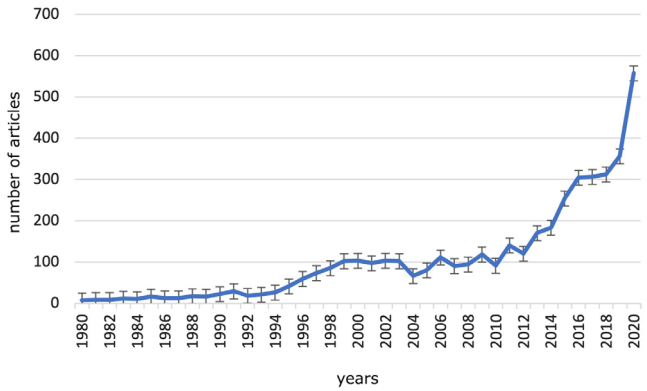

Fig. 1. Articles published in the years 1980–2020

Analysis of countries

According to the WoSCC database, 4350 articles originated from 129 countries. The top 25 countries contributing to ARDS articles between 1980 and 2020 are depicted in Fig. 2. The USA was at the top of the list with 5025 articles. China (n = 2146), France (n = 1676), Germany (n = 974), Italy (n = 941), Canada (n = 883), Japan (n = 781), Spain (n = 756), the UK (n = 516), Brazil (n = 503), and the Netherlands (n = 425) followed the USA.

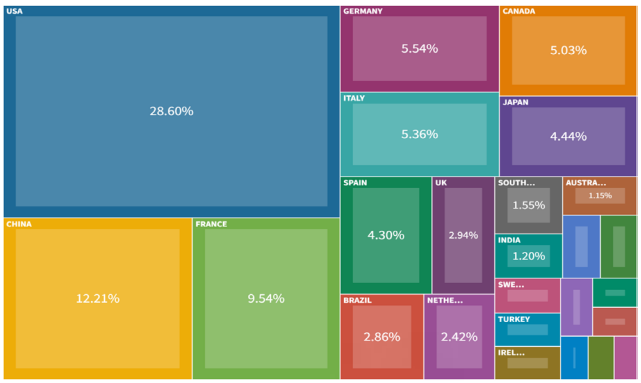

Fig. 2. The top 25 countries contributing to acute respiratory distress syndrome (ARDS) publications between 1980 and 2020

Analysis of institutions

We also analyzed the most productive institutions in ARDS research. Harvard University (USA) was the most contributing institution with 244 articles, followed by the Assistance-Publique Hôpitaux de Paris (France; n = 213), the University of California System (USA; n = 198), the University of Toronto (Canada; n = 178), Massachusetts General Hospital (USA; n = 176), and the Institut national de la santé et de la recherche médicale (INSERM; France; n = 173). The top 15 most productive institutions are listed in Table 2.

Table 2. Top 15 institutions in acute respiratory distress syndrome (ARDS) research

Institution	Number of articles
Harvard University, USA	244
Assistance-Publique Hôpitaux de Paris, France	213
University of California System, USA	198
University of Toronto, Canada	178
Massachusetts General Hospital, USA	176
Institut national de la santé et de la recherche médicale (INSERM), France	173
University of California San Francisco, USA	146
University of Washington, USA	119
University of Pennsylvania, USA	100
St. Michael's Hospital, Toronto, Canada	93
Pennsylvania State System of Higher Education, USA	92
University of Milan, Italy	92
University of Michigan, USA	88
Vanderbilt University, USA	86
Sorbonne University, France	85

Analysis of authors and citations

In the present study, we analyzed the total number of ARDS publications by author. M.A. Matthay (University of California San Francisco, USA) ranked first

Table 3. Top 15 most productive authors in acute respiratory distress syndrome (ARDS) research

Author	Country	Number of publications
Matthay MA	USA	87
Thompson BT	USA	79
Brochard L	Canada	57
Slutsky AS	Canada	57
Calfee CS	USA	56
Gattinoni G	Germany	52
Pesenti A	Italy	52
Pelosi P	Italy	50
Papazian P	France	49
Schultz MJ	the Netherlands	48
Christiani DC	USA	43
Ware LB	USA	41
Hudson LD	USA	39
Chiumello D	Italy	36
Gong MN	USA	35

with 87 publications, followed by B.T. Thompson (Massachusetts General Hospital, USA) with 79 publications, L. Brochard (St. Michael's Hospital, Toronto, Canada) with 57 publications, A.S. Slutsky (St. Michael's Hospital, Toronto, Canada) with 57 publications, and C.S. Calfee (University of California San Francisco, USA) with 56 publications. The top 15 most productive authors in ARDS research are shown in Table 3.

All publications on ARDS were cited 166,815 times altogether (139,359 times without self-citation). The average number of citations per article was 38.24, with an h-index of 172. The citation visualization map by country is shown in Fig. 3.

Analysis of publications and journals

The 10 most cited ARDS articles are shown in Table 4. With 6412 citations, the article entitled "Ventilation with lower tidal volumes as compared with traditional tidal volumes for acute lung injury and the acute respiratory distress syndrome" by R.G. Brower, published in *New England*

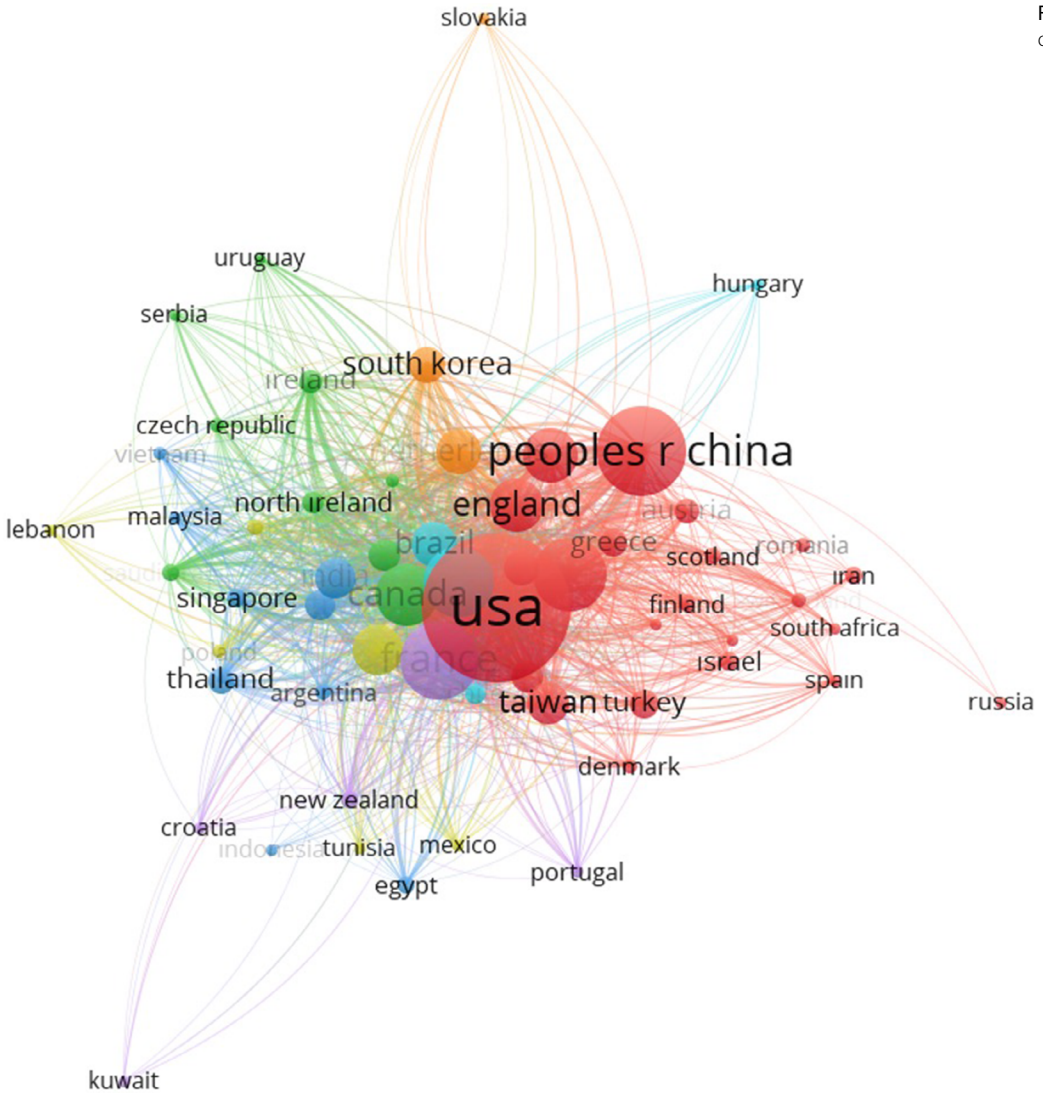

Fig. 3. Citation visualization map of the countries

Table 4. The most cited 10 articles in acute respiratory distress syndrome (ARDS) research

Title	Publication year	First author	Journal	Number of citations
Ventilation with lower tidal volumes as compared with traditional tidal volumes for acute lung injury and the acute respiratory distress syndrome	2000	Brower RG[24]	*New England Journal of Medicine*	6412
Acute respiratory distress syndrome: The Berlin definition	2012	Ranieri VM[4]	*Journal of the American Medical Association (JAMA)*	3987
Pathological findings of COVID-19 associated with acute respiratory distress syndrome	2020	Xu Z[25]	*Lancet Respiratory Medicine*	2597
Effect of a protective-ventilation strategy on mortality in the acute respiratory distress syndrome	1998	Amato MB[26]	*New England Journal of Medicine*	2183
Risk factors associated with acute respiratory distress syndrome and death in patients with coronavirus disease 2019 pneumonia in Wuhan, China	2020	Wu C[27]	*JAMA Internal Medicine*	1901
Epidemiology, patterns of care, and mortality for patients with acute respiratory distress syndrome in intensive care units in 50 countries	2016	Bellani G[7]	*Journal of the American Medical Association (JAMA)*	1518
Prone positioning in severe acute respiratory distress syndrome	2013	Guérin C[28]	*New England Journal of Medicine*	1381
Higher versus lower positive end-expiratory pressures in patients with the acute respiratory distress syndrome	2004	Brower RG[29]	*New England Journal of Medicine*	1359
One-year outcomes in survivors of the acute respiratory distress syndrome	2003	Herridge MS[30]	*New England Journal of Medicine*	1266
Neuromuscular blockers in early acute respiratory distress syndrome	2010	Papazian L[31]	*New England Journal of Medicine*	1238

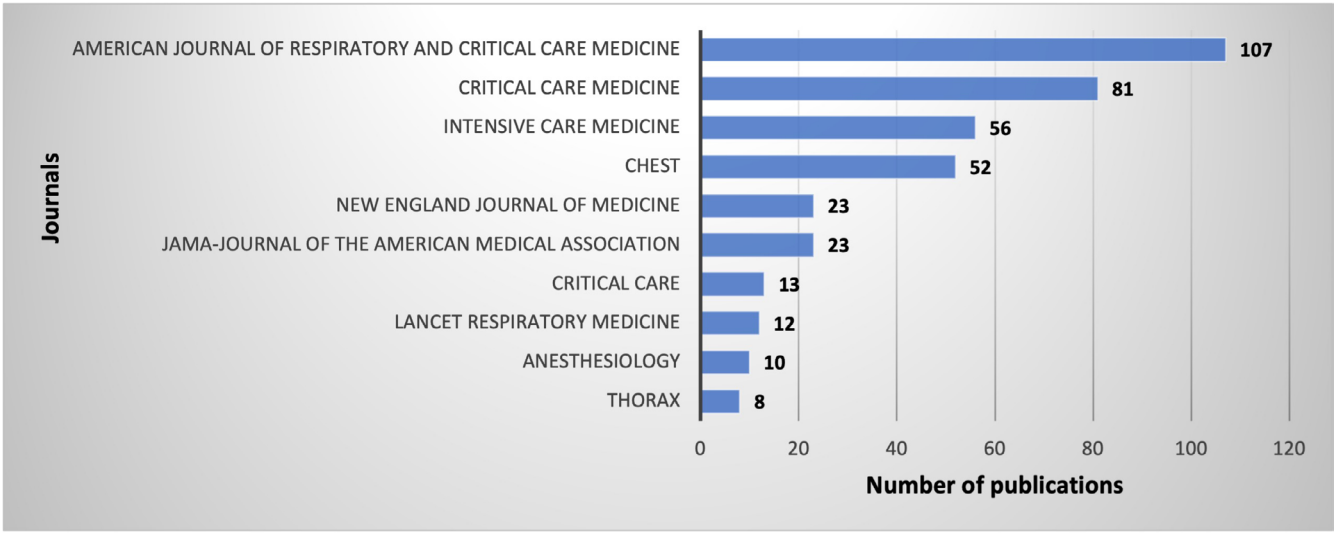

Fig. 4. Top 10 journals that published the 500 most cited acute respiratory distress syndrome (ARDS) articles

Journal of Medicine (impact factor (IF): 91.25) ranked first. It was followed by the article titled "Acute respiratory distress syndrome: The Berlin definition" by V.M. Ranieri, published in *Journal of American Medical Association* (*JAMA*; IF: 56.3; 3987 citations) and "Pathological findings of COVID-19 associated with acute respiratory distress syndrome" by Z. Xu, published in *Lancet Respiratory Medicine* (IF: 30.7; 2597 citations). Six of the top 10 most cited articles were published in *New England Journal of Medicine*, while 2 articles were published in *JAMA*. After the analysis of the top 500 most cited ARDS articles, we found that *American Journal of Respiratory and Critical Care Medicine* (IF: 21.41) ranked first with 107 articles published. *Critical Care Medicine* (IF: 7.60), *Intensive Care Medicine* (IF: 17.44) and *Chest* (IF: 9.41) were in the 2nd, 3rd and 4th place with 81, 56 and 53 articles, respectively, followed by *New England Journal of Medicine* (n = 23) and *JAMA* (n = 23). The top 10 journals that published the 500 most highly cited articles are listed in Fig. 4.

Discussion

Although bibliometric analyses have been recently used in almost all medical fields, there were almost no investigations on ARDS papers. We believe that our study will

contribute to summarizing and better understanding the literature on the subject. To the best of our knowledge, our study is the 3rd to investigate ARDS articles.[19,20] Nevertheless, the present study analyzed articles published in the last 40 years, the most extended period used for a bibliometric analysis of ARDS articles.

In the 1980s, the period immediately after ARDS was first described, we did not observe a significant increase in the number of ARDS studies. After the mid-1990s, the number of ARDS articles increased each year. In 1994, the American-European Consensus Conference on ARDS published a consensus report to bring clarity and uniformity to the ARDS definition and attract attention to mechanisms of the disease.[3] In this report, the need for studies on ARDS was strongly emphasized, and a large part of the report was devoted to recommendations for future studies. Therefore, the effect of this consensus report on increasing the number of ARDS studies cannot be ignored. A 2nd increase in the number of ARDS studies came after 2012 when the Berlin definition of ARDS was released.[2] Finally, in 2019 and 2020, the number of publications related to ARDS in coronavirus disease 2019 (COVID-19) increased, likely due to the fact that COVID-19 leads to ARDS in 16–31% of hospitalized patients.[32]

The main result of our study is that the USA is the most productive country in ARDS research, and 8 out of the 15 most cited authors were from the USA. Similarly, a previous study by Wang et al.,[21] which evaluated the publication trends of 7890 studies on ARDS between 2009 and 2019, revealed that the USA was the most contributing country with 2612 articles published (15.0%). In the current study, China was the 2nd largest contributor with 2146 ARDS articles. Wang et al.[21] also reported China as the 2nd most productive country between 2009 and 2019; however, since 2016, China has exhibited a rapid increase in the number of ARDS articles and has surpassed the USA in the number of articles per year. On the other hand, China could not reach the citation frequency or the h-index of the USA. This suggests that China conducts relatively fewer randomized clinical trials and more observational studies. Two previous bibliometric analyses of ARDS articles reported Germany as the 3rd most productive country, whereas in our research France ranked 3rd.[21,22] This may be due to more extended period of analysis in our study.

Two of the 10 most cited articles focus on COVID-19-associated ARDS. These articles were published in 2020 and have received a large number of citations in just 2 years. Pathophysiologically, ARDS is characterized by acute and diffuse inflammatory damage to the alveolar–capillary barrier, leading to an increased vascular permeability, decreased compliance, and hypoxemia due to impaired gas exchange.[23,24] Since COVID-19 has emerged, the central question of intensivists was whether COVID-19-related ARDS is a typical ARDS.[33,34] Numerous studies have examined the different pathophysiological features, characteristics and outcomes of patients with COVID-19-related ARDS and non-COVID-19-related ARDS. Gattinoni et al. described 2 different COVID-19-related ARDS patterns at the beginning of the disease course.[35,36] The 1st, termed Type L, is characterized by low elastance, low lung recruitability, low ventilation-to-perfusion ratio, and low lung weight. The 2nd, known as Type H, has a high elastance, high lung recruitability, high right-to-left shunt, and high lung weight. Gattinoni et al. suggested different ventilatory management strategies for these 2 types of cases.[36] Although there is not enough evidence to support the existence of these 2 types of COVID-19-related ARDS and the effectiveness of the different ventilatory management strategies, this hypothesis may direct researchers to perform more epidemiological and physiological investigations on COVID-19-related ARDS.

Eight of the 10 most cited ARDS articles were published in *New England Journal of Medicine* (n = 6) and *JAMA* (n = 2). In contrast, 107, 81, 56, and 52 of the top 500 most cited articles were published in *American Journal of Respiratory and Critical Care Medicine*, *Critical Care Medicine*, *Intensive Care Medicine*, and *Chest*, respectively. These findings suggest that journals with the highest IFs and those categorized as "general medicine" have published fewer but more influential articles than others classified as "critical care medicine" or "intensive care medicine." Since ARDS is still a syndrome with a high mortality in critically ill patients in ICUs, it is not surprising that ARDS articles are published in these journals.

Limitations

The present study produced a comprehensive, illustrative analysis of ARDS articles published in SCI and ESCI journals over the past 40 years. However, due to the nature of the bibliometric research, it has some limitations. First, the WoSCC database is constantly updated, meaning that our results will need to be validated over time. Second, as we excluded non-English articles, we may have ignored some influential and important non-English-language studies.

Conclusions

This study provides insight into the publications on ARDS. The number of publications has increased over the last 40 years, especially after the Berlin definition of ARDS was first formulated in 2012. The USA is the leading country contributing to the literature in terms of publication numbers, and most of the top-cited researchers are from the USA. M.A. Matthay, B.T. Thompson, R.L. Brochard, A.S. Slutsky, and C.S. Calfee are the most contributing authors in the ARDS field. This study can be helpful to future studies on ARDS. Although this study reported the numbers, countries, authors, and citations of ARDS-related studies (epidemiology, pathogenesis, pre-clinical,

clinical and treatment), it did not cover the content of these studies. More detailed bibliometric studies are needed to determine which areas (genetic, phenotype, microbiota, etc.) of ARDS research require more thorough exploration.

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