Global scientific outputs of extracorporeal membrane oxygenation in COVID-19: A bibliometric overview

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Abstract

Aim: Although the number of global studies on ECMO, which is an important support system in the treatment of COVID-19 related respiratory failure, has increased in recent months, there is still no bibliometric study on the use of ECMO in COVID-19 in the literature. The aim of this study is to analyze the scientific articles on the use of ECMO in COVID-19 by statistical and bibliometric methods.

Method: Articles published between 2019–2022 about the use of ECMO in COVID-19 were obtained from the Web of Science (WoS) database and analyzed using statistical and bibliometric methods. Spearman correlation coefficient was used for correlation studies. Network visualization maps were used to identify effective analysis and trending topics.

Results: A total of 1197 publications were found. 758 (63.3%) of these publications were articles. The top 3 contributing countries to the literature were USA (257, 33.9%), Germany (102, 13.4%) and Japan (87, 11.5%). The top 3 most active institutions were League of European Research Universities (90), Harvard University (50), and Udique French Research Universities (39). The top 3 journals with the highest count of publications were ASAIO Journal (n = 36), Frontiers in Medicine (22), and Perfusion-UK (n = 20). According to the average count of citations per article, the most influential journals were JAMA (1319), Intensive Care Medicine (327), and Lancet (95.7), respectively. We have shared a summary of 758 articles in this comprehensive bibliometric study on the use of ECMO in COVID-19.

Conclusion: It can be said that the use of ECMO in COVID-19 has been the trending topic recently and most of the studies are from countries in the ELSO Awards of Excellence list which indicates that the follow-up of ECMO in certain centers and teams can also be influencing the publications. This article can be a useful resource for clinicians, scientists, and students concerning global output for ECMO use in COVID-19.

Keywords

Extracorporeal membrane oxygenation, COVID-19, bibliometric analysis, trends

Introduction

Extracorporeal membrane oxygenation (ECMO), also known as Extracorporeal Life Support (ECLS), is a life support device providing an extracorporeal artificial support to the respiratory system and/or circulatory system, supporting both the heart and lung in patients with acute cardiopulmonary failure who do not respond well to conventional treatments. ECMO provides support to the patient while the healthcare team tries to resolve the underlying disease or injury, or as a bridge to transplant.1-3 There are basically two types of ECMO: veno-venous (V-V ECMO) or veno-arterial (V-A ECMO). While only respiratory support is provided in the V-V ECMO, both lung and heart support are provided in the V-A ECMO.1-3

After the successful implementation of ECLS in a patient with post-traumatic ARDS in 1972, ECMO is now widely used in adults, children, and neonates in many centers.4 During the A/H1N1 pandemic in 2009, the use of ECMO in ARDS cases resulted in lower mortality rates in treated patients, which in turn increased the use of ECMO in many intensive care units worldwide for the management of severe acute respiratory syndrome (SARS), Middle East respiratory...
syndrome (MERS) and new types of coronavirus (COVID-19) outbreaks. 5–8

Bibliometrics is the analysis of scientific outputs using statistical methods.9,10 With the help of results of the analysis of many studies on a subject, researchers can dominate the literature by reading the summary from the analysis of thousands of articles in a short time.11,12 In addition, bibliometric studies present past and current trends and provide researchers with additional ideas about new studies they can design.13,14 Thanks to bibliometric research, the most active authors, journals, institutions, countries and the most cited influential studies on a subject or a field are revealed.9–15 With the increase in the number of publications in the literature, studies based on statistical and bibliometric analysis have been carried out on many important medical issues, especially in recent years.9–15

Although the number of global studies has increased in recent months, there is still no bibliometric study in the literature concerning ECMO, which is a support system and has an important place in the recovery process in the treatment of COVID-19 related respiratory failure during the coronavirus pandemic. The aim of this study is to analyze the scientific articles published about ECMO use in COVID-19 between 2019 and 2022 using statistical and bibliometric methods. As a result we aimed to holistically summarize the issue of ECMO in COVID-19 by identifying the most influential researches, authors, journals, institutions and countries revealing cross-country collaborations and trending topics.

Material and methods

Web of Science (WoS) database (by Clarivate Analytics) was used for literature review. Only the Topic (Title, abstract and keywords) part of the studies were searched for publications. Extracorporeal membrane oxygenation (ECMO), Extracorporeal life support (ECLS) and COVID-19 related words were used as search keywords in WoS. With this search method, all articles with keywords in the title about ECMO and COVID-19 (coronavirus, SARS-CoV-2 etc.) were obtained and these articles were downloaded from the WoS database. The search process was determined as 2019–2022 (access date: 06.04.2022). Reproducibility codes for researchers to access similar documents (search findings may vary depending on different access dates): (TS = (“Covid-19”) AND TS = (“extracorporeal membrane oxygenation”)) OR (TS = (“Covid-19”) AND TS = (“ECMO”)) OR (TS = (“coronavirus”) AND TS = (“extracorporeal membrane oxygenation”)) OR (TS = (“Sars-cov-2”) AND TS = (“extracorporeal membrane oxygenation”)) OR (TS = (“Sars-cov-2”) AND TS = (“ECMO”)) OR (TS = (“n-CoV”) AND TS = (“extracorporeal membrane oxygenation”)) OR (TS = (“n-CoV”) AND TS = (“ECMO”)) OR (TS = (“Covid-19”) AND TS = (“extracorporeal life support”)) OR (TS = (“Covid-19”) AND TS = (“ECLS”)) OR (TS = (“coronavirus”) AND TS = (“extracorporeal life support”)) OR (TS = (“coronavirus”) AND TS = (“ECLS”)) OR (TS = (“Sars-cov-2”) AND TS = (“extracorporeal life support”)) OR (TS = (“Sars-cov-2”) AND TS = (“ECLS”)) OR (TS = (“n-CoV”) AND TS = (“extracorporeal life support”)) OR (TS = (“n-CoV”) AND TS = (“ECLS”)) Timespan:2019–2022. Indexes: SCI-EXPANDED, SSCI, A&HCI, CPCI-S, CPCI-SSH, BKCI-S, BKCI-SSH, ESCI. VOSviewer (Version 1.6.16, Leiden University’s Center for Science and Technology Studies) package program was used for bibliometric network visualizations.16 The website (https://app.datawrapper.de) was used for world map drawing. Statistical analysis were performed with the SPSS (Version 22.0, SPSS Inc., Chicago, IL, USA) package program. The normal distribution of data was tested with the Kolmogorov-Smirnov and Shapiro-Wilk tests. The correlation between the number of articles from the countries of the world and economic development indicators (Gross Domestic Product (GDP)) was examined in order to determine whether the economic potential has an effect on the publication efficiency on the subject of “The use of ECMO in COVID-19”. The Gross Domestic Product and Gross Domestic Product Per Capita (GDP per capita) of the world countries, whose data were obtained from the World Bank, were examined.17 Spearman correlation coefficient was used in accordance with the data distribution and p < 0.05 was considered statistically significant.

Results

As a result of the literature review, a total of 1197 publications on the use of ECMO in COVID-19 published in the WoS database between 2019 and 2022 were found. The distribution of these publications was article (758, 63.3%), review (166, 13.9%), letter (129, 10.8%), meeting abstract (57, 4.8%), and the remainder were editorial material, early access, and correction. Retracted articles in the WoS database are tagged in the “Retracted Publication” category. As a result of our literature search, there was no article in the Retracted Publication tag. However, 51 publications (42 articles) were tagged in the Early Access and 9 publications (no articles) were in the Correction category. Of the 758 articles, 34.2% (n = 259) were published in 2020, 53.5% (n = 406) in 2021, and 12.3% (n = 93) in 2022. Bibliometric analysis was carried out with 758 articles from 1197 publications.
in total. Of these articles, 97.9% (742) were published in English, 1.4% (11) in German, and the remainder were published in other languages (Hungarian (1), Polish (1), Russian (1), Spanish (1) and Turkish (1)). The h-index of 758 articles was 47, the average count of citations per article was 28.47, and the total count of citations was 21,577 (excluding self-citations: 20,354).

**Active Countries**

The distribution of articles by countries is shown in Figure 1. The first 17 countries with the highest number of articles published were USA (257, 33.9%), Germany (102, 13.4%), Japan (87, 11.5%), China (85, 11.2%), UK (65, 8.5%), Italy (63, 8.3%), France (57, 7.5%), South Korea (30, 4%), Australia (26, 3.4%), Spain (23, 3%), Belgium (21, 2.8%), Netherlands (21, 2.8%), Switzerland (19, 2.5%), Turkey (15, 2%), Austria (13, 1.7%), Canada (13, 1.7%), India (13, 1.7%), respectively (Figure 1). Cluster analysis was performed among 44 countries that published at least 2 articles and 71 countries that published articles on the use of ECMO in COVID-19 and whose authors have international cooperation, and is shown in Figure 2(a). According to the results of the clustering analysis, 6 different clusters related to international cooperation were formed (Cluster 1: Australia, Egypt, England, India, Kuwait, Pakistan, Qatar, Saudi Arabia, Scotland, South Africa, United Arab Emirates. Cluster 2: Austria, Belgium, Croatia, France, Israel, Italy, Norway, Slovenia, Sweden, Switzerland. Cluster 3: Canada, Denmark, Iran, Japan, China, South Korea, Spain, Taiwan. Cluster 4: Germany, Poland, Greece, USA, Hungary, Ireland. Cluster 5: Brazil, Chile, Mexico, Turkey, Wales. Cluster 6: Colombia, Czech Republic, Netherlands, Singapore). In addition, the total connection strength scores showing the cooperation power of 44 countries were calculated and the international collaboration density map was created according to these scores and is shown in Figure 2(b).

**Correlation Analysis**

There was a high correlation between the number of articles published by countries on the use of ECMO in COVID-19 and their GDP values, and a weak correlation between GDP per capita values. (respectively, 2018, 2019, 2020: \( r = 0.766, r = 0.771, r = 0.764, p < 0.001; 2018,2019,2020: r = 0.439, r = 0.449, r = 0.434, p < 0.001 \)). The scatter plot showing the correlation between the logarithm of the GDP values of the countries and the count of articles they published is presented in Figure 3.

**Active Authors**

The top 11 most active authors on the use of ECMO in COVID-19 are Combes A. (11), Lorusso R. (11), Supady A. (10), Bode C. (9), Brodie D. (9), Kluge S. (9), Wengenmayer T. (9), Duerschmied D. (8), Ohmagari N. (8), Staudacher DL. (8), and Suzuki T (8).

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*Figure 1.* (a). World map showing the distribution of articles published on ECMO in COVID-19. By world countries (b). Top 17 countries in the world that have published the most articles on ECMO in COVID-19.
Active Institutions

The top 16 institutions that published most of the articles on the use of ECMO in COVID-19 are League of European Research Universities (90), Harvard University (50), Udice French Research Universities (39), Assistance Publique Hopitaux Paris (38), Universite De Paris (34), Institut National de la Sante et de la Recherche Medicale (33), Columbia University (25), Newyork Presbyterian Hospital (24), University of California System (21), University of Pennsylvania (21), Sorbonne Universite (20), University of Freiburg (20), University of Texas System (19), Huazhong University of Science Technology (18), Mayo Clinic (17), and University of London (17).

Active Journals

758 articles published on the use of ECMO in COVID-19 were published in 361 different journals. The first 67 most active journals that published 3 or more articles from these journals, the total count of citations received by the journals and the average count of citations per article are presented in Table 1. The citation network visualization map of these journals is presented in Figure 4.

Citation Analysis

Among the 758 articles published on the use of ECMO in COVID-19, the first 25 articles with highest count of citations among the total count of citations are presented in Table 2. In the last column of Table 2, the average count of citations per year is given.

Co-citation Analysis

There were a total of 12,159 studies cited in the references section of the 758 articles analyzed. Among these studies, the top 5 studies that received highest co-citations (more than 80 citations) were Zhou (2020) (Number of citation: NC = 134), Huang (2020) (NC = 118), Combes (2018) (NC = 117), Yang (2020) (NC = 111), and Barbaro (2020) (NC = 106), respectively.18–22

Trending Topics

1283 different keywords were used in all 758 articles published on the use of ECMO in COVID19. Among these keywords, 74 different keywords that were used in at least 5 different articles are shown in Table 3. The cluster network visualization map showing the results of
clustering analysis performed between these keywords is shown in Figure 5. The trend network visualization map performed to reveal the trending topics is shown in Figure 6 and the citation network visualization map performed to reveal the most cited topics is shown in Figure 7.

**Discussion**

Mutation of the virus and disease severity varies throughout the pandemic. In relation to this, COVID-19 related to respiratory failure and treatment strategies also varied. In the pandemic, there has been an increase in the number of articles published in the literature over this period of more than 2 years. There are many articles in the literature not only related to the use of ECMO in COVID-19, but also on all topics related to COVID-19. It was determined in this article that there was an increase in the use of ECMO in COVID-19. While 259 articles were published in 2020, 406 articles were published in 2021. When the publication distributions of the countries are examined, the first 17 countries that are most active

| Journals                                      | RC  | C   | AC  | Journals                                      | RC  | C   | AC  |
|-----------------------------------------------|-----|-----|-----|-----------------------------------------------|-----|-----|-----|
| ASAIO journal                                 | 36  | 615 | 17.1| BMJ open                                      | 4   | 15  | 3.8 |
| Frontiers in medicine                         | 22  | 47  | 2.1 | Cardiology in the young                       | 4   | 5   | 1.3 |
| Perfusion-UK                                   | 20  | 43  | 2.2 | Clinical case reports                         | 4   | 0   | 0   |
| Journal of clinical medicine                  | 18  | 45  | 2.5 | ESC heart failure                             | 4   | 32  | 8   |
| Journal of cardiothoracic and vascular anesthesia | 15  | 87  | 5.8 | Heart and lung                                | 4   | 10  | 2.5 |
| Journal of cardiac surgery                    | 14  | 37  | 2.6 | Journal of critical care                      | 3   | 21  | 5.3 |
| Artificial organs                             | 13  | 30  | 2.3 | Intensive care medicine                       | 3   | 10  | 3   |
| Medicine                                      | 13  | 24  | 1.8 | Advances in therapy                           | 3   | 4   | 1.3 |
| Membranes                                     | 13  | 27  | 2.1 | Annals of thoracic surgery                    | 3   | 21  | 7   |
| Cureus                                        | 10  | 20  | 2.0 | BMJ case reports                              | 3   | 3   | 1   |
| Plos one                                      | 10  | 73  | 7.3 | British journal of haematology                | 3   | 6   | 2   |
| Journal of infection and chemotherapy         | 9   | 50  | 5.6 | Clinical infectious diseases                  | 3   | 87  | 29  |
| Acute medicine and surgery                    | 8   | 25  | 3.1 | Critical care and Resuscitation               | 3   | 93  | 31  |
| Critical care medicine                        | 8   | 129 | 16.1| European review for medical and pharmacological sciences | 3   | 30  | 10  |
| Cureus journal of medical science             | 8   | 3   | 0.4 | Heart surgery forum                           | 3   | 0   | 0   |
| Critical care                                 | 7   | 99  | 14.1| JAMA network open                             | 3   | 18  | 6   |
| Journal of Korean medical science             | 7   | 57  | 8.1 | Journal of critical care                      | 3   | 4   | 1.3 |
| European heart journal-case reports           | 6   | 8   | 1.3 | Journal of medical internet research          | 3   | 41  | 13.7|
| JAMA-journal of the American medical Association | 6   | 7913| 1318.8| Journal of intensive care medicine             | 3   | 15  | 5   |
| Journal of thrombosis and thrombolysis        | 6   | 37  | 6.2 | Lancet                                        | 3   | 287 | 95.7|
| Respiratory medicine case reports             | 6   | 7   | 1.2 | Lancet respiratory medicine                   | 3   | 234 | 78  |
| International journal of artificial organs    | 6   | 10  | 1.7 | Open forum infectious diseases                | 3   | 27  | 9   |
| American journal of case reports              | 5   | 21  | 4.2 | Signa vitae                                   | 3   | 2   | 0.7 |
| Chest                                         | 5   | 200 | 40  | Thoracic and cardiovascular surgeon          | 3   | 22  | 7.3 |
| Journal of artificial organs                  | 5   | 23  | 4.6 | Trials                                        | 3   | 10  | 3.3 |
| Journal of Pediatrics                         | 5   | 235 | 47  | World journal of clinical cases               | 3   | 4   | 1.3 |
| Medicina-Lithuania                            | 5   | 5   | 1   | Wiener Klinische Wochenschrift                | 3   | 17  | 5.7 |
| Respiratology case reports                    | 5   | 4   | 0.8 | Indian journal of thoracic and cardiovascular surgery | 3   | 3   | 1   |
| American journal of Emergency medicine        | 4   | 30  | 7.5 | Interactive cardiovascular and thoracic surgery | 3   | 8   | 2.7 |
| Anaesthesia                                   | 4   | 2   | 0.5 | Internal and Emergency medicine               | 3   | 6   | 2   |
| Annals of medicine and surgery                | 4   | 0   | 0   | Internal medicine                             | 3   | 10  | 3.3 |
| Annals of surgery                             | 4   | 76  | 19  | International journal of cardiology          | 3   | 47  | 15.7|
| Annals of translational medicine              | 4   | 16  | 4   | International journal of Environmental research and public health | 3   | 13  | 4.3 |

RC: Record Count, C: Number of Citation, AC: Average Citation Per Document.
in the production of articles on the use of ECMO in COVID-19 were USA, Germany, Japan, China, UK, Italy, France, South Korea, Australia, Spain, Belgium, Netherlands, Switzerland, Turkey, Austria, Canada, India respectively. While 14 of these countries were developed countries, only Turkey, China and India were a developing country. However, although these countries are developing, they are countries with large economies. According to the results of the correlation analysis in our study, there was high correlation between article productivity and GDP and the weak correlation between GDP per capita which shows the economic size of the countries. In the bibliometric studies conducted on many different medical issues in the literature, it has been concluded that economic potential is effective in publication productivity. Life support systems such as ECMO are costly devices and the economic size of countries can be effective in using these systems. As the respiratory failure cases due to COVID-19 and the need for ECMO suddenly increased during the pandemic, access to ECMO may have been insufficient in countries with low economic potential. When the density map created according to the total cooperation score between the countries was evaluated, it was determined that the countries with highest cooperation were USA, Italy, England in UK, France, Germany, Spain, Australia and Netherlands respectively. A common feature of these countries is that they have hospitals working as ECMO centers in the ELSO Award of Excellence list. When the co-authorship collaborations of countries on the use of ECMO in COVID-19 were examined, it was seen that geographical-based collaborations did not have a significant effect on article production.

The journals that published the most articles on the use of ECMO in COVID-19 were determined as ASAIO Journal, Frontiers in Medicine, Perfusion-UK, Journal of Clinical Medicine, Journal of Cardiothoracic and Vascular Anesthesia, Journal of Cardiac Surgery, Artificial Organs, Medicine, and Membranes, respectively. We can suggest that authors who want to publish on the use of ECMO in COVID-19 should first consider these journals. When the citations of the journals were evaluated, the most influential journals according to the average count of citations per article were JAMA-Journal of the American Medical Association, Intensive Care Medicine, Lancet, Journal of Pediatrics, Chest respectively. The influential journals after these journals were Critical Care and Resuscitation, Critical Care, Critical Care Medicine, International Journal of Cardiology, and Critical Care. We can recommend that researchers who want their articles to be cited more, should primarily consider these journals.

When the articles are evaluated according to the count of total citations and the average count of citations per year, the most influential study was published in JAMA by Wang et al. (2020) titled "Clinical characteristics of 138

![Figure 4. Network visualization map for citation analysis of active journals on ECMO in COVID-19. Footnote: The average count of citations per article by journals increases from blue to red (blue-green-yellow-red). The size of the circle indicates the large number of articles.](image-url)
| No. | Article                                                                 | Author                        | Journal                                      | PY   | TC  | AC   |
|-----|-------------------------------------------------------------------------|-------------------------------|----------------------------------------------|------|-----|------|
| 1   | Clinical characteristics of 138 hospitalized patients with 2019 novel coronavirus-infected pneumonia in Wuhan, China | Wang D. et al.                | JAMA-journal of the American medical Association | 2020 | 6089| 2029.7|
| 2   | Clinical management of severe acute respiratory infection (SARI) when COVID-19 disease is suspected. Interim guidance | WHO                           | Pediatric i medycyna Rodzinna               | 2020 | 1865| 621.7|
| 3   | Compassionate use of remdesivir for patients with severe COVID-19        | Grein J. et al.               | New England journal of medicine             | 2020 | 1419| 473  |
| 4   | Treatment of 5 critically III patients with COVID-19 with convalescent plasma | Shen C. et al.               | JAMA-journal of the American medical Association | 2020 | 1340| 446.7|
| 5   | High risk of thrombosis in patients with severe SARS-CoV-2 infection: a multicenter prospective cohort study | Helm J. et al.                | Intensive care medicine                     | 2020 | 1263| 421  |
| 6   | Acute heart failure in multisystem inflammatory syndrome in children in the context of global SARS-CoV-2 pandemic | Belhadjer Z. et al.           | Circulation                                 | 2020 | 514 | 171.3|
| 7   | Myocardial localization of coronavirus in COVID-19 cardiogenic shock     | Pediatria i medycyna Rodzinna | European journal of heart failure           | 2020 | 503 | 167.7|
| 8   | COVID-19 in children and adolescents in Europe: a multinational, multicentre cohort study | Goetzinger F. et al.          | Lancet child and Adolescent health          | 2020 | 474 | 158  |
| 9   | Characteristics and outcomes of children with coronavirus disease 2019 (COVID-19) infection admitted to US and canadian pediatric intensive care units | Shekerdemian LS. et al.      | JAMA pediatric                               | 2020 | 427 | 142.3|
| 10  | Intubation and ventilation amid the COVID-19 outbreak: Wuhan’s experience | Meng L. et al.                | Anesthesiology                               | 2020 | 291 | 97   |
| 11  | Extracorporeal membrane oxygenation support in COVID-19: an international cohort study of the Extracorporeal life support organization registry | Barbare RP. et al.           | Lancet                                       | 2020 | 244 | 81.3 |
| 12  | COVID-19 associated pulmonary aspergillosis                             | Koxhe P. et al.               | Mycoses                                      | 2020 | 228 | 76   |
| 13  | Intensive care admissions of children with paediatric inflammatory multisystem syndrome temporarily associated with SARS-CoV-2 (PIMS-TS) in the UK: a multicentre observational study | Davies P. et al.             | Lancet child and Adolescent health          | 2020 | 188 | 62.7 |
| 14  | Effect of hydrocortisone on 21-day mortality or respiratory support among critically III patients with COVID-19 a randomized clinical trial | Dequin PF. et al.             | JAMA-journal of the American medical Association | 2020 | 182 | 60.7 |
| 15  | Comparison of hospitalized patients with ARDS caused by COVID-19 and H1N1 | Tang X. et al.                | Chest                                        | 2020 | 181 | 60.3 |
| 16  | Multisystem inflammatory syndrome in children associated with severe acute respiratory syndrome coronavirus 2 infection (MIS-C): a multi-institutional study from New York city | Kaushik S. et al.             | Journal of Pediatrics                         | 2020 | 165 | 55   |
| 17  | Extracorporeal membrane oxygenation for severe acute respiratory distress syndrome associated with COVID-19: a retrospective cohort study | Schmidt M. et al.            | Lancet respiratory medicine                  | 2020 | 164 | 54.7 |
| 18  | Effect of intermediate-dose versus standard-dose prophylactic anticoagulation on thrombotic events, extracorporeal membrane oxygenation treatment, or mortality among patients with COVID-19 admitted to the intensive care unit the INSPIRATION randomized clinical trial | Sadeghpoor P. et al.          | JAMA-journal of the American medical Association | 2021 | 161 | 80.5 |
| 19  | Paediatric inflammatory multisystem syndrome: temporally associated with SARS-CoV-2 (PIMS-TS): Cardiac features, management and short-term outcomes as a UK tertiary paediatric hospital | Ramcharan T. et al.           | Pediatric cardiology                         | 2020 | 147 | 49   |
| 20  | Initial ELSO guidance document: ECMO for COVID-19 patients with severe cardiopulmonary failure | Bartlett RH. et al.           | ASAIO journal                               | 2020 | 142 | 47.3 |
| 21  | Effect of hydroxychloroquine on clinical status at 14 days in hospitalized patients with COVID-19 a randomized clinical trial | Self WH. et al.               | JAMA-journal of the American medical Association | 2020 | 141 | 47   |
| 22  | Blood type and outcomes in patients with COVID-19                      | Latz CA. et al.               | Annals of hematology                         | 2020 | 132 | 44   |
| 23  | The 2019–2020 novel coronavirus (severe acute respiratory syndrome coronavirus 2) pandemic: a joint American college of Academic international medicine-world Academic council of Emergency medicine multidisciplinary COVID-19 working Group consensus paper | Stawinski SP. et al.          | Journal of global infectious diseases        | 2020 | 127 | 42.3 |
| 24  | Coronavirus disease 2019 in patients with inborn errors of immunity: An international study | Meyts I. et al.               | Journal of Allergy and clinical immunology   | 2021 | 126 | 63   |
| 25  | SARS-CoV-2 in Spanish intensive care units: Early experience with 15-day survival in vitoria | Barrasa H. et al.             | Anaesthesia critical care and pain medicine  | 2020 | 108 | 36   |

PY: Publication year, TC: Total citation, AC: Average citations per year.
hospitalized patients with 2019 novel coronavirus-infected pneumonia in Wuhan, China. The second most influential study is by World Health Organization's article titled "Clinical management of severe acute respiratory infection (SARI) when COVID-19 disease is suspected. Interim guidance" published in the Pediatrica i Medycyna Rodzinna. The third most influential study is by Grein et al. (2020)’s article titled "Compassionate use of remdesivir for patients with severe COVID-19" published in the New England Journal of Medicine. The fourth most influential study is by Shen et al. (2020) titled "Treatment of 5 critically ill patients with COVID-19 with convalescent plasma" published in JAMA. The fifth most influential study is by Helms et al. (2020) titled "High risk of thrombosis in patients with severe SARS-COV-2 infection: a multicenter prospective cohort study" published in Intensive Care Medicine. According to the count of co-citations, the studies of Zhou (2020), Huang (2020), Combes (2018), Yang (2020), Barbaro (2020) were determined as the most influential. We suggest that clinicians and researchers interested in this subject should read these publications first.

When the keyword analysis was evaluated using the cluster analysis, the topics concerning the use of ECMO in COVID-19 formed clusters in 8 different colors. The most cited keywords were thrombosis, cardiogenic shock, severe acute respiratory syndrome coronavirus 2, coagulopathy, heart failure, ICU, ARDS, risk factors and MIS-C. The use of keywords such as thrombosis and coagulopathy may be due to their major role in COVID-19 patients followed in the ICU. Trend topics may change over time as research on the clinical course and pathogenesis of COVID-19 and the effectiveness of treatment methods (such as favipiravir, prone position, tracheostomy) enhance. According to the analysis to

### Table 3. The 74 most frequently used keywords in articles about extracorporeal membrane oxygenation (ECMO).

| Keywords                                      | Number of uses | Keywords                                      | Number of uses | Keywords                                      | Number of uses |
|-----------------------------------------------|----------------|-----------------------------------------------|----------------|-----------------------------------------------|----------------|
| COVID-19                                      | 444            | Extracorporeal life support                   | 11             | Fulminant myocarditis                         | 6              |
| Extracorporeal membrane oxygenation           | 185            | myocarditis                                   | 11             | Hypoxemia                                     | 6              |
| Sars-cov-2                                    | 138            | acute respiratory distress syndrome (ARDS)    | 10             | ICU                                           | 6              |
| ECMO                                          | 111            | Bleeding                                      | 10             | Influenza                                     | 6              |
| acute respiratory distress syndrome            | 94             | Lung transplantation                          | 10             | Lung ultrason sound                          | 6              |
| ARDS                                          | 79             | Pulmonary embolism                            | 10             | risk factors                                  | 6              |
| Coronavirus                                    | 51             | Coronavirus disease                           | 9              | Venous thromboembolism                        | 6              |
| Coronavirus disease 2019                      | 46             | Prognosis                                     | 9              | Clinical characteristics                      | 5              |
| mortality                                      | 36             | VV-ECMO                                       | 9              | Dexamethasone                                 | 5              |
| mechanical ventilation                        | 35             | mechanical circulatory support                | 8              | Impella                                       | 5              |
| Pandemic                                      | 26             | Prone position                                | 8              | Infection                                     | 5              |
| respiratory failure                           | 24             | Shock                                         | 8              | Inflammation                                  | 5              |
| Critical care                                  | 23             | Children                                      | 7              | Japan                                         | 5              |
| Case report                                   | 22             | Heart failure                                 | 7              | Pediatrics                                    | 5              |
| Intensive care unit                           | 21             | MIS-C                                         | 7              | Personal protective equipment                 | 5              |
| Severe acute respiratory syndrome coronavirus 2| 20             | multisystem inflammatory syndrome in children | 7              | Sedation                                      | 5              |
| Cardiogenic shock                             | 18             | resource allocation                           | 7              | Severe acute respiratory syndrome             | 5              |
| Outcome (s)                                   | 18             | respiratory distress syndrome                 | 7              | Severe acute respiratory syndrome coronavirus 2| 5              |
| thrombosis                                    | 18             | Coagulopathy                                  | 6              | Severity                                      | 5              |
| anticoagulation                               | 16             | COVID                                         | 6              | stemi                                         | 5              |
| Pneumonia                                     | 16             | Critically ill                                | 6              | Survival                                      | 5              |
| Pregnancy                                      | 16             | Cytokine storm                                | 6              | tracheostomy                                  | 5              |
| Extracorporeal membrane oxygenation (ECMO)    | 14             | Cytosorb                                      | 6              | treatment                                     | 5              |
| Coronavirus disease 2019 (COVID-19)           | 13             | Epidemiology                                  | 6              | Veno-venous extracorporeal membrane oxygenation | 5              |
| Intensive care                                 | 13             | Favipiravir                                   | 6              | —                                            | —              |
identify trending topics, the most frequent keywords on the topic in recent months were pediatrics, multisystem inflammatory syndrome in children, prone position, intensive care, veno-venous extracorporeal membrane oxygenation, dexamethasone, thrombosis, anticoagulation, and lung transplantation. These findings suggest that the need for intensive care and ECMO in pediatric patients also increased due to the increase in the number of pediatric patients in the course of the pandemic and the development of MIS-C. Further, it is a normal result that dexamethasone is a trending topic, its use has become widespread after the effectiveness of steroid treatment in COVID-19 has been demonstrated. Various data on the development of COVID-19 in immunosuppressed lung transplant patients and lung transplantation due to COVID-19-related respiratory failure have been published in the literature. ECMO, which acts as a bridge until transplantation, is frequently used, especially in patients undergoing lung transplantation for COVID-19. In other words, ECMO is often used not only for treatment, but also during the process of treatment and to save time for the patient while waiting for the natural lungs to heal.

Figure 5. Network visualization map for cluster analysis based on keyword analysis on ECMO in COVID-19. Footnote: Colors indicate clustering. Keywords in the same cluster are of the same color. The size of the circle indicates the number of uses of the keyword. (Cluster 1: acute respiratory distress syndrome, children, coronavirus disease, epidemiology, favipiravir, hypoxemia, ICU, intensive care unit, Japan, lung ultrasound, mortality, prognosis, SARS-CoV-2, sedation, VV-ECMO, Cluster 2: cardiogenic shock, case report, COVID-19, cytokine storm, fulminant myocarditis, heart failure, impella, mechanical circulatory support, myocarditis, pulmonary embolism, shock, STEMI, Cluster 3: clinical characteristics, coronavirus disease 2019, critically ill, infection, influenza, outcome (s), risk factors, severity, venous thromboembolism Cluster 4: critical care, cytosorb, extracorporeal life support, inflammation, MIS-C, multisystem inflammatory syndrome in children, pediatrics, resource allocation Cluster 5: coronavirus, extracorporeal membrane oxygenation, intensive care, pandemic, pregnancy, respiratory distress syndrome, severe acute respiratory syndrome coronavirus 2, treatment Cluster 6: ARDS, dexamethasone, ECMO, personal protective equipment, pneumonia, respiratory failure, survival, tracheostomy Cluster 7: acute respiratory distress syndrome (ARDS), coronavirus disease 2019 (COVID-19), extracorporeal membrane oxygenation (ECMO), lung transplantation, mechanical ventilation, prone position, severe acute respiratory syndrome coronavirus 2 (sars-cov-2) Cluster 8: anticoagulation, bleeding, coagulopathy, thrombosis).
analysis, 22 different case reports were determined. Although there are not many, we believe that case reports are also important for the analysis and should be included, which can not be regarded as a limitation.

The count of publications concerning the use of ECMO in COVID-19 does not reflect whole ECMO studies. This study only offers a perspective to researchers on the use of ECMO in COVID-19. Another limitation of the study is that the results are based only on statistical findings from studies in the literature. This study can help physicians find the right journal for publication, provides a holistic view of the summary of scientific output published on this topic in the literature, but does not improve patient management. However, as a result of the detailed analysis of all the articles on this important issue published during the COVID-19 pandemic, we believe that the most influential studies, the most focused topics, global productivity and their...
discussion are important statistical information on this subject.

**Conclusion**

We shared a summary of 758 articles published between 2019–2022 in this comprehensive bibliometric study on the use of ECMO in COVID-19, which is seen more frequently in recent articles. The trending topics in the use of ECMO in COVID-19 studies in recent months are pediatrics, multisystem inflammatory syndrome in children, prone position, intensive care, veno-venous extracorporeal membrane oxygenation, venous thromboembolism, dexamethasone, thrombosis, anti-coagulation, and lung transplantation. The fact that most of the studies are from countries in the ELSO Awards of Excellence list indicates that the follow-up of ECMO in certain centers and teams can also be influencing the publications. This article can be a useful source for clinicians, scientists, and students on the global output of the use of ECMO in COVID-19. Although ECMO has been used for respiratory failure for many years, we believe that the use of ECMO due to COVID-19 related respiratory failure and the publications on the subject have increased simultaneously all over the world. When the highly cited publications mentioned in this study are examined, it can help physicians or centers applying ECMO to review their practices in line with who, why and how ECMO is applied and the results obtained. Another contribution is that although there are not enough intensive care specialists today, it can help most physicians who follow COVID-19 patients in intensive care to raise awareness about ECMO and direct patients to the relevant centers at the right time.

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