

# Trends in the Extracorporeal Membrane Oxygenation Literature: A Bibliometric Analysis in the COVID-19 Era

Aashray K. Gupta, MBBS, GDipSurgAnat, MS;\* Lachlan D. Kerr, MBBS;\*  
Brandon Stretton, MBBS, GCertClinEd;† Joshua G. Kovoov, MBBS, BHlthMedSc (Hons);‡  
Christopher D. Owenden, MBBS, GDipSurgAnat, MS;§ Joseph N. Hewitt, MBBS, MMed;‡  
Justin C.Y. Chan, MBBS, MPhil, FRACS†

\*Discipline of Surgery, University of Adelaide, Royal Adelaide Hospital, Adelaide, South Australia, Australia; †University of Adelaide, Adelaide, South Australia, Australia; ‡Discipline of Surgery, University of Adelaide, The Queen Elizabeth Hospital, Adelaide, South Australia, Australia; and §Discipline of Surgery, University of Adelaide, Women's and Children's Hospital, Adelaide, South Australia, Australia

**Abstract:** Extracorporeal Membrane Oxygenation (ECMO) was first used in the 1970s. Its use is increasingly common in critical care and perioperative settings and has gained newfound prominence during COVID-19. To guide future research, we conducted a bibliometric analysis of ECMO literature. Thomson Reuters Web of Science was searched to March 7, 2021. Articles were ranked by total number of citations. Data was extracted from the 100 most cited papers relevant to ECMO for study design, topic, author, year, and institution. Journal impact factor for 2019 and Eigenfactor scores were also recorded. Our search retrieved a total of 18,802 articles. Median number of citations for the top 100 articles was 220 (range 157–1,819). These were published in 34 journals, with first authors originating from 15 countries. The *Annals of Thoracic Surgery* had the highest number of articles (n = 9) while *Lancet* publications had the most

citations (n = 3,191). Use of ECMO was most commonly observed in cardiogenic shock or acute respiratory distress syndrome. United States had the greatest article output (n = 49). With 10 publications, 2013 was the most prolific year. Using linear regression, when controlled for time since publication, there was no statistically significant relationship between 2019 journal impact factor and number of article citations ( $p = .09$ ). Top articles in the ECMO literature are of considerable impact and quality. As the United States produced the bulk of the prominent evidence base, and most data were regarding respiratory issues, out-sized advances in ECMO may be possible within the United States during the COVID-19 era. **Keywords:** COVID-19, extracorporeal membrane oxygenation, bibliometric analysis, outcomes, mortality. *J Extra Corpor Technol. 2022;54:19–28*

Extracorporeal Membrane Oxygenation (ECMO) is a form of advanced life support for patients with critical cardiac and respiratory illness that have exhausted other forms of medical management. ECMO was first described in the 1970s by Hill et al. (1) for patients with shock-lung syndrome and Robert Bartlett for infants with critical illness (2). Via subsequent advances disseminated in the literature,

ECMO has become widely adopted in well-resourced healthcare systems and has proven to be effective during the H1N1 and SARS-CoV-2 (COVID-19) pandemics (3–8).

The number of citations gained by an article is commonly used as an indicator of its importance in the literature, and can signal the impact it has on clinical practice (9). This is based on the premise that top-cited works are likely to be championed by experts in the field and by extension, confer a better understanding of trends and room for future advances. The argument is that the greater the value of the article, the more citations it will receive. In the scientific community, citations can be used to judge the reputation of a scientist or researcher, and many institutions use this measure to decide on appointments and promotions of academic staff through metrics such as the

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Address correspondence to: Aashray K. Gupta, Department of Cardiothoracic Surgery, Royal Adelaide Hospital, Port Road, Adelaide, South Australia 5000, Australia. E-mail: aashray.gupta@adelaide.edu.au  
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h-index (10). Citation analysis can also show which authors, journals, and countries are responsible for pioneering a field of interest and contributing to high impact research.

Bibliometric analyses have been performed in many areas previously, including ECMO (11). However, none have been performed during the COVID-19 era. As the literature has evolved dramatically during the COVID-19 pandemic, future evidence-based progression relies on understanding these changes and resultant trends (12). Given the important role of ECMO for patients with life-threatening cardiopulmonary conditions, reliable innovation is essential. Therefore, to inform evidence-based innovation, we performed a bibliometric analysis identifying key trends in the ECMO literature including changes during the COVID-19 era.

## METHODS

We searched the Thomson Reuters Web of Science citation indexing database and research platform from inception to March 7, 2021, using terms “ECMO,” “extracorporeal membrane oxygenation,” “extracorporeal membranous oxygenation,” “extracorporeal membrane oxygen,” or “extracorporeal membranous oxygen.” The 100 most cited papers relevant to the field of ECMO were retrieved and data was extracted for design, topic, author, year, and institution. The journal impact factor for the year 2019 was recorded along with Eigenfactor, which measures the importance of a journal to the scientific community, sourced online. Apart from relevance to the field of ECMO, no exclusion criteria were implemented. Two reviewers (AKG and LDK) independently screened titles, abstracts, and full text to determine included and excluded articles based on relevance to the field of ECMO. Disagreements were resolved via consensus. The list of included articles is shown in Table 1.

Time-dependent variables were tested by Mann-Kendall trend analysis. Correlation analysis was performed with Spearman rank test. Normality for individual variables was tested using either Kolmogorov-Smirnov or Shapiro-Wilk testing. The relationship between total number of citations for an article and its journal impact factor and Eigenfactor in the year 2019 was analyzed using linear regression. IBM SPSS version 27.0 (IBM Corp., Armonk, NY) (13) was used for all statistical analysis. Microsoft Excel was used for data collection and analysis as presented in Figures 1 and 2 (14). No other statistical software was used for analysis.

## RESULTS

A total of 18,802 articles were retrieved and these were ranked by total number of citations. The top 100 articles by citation are listed in Table 1, whereas the

articles with the greatest number of citations in the past 5 years and past 12 months are listed in Tables 2 and 3 respectively. The median number of total citations was 235.5 (range 157–1,819). Half of these articles ( $n = 50$ ) were published in the 2010s, with 27 publications in the 2000s, 15 in the 1990s, three in the 1980s, four in the 1970s, and one in the year 2020 (Figure 1). These were published in 34 journals and first authors originated from 15 different countries, with the largest numbers from the United States (49%), Europe (32%), and Australia (6%) (Table 4). Of the first authors who published an article in the top 100 list, 86% were male. The number of articles per journal ranged from 1 to 9. *The Annals of Thoracic Surgery* featured the most ( $n = 9$ ) (Table 5) whereas papers published in *Lancet* had the highest total citations ( $n = 3,191$ ). Of the top 100 articles, the majority were cohort studies (41%). The prevalence of case series, reviews, and randomized controlled trials (RCTs) were relatively equal at 18%, 16%, and 13% respectively. The most common topics of research were respiratory failure, heart and lung transplantation, and cardiac arrest. Keyword terms were found for 91 articles, for which 89 articles had Web of Science algorithm-generated “keywords plus” and 49 had “author keywords.” The top five most common keyword terms identified were “extracorporeal membrane oxygenation” ( $n = 30$ ), “outcomes” ( $n = 18$ ), “survival” ( $n = 13$ ), “mortality” ( $n = 10$ ), and “respiratory distress syndrome” ( $n = 9$ ).

The most recently published paper was by Meng et al. (3) in the *New England Journal of Medicine*, relating to the use of ECMO during the COVID-19 pandemic. The top-cited article was from 2009 and had 1,819 citations. The least cited article was from 1993 and had 157 citations. The earliest article, published in 1972, was a case report on ECMO for post-traumatic respiratory failure. This was one of only four articles from the 1970s, while only three articles were published in the 1980s. The three most cited articles related to the use of ECMO in patients with acute respiratory distress syndrome (ARDS), respiratory failure secondary to H1N1 influenza infection or compared its use to patients undergoing mechanical ventilation. A total of four of the top 100 articles describe the use of ECMO in H1N1 or COVID-19.

Peek et al.’s (15) 2009 RCT was the most cited article with 1,819 citations. They assessed and compared the medical and economic viability of ECMO with conventional ventilatory support for ARDS. Conducted in the United Kingdom, funded by National Health Service, Medical Research Council (MRC), and the National Institute for Health Research (NIHR), 180 patients with respiratory failure were randomized to either arm. They discovered a significant improvement in survival without resultant disability at 6 months in patients who were

**Table 1.** Hundred most cited papers in the ECMO literature.

	Title	First Author	Number of Citations
1	Efficacy and economic assessment of conventional ventilatory support	Peek	1,819
2	Extracorporeal membrane oxygenation in severe acute respiratory failure: A randomized prospective study	Zapol	1,064
3	Extracorporeal membrane oxygenation for 2009 Influenza A(H1N1) acute respiratory distress syndrome	Davies	1,041
4	Cardiopulmonary resuscitation with assisted extracorporeal life-support vs. conventional cardiopulmonary resuscitation in adults with in-hospital cardiac arrest: an observational study and propensity analysis	Chen	686
5	Prolonged extracorporeal oxygenation for acute post-traumatic respiratory failure (shock-lung syndrome). Use of the Bramson membrane lung	Hill	676
6	Randomized clinical trial of pressure-controlled inverse ratio ventilation and extracorporeal CO <sub>2</sub> removal for adult respiratory distress syndrome	Morris	665
7	Extracorporeal membrane oxygenation for severe acute respiratory distress syndrome	Combes	529
8	Referral to an extracorporeal membrane oxygenation center and mortality among patients with severe 2009 Influenza A (H1N1)	Noah	515
9	UK collaborative randomised trial of neonatal extracorporeal membrane oxygenation	Field	505
10	Extracorporeal membrane oxygenation for ARDS in adults	Brodie	492
11	Low-dose nitric oxide therapy for persistent pulmonary hypertension of the newborn.	Clark	462
12	Extracorporeal Life Support Organization Registry Report 2012	Paden	435
13	Part 14: Pediatric Advanced Life Support 2010 American Heart Association Guidelines for Cardiopulmonary Resuscitation and Emergency Cardiovascular Care	Kleinman	412
14	Outcomes and long-term quality-of-life of patients supported by extracorporeal membrane oxygenation for refractory cardiogenic shock	Combes	400
15	Tidal Volume Lower than 6 ml/kg Enhances Lung Protection Role of Extracorporeal Carbon Dioxide Removal	Terragni	399
16	Contemporary management of cardiogenic shock a scientific statement from the American Heart Association	Van Diepen	396
17	Complications of extracorporeal membrane oxygenation for treatment of cardiogenic shock and cardiac arrest: A meta-analysis of 1866 adult patients	Cheng	376
18	Extracorporeal membrane oxygenation in awake patients as bridge to lung transplantation	Fuehner	366
19	Extracorporeal membrane oxygenation and conventional medical therapy in neonates with persistent pulmonary hypertension of the newborn: a prospective randomized study	O'Rourke	361
20	Extracorporeal membrane oxygenation (ECMO) cardiopulmonary support in infancy	Bartlett	348
21	Extracorporeal Life Support Organization Registry International Report 2016	Thiagarajan	341
22	Early and late outcomes of 517 consecutive adult patients treated with extracorporeal membrane oxygenation for refractory postcardiotomy cardiogenic shock	Rastan	328
23	Predicting survival after extracorporeal membrane oxygenation for severe acute respiratory failure: The Respiratory Extracorporeal Membrane Oxygenation Survival Prediction (RESP) score	Schmidt	320
24	Acute respiratory distress syndrome advances in diagnosis and treatment	Fan	314
25	Prospective trial of a pediatric ventricular assist device	Fraser	312
26	Predicting survival after ECMO for refractory cardiogenic shock: the survival after veno-arterial-ECMO (SAVE)-score	Schmidt	312
27	Refractory cardiac arrest treated with mechanical CPR, hypothermia, ECMO and early reperfusion (the CHEER trial)	Stub	309
28	Extracorporeal membrane oxygenation for pandemic influenza A(H1N1)-induced acute respiratory distress syndrome a cohort study and propensity-matched analysis	Pham	306
29	Extracorporeal membrane oxygenation in adults with severe respiratory failure: a multi-center database	Brogan	302
30	Randomized, multicenter trial of inhaled nitric oxide and high-frequency oscillatory ventilation in severe, persistent pulmonary hypertension of the newborn	Kinsella	301
31	Extracorporeal membrane-oxygenation (ECMO) in neonatal respiratory failure—100 Cases	Bartlett	296
32	Extracorporeal life support for severe acute respiratory distress syndrome in adults	Hemmila	295
33	The PRESERVE mortality risk score and analysis of long-term outcomes after extracorporeal membrane oxygenation for severe acute respiratory distress syndrome	Schmidt	288

(continued)

**Table 1.** Hundred most cited papers in the ECMO literature. (cont.)

	Title	First Author	Number of Citations
34	Berlin Heart EXCOR pediatric ventricular assist device for bridge to heart transplantation in US children	Almond	283
35	Position paper for the organisation of Extracorporeal Membrane Oxygenation programs for acute respiratory failure in adult patients	Combes	282
36	Association of hospital-level volume of extracorporeal membrane oxygenation cases and mortality analysis of the extracorporeal life support organization registry	Barbaro	281
37	Extracorporeal cardiopulmonary resuscitation vs. conventional cardiopulmonary resuscitation in adults with out-of-hospital cardiac arrest: A prospective observational study	Sakamoto	262
38	Clinical responses to prolonged treatment of persistent pulmonary hypertension of the newborn with low-doses of inhaled nitric oxide	Kinsella	257
39	A meta-analysis of complications and mortality of extracorporeal membrane oxygenation	Zangrillo	257
40	Contemporary extracorporeal membrane oxygenation for adult respiratory failure: life support in the new era	MacLaren	256
41	Mechanical circulatory support in cardiogenic shock	Werdan	256
42	Outcomes of children bridged to heart transplantation with ventricular assist devices—A multi-institutional study	Blume	255
43	Analysis and results of prolonged resuscitation in cardiac arrest patients rescued by extracorporeal membrane oxygenation	Chen	254
44	Inhaled nitric oxide and hypoxic respiratory failure in infants with congenital diaphragmatic hernia	Finer	250
45	2015 SCAI/ACC/HFSA/STS Clinical Expert Consensus Statement on the Use of Percutaneous Mechanical Circulatory Support Devices in Cardiovascular Care	Rihal	249
46	Extracorporeal membrane oxygenation for newborn respiratory failure—45 cases	Bartlett	245
47	Extracorporeal life support—The University of Michigan experience	Bartlett	240
48	Extracorporeal cardiopulmonary resuscitation in patients with in-hospital cardiac arrest: A comparison with conventional cardiopulmonary resuscitation	Shin	240
49	Management of cardiogenic shock	Thiele	239
50	Single-institution experience with interhospital extracorporeal membrane oxygenation transport: A descriptive study	Clement	236
51	Review of ECMO (Extra Corporeal Membrane Oxygenation) support in critically ill adult patients	Marasco	235
52	Extracorporeal Life support Registry Report 2004	Conrad	233
53	Five-year results of 219 consecutive patients treated with extracorporeal membrane oxygenation for refractory postoperative cardiogenic shock	Doll	229
54	Extracorporeal Membrane Oxygenation in Cardiopulmonary Disease in Adults	Abrams	228
55	Pulmonary morphology in a multi-hospital collaborative extracorporeal membrane oxygenation project. 1. Light Microscopy	Pratt	227
56	Inhaled nitric oxide for the early treatment of persistent pulmonary hypertension of the term newborn: A randomized, double-masked, placebo-controlled, dose-response, multicenter study	Davidson	227
57	Anticoagulation and Coagulation Management for ECMO	Oliver	226
58	Clinical-experience with 202 adults receiving extracorporeal membrane oxygenation for cardiac failure: Survival at five years	Smedira	224
59	The Italian ECMO network experience during the 2009 influenza A(H1N1) pandemic: preparation for severe respiratory emergency outbreaks	Patroniti	223
60	Extracorporeal membrane oxygenation: evolving epidemiology and mortality	Karagiannidis	218
61	Extracorporeal membrane oxygenation to aid cardiopulmonary resuscitation in infants and children	Thiagarajan	215
62	Liver transplant using donors after unexpected cardiac death: Novel preservation protocol and acceptance criteria	Fondevila	212
63	Extracorporeal cardiopulmonary resuscitation for patients with out-of-hospital cardiac arrest of cardiac origin: a propensity-matched study and predictor analysis	Maekawa	207
64	Back from irreversibility: Extracorporeal life support for prolonged cardiac arrest	Masseti	205
65	Extracorporeal life support during cardiac arrest and cardiogenic shock: a systematic review and meta-analysis	Ouweneel	203
66	American College of Critical Care Medicine Clinical Practice Parameters for hemodynamic support of pediatric and neonatal septic shock	Davis	201
67	Multicenter study of surfactant (beractant) use in the treatment of term infants with severe respiratory failure	Lotze	200
68	Extracorporeal life support for 100 adult patients with severe respiratory failure	Kolla	197
69	Extracorporeal membrane oxygenation support for adult postcardiotomy cardiogenic shock	Ko	194
70	Inhaled nitric oxide in infants referred for extracorporeal membrane oxygenation: dose response	Finer	193
71	High survival rate in 122 ARDS patients managed according to a clinical algorithm including extracorporeal membrane oxygenation	Lewandowski	193

(continued)

**Table 1.** Hundred most cited papers in the ECMO literature. (cont.)

	Title	First Author	Number of Citations
72	Outcome of veno-arterial extracorporeal membrane oxygenation for patients undergoing valvular surgery	Wang	192
73	Concomitant implantation of Impella (R) on top of veno-arterial extracorporeal membrane oxygenation may improve survival of patients with cardiogenic shock	Pappalardo	192
74	The ENCOURAGE mortality risk score and analysis of long-term outcomes after VA-ECMO for acute myocardial infarction with cardiogenic shock	Muller	190
75	Extra Corporeal Membrane Oxygenation (ECMO) review of a lifesaving technology	Makdisi	190
76	Clinical transplantation of initially rejected donor lungs after reconditioning ex vivo	Ingemansson	188
77	Vascular complications in patients undergoing femoral cannulation for extracorporeal membrane oxygenation support	Bisdas	188
78	Variability in anticoagulation management of patients on extracorporeal membrane oxygenation: An international survey	Bembea	188
79	One hundred patients with the HeartMate left ventricular assist device: Evolving concepts and technology	McCarthy	185
80	Extracorporeal membrane oxygenation in nonintubated patients as bridge to lung transplantation	Olsson	185
81	Extracorporeal membrane oxygenation to support cardiopulmonary resuscitation in adults	Thiagarajan	185
82	Hemodynamics of mechanical circulatory support	Burkhoff	185
83	Intubation and ventilation amid the covid-19 outbreak: Wuhan's experience	Meng	184
84	Inhaled nitric oxide in premature neonates with severe hypoxaemic respiratory failure: a randomised controlled trial	Kinsella	181
85	Bridging children of all sizes to cardiac transplantation: The initial multicenter North American experience with the Berlin Heart EXCOR ventricular assist device	Morales	181
86	Liver position and lung-to-head ratio for prediction of extracorporeal membrane oxygenation and survival in isolated left congenital diaphragmatic hernia	Hedrick	179
87	First human transplantation of a nonacceptable donor lung after reconditioning ex vivo	Steen	175
88	Extracorporeal life support following out-of-hospital refractory cardiac arrest	Le Guen	175
89	A Factor XIIa inhibitory antibody provides thromboprotection in extracorporeal circulation without increasing bleeding risk	Larsson	174
90	Factors associated with outcomes of patients on extracorporeal membrane oxygenation support: a 5-year cohort study	Aubron	174
91	Mechanical circulatory support for the treatment of children with acute fulminant myocarditis	Duncan	172
92	Pulmonary morbidity in 100 survivors of congenital diaphragmatic hernia monitored in a multidisciplinary clinic	Muratore	170
93	Recommendations for the use of mechanical circulatory support: Device strategies and patient selection a scientific statement from the American Heart Association	Peura	170
94	Extracorporeal membrane oxygenation and neonatal respiratory failure: Experience from the extracorporeal life support organization	Stolar	168
95	Bridge to lung transplantation with the novel pumpless interventional lung assist device NovaLung	Fischer	165
96	Circulatory support with pneumatic paracorporeal ventricular assist device in infants and children	Hetzer	163
97	Should we emergently revascularize occluded coronaries for cardiac arrest? rapid-response extracorporeal membrane oxygenation and intra-arrest percutaneous coronary intervention	Kagawa	162
98	Anesthesia-related cardiac arrest in children with heart disease: Data from the Pediatric Perioperative Cardiac Arrest (POCA) Registry	Ramamoorthy	162
99	Emergency circulatory support in refractory cardiogenic shock patients in remote institutions: a pilot study (the cardiac-RESCUE program)	Beurtheret	159
100	Elevated immunoreactive endothelin-1 levels in newborn-infants with persistent pulmonary hypertension	Rosenberg	157

ECMO, extracorporeal membrane oxygenation.

transferred to a specialist center for consideration of ECMO compared with continued conventional ventilation (63% ECMO VS 47% conventional, relative risk .69; 95% CI .05–.97,  $p = .03$ ). There was a difference in costs of £40,544 (95% CI 24,799–56,288 [US\$65,519, 40,076–90,963]).

The second most cited article, from 1979, out of the United States and funded by the Division of Lung Diseases was another RCT by Zapol et al. (16). They compared conventional mechanical ventilation with ECMO. Ninety patients with arterial hypoxemia were randomized to either arm and four in each arm survived. All

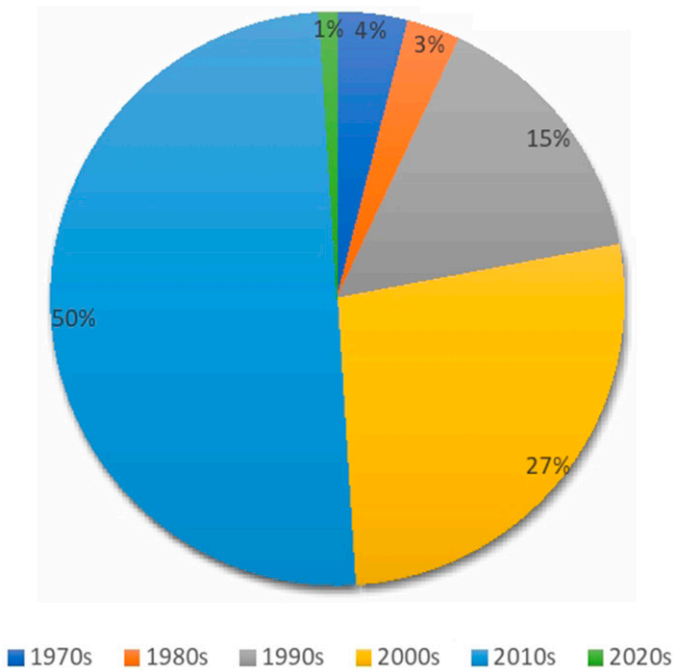


Figure 1. Proportion of articles published by decade.

patients with pulmonary embolism and post-traumatic respiratory failure died and the majority suffered a bacterial and/or viral pneumonia. They concluded ECMO can support respiratory gas exchange but did not increase the long-term survival in patients with severe acute respiratory failure.

A case series by Davies et al. (7) from Australia in 2009, with undisclosed funding, was the third most cited article. They conducted an observational study of 68 H1N1 patients with ARDS treated in 15 different intensive care

units (ICUs). These patients were on average 34 years old with a median acute lung injury score of 3.8 and had a median PEEP of 18 and  $paO_2: FiO_2$  of 56 prior to ECMO initiation. At the time of reporting, 48 of the 68 survived ICU, 16 of which were deescalated to ward-based management and 32 had been discharged. They observed a 21% mortality rate at the end of the study period.

Using linear regression, when controlled for time since publication, there was no statistically significant relationship between number of article citations and either the 2019 journal impact factor ( $p = .09$ ) or 2019 Eigenfactor ( $p = .33$ ). The Mann-Kendall test (Figure 2) demonstrates a trend that more recent publications had a higher number of citations per year ( $p < .05$ ). With regards to authorship, eight authors published multiple first author papers (Table 6); Bartlett contributed the most with four papers totaling 1,129 citations. The highest number of overall citations was received by Peek et al. (15) for the report of a RCT comparing ECMO with conventional ventilatory support.

DISCUSSION

ECMO is an advanced life-support technique to rescue critically ill patients with severe cardiac and pulmonary disease. Our results identified and characterized the top 100 cited articles relating to ECMO. Our data demonstrates the considerable growth in the field of ECMO since its inception in 1972 (Figure 2). There was a considerable male predominance in the lead authors within the literature. *The Annals of Thoracic Surgery* published the most articles whereas papers in the *Lancet* were cited the most. Cohort studies were the most

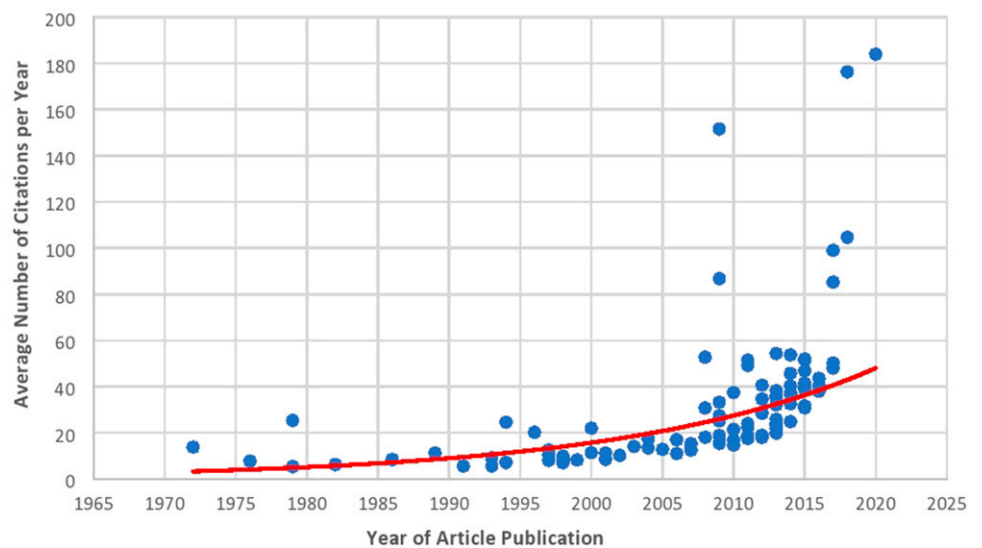


Figure 2. Trend by time of overall citation rate (Mann-Kendall).

**Table 2.** The top 10 ECMO papers listed in descending order by the recent 5 years' citation number.

	Title	First Author	Number of Citations
1	Efficacy and economic assessment of conventional ventilatory support	Peek	783
2	Extracorporeal membrane oxygenation for severe acute respiratory distress syndrome	Combes	508
3	Contemporary management of cardiogenic shock: A scientific statement from the American Heart Association	Van Diepen	394
4	Extracorporeal membrane oxygenation for 2009 influenza A(H1N1) acute respiratory distress syndrome	Davies	340
5	Extracorporeal Life support Organization Registry International Report 2016	Thiagarajan	321
6	Acute respiratory distress syndrome advances in diagnosis and treatment	Fan	313
7	Cardiopulmonary resuscitation with assisted extracorporeal life-support vs. conventional cardiopulmonary resuscitation in adults with in-hospital cardiac arrest: an observational study and propensity analysis	Chen	309
8	Predicting survival after ECMO for refractory cardiogenic shock: The survival after veno-arterial-ECMO (SAVE)-score	Schmidt	270
9	Complications of extracorporeal membrane oxygenation for treatment of cardiogenic shock and cardiac arrest: A meta-analysis of 1866 adult patients	Cheng	252
10	Referral to an extracorporeal membrane oxygenation center and mortality among patients with severe 2009 influenza A(H1N1)	Noah	238

ECMO, extracorporeal membrane oxygenation.

common study design, comprising almost half the evidence base. The most common clinical questions investigated were respiratory failure, heart and lung transplantation, and cardiac arrest. The high frequency of keywords relating to outcomes and mortality suggests a large interest in characterizing the effectiveness of ECMO. Although our searches covered the time of the COVID-19 pandemic, only one paper relating to this was included, and the majority of our analysis relates to non-COVID uses of ECMO.

This study improves knowledge regarding the highest cited literature regarding ECMO published in recent years. Our study is unique in that we analyzed key trends of ECMO during the COVID-19 pandemic. This differs to other bibliometric analyses, which usually demonstrate a

larger proportion of articles from the 1990s (17). The Mann-Kendall trend chart (Figure 2) demonstrates that more recent publications had a greater proportion of citations per year. These trends may be attributable to several factors. Firstly, increased awareness and uptake of ECMO in recent years. Secondly, earlier publications were cases series concerned with respiratory failure in trauma and infancy whereas newer publications were cohort studies and reviews of ECMO in valvular surgery, cardiac arrest, percutaneous coronary intervention, pandemics, and long-term mortality. Thirdly, it suggests large developments have been made in the availability of ECMO.

The United States was responsible for the majority of research output, which, considering the larger scientific community and availability of funding in the United

**Table 3.** The top 10 ECMO papers listed in descending order by the recent 12 months' citation number.

	Article	First Author	Number of Citations
1	Extracorporeal membrane oxygenation for severe acute respiratory distress syndrome	Combes	304
2	Efficacy and economic assessment of conventional ventilatory support	Peek	255
3	Contemporary management of cardiogenic shock: A scientific statement from the American Heart Association	Van Diepen	235
4	Acute respiratory distress syndrome advances in diagnosis and treatment	Fan	209
5	Intubation and ventilation amid the COVID-19 outbreak: Wuhan's experience	Meng	184
6	Extracorporeal Life support Organization Registry International Report 2016	Thiagarajan	134
7	Extracorporeal membrane oxygenation for 2009 influenza A(H1N1) acute respiratory distress syndrome	Davies	119
8	Predicting survival after ECMO for refractory cardiogenic shock: The survival after veno-arterial-ECMO (SAVE)-score	Schmidt	118
9	Complications of extracorporeal membrane oxygenation for treatment of cardiogenic shock and cardiac arrest: A meta-analysis of 1866 adult patients	Cheng	99
10	Predicting survival after extracorporeal membrane oxygenation for severe acute respiratory failure: The Respiratory Extracorporeal Membrane Oxygenation Survival Prediction (RESP) Score	Schmidt	94

ECMO, extracorporeal membrane oxygenation.

**Table 4.** Country of origin of authors.

Country	Number of Articles	Total Number of Citations
United States	49	14,085
Germany	11	2,530
France	9	2,534
Australia	6	1,249
Italy	4	1,071
UK	3	3,354
Taiwan	3	1,134
Canada	3	903
Japan	3	631
Sweden	3	537
China	2	376
Singapore	1	256
South Korea	1	240
Spain	1	212
Netherlands	1	203

States, is unsurprising. This sizable dominance from the United States is less pronounced when compared with other surgical fields such as ear, nose, and throat surgery (85%) (18), general surgery (78%) (19), and orthopedic surgery (76%) (20). Robert Bartlett is responsible for four articles (2,21–23) and a cumulative 1,129 citations. His seminal work on the use of ECMO in pediatrics spans three decades (1976–2000) and continues to be

**Table 6.** Authors with multiple papers in the top 100.

Author	Number of Articles	Total Citations	Timespan of Published Articles
Bartlett	4	1,129	1976–2000
Combes	3	1,211	2008–2018
Schmidt	3	920	2013–2015
Thiagarajan	3	741	2009–2017
Kinsella	3	739	1993–1999
Brodie	2	720	2011–2014
Finer	2	443	1994–1997
Chen	2	940	2003–2008

relevant and citable with 38 citations in the past 12 months. Brodie, D, also based in the United States has 720 citations on his two ECMO articles (24,25), which focus on the indications and techniques. Alain Combes of France has 1,211 citations on his three publications (26–28), which tend to focus on the mortality of ECMO in respiratory failure.

There was no observable trend regarding the type of article published and the respective journal. *Annals of Thoracic Surgery* had the greatest volume (9%), *Lancet* had the highest volume of total citations (n = 3,191) and the highest volume of citations in the past 5 years (n = 1,196) while *JAMA* had the highest volume of citations in the last

**Table 5.** Journal of publication within top 100 manuscripts.

Journal	2019 Impact Factor	Number of Articles	Eigenfactor	Total Citations
<i>Lancet</i>	59.10	4	0.428	3,191
<i>JAMA</i>	51.27	4	0.274	3,174
<i>NEJM</i>	70.67	5	0.687	2,471
<i>American Journal of Respiratory and Critical Care Medicine</i>	16.49	6	0.091	2,220
<i>Annals of Thoracic Surgery</i>	3.92	9	0.041	1,903
<i>Circulation</i>	23.05	7	0.211	1,893
<i>Intensive Care Medicine</i>	18.97	8	0.040	1,873
<i>ASAIO</i>	2.49	4	0.006	1,357
<i>Journal of Pediatrics</i>	3.74	5	0.045	1,108
<i>JTCVS</i>	5.26	5	0.037	1,074
<i>Critical Care Medicine</i>	6.97	4	0.055	1,048
<i>EHJ</i>	23.24	4	0.126	966
<i>JACC</i>	18.63	4	0.193	916
<i>Pediatrics</i>	5.40	3	0.109	838
<i>Annals of Surgery</i>	9.48	3	0.067	788
<i>Resuscitation</i>	4.57	2	0.029	571
<i>Anesthesiology</i>	6.42	2	0.028	483
<i>Pediatric Critical Care Medicine</i>	2.80	2	0.011	424
<i>American Journal of Transplantation</i>	7.16	2	0.051	397
<i>Critical Care</i>	6.96	2	0.045	349
<i>Journal of Pediatric Surgery</i>	2.09	2	0.016	338
<i>Critical Care and Resuscitation</i>	2.52	1	0.003	257
<i>Surgery</i>	3.48	1	0.027	245
<i>Heart, Lung, Circulation</i>	2.08	1	0.006	235
<i>American Journal of Pathology</i>	3.76	1	0.026	227
<i>Seminars in Cardiothoracic and Vascular Anesthesia</i>	1.04	1		226
<i>PLOS ONE</i>	2.78	1	1.707	192
<i>European Journal of Heart Failure</i>	13.97	1	0.028	192
<i>Journal of Thoracic Disease</i>	2.03	1	0.017	190
<i>Journal of Heart and Lung Transplantation</i>	8.58	1	0.027	181
<i>American Journal of Obstetrics and Gynaecology</i>	6.12	1	0.049	179
<i>Science Translational Medicine</i>	17.16	1	0.010	174
<i>Anesthesia and Analgesia</i>	3.49	1	0.023	162



12 months (457). Despite the two most heavily cited articles in the past 12 months being from high impact journals, there is no statistically significant relationship between the impact factor of an article's journal and the quantity of citations. This suggests that ECMO articles' importance within the literature are independent of journal status to some degree; a novel finding within the body of knowledge on the topic. Alternatively, this may be regarded as an important but specialist area that does not obtain much exposure in journals with a broader focus.

The uptake and use of ECMO by institutions has evolved over time and has proven to be a valuable tool in recent pandemics. Four of the top 100 articles describe the use of ECMO in H1N1 (4,5,7) and COVID-19 (3) pandemics. Considering the specialized use of ECMO in critically ill patients and that these two pandemics have occurred only recently, this demonstrates the impact ECMO has had globally and highlights its role in future pandemics.

With respect to inadequate access to ECMO, there are numerous socioeconomic factors and consequent ramifications that affect the uptake of this technology. There is a notable lack of geographical diversity in the publishing authors of the top 100 cited ECMO articles. This suggests we should aim to increase the equitable access to ECMO. This is particularly pertinent for heavily populated developing countries that are additionally burdened by pandemics due to the difficulties enacting social distancing and other precautionary measures present. This is representative of a broader issue in research systems and equitable access to healthcare. High-income developed nations invariably have more access to funding for research, larger scientific communities, and American authors tend to preferentially cite American articles and publish to American journals (29). This has led to an inappropriate Anglicization, Anglo-Saxon bias, and disproportionate strengthening of Western research at the detriment of smaller publishers and countries in the research sector. To further compound this issue in the context of ECMO research, the cost of its use is still outside the realm of possibility for many third world countries. The lifetime predicted cost-utility per Quality-associated Life Year (QALY) is \$31,000 USD and while this is within the range of cost-effective health technology for advanced economies, it is unaffordable for many developing countries and poorly resourced healthcare systems (3). Additionally, we observe a significant gender disparity in the authorship, which may resemble the underrepresentation of women in this area of medicine (30,31).

Our study has several limitations. We used only the Web of Science database to search articles, and so some papers ranked higher by other databases may have been excluded from our analysis. Inherent to any bibliometric approach is the reliance on indexing in MEDLINE for classifications. Although indexation is mostly automated,

the accuracy of indexing was not manually verified and possible error in the citation count may exist. However, this is likely to be small and would not affect the overall result. We assigned gender of authors on the data collector's best judgment regarding the usual gender association with each name, and this is a subjective approach. Citation analysis suffers from inherent bias. Recent studies have demonstrated that citations may be associated with positive study outcomes, the authority of authors, and the journal in which an article is published (32). Similarly, open access journals may confer a citation advantage giving articles published in these journals a higher level of recognition by the scientific community (33).

There is also the issue of recency bias, with more recently published articles not having the opportunity to obtain a high number of citations to be included in our analysis, despite being of good and high impact. These articles, and the authors that produce them, may gain recognition in later years (34). Although our study captures more than 12 months of the COVID-19 pandemic, analysis today may not fully capture the longer-term impact of COVID-19-related research because of the lag associated in the publication of research and gaining citations.

## CONCLUSION

Our study details the key trends in the literature for ECMO. We identified the landmark papers in the field and discussed the importance of ECMO as an important clinical technique. This paper is valuable for healthcare professionals who use ECMO and improves understanding of which factors influence the publication of ECMO research and identifying key papers, which have impacted this field.

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