Vol. 3, No. 2, 1-15. DOI: 10.47909/ijsmc.48

Pro-Metrics

ORIGINAL ARTICLE

Covid-19 associated coagulopathy (CAC): Global research output, 2020-2022

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ABSTRACT

Objective. This study examined the Covid-19 associated coagulopathy (CAC) publication and citation trends, focusing on the top authors, countries, organizations, journals, collaboration, subject areas, keywords, and high-cited articles.

Design/Methodology/Approach. Publications data on Covid-19 associated coagulopathy (CAC) were identified and extracted from the Scopus database. Data analysis has been performed using VOS viewer software, Biblioshiny, and MS Excel Software.

Results/Discussion. The study identified 1740 articles on Covid-19 associated coagulopathy from the Scopus database, which received 47,502 citations, averaging 27.3 citations per paper. In all, 905 authors from 601 organizations originating in 96 countries participated in research and published in 776 journals. United States (n=498), Italy (n=258), and China (n=164) contributed the most publications. While China (73.43 and 2.69), France (57.60 and 2.11,) and Germany (50.13 and 1.84) registered the highest citation per paper (CPP) and relative citation index (RCI). Harvard Medical School, USA (N=44), Huazhong University of S&T, China (N=41), and Tongji Medical College, China (N=39), lead with most of the publications. In contrast, Tongji Medical College, China (198.31 and 7.26), Huazhong University of S&T, China (198.15 and 7.26), and University College Hospital NHS Foundation Trust, U.K (129.23 and 4.73) lead in citation impact. *J. H. Levy, T. Iba* and *M. Levy* contributed to most of the publications (27, 25, and 20), while *N. Tag* (804.75 and 29.48), *A. Tripodi* (157.83 and 5.78), and *J. Thachil* (154.17 and 5.65) registered the highest citation impact by CPP and RCI. *Journal of Thrombosis and Haemostasis, Journal of Thrombosis and Thrombolysis,* and *Thrombosis Research* were the most productive ones (with 55, 51, and 46 publications). At the same time, *Medical Hypotheses* (1222), *Blood* (355.71) and *Thrombosis Journal* (233.86) were the most impactful journals. The top 9 keywords in terms of frequency of occurrences were "Covid-19" (n=1681), "Blood Clotting" (n=952), "D Dimer" (n=652), "Coagulopathy" (n=628), "Thrombosis" (n=584), "Blood" (506), "Anticoagulants" (n=499), "Blood Coagulation" (n=426) and "Fibrinogen" (n=376).

Received: 12-11-2022. **Accepted:** 28-05-2023

Editor: Carlos Luis González-Valiente

How to cite: Gupta, B., Kappi, M. M., Walke, R., Bansal, M., & Mandal, A. (2022). Covid-19 associated coagulopathy (CAC): Global research output, 2020-2022. *Iberoamerican Journal of Science Measurement and Communication; 3*(2), 1-15. DOI: 10.47909/ijsmc.48

Conclusions. Global research on Covid-19 associated coagulopathy since the pandemic was considered for scientometric assessment for the first time, combining the productivity and citation measures to present an overall picture of the literature in this area. Such an analysis will provide scholars and policy-makers with a meaningful reference for further exploration of topical issues and research trends in the field.

Keywords: Covid-19; coagulopathy; research trends; bibliometrics.

1. INTRODUCTION

Covid-19 originated for the first time in China in December 2019, spreading dramatically worldwide, affecting millions of people and causing thousands of deaths. Because of its fast spread, the WHO declared a pandemic in March 2020 (Solanki, 2021). Although Covid-19 was considered a respiratory disease, it was later redefined as a multisystem after clinical evidence accumulated over time. The Covid-19 disease led to high mortality in patients, particularly those with associated comorbidities, such as hypertension, diabetes, obesity, and cancer, as well as pulmonary, cardiovascular, liver, neurological, and renal disorders (Mahase, 2020).

The main effects of Covid-19 were seen in patients through dysregulation of multiple biological pathways, an abnormal immune response, and an exaggerated pro-inflammatory state, which finally leads to profound hemostasis disturbance (Lauretani *et al.,* 2020) in the form of coagulopathies and thrombotic events. This approach has been termed Covid-19-associated coagulopathy (CAC), correlating with the severity of illness, with those in the ICU suffering the most significant derangements (Connors & Levy, 2020).

Thrombotic or thromboembolic complications related to Covid-19 infections have generally been observed in arteries/arterioles, the microcirculation, and the venous system. CAC involves both the venous and arterial systems, and it develops due to coagulation activation by several factors that affect Virchow's triad: endo-theliitis, hyper-coagulopathy, and stasis(Connors & Levy, 2020). Understanding Covid-19 associated coagulopathy condition at the genomic, molecular, and cellular levels is needed by global scholars to mitigate thrombosis formation in at-risk patients (Lippi *et al.,* 2021).

Several bibliometric studies related to Covid-19 and co-coagulopathy-related research (Gupta *et al.,* 2021a) have been conducted in the past, covering areas such as thrombosis (Gupta *et al.,* 2021b), deep vein thrombosis (Özyalçın & Erol, 2021), central venous catheterization-associated thrombosis (Sun *et al.,* 2022) and anticoagulation therapy (Mian *et al.,* 2020). However, no bibliometric study exists today on the current topic of "Covid-19 assisted coagulopathy". However, some related bibliometric studies do exist. Under such studies, Durgun *et al.* (Durğun *et al.,* 2021) examined 159 studies related to pulmonary associated with Covid-19, Covid-19 laboratory hematology (Bell *et al.,* 2021) and hematology and oncology on Covid-19.

The present study analyses Covid-19 associated coagulopathy publications, as indexed in the Scopus database during 2020-22, with a focus on the analysis of their characteristics, distribution by document and source types, analyzing the leading actors (countries, organizations, authors, and journals), mapping the collaborative linkages among actors; analyzing the distribution of publications by broad subject areas and by significant keywords; and identifying the leading media of research communication and describing the bibliographic features of its highly-cited papers.

2. METHODOLOGY

Publications related to "Covid-19 and coagulopathy" were identified from the Scopus database using search terms related to "Covid-19" and "coagulopathy", covering the period from December 2019 to August 8, 2022. The search strategy used is listed below. A total of 1740 documents were downloaded from the database. For identification of the top 10 most productive countries, the search string was further restricted by country of publication one by one

in "country tag". Using analytical provisions provided in the Scopus database, additional information was generated using the "subject area tag," "source title tag", and "affiliation tag". The citation data was collected from the date of publication till 4.8.2022. The final publication data were exported in plain text format to computer software for final analysis.

TITLE ("covid 19" *OR* "2019 novel coronavirus" *OR* "coronavirus 2019" *OR* "coronavirus disease 2019" *OR* "2019-novel CoV" *OR* "2019 nov" *OR* covid 2019 *OR* corvidae *OR* "corona virus 2019" *OR* ncov-2019 *OR* ncov2019 *OR* "nov 2019" *OR* 2019-ncov *OR* covid-19 *OR* "Severe acute respiratory syndrome coronavirus 2" *OR* "SARS-CoV-2"*) OR KEY (*"covid 19" *OR* "2019 novel coronavirus" *OR* "coronavirus 2019" *OR* "coronavirus disease 2019" *OR* "2019-novel CoV" *OR* "2019 nov" *OR* covid 2019 *OR* corvidae *OR* "corona virus 2019" *OR* ncov-2019 *OR* ncov2019 *OR* "nov 2019" *OR* 2019-ncov *OR* covid-19 *OR* "Severe acute respiratory syndrome coronavirus 2" *OR* "SARS-CoV-2"*) AND KEY (*coagulation *OR* coagulopathy*)*

3. RESULTS

From the Scopus database, 1740 publications were found on the topic "Covid-19 associated coagulopathy" (CAC) from December 2019 to August 8, 2022. The 1740 publications (2020=618; 2021=883 and 2022=234) received 47502 citations, averaging 27.3 citations per paper (CPP). The 384 funded papers (22.07% share) out of 1740 have received external support from more than 150 global agencies. These 384 funded papers registered 14703 citations, averaging 38.29 CPP. The major external funding agencies supporting research (along with their output) were: National Institute of Health (n=91), National Natural Science Foundation of China (n=48), National Heart, Lung & Blood Institute, USA (n=37), U.S. Department of Health & Human Service (n=32), Bayer (n=20), Deutsche Forschungsgemeinschaft (n=19), Pfizer (n=18), Bristol-Mayer's Squibb (n=17), Boehringer Ingelheim (n=14), etc.

By document type, 949 (54.54%) global publications appeared as articles, followed by reviews (26.49% and 461 papers), letters (12.64% and 220 papers), notes (2.92% and 52 papers), editorials (2.59% and 45 papers), short surveys (0.40% and 7 papers), book chapters (0.29% and 5 papers each) and conference paper (0.06% and 1 paper. Of the total output, 93.85% (1633) appeared in English language, followed by Russian (2.13%), Spanish (1.49%), Chinese and French (0.63, Polish, and Slovak (0.06% each). In terms of population age group, adults constitute the largest publications group (n=598), followed by middle-aged (n=464), aged (n=453), child (n=51), and adolescents (n=45). From the medical perspective, the central focus of global studies in this area was on clinical studies (n=706), followed by complications (n=611), treatment (n=511), pathophysiology (n=466), risk factors (n=310), epidemiology (n=240), and genetics (n=63).

Geographical distribution

Among global research on "Covid-19 associated coagulopathy", 96 countries unevenly participated. On the one hand, 64 countries contributed 1-10 papers, 6 countries 11-20 papers, and 12 countries 21-50 papers each, while on the other hand, 10 countries contributed 51-100 and 4 countries 101-498 papers each. The top 10 countries individually published 67 to 498 papers on this topic. Collectively, they published 1571 papers which received 61031 citations, accounting for 90.29% and more than 100% share each of global publications and citations. USA and Italy were the main publishing countries, having contributed 498 and 258 papers (28.62% and 14.83% global share), followed by the U.K. (8.39% share), France, Germany, India, and Spain (from 5.06% to 5.52%) and Japan and Canada (3.97% and 3.85%). Six countries registered CPP & RCI above their group average (38.85 and 1.42): Canada (49.82 and 1.82), the U.K. (46.07 and 1.69), and Japan (43.71 and 1.60). China (73.43 and 2.69), France (57.60 and 2.11), Germany (50.13 and 1.84) (Table 1)

Measured by total link strength or collaborative linkages, the top 10 countries depicted such linkages varying from 45 to 322. The USA (n=322), Italy (n=153), and the U.K.(n=137) depicted the highest collaborative linkages.

In terms of country-to-country collaborative linkages, the most significant number of bilateral collaborative linkages (n=52) are made by "USA-Italy" pair, followed by country pairs such as "USA-U.K." (n=36), "USA-Japan" and "USA-Canada" (n=25 each), "U.K.-Italy" (n=24), "U.K.-France" (n=23), "USA-China" (n=22), "Italy-Germany" (n=14), etc. (Table 2)

No.	Country	TP	TC	CPP	RCI	HI	%TP	ICP	%ICP
1	United States	498	15152	30.43	1.11	53	28.62	201	40.36
2	Italy	258	8561	33.18	1.22	39	14.83	111	43.02
3	China	164	12043	73.43	2.69	34	9.43	41	25.00
4	U.K.	146	6726	46.07	1.69	32	8.39	98	67.12
5	France	96	5530	57.6	2.11	26	5.52	49	51.04
6	Germany	93	4662	50.13	1.84	23	5.34	49	52.69
7	India	92	756	8.22	0.3	15	5.29	30	32.61
8	Spain	88	1247	14.17	0.52	18	5.06	36	40.91
9	Japan	69	3016	43.71	1.6	15	3.97	32	46.38
10	Canada	67	3338	49.82	1.82	23	3.85	56	83.58
Total of 10 Countries		**1571**	**61031**	**38.85**	**1.42**	**27.81**	**90.30**	**703**	**44.75**
Global Total		**1740**	**47502**	**27.3**	**1.00**				
Share of top 10 countries in global total		**90.29**							

TP: Total papers; TC; Total citations; CPP: Citations per paper;
ICP: International collaborative papers; RCI: Relative citation index; hi=Hersh Index.

Table 1. Contributions of Top 10 Countries in "Covid -19 associated coagulopathy".

S. No.	Country	Collaborative linkages with other top 10 countries	TCL (NOC)
1	United States	2(52), 3(22), 4(36), 5(14), 6(18), 7(14), 8(16), 9(25), 10(25)	322 (9)
2	Italy	1(52), 3(5), 4(24), 5(23), 6(14), 7(4), 8(17), 9(5), 10(9)	153 (9)
3	China	1(22), 2(5), 4(5), 5(3), 6(1), 8(1), 9(3), 10(3)	46(8)
4	U.K.	1(36), 2(24), 3(4), 5(8), 6(17), 7(9), 8(7), 9(16), 10(17)	137(9)
5	France	1(14), 2(23), 3(3), 4(8), 6(6), 7(6), 8(12), 9(1), 10(8)	61 (9)
6	Germany	1(18), 2(14), 3(1), 4(17), 5(6), 7(4), 8(7), 9(1), 10(4)	72(9)
7	India	1(14), 2(4), 4(9), 5(6), 6(4), 8(1), 9(4), 10(3)	45(8)
8	Spain	1(16), 2(17), 3(1), 4(7), 5(12), 6(7), 7(1), 9(1), 10(6)	68(9)
9	Japan	1(25), 2(5), 3(3), 4(16), 5(1), 6(1), 7(4), 8(1), 10(10)	66(9)
10	Canada	1(25), 2(9), 3(3), 4(17), 5(8), 6(4), 7(3), 8(6), 9(10)	85(9)

TCL=Total collaborative linkages; NOC=Number of countries

Table 2. Collaborative linkages among top 10 countries.

Visualization and mapping of collaborative linkages of the top 10 countries with 67 and more published documents were undertaken, as depicted in Figure 1. In this figure, each node represents a country. The node's size is proportional to the number of publications published in a country. The links between the nodes represent the collaboration between the countries, with line thickness indicating the number of collaborations. All ten countries are placed in three clusters. Different colors represent different clusters formed by the nations. Cluster 1 (Red, 5 countries) includes Canada, India, Japan, the UK, and the USA. Cluster 2 (Green, 4 countries) includes France, Germany, Italy, and Spain. Cluster 3 (Blue, 2 countries) includes China and USA. The countries with the highest collaborations include the USA, Italy, China, U.K, France, Germany, India, Spain, Japan, and Canada. These ten countries were connected with 44 links and had 480 total link strengths.

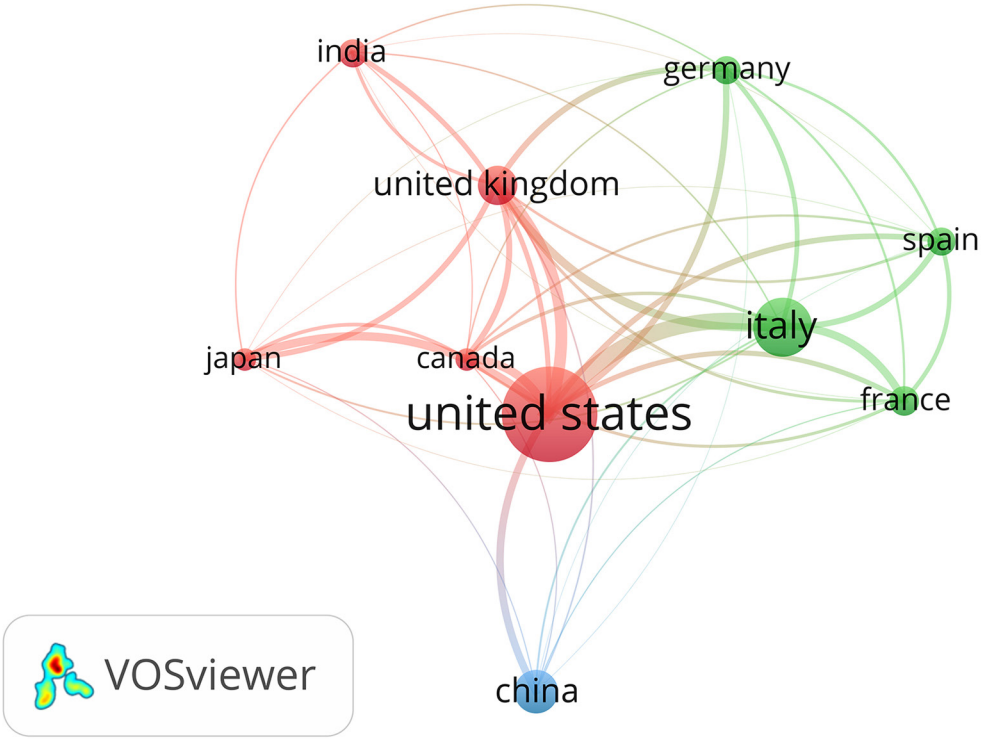

Figure 1. Top 10 Countries Collaboration Network.

Broad subject areas

Using Scopus database classification, the publications on "Covid-19 associated coagulopathy" were broadly classified under five subjects. Medicine (with 86.49% share) contributed the most publications, followed by Biotechnology, Genetics & Molecular Biology (17.41% share), Immunology & Microbiology (8.79% share), Pharmacology, Toxicology & Pharmaceutics (4.14% share), and Neurosciences (3.16% share). Regarding CPP, Immunology & Microbiology are placed top of the table, with 36.61 CPP and Pharmacology, Toxicology & Pharmaceutics the least (10.61 CPP) (Table 3).

No.	Broad Subject	TP	TC	CPP	%TP
1	Medicine	1505	44439	29.53	86.49
2	Biotechnology, Genetics & Molecular Biology	303	7194	23.74	17.41
3	Immunology & Microbiology	153	5601	36.61	8.79
4	Pharmacology, Toxicology & Pharmaceutics	72	764	10.61	4.14
5	Neurosciences	55	896	16.29	3.16
	Global Total	**1740**	**47502**	**27.3**	

TP: Total papers; TC: Total citations; CPP: Citations per paper

Table 3. Distribution of global publications on "Covid-19 associated coagulopathy" by Scopus defined subject areas.

Term co-occurrence analysis

Keywords represent central ideas in publications. They can be studied either independently or in combination with other keywords. The authors identified 8025 significant author keywords from the 1740 publications to elucidate the research focus in this area. Furthermore,

351 keywords occurred 35 or more times, of which 50 were selected, representing the research mainstream. The top 50 significant author keywords by the number of occurrences were shown in Table 4, with "Covid-19" considered as the most occurred keyword (n=1681), followed by "Blood Clotting" (n=952), "D Dimer" (n=652), "Coagulopathy" (n=628), "Thrombosis" (n=584), etc. The top 50 selected significant co-occurrence keyword network was visualized and clustered in Figure 2 to indicate the theme clusters, represented by various colors. The keywords' co-occurrence network comprised 1223 links and 55852 link strengths. It provides a helpful indication of the main topics within this research field. According to the cluster results in VOSViewer, 4 clusters were identified, which vary in size.

Cluster 1 (Red, 18 keywords) includes Coagulation, Coagulopathy, Covid-19, Cytokine Storm, Disseminated Intravascular Clotting, Disseminated Intravascular Coagulation, and others). Cluster 2 (Green, 16 keywords) include Acetylsalicylic Acid, C Reactive Protein, Comorbidity, Creatinine, D Dimer and others); Cluster 3 (Blue, 9 keywords) includes Anticoagulant Therapy, Anticoagulants, Enoxaparin, Heparin, and others; and Cluster 4 (Pink, 7 keywords) includes Blood, Blood Clotting, Blood Coagulation, Metabolism, and others). Figure 3 displays the word cloud map of significant author keywords.

No.	Keyword	Occurrences	No.	Keyword	Occurrences
1	Covid-19	1681	26	Hyper coagulation	178
2	Blood Clotting	952	27	Cytokine Storm	177
3	D Dimer	652	28	Biology Marker	176
4	Coagulopathy	628	29	Thrombocytopenia	174
5	Thrombosis	584	30	Deep Vein Thrombosis	163
6	Blood	506	31	Hypertension	160
7	Anticoagulants	499	32	Fibrinolysis	157
8	Blood Coagulation	426	33	Haemostasis	149
9	Fibrinogen	376	34	Ferritin	139
10	Heparin	363	35	Hydroxycholoroquine	134
11	Disseminates Intravascular Clotting	332	36	Comorbidity	133
12	Inflammation		37	Pulmonary Embolism	129
13	Venous Thromboembolism	309	38	Thrombophilia	128
14	C. Reactive Protein	298	39	Diabetes Mellitus	122
15	Anti-Coagulant Therapy	296	40	Respiratory Failure	122
16	Lung Embolism	295	41	Lactate Dehydrogenase	120
17	Metabolism	260	42	Cerebrovascular Accident	118
18	Interleukin 6	222	43	Sepsis	106
19	Disseminates Intravascular Coagulopathy	217	44	Oxygen Saturation	99
20	Adult Respiratory Syndrome	213	45	Tocilizumab	99
21	Coagulation	210	46	Endothelial Dysfunction	95
22	Enoxaparin	203	47	Creatinine	94
23	Thromboembolism	197	48	Acetylsalicylic Acid	92
24	Fibrin Degradation Product	210	49	Thromboelastography	91
25	Fibrin Fragment D	182	50	Cardiovascular Disease	84

Table 4. Most occurred author keywords.

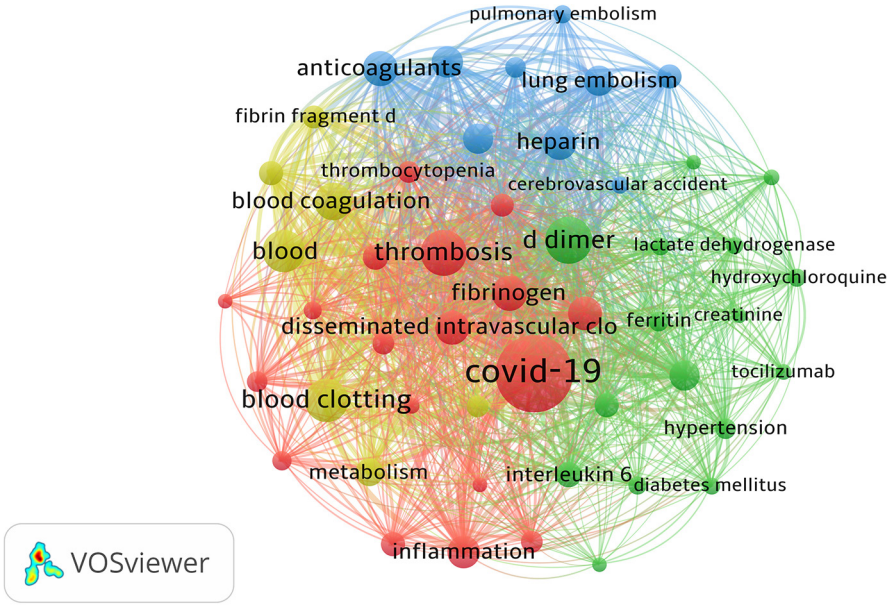

Figure 2. Author keywords co-occurrences network.

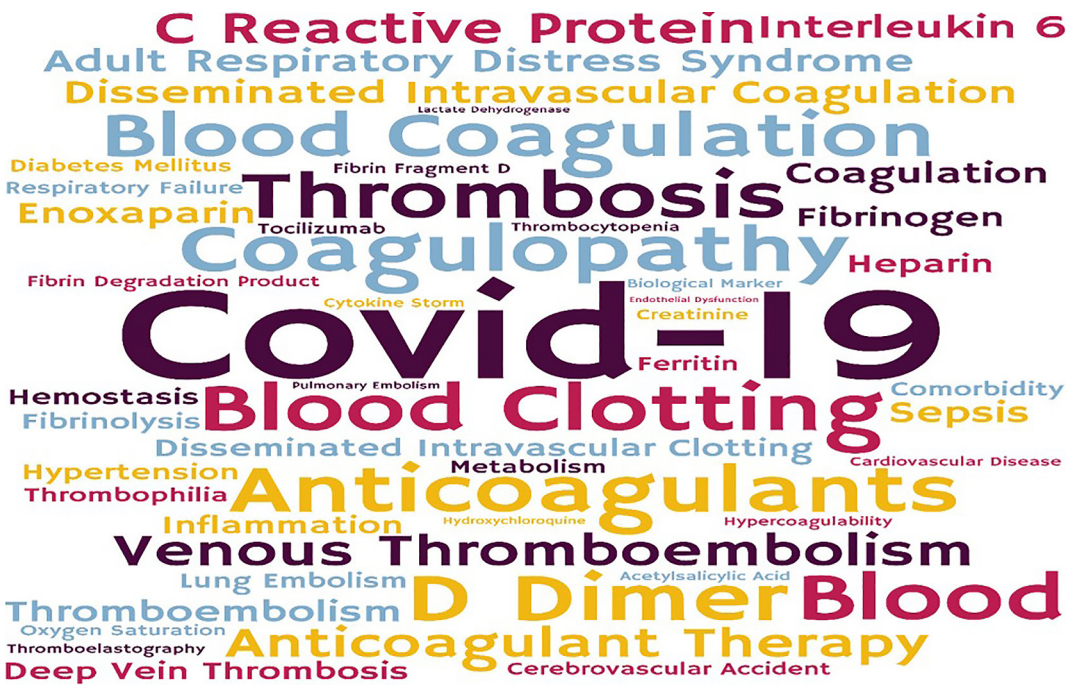

Figure 3. Author keywords cloud map.

Most productive organizations

The global research on "Covid-19 global research on "Covid-19 associated coagulopathy", associated coagulopathy" witnessed the uneven participation of 601 organizations: 401 and 146 organizations contributed 1-5 and 6-10 papers each on the one hand, and 30 and 15 organizations contributed 11-20 and 21-41 papers each on the other hand. Individually, the top 30 organizations published 15 to 44 papers. Together, they published 703 papers with 55846 citations, constituting 40.40% and more than 100.0% share of global papers and citations. Of amongst top 30 organizations, 10 were from the USA, followed by Italy (5), France (4), China

and the U.K. (3 each), Canada and the U.K. (2 each), and Brazil, Greece, and Japan, Spain and Russia Federation (1 each).

The average publication contributed by the top 30 organizations was 23.43. Only 5 organizations contributed more than this average publication productivity: Harvard Medical School, USA (n=44), Huazhong University of S&T, China (n=41), Tongji Medical College, China (n=39), INSERM, France (n=35) and University College London, U.K. (n=33). The average CPP and RCI registered by the top 30 organizations were 79.44 and 2.91. Only 10 organizations registered more than average: Tongji Medical College, China (198.31 and 7.26). Huazhong University of S&T, China (198.15 and 7.26), University College Hospital NHS Foundation Trust, U.K. (129.23 and 4.73), Universita degli Studi di Milano, Italy (125.20 and 4.59), National Institute of Health, USA (101.74 and 3.73), Brigham & Women's Hospital, USA (98.67 and 3.61), Duke University School of Medicine, USA (96.50 and 3.53), University College London, U.K. (94.06 and 3.45), Harvard Medical School, USA (87.6 and 3.19) and Universite Paris Cite, France (86.68 and 3.18). Table 5 provides information on the 6 top most productive and impact organizations.

No.	Name of the organization	TP	TC	CPP	RCI	TCL
	Top 6 most productive organizations					
1	Harvard Medical School, USA	44	3835	87.16	3.19	283
2	Huazhong University of S&T, China	41	8124	198.15	7.26	116
3	Tongji Medical College, China	39	7734	198.31	7.26	115
4	INSERM, France	35	2680	76.57	2.80	309
5	University College London, U.K.	33	3104	94.06	3.45	272
6	Universita degli Studi di Milano, Italy	20	2504	125.20	4.59	210
	Top 6 Most Impactful Organizations					
1	Tongji Medical College, China	39	7734	198.31	7.26	115
2	Huazhong University of S&T, China	41	8124	198.15	7.26	116
3	University College Hospital NHS Foundation Trust, U.K.	22	2843	129.23	4.73	207
4	Universita degli Studi di Milano, Italy	20	2504	125.20	4.59	210
5	National Institute of Health, USA	19	1933	101.74	3.73	88
6	Brigham & Women's Hospital, USA	27	2664	98.67	3.61	178

TP=Total papers; TC=Total citations; CPP=Citations per paper;
RCI=Relative citation index; TCL=Total collaborative linkages

Table 5. Publication profile of top 6 most productive and 6 most impactful organizations.

Collaborative linkages among the top 30 organizations

The total collaborative linkages of top 30 organizations varied from 56 to 309 and their collaborative linkages within the top 30 organizations varied from 1 to 38. The largest number of collaborative linkages (n=389" was shown by institutional pair "Huazhong University of S&T, China and Tongji Medical College, China", followed by institutional pairs sych as "Harvard Medical School, USA and Brigham & Women's Hospital, USA" and "University College London, U.K. and University College London Hospitals NHS Foundation Trust, U.K." (n=20 each), "Duke University School of Medicine, USA and Juntendo University Graduate School of Medicine, Japan" (n=17), "INSERM, France and Universite Paris Cite, France" and "Hospital Clinic Barcelona, Spain and Institut d'Investigacions Biomediques August Pi I Sunyer (IDIBAPS)" (n=16 each), "INSERM, France and AP-HP Assistance Publique de Paris, France" (n=15), "AP-HP Assistance Publique de Paris, France and Sirbonne University, France" (n=14), "Harvard Medical School, USA and Beth Israel Deaconess Medical Center, USA" and "AP-HP Assistance Publique de Paris, France and Universite

Paris Cite, France" (n=13 each), "Harvard Medical School, USA and Brigham & Women's Hospital, USA" , "Universita degli Studi di Milano, Italy and Ospedale Maggiore Policlinico Milano, Italy" and "Brigham & Women's Hospital, USA and Duke University School of Medicine, USA"(n=12 each), "Harvard Medical School, USA and Duke University School of Medicine, U.K." (n=11), etc.

The top 30 organizations' collaboration networks are shown in Figure 4. All 30 organizations were divided into 4 clusters. Cluster 1 (Violet, 11 institutions) includes the University of Toronto, Massachusetts General Hospital, Albert Einstein College of Medicine, Université Catholique De Louvain, University of Catania, Isfahan University of Medical Sciences, Johns Hopkins University School of Medicine, Emory University School of Medicine, Mayo Clinic, University of Verona and others. Cluster 2 (Green, 11 organizations) includes Université De Paris, University of Michigan, University of Milan, Hôpitaux Universitaires De Strasbourg, Medical University of Vienna, Georges Pompidou European Hospital, University College London, National and Kapodistrian University of Athens, University of Barcelona University of Genoa. Cluster 3 (Blue, 5 institutions) includes Harvard Medical School, Duke University School of Medicine, McMaster University, Juntendo University Graduate School of Medicine, University College London Hospitals NHS Foundation Trust. Cluster 4 (Red, 3 institutions) includes the Huazhong University of Science and Technology, Peking Union Medical College Hospital, and Uppsala University. The network visualization reveals that the Harvard Medical School, Massachusetts General Hospital, and University of Michigan are the top contributors in this research field.

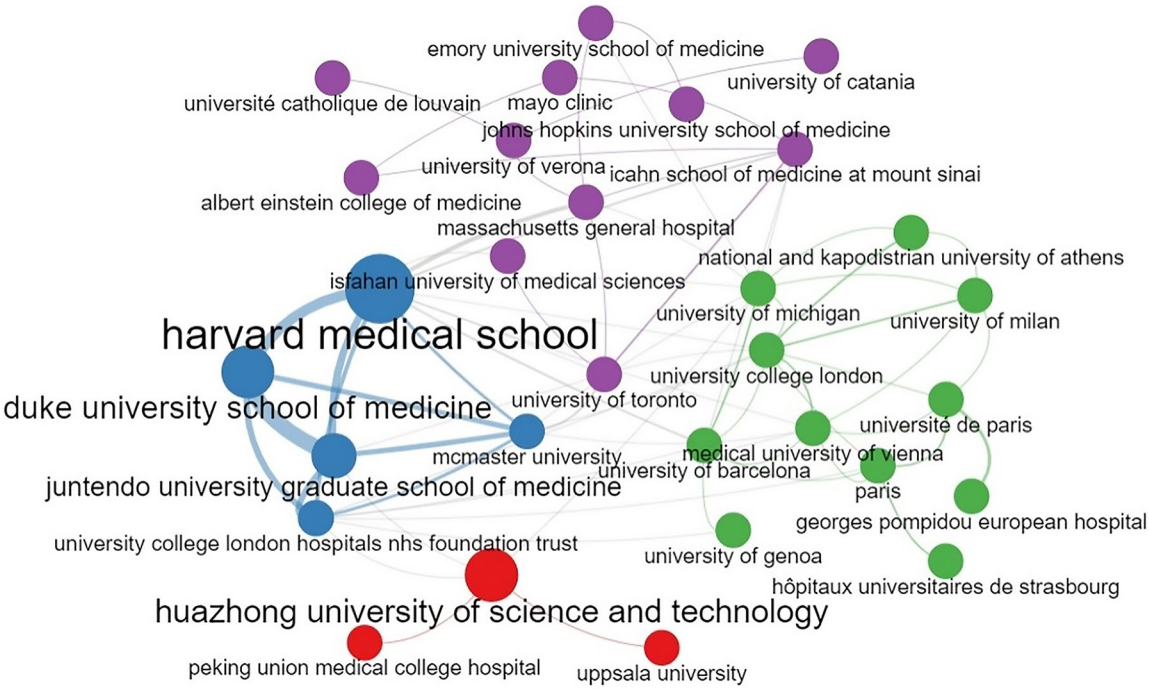

Figure 4. Top 30 organizations collaboration network map.

Most productive authors

In all, 905 authors participated in global research on "Covid-19 associated coagulopathy" (877 authors published 1-5 papers each; 22: 6-10 papers each, 4: 11-20 papers each, and 2: 21-27 papers each). The top 30 authors contributed 5 to 27 papers and published 294 papers with 29667 citations, constituting 16.90% and 62.45% share of global papers and citations. On further analysis, it was observed that 7 authors contributed more than average group publication productivity (9.80) of the top 30 authors: J.H. Levy (n=27), T. Iba

(n=25), M. Levy (n=20), I. Elalamy (n=19), J. Thachil (n=18), J.M. Connors (n=17), and G. Lippi (n=15). Eleven authors registered CPP and RCI more than the group average of top 30 authors (100.91 and 3.70): N. Tag (804.75 and 29.48), A. Tripodi (157.83 and 5.78), J. Thachil (154.17 and 5.65), M. Levy (140.75 and 5.16), T.E. Warkentin (137.44 and 5.03), G. Grasselli (132.67 and 4.86), M. Panigada (132.67 and 4.86), F. Peyvandi (114.86 and 4.21), J.M. Connors (111.41 and 4.08), J.H. Levy (110.81 and 4.06) and T.Iba (108.16 and 3.96). Table 6 provides information on the 6 top most productive and impact authors.

S. No.	Author	Affiliation	TP	TC	CPP	RCI	TCL
		Top 6 most productive authors					
1	J.H. Levy	Duke University School of Medicine, USA	27	2992	110.81	4.06	152
2	T. Iba	Juntendo Univ., Graduate School of Medicine, Japan	25	2704	108.16	3.96	96
3	M. Levy	Univ. College London Hospitals NHS Foundation Trust, U.K.	20	2815	140.75	5.16	85
4	I. Elalamy	Sorbonne University, France	19	1085	57.11	2.09	113
5	J. Thachil	University College London, U.K.	18	2775	154.17	5.65	77
6	J. M. Connors	Brigham & Women's Hospital, USA	17	1894	111.41	4.08	55
		Top 6 most impactful authors					
1	N. Tang	Huazhong University of S & T, China	8	6438	804.75	29.48	32
2	A.Tripodi	Ospedale Maggiore Policlinico Milano, Italy	6	947	157.83	5.78	55
3	J. Thachil	University College London, U.K.	18	2775	154.17	5.65	77
4	M. Levy	Univ. College London Hospitals NHS Foundation Trust, U.K.	20	2815	140.75	5.16	85
5	T. E.Warkentin	McMaster University,, Canada	9	1237	137.44	5.03	34
6	G. Grasselli	Ospedale Maggiore Policlinic Milano, Italy	6	796	132.67	4.86	63

TP: Total papers; TC: Total citations; CPP: Citations per paper;
RCI: Relative citation index; TCL: Total collaborative linkages

Table 6. Publication profile of top 6 most productive and 6 most impactful authors.

Collaborative linkages among top 30 authors

The individual total link strength or collaborative linkages of the top 30 authors varied from 12 to 152, with the highest collaborative linkages (152, 113, 96, 87, and 85) reported by J.H. Levy, I. Elalamy, T. Iba, F. Muller, and M. Levy. The bilateral collaborative linkages between authors varied from 1-20 among the top 30 authors. The author pair "J.H. Levy and T. Iba" depicted together the largest number of bilateral collaborative linkages (n=20), followed by author pairs such as "J. H. Levy - J. M. Connors" (n=14), "T. Iba - M. Levi" (n=13), "T. Iba - J.M. Connors" (n=12), "J. H. Levy - M. Levi" (n=11), "T. Iba - T. Thachil" (n=11), "M. Levy - J. Thachil" (n=11), "J. H. Levy - J. Thachil" (n=9), "G. Lippi - B.M. Henry" (n=8), "G. Lippi - E.J. Favaloro" (n=8), "V. O. Bitsadze - A. D. Makatsariya", "V. O. Bitsadze - M. V. Tretyakova" and "E. E. Moore - H. B. Moore" (n=7 each), "G. Grasselli - M. Panigrada", "M. V. Tretyakova - A. S. Shkoda", "A. D. Makatsariya - Shkoda", "V. O. Bitsadze - A. S. Shkoda", "J. H. Levy - T.E. Warkentin", "T. Iba - T.E. Warkentin", "M. Levy - J. M. Connors" and "J. Thachil - J. M. Connors" (n=6 each),

The top 30 most productive authors with 6 and more publications were visualized and mapped using VOSview software. The co-authorship network is shown in Figure 5, where each node represents an author. The node's size is proportional to the number of publications published by an author. The links between the nodes represent the collaboration between the authors, with line thickness indicating the number of collaborations. All these 30 authors are divided into four clusters. Different colors represent different clusters. Cluster 1 (Red, 14 authors) includes Chen L, Chen S, Chen X, Chen Y, Li X, Li Y, and others;

Cluster 2 (Green, 9 authors) includes Favaloro EJ, Henry BM, Li J, Li X, Li Y, Lippi G, Liu X, Liu Y, Moore EE, Moore HB, and others. Cluster 3 (Blue, 5 authors) includes Iba T, Levi M, and Levy JH. Lastly, Cluster 4, in yellow, has two authors: Liu X and Zhang D. These 30 authors connected with 100 links and 308 total link strengths.

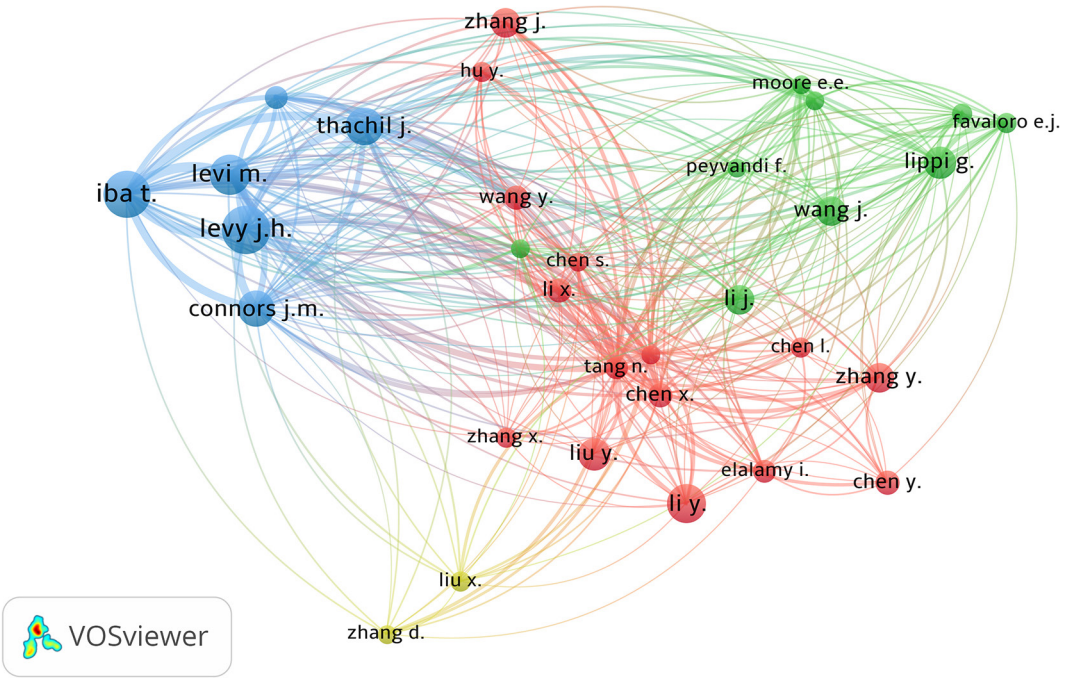

Figure 5. Top 30 authors collaboration network map.

Most productive journals

Of the 1740 Covid-19 associated coagulopathy papers, 1730(99.59%) are published in journals, 6(30.34%) in book series, and 1(0.06%) as a book and 3 as undefined. The 1730 papers are published in 340 journals, of which 297 journals published 1-5 papers each, 26 journals 6-10 papers, 10 journals 11-20 papers each, and 7 journals 21-55 papers each. The top 8 most productive journals include *Journal of Thrombosis and Haemostasis* (n=55), *Journal of Thrombosis and Thrombolysis* (n=51), *Thrombosis Research* (n=46), *Journal of Clinical Medicine* (n=30), *Clinical and Applied Thrombosis Hemostasis* (n=28), *Frontiers in Immunology* (n=22), *Thrombosis and Haemostasis* (n=21), and *International Journal of Laboratory Hematology* (n=20). In terms of CPP, *Medical Hypotheses achieved the highest value* (1222 CPP), followed by *Blood* (355.71), *Thrombosis Journal* (233.86), *Platelets* (212.62), *Clinical Case Reports* (39.41), and *Diagnostics* (32.67). In terms of total citations, *Medical Hypotheses* registered the highest number of citations (10998), followed by *Blood* (2490), *Platelets* (1701), and *Thrombosis Journal* (1637).

Top 30 journals co-citation network

Journal co-citation analysis is an effective way to study the structure and characteristics of a topic and also reveals the overall structure and character of a journal. Figure 6 shows the visualization of citation analysis of source titles. This study sets the minimum threshold of seven publications of source titles with minimum 10 citations of a source. Of the total 340 journals, 30 journals meet the thresholds. A total of 221 link strengths, 9 clusters, and 1252 links were reported in the VOSviewer analysis. *Journal of Thrombosis and Haemostasis* and *Journal of Thrombosis and Thrombolysis* has strong citations link strength (71 links), followed by *Journal of Thrombosis and Haemostasis* and *Thrombosis Research* (62 links), and the *Journal of Thrombosis and Haemostasis* and *Thrombosis and Haemostasis* (57 links each).

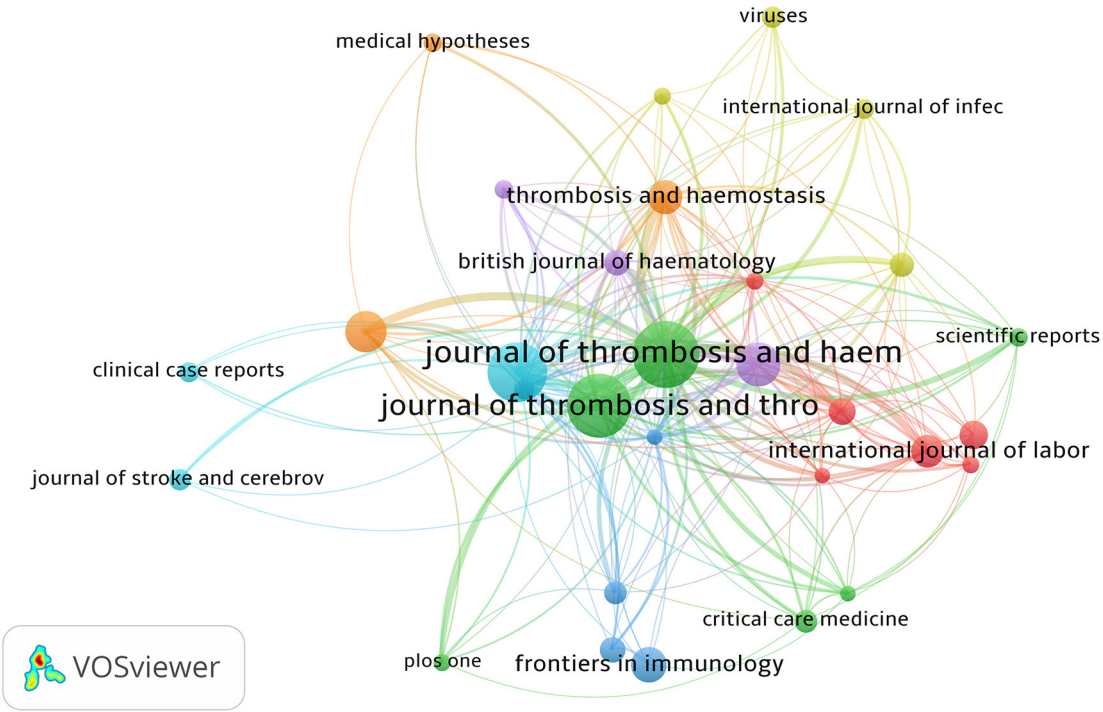

Figure 6. Co-citation network of top 30 journals.

High-cited papers (HCPs)

Only 89 (5.11%) of the total 1740 global publications on "Covid-19 associated coagulopathy" research received 100 to 1318 citations per paper (assumed here as high-cited papers (HCPs)) since their publication during 2020-22. Together these 89 papers received 32403 citations, averaging 364.08 per paper. The 89 HCPs distribution in different citation ranges indicates a highly skewed pattern, with 64 papers falling in the citation range 101-299, 14 papers in the citation range 300-499, 11 papers in the citation range 501-999, and 7 papers in citation range 1001-3069. The 89 HCPs include 44 articles, 28 reviews, 8 letters, 7 notes, and 2 editorials. Among 89 HCPs, only 14 papers are contributed by a single organization indicating zero collaboration, and 75 are contributed by 2 or more organizations (43 national and 32 international collaborative). The USA contributed the most papers (n=38) among 89 HCPs, followed by the U.K. (n=17), Italy (n=16), China (n=15), Germany (n=10), Canada, and France (n=9), Japan (n=6), Brazil (n=4), Greece, Iran, and the Netherlands (n=3 each), Ireland, Israel, Norway, Spain, and Switzerland (n=2 each), and 10 other countries 1 paper each

Among 89 HCPs, a total 746 authors from 436 organizations contributed. Harvard Medical School, USA contributed the largest number of papers (n=10) in 89 HCPs, followed by Huazong University of Science & Technology, China, Tongji Medical College, China and University College London, U.K. (n=8 each), Brigham & Women's Hospital, USA and University College Hospital NHS Foundation Trust, U.K. (n=6 each), INSERM, France, Universita degli Studi di Milano, Italy and Duke University School of Medicine, USA (n=4 each), Ospedale Maggiore Policlinico Milano, Italy (n=3), AP-HP Assistance Publique-Hopitauxde Paris, France, Sechenov First Moscow State Medical University, Russia, University of Sao Paulo, Brazil, Sorbonne University, France, Universite Paris Cite, France, Icahn School of Medicine at Mount Sinai, USA, Ethniko Ke Kapadistriako Panepistimio Athinon, Greece, Massachusetts General Hospital, USA, Junetendo University School of Medicine, Japan, National Institute of Health, USA, McMaster University, Canada and Chinese Academy of Medical Science Peking Union Medical College, China (n=2 each).

Among 89 HCPs, J.H. Levy (Duke University School of Medicine, USA), T. Iba (Juntendo Univ., Graduate School of Medicine, Japan,

M. Levy (Univ. College London Hospitals NHS Foundation Trust, U.K.) and J. Thachil (University College London, U.K.) contributed the most high-cited papers (n=6 each), followed by N. Tang (Huazazhong University of Science & Technology, China) (n=5), J.M. Connors (Brigham & Women's Hospital, USA)(n=4), E.E. Moore (Denver Health, USA) and H.B. Moore (Denver Health, USA)(n=3 each), I. Elalamy (Sorbonne University, France), .E. Warkentin (McMaster University, Canada) and A.Tripodi (Ospedale Maggiore Policlinico Milano, Italy) (n=2 each), etc.

The 89 HCPs were published in 53 journals, of which 14 papers were published in the *Journal of Thrombosis & Hemostasis,* 6 papers in the *Journal of Thrombosis & Thrombolysis,* 5 papers in *Thrombosis Research,* 4 papers each in *Blood* and *The Lancet Haematology,* 3 papers each in *British Journal of Haematology* and *New England Journal of Medicine,* 2 papers in *Circulation, Intensive Care Medicine, The Lancet, Nature Medicine, Nature Reviews Cardiology,* and *Thrombosis & Hemostasis* and 1 paper each in 38 other journals.

From the medical perspective, the 89 HCPs may be classified as clinical studies (n=49), pathophysiology (n=48), complications (n=44), risk factors (n=26), treatment (n=35), epidemiology (n=9), and genetics (n=4). There is an overlapping of papers under the above classification.

In terms of the type of studies, the 89 HCPs include reviews (n=26), controlled studies (n=20), retrospective studies (n=14), letters (n=8), prospective studies (n=6), procedures and observational studies (n=5 each) and case reports (n=4). The most significant keywords appearing in 89 HCPs (along with their frequency of appearance) include "Covid-19" (n=87), "Blood Clotting" (n=71), "Thrombosis" (n=48), "D Dimer" (n=42), "Anticoagulants" (n=38), "Heparin" (n=37), "Intravascular Clotting" (n=33), "Coagulation" (n=29), "Fibrin Fragment Degradation" (n=26), "Disseminated Intravascular Coagulation" and "Venus Thromboembolism" (n=24 each), "Fibrinogen" (n=20), "Lung Embolism" (n=19), "Fibrinolysis" (n=15), "Coagulopathy" (n=15), "Thrombcytopenia" (n=14), "Biomarkers" (n=13), "Thrombophilia" (n=12), "Hypercoagulability" (n=11), etc.

DISCUSSION

The scientific, economic, and political landscape controlling the Covid-19 pandemic and strengthening disease prevention and treatment measures should remain a top priority for various affected countries around the globe. The substantial knowledge about this virus is still undiscovered, despite various vaccines rollout from different countries to control the disease. Several thrombotic or thromboembolic complications continue to be observed in arteries/arterioles, microcirculation, and the venous system of Covid-19 patients, challenging researchers, policy-makers, and governments to develop suitable treatment measures.

The present study examined Covid-19 associated-coagulopathy literature (n=1740) published since the pandemic's start till 7.4.2023 as indexed in the Scopus database. It identified the leading actors, such as countries, organizations, authors, and journals. It studied their collaborating linkages, significant keywords in the area, and their co-occurrence linkages, throwing light on research dynamics in the field.

Organizations from USA and Italy are observed to be leading in publication productivity in this domain, and organizations from France, Germany, India, Spain, Japan, and Canada closely follow in publication productivity. In sharp contrast, China, France, and Germany, followed by the U.K and Japan, registered comparatively higher impact measured by CPP and RCI. Unsurprisingly, North America and Europe are at the forefront of scientific productivity. Still, Asian countries, notably China, India, and Japan, play an essential role in this emerging research domain. Surprisingly, China ranks at 3rd rank in publication productivity, ranking top in citation impact to be followed by European countries. Governments must provide funding and evolve national policies and strategies to control different aspects of this disease. We also observe that the U.S. has the highest number of collaborative publications (201), collaborating largely with countries like Italy (52), the U.K. (36), Japan and Canada (22 each), and China (22).

Similarly, the USA, Italy, and U.K have depicted the highest collaboration linkages with 9 out of the top 10 countries. However, the ratio of such collaboration compared to the total publications

is relatively lower than the other top countries compared to the USA. In essence, Canada has a higher collaboration rate (83.58%), followed by the U.K. (67.12%), Germany (52.69%), France (51.04%), etc. In contrast, China, India, and Japan have diverse collaborative research outputs: (i) their most active collaborating partners remained the USA, (ii) collaboration with other European partners is comparatively much smaller, and (III) regional collaboration was almost absent among Asian countries.

It was observed that among the top 30 participating organizations, 10 were from the USA, 4 each from Italy and France, 3 from China, 2 each from Canada and U.K., one each from remaining 5 countries. This US dominance is also reflected in the research output of its organizations, such as Harvard Medical School, USA, published the most papers (n=44). Other prominent productive organizations from different countries include the Huazhong University of S&T, China (n=41); Tongji Medical College, China (n=39); INSERM, France (n=35); and University College London, U.K. (n=33). In contrast, Tongji Medical College, China (198.31 and 7.26), Huazhong University of S&T, China (198.15 and 7.26), University College Hospital NHS Foundation Trust, U.K. (129.23 and 4.73) and Universita degli Studi di Milano, Italy (125.20 and 4.59) registered the highest CPP and RCI. We also observe that several organizations (7 and 6) participated in the top 30 most productive authors from the USA and Italy, 4 from Russia, 2 from China, Japan, Singapore, and the U.K., and 1 from 5 other countries. J. H. Levy (USA) was the most published author, having published 27 papers, followed by T. Iba (n=25), M. Levy (n=20), and I. Elalamy (n=19). In contrast, N. Tag (804.75 and 29.48) was the most impactful author in terms of CPP and RCI, followed by A. Tripodi (157.83 and 5.78), J. Thachil (154.17 and 5.65) and M. Levy (140.75 and 5.16).

As a publication source, the *Journal of Thrombosis and Haemostasis* published the most papers (n=55), followed by the *Journal of Thrombosis and Thrombolysis* (n=51), *Thrombosis Research* (n=46) and *Journal of Clinical Medicine* (n=30). *Medical Hypotheses* achieved the highest citation impact per paper (1222 CPP), followed by *Blood* (355.71), *Thrombosis Journal* (233.86), *Platelets* (212.62), and *Clinical Case Reports* (39.41). Keyword analysis identified the essential concepts and research areas. Our study identifies four main research clusters based on the association of keywords used in the publications. Cluster 1 (Red, 18 keywords) includes Coagulation, Coagulopathy, Covid-19, Cytokine Storm, Disseminated Intravascular Clotting, and Disseminated Intravascular Coagulation. Cluster 2 (Green, 16 keywords) includes Acetylsalicylic Acid, C Reactive Protein, Comorbidity, Creatinine, D Dimer, and others); Cluster 3 (Blue, 9 keywords) includes Anticoagulant Therapy, Anticoagulants, Enoxaparin, Heparin, and others; and Cluster 4 (Pink, 7 keywords) includes Blood, Blood Clotting, Blood Coagulation, Metabolism, and others. The keywords in each cluster together represent different areas of research currently pursued.

The present study provides a framework to profile the research landscape and exploit Covid-19 associated coagulopathy disease literature, which may help clinical researchers and policy-makers to take preemptive actions through developing a national strategy for preventing and treating Covid-19 associated coagulopathy. The Covid-19 pandemic can affect thrombotic or thromboembolic diseases directly or indirectly: (i) Cytokine storm that precipitates the onset of the systemic inflammatory response and predisposes to the development of thrombotic events; and (ii) Covid-19 treatment interventions may have drug interactions with anti-platelets and/or anticoagulants. The thromboprophylaxis and anticoagulation protocols for managing coagulopathy and bleeding should be implemented in each organization following the most current national and international recommendations.

Contribution statement

Conceptualization: B. M. Gupta.

Data Curation and visualization: Mallikarjun Kappi and Rajpal Walke.

Investigation, methodology, writing-original draft and project administration: B. M. Gupta.

Writing and editing the manuscript: B. M. Gupta and Madhu Bansal.

Conflict of interest

The authors declare that there is no conflict of interest.

Statement of data consent

The data generated during the development of this study has been included in the manuscript. ●

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