

COVID-2019 Vaccine A Scientometric Assessment of Global Publications during 2020

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ABSTRACT

Objectives: The study presents a bibliometric assessment of COVID-19 vaccine research publications to understand the current and up-to-date scenario of COVID-19 vaccine research and to track important research players and identify the current areas. **Materials and Methods:** The global literature on COVID-19 vaccine research published during 2020 were searched in the Scopus database, using the keywords "COVID-19 vaccine" or "Coronavirus 19 vaccine" on 12 September 2020. The 343 global records on COVID-19 vaccine research were obtained which received 2636 citations and were published in 66 countries involving 280 organizations, 259 authors and 191 journals. The publication records obtained were statistically analyzed by using various bibliometric indices: document type, country, collaboration patterns, affiliation, journal name, and citation patterns. **Results:** Among top 12 countries, USA, U.K and China were the most productive and China, South Korea and USA were the most impactful. Nearly 51% publications of these top 12 countries were international collaborative. The top most productive organizations were Harvard Medical School, USA (12 papers), University of Washington, Seattle, USA (10 papers) and Fudan University, China (with 12, 10 and 8 papers.

Th. top most impactful organizations in terms of citation per paper and relative citation index were Tongji Medical College, China (56.0 and 7.28), Shanghai Medical College, China (33.2 and 4.32) and Chinese Center for Disease Control and Prevention, China (23.5 and 3.06). The most productive journals were Nature, Science and Vaccine (24, 18 and 18 papers each) and the most impactful journals in terms of citations per paper were: Journal of Medical Virology (66.5), Cell (27.2) and New England Journal of Medicine (23.4). **Conclusion:** This results and findings emerging from the study shed new light on the major progress in the present time on hot topics on COVID-19 vaccine research.

Key words: COVID-19, Vaccine, Global publications, Bibliometrics, Scientometrics.

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INTRODUCTION

In both developed countries and developing world in particular, infectious diseases account for significant worldwide morbidity and mortality. Three infectious diseases among top 10, are the major cause of death globally according to WHO. The burden of infectious diseases is expected to become even greater in the near future in the light of the continuous emergence of infections worldwide.¹

Within the past two decades, coronavirus infection has broken out recurrently and triggered three widespread epidemics: The severe acute respiratory syndrome (SARS) occurred in China in 2002, the Middle East respiratory syndrome (MERS) emerged in Saudi Arabia in 2012, and now, COVID-19. Pathogens of the above diseases are species in the genus of Betacoronavirus belonging to the family Coronaviridae in the order Nidovirales.²

In December 2019, a cluster of viral pneumonia cases of unknown cause, subsequently identified as a novel coronavirus, named as 2019-nCoV or COVID-19 was first reported in Wuhan, China, then spread to all the provinces of China and now has become a global pandemic.³ By 16 September 2020, a total of 29,444,198 confirmed cases of COVID-19 in 213 countries, including 931,321 deaths, reported to WHO, which resulted in a great public concern.⁴

The Coronavirus Study Group of the International Committee on Taxonomy of Viruses designated the causative virus as severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2), and the disease, which subsequently spread globally, was named coronavirus disease

of 2019 (COVID-2019) by the World Health Organization (WHO). In March 2020, the WHO declared COVID-19 a pandemic.⁵

The clinical symptoms of COVID-19 range from asymptomatic to severe pneumonia and multiple organ failure. The most commonly reported clinical features are fever, cough, breathlessness, myalgia, and fatigue, whereas less common reported clinical features to include diarrhea, headache, conjunctivitis, and runny nose. For a subset of patients, the disease may progress to pneumonia with respiratory failure and even death by the end of the first week. The virus primarily spreads between people through close contact and via respiratory droplets produced from coughs or sneezes. It mainly enters human cells by binding to the receptor angiotensin converting enzyme-2.⁶

Consequently, considerable attention has been focused on COVID-19 from medical practitioners/scientists around the world to inhibit/stop the continuous transmission of SARS-CoV-2 and to develop guidelines for the effective treatment of severe cases. As an emerging infectious disease, COVID-19 has garnered great research interest. Medical practitioners/scientists are studying the disease from various scientific and clinical areas, including specialists in infectious diseases, virology and microbiology.⁷

The seriousness of the rapid spread of the SARS-CoV-2 virus has caused people to panic around the world since December 2019. Many uncertainties remain as to certain epidemiological, seroepidemiological, clinical and virological characteristics of the virus and associated clinical

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features. The key task is to explore how to enhance host defenses and/or destroy viral resistance.⁷

The availability of a safe and effective vaccine for COVID-19 is well-recognized as an additional tool to contribute to the control of the pandemic. At the same time, the challenges and efforts needed to rapidly develop, evaluate and produce this at scale are enormous. A global effort is underway round the clock to develop and mass-produce an effective vaccine to counter the new, deadly, and highly infectious coronavirus disease, COVID-19. For developing COVID-19 vaccines, besides substantial efforts made by international agencies, we notice an increasing number of public/private partnership and collaborations taking place between multinational pharmaceutical industry, biotechnology companies with national governments for development of COVID-19 vaccine.^{8,9}

In international level, organizations have formed international alliances to expedite vaccine development and prepare for distribution of COVID-Vaccines. In this regard, WHO has undertaken a major and extraordinary effort: (i) Harnessing a broad global coalition to develop and evaluate candidate vaccines as quickly and safely as possible; (ii) Mapping candidate vaccines and their progress across the world; (iii) Defining the desired characteristics of safe and effective vaccines to combat the pandemic; (iv) Coordinating clinical trials across the world – giving humanity the best chance of safe and effective vaccines for all.^{8,9}

As of September 2020, there were 321 vaccine candidates in development, a 2.5 fold increase since April. However, no candidates have completed clinical trials to prove its safety and efficacy.¹ In September, some 39 vaccine candidates were in clinical research, 33 in Phase I–II trials, and 6 in Phase II–III trials.¹⁰⁻¹⁴

In September 2020 the Coalition for Epidemic Preparedness Innovations (CEPI) scientists reported that 9 different technology platforms – with the technology of numerous candidates remaining undefined – were under research and development during 2020 to create an effective vaccine against COVID-19.¹ According to CEPI, most of the platforms of vaccine candidates in clinical trials as of September are focused on the coronavirus spike protein and its variants as the primary antigen of COVID-19 infection.¹ DNA or messenger RNA, i.e. DNA vaccines or RNA vaccines, offer considerable promise to alter COVID-19 antigen functions for strong immune responses, and can be rapidly assessed, refined for long-term stability, and prepared for large-scale production capacity. Other platforms being developed in 2020 focus on non-replicating viral vectors, peptides, recombinant proteins, live attenuated viruses, and inactivated viruses.¹⁰⁻¹⁴

Literature Review

There is no bibliometric study available so far on assessment of global output on COVID-19 vaccine research both at national and international level. However, quite a good number of studies (published mainly in 2020) are available on bibliometric assessment of Coronavirus research and particularly on COVID-19. In view of shortage of space, we review only few studies here.

Among studies focusing on Coronavirus research, Sri Ram² traced research trends on Coronavirus during 50 years through Scopus database, focusing it analysis on annual growth, productive countries, institutes, authors, journals, highly cited papers, and research focus using keywords. Joshua and Sivaprakasam¹⁵ analysed research outputs (6424) related to the Coronavirus during January 1968 to March 2020, based on the number of research publications per year, contributing author's clustering pattern, most preferred journals, leading publication, document type, broad research areas, commonly used keywords, the geographical distribution of publications, commonly used languages, and productive institutes.

Among studies focusing on COVID-19, Zyoud and Al-Jabi¹⁶ used bibliometric analysis to examine global research output (19,044 publications from 159 countries and involving 8387 institutions) related to COVID-19, covered in Scopus database during December 2019 up until June 19, 2020) to determine the top-cited publications, identify current hot topics and the current research priorities. Lou, Tian, Niu, Kang, Lian, Zhangof and Zhang¹⁷ examined 183 publications (published from 2020 January 14 to 2020 February 29) on Covid-19 originating from 20 different countries and published in 80 different journals. It identified and analyzed the data included title, corresponding author, language, publication time, publication type and research focus. Jingchun, Ya, Na, Runjing, Hailiang, Xiaoyan, Guoxiu, Jinhui, Che, Brett D. and Shisan⁷ explored the 143 English and 721 Chinese original research articles and reviews retrieved from both English and Chinese databases in relation to the outcomes of management and characterization of COVID-19 during the early stage of COVID-19 pandemic. Network maps were generated to evaluate the collaborations between different authors, countries/provinces, and institutions. Felice and Polimeni¹⁸ examined and evaluated the research trends in coronavirus disease (COVID-19) research output (1883 papers published from 94 countries and in 644 journals), using publication outputs, countries, institutions, journals, keywords, funding and citation counts, retrieved from Scopus database.

Gupta, Dhawan, Ahmed and Mamdapur¹⁹ evaluated global research output (103054 records) on COVID-19 based on quantitative and qualitative indicators. It presents a bibliometric profile of most influential countries, organizations, authors and journals and their collaborative linkages, besides identifying broad subject areas of research, most significant keywords and highly-cited papers related to COVID-19.

In view of this background and due to non-availability of quantitative and qualitative assessment of any COVID-10 vaccine global literature, we decided to undertake a study which aims to examine global scientific output of COVID-19 vaccine research with a view to assess the literature type and source, subject-wise spread and the existing focus and research priorities, identify, significant countries, organizations and authors involved, identify important channels of communications and determine the top-cited publications.

MATERIALS AND METHODS

Published papers on COVID-19 vaccine research was first identified, retrieved and downloaded on 12.9.2020 in a excel file using a comprehensive search strategy using a Scopus database, considered as the world's largest abstract and citation database of peer-reviewed scientific literature compared with PubMed or Web of Science. The terms used in the search engine of Scopus were either in "Keyword" or "Title" ("COVID 19 Vaccine" or "Coronavirus 2019 Vaccine"). The search yielded 343 global records which were further analyzed to collect data using Excel on the following bibliometric aspects: publication output, document types, country/regions, institute/authors, journals, and citations and international collaboration.

(KEY ("COVID-19 vaccine" or "coronavirus 19 vaccine") or TITLE ("COVID-19 vaccine" or "Coronavirus 19 vaccine"))

ANALYSIS AND RESULTS

The world publications on Covid-19 vaccine, as indexed in Scopus database (till 12.9.2020) consisted of 343 publications during 2020. These 343 publications have received 2636 citations, averaging to 7.68 citations per paper. Out of 343 publications, 84 papers received funding support from more than 100 national and international funding agencies. The 84 funded papers received 1388 citations, averaging to 16.52 citations per paper. The major funding agencies supporting research in this area

are: National Institute of Health, USA (17 PAPERS), National Natural Science Foundation of China (11 papers), National Institute of Allergy and Infectious Diseases (10 papers), Bill and Melinda Gates Foundation (7 papers), European Research Council (4 papers), Wellcome Trust (4 papers), Engineering and Physical Science Research Council (3 papers), etc. Of the 343 global publications, 132 were articles, 74 reviews, 63 notes, 43 editorials, 18 letters, 11 short notes and 2 conference papers.

Top 12 Most Productive Countries

66 countries unevenly participated in global research on COVID-19 vaccine research: 52 countries contribute 1-5 papers each, 7 countries 6-10 papers each, 3 countries each 11-20 and 21-50 papers and 1 countries 110 papers. The 91.25% share of the global research output and more than 100.0% share of global citations come from top 12 countries. USA contributed the largest share (32.07%) to global output, followed by U.K., China and India (13.41% and 11.95% and 9.04% respectively), Germany, Italy and Switzerland (from 4.08% to 4.37%) and Canada, South Korea, Australia, France and Russia Federation (from 2.04% to 2.92%) during 2020. Of the top 12 countries, only three countries registered relative citation above their group average of 1.15: China (2.27), South Korea (2.11) and USA (1.32). The share of international collaborative papers among top 12 countries varied from 0.00% to 78.57%, with an average of 51.76%. The share of funded papers in country output varied from 4.76% to 42.86 (Table 1).

Collaborative Linkages among Top 12 Countries

All the top 12 countries have one to one collaborative linkages, as observed from Table 2. The top three countries with largest collaborative linkages (63, 41 and 27) with 10-11 countries each were depicted by USA, U.K. and Germany. The top three countries with least collaborative linkages (7, 9 and 9) with 4-7 countries were Australia, Canada, South Korea and Russia Federation. Among country-country collaborative linkages, China-U.K. had registered highest number of collaborative linkages (14), followed by USA-U.K., followed by USA-China (13), USA-Germany (8 linkages), USA-India and USA-Switzerland (7 linkages each), India-South Korea (6 linkages), U.K.-Germany (5 linkages), etc (Table 2).

Subject-Wise Distribution of Research Output

Medicine contributed the largest publication share (56.56%) to global COVID-19 vaccine research, followed distantly by immunology and microbiology (29.15%), biochemistry, genetics and molecular biology (25.66%), pharmacology, toxicology and pharmaceuticals (13.41%) and veterinary science (6.71%) during 2020. Among these 5 subjects, immunology and microbiology registered the highest citation impact per paper (11.69) and veterinary science the least (0.96)(Table 3).

Significant Keywords

62 important keywords (having more than 18 frequencies and are assumed to be significant) have been identified from the literature on global COVID-19 vaccine research, which through light on the research trends in this research. These keywords are listed in Table 5 in the decreasing order of the frequency of their occurrence in the literature during 2020. The maximum frequency (310) was observed by Virus Vaccine, followed by COVID-19 Vaccine (303), Coronavirus Infection (299), Human (301), Viral Vaccine (299), etc. (Table 4)

Top 17 Most Productive Global Organizations

159 organizations participated unevenly in global COVID-19 vaccine research during 2020: 150 organizations published 1-5 papers each, 8 organizations 6-10 papers each and 1 organization 12 papers. Of the top 17 organizations, 10 are from USA, 4 from China, 2 from U.K. and 1 from India.

The productivity of top 17 most productive organizations varied from 5 to 12 publications per organization; together they contributed 32.07% (110) global publications share and 52.50% (1384) global citations share during 2020. The scientometric profile of top 17 most productive organizations having published 5 and more papers is presented in Table 5.

- Six organizations registered their publication output above the group average (6.64) of all organizations: Harvard Medical School, USA (12 papers), University of Washington, Seattle, USA (10 papers), Fudan University, China and University of Oxford, U.K (8 papers each), Baylor College of Medicine, USA and Massachusetts Institute of Technology, USA (7 papers each);

Table 1: Global Publication Output and Share of Top 10 Most Productive Countries in COVID-19 Vaccine Research during 2020.

S.No	Name of the Country	TP	TC	CPP	ICP	%ICP	FP	%FP	RCI	%TP
1	USA	110	1116	10.15	49	44.55	31	36.9	1.32	32.07
2	U.K.	46	239	5.2	27	58.7	15	17.86	0.68	13.41
3	China	41	715	17.44	18	43.9	21	25.00	2.27	11.95
4	India	31	219	7.06	15	48.39	8	9.52	0.92	9.04
5	Germany	15	73	4.87	11	73.33	5	5.95	0.63	4.37
6	Italy	14	67	4.79	4	28.57	3	3.57	0.62	4.08
7	Switzerland	14	42	3	11	78.57	5	5.95	0.39	4.08
8	Canada	10	54	5.4	5	50	5	5.95	0.7	2.92
9	South Korea	9	146	16.22	7	77.78	4	4.76	2.11	2.62
10	Australia	8	11	1.38	5	62.5	3	3.57	0.18	2.33
11	France	8	47	5.88	7	87.5	4	4.76	0.76	2.33
12	Russian Federation	7	37	5.29	3	42.86	3	42.86	0.69	2.04
	Total of 12 countries	313	2766	8.84	162	51.76	107		1.15	
	Global Total	343	2636	7.69						
	Share of top 12 in global total	91.25								

TP=Total publications; TC=Total citations; CPP=Citations per paper; ICP=International collaborative papers; RCI=Relative citation index; FP=Funded papers

Table 2: Collaboration Linkages among Top 12 Countries during 2020.

S.No	Name of the Country	Number of Collaborative Linkages with Other Countries	TCL(NC)
1	USA	2(14), 3(11), 4(7), 5(8), 6(3), 7(7), 8(2), 9(4), 10(2), 11(3), 12(2)	63(11)
2	U.K.	1(14), 3(3), 4(3), 5(5), 6(1), 7(4), 8(2), 9(3), 10(3), 11(3)	41(10)
3	China	1(11), 2(3), 4(1), 5(1), 7(2), 8(1), 9(1), 10(1), 11(1), 12(1)	23(10)
4	India	1(7), 2(3), 3(1), 5(3), 7(1), 9(6), 11(1), 12(1)	23(8)
5	Germany	1(8), 2(5), 3(1), 4(3), 6(3), 7(1), 8(1), 9(2), 11(2), 12(1)	27(10)
6	Italy	1(3), 2(1), 5(3), 7(1), 8(1), 11(1), 12(1)	11(7)
7	Switzerland	1(7), 2(4), 3(2), 4(1), 5(1), 6(1), 8(1), 9(1), 10(1), 11(3), 12(2)	24(11)
8	Canada	1(2), 2(2), 3(1), 5(1), 6(1), 7(1), 11(1)	9(7)
9	South Korea	1(4), 2(3), 3(1), 4(6), 5(2), 7(1), 12(1)	18(7)
10	Australia	1(2), 2(3), 3(1), 6(1)	7(4)
11	France	1(3), 2(3), 3(1), 4(1), 5(2), 6(1), 7(3), 8(1)	15(8)
12	Russian Federation	1(2), 3(1), 4(1), 5(1), 6(1), 7(2), 9(1)	9(7)

*TCL=Total Collaborative linkages; NC=Number of countries

- Six organizations registered their citation per paper and relative citation index above the group average (12.58 and 1.64) of all organizations: Tongji Medical College, China (56.0 and 7.28), Shanghai Medical College, China (33.2 and 4.32), Chinese Center for Disease Control and Prevention, China (23.5 and 3.06), Fudan University, China (22.88 and 2.97), Massachusetts General Hospital, USA (14.20 and 1.85) and Imperial College London, U.K.(13.4 and 1.74).

Table 3: Subject-Wise Breakup of Global Publications on COVID-19 Vaccine Analysis Research during 2020.

S.No.	Subject	TP	TC	CPP	%TP
1	Medicine	194	1579	8.14	56.56
2	Immunology and Microbiology	100	1169	11.69	29.15
3	Biochemistry, Genetics and Molecular Biology	88	571	6.49	25.66
4	Pharmacology, Toxicology and Pharmaceutics	46	341	7.41	13.41
5	Veterinary Science	23	22	0.96	6.71
	Global total	343	2636	7.69	

Table 4: List of Significant Keywords Appearing in Global Publications on COVID-19 Vaccine Research during 2020.

S.No	Name of the Keyword	Frequency	S.No	Name of the Keyword	Frequency	S.No	Name of the Keyword	Frequency
1	Virus Vaccine	310	23	Drug Efficacy	47	43	Biosynthesis	23
2	COVID-19 Vaccine	303	24	SARS Coronavirus	47	44	Vaccine Immunogenicity	23
3	Coronavirus Infection	299	25	Middle East Respiratory Syndrome Coronavirus	46	45	Drug Repositioning	22
4	Human	301	26	Immune Response	46	46	Virus Genome	22
5	Viral Vaccine	299	27	Drug Development	45	47	Passive Immunization	20
6	Pandemic	289	28	Drug Safety	45	48	Cellular Immunity	19
7	Virus Pneumonia	276		Virus Antibody	44		Lopinavir Plus Ritonavir	19
8	Coronavirus Disease 2019	234	29	Angiotensin Converting Enzyme 2	39	49	Epitope	19
9	Severe Acute Respiratory Syndrome 2 Vaccine	189	30	Virus Transmission	38	50	Favipiravir	18
10	Immunology	172	31	Drug Design	38	51	Viral Neutralization	18
11	Non-humans	143	32	Laboratory Techniques	33	52	Amino Acid Sequence	17
12	Vaccine	98	33	Drug Effect	32	53	Live Vaccine	16
13	Vaccination	87	34	Remdesivir	32	54	Rtidyl-Dipecombinant Vaccine	16
14	Virology	79	35	SARS Syndrome	28	55	Messenger RNA	15
15	Genetics	66	36	Vaccine Production	28	56	Virus RNA	14
16	Severe Acute Respiratory Syndrome (SARS) Vaccine	63	37	Viral Protein	28	57	RNA Vaccine	14
17	Coronavirus	60	38	DNA Vaccine	26	58	Peptidyl-Dipeptidare A	14
18	Clinical Trial	58	39	Virus Spike Protein	26	59	Virus Vector	13
19	SARS-COV-2 Spike Protein	57	40	Chloroquine	25	60	Adenovirus Vector	13
20	Clinical Trials	57	41	Hydrochloroquine	24	61	Epitope	19
21	Neutralizing Antibody	56	42	Virus Replication	23	62	Favipiravir	18
22	Anti-Viral Agents	47						

Table 5: Top 17 Most Productive Organizations in COVID-19 Vaccine during 2020.

S.No	Name of the Organization	TP	TC	CPP	HI	ICP	ICP (%)	RCI
1	Harvard Medical School, USA	12	138	11.50	6	5	41.67	1.50
2	University of Washington, Seattle, USA	10	27	2.70	3	7	70.00	0.35
3	Fudan University, China	8	183	22.88	5	6	75.00	2.97
4	University of Oxford, U.K.	8	81	10.13	5	4	50.00	1.32
5	Baylor College of Medicine, USA	7	50	7.14	4	1	14.29	0.93
6	Massachusetts Institute of Technology, USA	7	81	11.57	4	2	28.57	1.50
7	John Hopkins University, USA	6	7	1.17	2	4	66.67	0.15
8	National Institute of Health, Bethesda, USA	6	56	9.33	3	3	50.00	1.21
9	Chinese Center for Disease Control and Prevention, China	6	141	23.50	4	1	16.67	3.06
10	Global Healthcare Consulting, India	5	0	0.00	0	0	0.00	0.00
11	Tongji Medical College, China	5	280	56.00	3	1	20.00	7.28
12	Baylor University, USA	5	30	6.00	2	0	0.00	0.78
13	University of Florida, USA	5	5	1.00	1	5	100.00	0.13
14	Imperial College London, U.K.	5	67	13.40	4	4	80.00	1.74
15	Massachusetts General Hospital, USA	5	71	14.20	3	2	40.00	1.85
16	Stanford University, USA	5	1	0.20	1	5	100.00	0.03
17	Shanghai Medical College, China	5	166	33.20	3	5	100.00	4.32
	Total of top 17 organizations	110	1384	12.58	3.12	55	50.00	1.64
	Global total	343	2636	7.69				
	Share of Top 17 organizations in global total	32.07	52.50					

*TP=Total publications; TC=Total citations; CPP=Citations per paper; ICP=International collaborative papers; RCI=Relative citation index

Institutional Collaboration among Top 15 Organizations

The total number of collaborative linkages among top 10 organizations is small and varies from 2 to 11 linkages. The top 3 organizations registering highest institutional collaboration linkages were: University of Washington, Seattle, USA, Global Healthcare Consulting, India and Harvard Medical School, USA (11, 7 and 6 linkages with 3-4 organizations. In contrast, the organizations registered the least linkages are: University of Oxford, U.K., Massachusetts Institute of Technology, USA and National Institute of Health, USA (2, 4 and 4 linkages) with 2 organizations each. On individual to individual basis the largest number of collaborative linkages (5) are between University of Washington, Seattle, USA and Global Healthcare Consulting, India, followed by University of Washington, Seattle, USA and National Institute of Health, Bethesda, USA (3 linkages), Harvard Medical School, USA and Massachusetts Institute of Technology, USA (3 linkages), etc. (Table 6).

Top 31 Most Productive Authors

280 authors unevenly participated in global COVID-10 vaccines research during 2020: 168 authors published 1 papers each, 81 authors 2 papers each, 23 authors 3 papers each, 4 authors 4 papers each, 3 authors 5 papers each and 1 author 6 papers. Of the 31 top authors, 8 each were from USA and India, 7 from U.K., 6 from China, 1 from Russian Federation and 1 not available.

The research productivity of top 31 most productive authors varied from 3 to 6 publications per author. Together they contributed 31.20% (107) global publications share and 43.74% (1153) global citations share

Table 6: Collaborative linkages among top 10 organizations in COVID-10 Vaccine Research during 2020.

S.No	Name of Organization	Collaborative Linkages with other Organization	Total Collaborative Linkages
1	Harvard Medical School, USA	2(1), 6(3), 7(2)	6(3)
2	University of Washington, Seattle, USA	1(1), 7(2), 8(3), 10(5)	11(4)
3	Fudan University, China		
4	University of Oxford, U.K.	6(1), 8(1)	2(2)
5	Baylor College of Medicine, USA		
6	Massachusetts Institute of Technology, USA	1(3), 4(1)	4(2)
7	John Hopkins University, USA	1(2), 2(2), 10(1)	5(3)
8	National Institute of Health, Bethesda, USA	2(3), 10(1)	4(2)
9	Chinese Center for Disease Control and Prevention, China		
10	Global Healthcare Consulting, India	2(5), 7(1), 8(1)	7(3)

during 2020. The scientometric profile of top 31 productive authors is presented in Table 7.

- Eight authors registered their publications output above the group average of 3.45: M.E. Bottazzi (Baylor College of Medicine, USA) (6 papers), P.J. Hotez (Baylor College of Medicine, USA), S. Kochhar (Global Healthcare Consultancy, India), C.Qin (Peking Union Medical College, CAS, China) and L.R. Baden (Brighton's and Women's Hospital, Boston, USA)(5 papers each), R.T. Chen (Brighton Collaboration, U.K), S. Morrissey (National Institute of Aging, Baltimore, USA) and E.J. Rubin (Harvard TH Chan School of Public Health, Boston, USA)(4 papers each);

- Eight authors registered their citation per paper and relative citation index above the group average (10.78 and 1.40) of all authors: M. Saville (Coalition for Epidemic Preparedness Innovation, London, U.K (97.0 and 12.61), L. Du (Fudan University, China) (44.0 and 5.72), S. Jiang (Fudan University, China)(44.0 and 5.72), L. Bao (Harvard Medical School, USA)(29.0 and 3.77), J. Liu (Chinese Center for Disease Control and Prevention, China)(29.0 and 3.77), W. Chen (Beijing Institute of Biotechnology, China)(24.0 and 3.12), C.Qin (Peking Union Medical College, CAS, China)(18.6 and 2.42) and N. Eyal (Harvard T.H.Chan School of Public Health, USA)(11.67 and 1.52).

Table 7: Top 31 Most Productive Authors in COVID-19 Vaccine during 2020.

S.No	Name of the Author	Affiliation of the Author	TP	TC	CPP	HI	ICP	ICP (%)	RCI
1	M.E. Bottazzi	Baylor College of Medicine, USA	6	39	6.50	3	0		0.85
2	P.J. Hotez	Baylor College of Medicine, USA	5	39	7.80	3	0		1.01
3	S.Kochhar	Global Healthcare Consultancy, India	5	0	0.00	0	0	0.00	0.00
4	C.Qin	Peking Union Medical College, CAS, China	5	93	18.60	4	3	60.00	2.42
5	L.R. Baden	Brighton's and Women's Hospital, Boston, USA	5	0	0.00	0	0		0.00
6	R.T. Chen	Brighton Collaboration, U.K.	4	5	1.25	1	4	100.00	0.16
7	S. Morrissey	National Institute of Aging, Baltimore, USA	4	0	0.00	0	0		0.00
8	E.J. Rubin	Harvard TH Chan Sch. of Public Health., USA	4	0	0.00	0	0		0.00
9	E. Allen	University of Oxford, U.K.	3	22	7.33	2	1	33.33	0.95
10	L. Bao	Harvard Medical School, USA	3	87	29.00	3	1	33.33	3.77
11	S. Belij-Rammerstorfer	University of Oxford, U.K.	3	22	7.33	2	1	33.33	0.95
12	W. Chen	Beijing Institute of Biotechnology, China	3	72	24.00	2	0		3.12
13	J. Cohen	Independent Scholar, Russia Federation	3	2	0.67	1	0		0.09
14	R.C.Condit	Global Healthcare Consultancy, India	3	0	0.00	0	0		0.00
15	D.B. Cory	Baylor College of Medicine, USA	3	30	10.00	2	0		1.30
16	L. Du	Fudan University, China	3	132	44.00	2	3	100.00	5.72
17	J.L.Excler	Global Healthcare Consultancy, India	3	0	0.00	0	0		0.00
18	N. Eyal	Harvard T.H.Chan School of Public Health, USA	3	35	11.67	1	1	33.33	1.52
19	G.F. Gao	Institute of Microbiology, CAS, China	3	9	3.00	2	1	33.33	0.39
20	C. Gilbride	University of Oxford, U.K.	3	22	7.33	2	1	33.33	0.95
21	M.Guruwith	Global Healthcare Consultancy, India	3	0	0.00	0	0		0.00
22	S. Jiang	Fudan University, China	3	132	44.00	2	3	100.00	5.72
23	D. Kim	Global Healthcare Consultancy, India.	3	0	0.00	0	0		0.00
24	T. Lambe	University of Oxford, U.K.	3	22	7.33	2	1	33.33	0.95
25	H.Ledford	Not Available	3	12	4.00	1	0		0.52
26	J. Liu	Chinese Center for Disease Control and Prevention, China	3	87	29.00	3	1	33.33	3.77
27	J.Y.Nau	NA	3	0	0.00	0	0		0.00
28	J.S.Robertson	Global Healthcare Consultancy, India	3	0	0.00	0	0		0.00
29	M. Saville	Coalition for Epidemic Preparedness Innovation, London, U.K.	3	291	97.00	2	2	66.67	12.61
30	E.R.Smith	Global Healthcare Consultancy, India	3	0	0.00	0	0		0.00
31	D.Wood	Global Healthcare Consultancy, India	3	0	0.00	0	0		0.00
		Total of 31 top authors	107	1153	10.78	1.29	23	21.50	1.40
		Global total	343	2636	7.69				
		Share of 31 top authors in global total	31.20	43.74					

*TP=Total publications; TC=Total citations; CPP=Citations per paper; ICP=International collaborative papers; RCI=Relative citation index

Medium of Research Communication

Of the total global output on COVID-19 vaccine research, all output (100.0%) was published in 191 journals. Of the 191 journals which reporting 343 articles, 137 published 1 papers each, 47 published 2-5 papers each, 3 published 6-10 papers each and 4 journals published 12-24 papers during 2020. The top 16 most productive journals accounted for 38.78% share of total global COVID-19 vaccine research output and 50.27% share of global citations output in this area that appeared in journal medium during 2020. The top 5 most productive journals were: Nature (24 papers), Science and Vaccine (18 papers each), Lancet (12 papers) and Lancet Infectious Disease (7 papers). The top 5 most impactful journals in terms of citations received were: Journal of Medical Virology (266 citations), Science (212 citations), Cell (136 citations), Lancet (119 citations) and New England Journal of Medicine (117 citations). The top 5 journals in terms of citations per paper were: Journal of Medical Virology (66.5), Cell (27.2), New England Journal of Medicine (23.4), Human Vaccine and Immunotherapeutics (19.25) and Nature Communications (18.17) (Table 8).

Highly-Cited Papers

Of the 343 global publications on COVID-19 vaccine research during 2020, only 15 publications registered 55 to 222 citations per paper (assumed here highly- cited) and they together received a total of 1546 citations, since their publication, averaging to 103.07 citations per paper. The distribution of 15 highly cited papers is highly skewed: 8 papers each were in the range 55-83, 6 papers in citation range 119-182 and 1 paper 222 citations. Among 15 high-cited papers, USA contributed the highest number of papers (6), followed by China (5), South Korea (2), Iran, Netherland, Norway, Taiwan and Thailand (1 paper each). The 15 high cited papers (7 articles, 6 reviews and 2 notes) involve 63 organizations

and 191 authors. Of the 15 high cited papers, 2 involved zero collaboration, 8 national and 5 international collaboration. In all 13 journals participated in 15 high cited papers. Of these, the largest number of papers (2 each) was published in Journal of Medical Virology and Science, and 1 paper each in Cell, Cellular and Molecular Immunology, Human Vaccines and Immunotherapeutic, Immunity, International Journal of Molecular Science, Journal of Microbiology and Biotechnology, The Lancet, Nature Reviews- Drug Discovery, Nature Reviews-Immunology, New England Journal of Medicine and Viruses. The list of top 10 high-cited papers is presented in Table 9.

SUMMARY AND CONCLUSION

The global COVID-19 vaccine research resulted in 343 publications, which in turn received 2636 citations registering a citation per paper of 7.68. Of the 343 publications, only 84 publications were found to be supported by more 50 funding agencies, which as expected, averaged a much higher average citation per paper of 16.52 citations per paper. Among 66 participating countries in COVID-19 vaccine research, the top 12 countries alone contributed 91.25% share of the global publication output and above 100.0% share of global citations received. The largest publication share (32.07%) to global output, among top 12 countries, is contributed by USA, followed by U.K., China and India (13.41% and 11.95% and 9.04% respectively), Germany, Italy and Switzerland (from 4.08% to 4.37%) etc. The USA and China, being the top most productive country also registered the highest and above average relative citation index (1.32 and 2.27) and share of funded papers (36.90% and 25.0%). U.K. and South Korea were also the third most productive and second most impactful country among top 12 countries. USA, U.K. and Germany had made the largest collaborative linkages (63, 41 and 27) amongst top 12 countries, but across countries (14), USA-U.K collaboration seems to be the strongest (with 14 links), followed by USA-China (13 links), USA-Germany (8 links), USA-India and USA-Switzerland (7 links), India-South Korea (6 links and U.K.-Germany (5 links). Among five subjects intersecting with global COVID-19 research, medicine received the highest publication share (56.56%) to global COVID-19 vaccine research, followed distantly by immunology and microbiology (29.15%), biochemistry, genetics and molecular biology (25.66%), pharmacology, toxicology and pharmaceuticals (13.41%) and veterinary science (6.71%) during 2020. 159 organizations and 280 authors unevenly participated in global research on COVID-19 vaccine research during 2020, of which the top 17 global most productive organizations and 31 global most productive authors contributed 32.07% and 31.20% to global publication share and 52.50% and 43.74% global citation share respectively. The five leading organizations in terms of publication productivity were: Harvard Medical School, USA (12 papers), University of Washington, Seattle, USA (10 papers), Fudan University, China and University of Oxford, U.K (8 papers each) and Baylor College of Medicine, USA (7 papers). The five leading organizations in terms of citation impact per paper and relative citation index were: Tongji Medical College, China (56.0 and 7.28), Shanghai Medical College, China (33.2 and 4.32), Chinese Center for Disease Control and Prevention, China (23.5 and 3.06), Fudan University, China (22.88 and 2.97) and Massachusetts General Hospital, USA (14.20 and 1.85). The five leading authors in terms of publication productivity were: M.E. Bottazzi (Baylor College of Medicine, USA)(6 papers), P.J. Hotez (Baylor College of Medicine, USA), S. Kochhar (Global Healthcare Consultancy, India), C. Qin (Peking Union Medical College, CAS, China) and L.R. Baden (Brighton's and Women's Hospital, Boston, USA)(5 papers each). The five leading authors in terms of citation impact per paper and relative citation index were: M. Saville (Coalition for Epidemic Preparedness Innovation, London, U.K (97.0 and 12.61), L. Du (Fudan University, China)(44.0 and 5.72), S. Jiang

Table 8: Top 10 Most Productive Journals in COVID-19 Vaccine Research during 2020.

S.No	Name of the Journal	TP	TC	CPP
1	Nature	24	110	4.58
2	Science	18	212	11.78
3	Vaccine	18	17	0.94
4	Lancet	12	119	9.92
5	Lancet Infectious Disease	7	13	1.86
6	Nature Reviews Immunology	7	85	12.14
7	Nature Communications	6	109	18.17
8	American Journal of Tropical Medicine and Hygiene	5	8	1.60
9	Cell	5	136	27.20
10	JAMA Journal of the American Medical Association	5	2	0.40
11	Journal of Infectious Diseases	5	36	7.20
12	New England Journal of Medicine	5	117	23.40
13	BMJ	4	9	2.25
14	Human Vaccine and Immunotherapeutics	4	77	19.25
15	Journal of Medical Virology	4	266	66.50
16	Theranostics	4	9	2.25
	Total of 16 journal	133	1325	9.96
	Global total	343	2636	7.69
	Share of 16 journals in global total	38.78	50.27	

Appendix 1: List of Top 10 High Cited Papers on COVID-19 Vaccine during 2020.

S.No.	Name of the author	Title of the Paper	Source	Times Cited
1	Wang, Y. <i>et al.</i>	Unique epidemiological and clinical features of the emerging 2019 novel coronavirus pneumonia (COVID-19) implicate special control measures (Review)	Journal of Medical Virology 2020, 92 (6), 568-576.	222
2	Thanh Le, T <i>et al.</i>	The COVID-19 vaccine development landscape (Note)	Nature Reviews. Drug discovery 2020, 19 (5), 305-306.	182
3	Tai, W. <i>et al.</i>	Characterization of the receptor-binding domain (RBD) of 2019 novel coronavirus: implication for development of RBD protein as a viral attachment inhibitor and vaccine (Article)	Cellular and Molecular Immunology 2020, 17 (6), 613-620.	135
4	Grifoni, A. <i>et al.</i>	Targets of T Cell Responses to SARS-CoV-2 Coronavirus in Humans with COVID-19 Disease and Unexposed Individuals (Article)	Cell 2020, 181 (7), 1489-1501.e15.	129
5	Amanat, F. and Krammer, F.	SARS-CoV-2 Vaccines: Status Report (Review)	Immunity, 2020, 52 (4), 583-589	126
6	Lurie, N. <i>et al.</i>	Developing covid-19 vaccines at pandemic speed (Review)	New England Journal of Medicine 2020, 382 (21), 1969-1973	121
7	Jin, Y. <i>et al.</i>	Virology, epidemiology, pathogenesis, and control of covid-19 (Review)	Viruses 2020, 12 (4), art. no. 372,	119
8	Ahn, D.G <i>et al.</i>	Current status of epidemiology, diagnosis, therapeutics, and vaccines for novel coronavirus disease 2019 (COVID-19) (Review).	Journal of Microbiology and Biotechnology, 30 (3), 313-324	83
9	Dharma, K. <i>et al.</i>	COVID-19, an emerging coronavirus infection: advances and prospects in designing and developing vaccines, immunotherapeutics, and therapeutics (Review) .	Human Vaccines and Immunotherapeutics 2020, 16 (6), 1232-1238	69
10	Gao, Q. <i>et al.</i>	Development of an inactivated vaccine candidate for SARS-CoV-2 (Article)	Science 2020, 369 (6499), 77-81	68

(Fudan University, China)(44.0 and 5.72), L. Bao (Harvard Medical School, USA)(29.0 and 3.77) and, J. Liu (Chinese Center for Disease Control and Prevention, China)(29.0 and 3.77).

The journals medium (343 papers) accounted for 100.0% share of global publications on COVID-19 vaccine research and witnessed the participation of 280 journals. The top 16 journals alone accounts for 38.78% share and 50.27% share respectively of global COVID-19 vaccine research output and citations during 2020. The serial publication *Nature* contributed the largest number of papers (24) among top 16, followed by *Science* and *Vaccine* (18 papers each), *The Lancet* (12 papers) and *The Lancet Infectious Disease* (7 papers). The serial *Journal of Medical Virology* registered the highest number of citations (266) among top 16, followed by *Science* (212 citations), *Cell* (136 citations), *The Lancet* (119 citations) and *New England Journal of Medicine* (117 citations). The serial *Journal of Medical Virology* also received the top slot in citations impact per paper (66.5), followed by *Cell* (27.2), *New England Journal of Medicine* (23.4), *Human Vaccine and Immunotherapeutics* (19.25) and (18.17). From the above it is observed that all leading journals constitute high- impact journals and they took lead in highlighted various issues of COVID-19 vaccine research and they gave top priority in publishing such research, besides providing free access to global community. Only 15 out of 343 global publications on COVID-19 vaccine research during 2020 received 1546 citations (ranging from 55 to 222 citations per paper), averaging 103.07 citations per paper. USA contributed the highest number of papers (6), followed by China (5), etc. These 15 high-cited papers were published in 13 journals, with 2 papers published each in *Journal of Medical Virology* and *Science* and 1 paper each in 11 other journals.

Conclude that currently there is no vaccine to prevent COVID -19 and the analysis presented in this paper hopes to provide useful information on the present status and future directions for COVID-19 vaccine research which can be utilized by policy-makers in improving the

research in their countries. We hope that vaccine for COVID-19 will be available within the next few months.

CONFLICT OF INTEREST

The authors declare that there is no conflict of interest.

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