



Bibliometric analysis of the highly cited publications in COVID-19 vaccine

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ABSTRACT

The coronavirus disease 2019 (COVID-19) pandemic has had widespread effects across the globe and continues to affect global public health. This study aims to select and feature highly cited publications on the COVID-19 vaccine. The Web of Science core database was used to extract relevant articles published in recent years. Progress of vaccine studies made in recent two years has mainly focused on the development of different vaccines and the evaluation of their safety and efficacy for population immunity. Clinical trials mainly focusing on the safety and efficacy of diverse vaccines have flourished. Lipid nanoparticle-formulated, nucleoside-modified RNA vaccine and recombinant adenovirus type-5 (26) vectored SARS-CoV-2 vaccines are most commonly studied. Vaccine application-associated challenges mainly include antibody resistance of new variants and unusual severe complications. The correlation between booster immunizations and reinfection is still in the explored state. Currently, antibody resistance of emerging variants is the main vaccine application-associated challenge and the primary reason for vaccine hesitancy. Effective strategies for reinfection prevention are also urgently needed.

1. Introduction

The SARS-CoV-2 pandemic has had widespread effects across the globe, and the coronavirus and its variants continue to spread [1]. There has been an effective global response to the emergence, rapid spread, and viral mutation of SARS-CoV-2. Researchers generally agree that despite the global spread of SARS-CoV-2, there is still a large proportion of the population in many countries who have escaped infection and lack immunity to the virus [2]. Vaccines play an important role in the enhancement of population immunity and the prevention of global severe disease [3]. Vaccination is a convenient, economical, and effective measure among diverse prevention measures of infectious disease [4,5]. Therefore, research teams in various institutions in various countries have undertaken the development and randomized controlled trials of the SARS-CoV-2 vaccine, particularly in 2020 and 2021 [2,6–10]. Recently, the presence of virus variants brings new challenges to vaccine design and population immunity [11,12]. Studies related to vaccine design and large clinical trials were continued, focusing on the safety and effectiveness of the vaccine.

As international epidemic prevention and control has entered a new stage, new prevention and control policies need to be formulated accordingly [13]. The focus of international prevention and control work has shifted from “preventing infection” to “protecting the health and preventing severe diseases”. In this process, vaccine research and development and experimental work remain the top priority [13,14]. By focusing on the current international research on COVID-19 vaccines and conducting targeted

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scientific research and large-scale clinical trials, the prevention and control work will continue to be more scientific, precise, and effective [14,15]. Undoubtedly, building a robust immune barrier is the key to ending COVID-19. Accordingly, a growing number of cross-sectional studies focusing on the current situations and characteristics of COVID-19 vaccine research have been carried out to provide insight into the scientific output in this domain and suggest scaling-up study and information dissemination on SARS-CoV-2 and vaccine safety and efficacy [16–22]. These studies, however, were concerned mostly with the rough research trends and focused on SARS-CoV-2 rather than the precise study direction and challenges.

Bibliometrics consists mainly of collaborative network analysis of literature data, co-citation analysis, and coupling analysis. The most important of these is citation analysis [23]. Bibliometrics aims to analyze publication tendencies and key points in a particular field of study. The authors, institutions, and countries with a high number of citations are considered to be leading players in the given domain [24]. Thus, top and highly cited publications can provide primary information on publication tendencies and scientific progress [25]. To the best of our knowledge, few highly cited studies have been conducted for the COVID-19 vaccine. Here, we intend to select the highly cited publications on the COVID-19 vaccine and characterize these articles.

Table 1
The top 20 most-cited COVID-19 vaccine publications and their features.

Rank	Article	Type of Article	No. of citations	Citations over year			Author (first)	Journal
				2020	2021	2022		
1	Safety and Efficacy of the BNT162b2 mRNA Covid-19 Vaccine	Clinical trial	6349	15	3257	3069	Polack [26]	NEJM
2	Structure, Function, and Antigenicity of the SARS-CoV-2 Spike Glycoprotein	Basic research	4775	1374	2224	1174	Walls [27]	Cell
3	Cryo-EM structure of the 2019-nCoV spike in the prefusion conformation	Basic research	4677	1589	2064	1022	Wrapp [28]	Science
4	Efficacy and Safety of the mRNA-1273 SARS-CoV-2 Vaccine	Clinical trial	4211	5	2077	2125	Baden [6]	NEJM
5	Safety and efficacy of the ChAdOx1 nCoV-19 vaccine (AZD1222) against SARS-CoV-2: an interim analysis of four randomized controlled trials in Brazil, South Africa, and the UK	Clinical trial	2142	6	1215	921	Voysey [9]	Lancet
6	Targets of T Cell Responses to SARS-CoV-2 Coronavirus in Humans with COVID-19 Disease and Unexposed Individuals	Basic research	1933	418	963	551	Grifoni [29]	Cell
7	Structure of M-pro from SARS-CoV-2 and discovery of its inhibitors	Basic research	1885	403	844	633	Jin [30]	Nature
8	Characterization of spike glycoprotein of SARS-CoV-2 on virus entry and its immune cross-reactivity with SARS-CoV	Basic research	1746	520	774	449	Ou [31]	Nature Communications
9	An mRNA Vaccine against SARS-CoV-2-Preliminary Report	Clinical trial	1662	179	945	537	Jackson [32]	NEJM
10	A SARS-CoV-2 protein interaction map reveals targets for drug repurposing	Basic research	1556	258	783	509	Gordon [33]	Nature
11	Effectiveness of Covid-19 Vaccines against the B.1.617.2 (Delta) Variant	Basic research	1447	1	442	1001	Bernal [11]	NEJM
12	Neutralizing antibody levels are highly predictive of immune protection from symptomatic SARS-CoV-2 infection	Basic research	1446	1	358	1084	Khoury [34]	Nature Medicine
13	Immunological memory to SARS-CoV-2 assessed for up to 8 months after infection	Basic research	1279	0	661	616	Dan [7]	Science
14	Safety and immunogenicity of the ChAdOx1 nCoV-19 vaccine against SARS-CoV-2: a preliminary report of a phase 1/2, single-blind, randomized controlled trial	Clinical trial	1256	179	664	413	Folegatti [35]	Lancet
15	Safety and Immunogenicity of Two RNA-Based Covid-19 Vaccine Candidates	Clinical trial	1253	17	733	503	Walsh [36]	NEJM
16	BNT162b2 mRNA Covid-19 Vaccine in a Nationwide Mass Vaccination Setting	Cross-sectional study	1244	5	641	597	Dagan [37]	NEJM
17	Thrombotic Thrombocytopenia after ChAdOx1 nCov-19 Vaccination	Basic research	1149	2	597	550	Greinacher [38]	NEJM
18	Estimated transmissibility and impact of SARS-CoV-2 lineage B.1.1.7 in England	Basic research	1101	2	533	565	Davies [39]	Science
19	Safety and Efficacy of Single-Dose Ad26.COV2.S Vaccine against Covid-19	Clinical trial	1100	2	416	682	Sadoff [22]	NEJM
20	Antibody resistance of SARS-CoV-2 variants B.1.351 and B.1.1.7	Basic research	1015	1	464	548	Wang [40]	Nature

2. Results

2.1. Characteristics of highly cited articles

Vaccine design, development, and clinical trials are the primary research areas of these articles, and the results have been published in leading international journals. The number of citations of the highly cited articles ranged from 6349 to 5 (median: 86). Forty-five percent of the highly cited publications were published in 2021. All of these articles were published in 55 journals and conducted by 10,604 authors, with an overall 161,359 global citations (with 16,867 citations in 2020, 69,099 citations in 2021, and 75,145 citations in 2022). The top 20 most cited publications on the COVID-19 vaccine and corresponding citation frequency was shown in [Table 1](#). The table also shows the article title, type of study, first author, and journal information of relevant articles. The article with the highest total citation was published in the *New England Journal of Medicine* in 2021 by Polack FP et al. They conducted a phase 3 RCT including a total of 43,548 participants to observe the vaccine against laboratory-confirmed SARS-CoV-2 and the incidence of vaccine-associated adverse events [26]. Their results demonstrated that RNA-based vaccines may be a promising new approach against this expanding pandemic. In addition, this report has significance beyond encouraging vaccine performance: the basis of approval to reduce the devastating loss of health, economy, and social well-being that has resulted from the pandemic.

The highly cited articles were published in 55 journals, led by *Nature* (n = 53) and followed by the *New England Journal of Medicine* (n = 53), *Science* (n = 47), and *Cell* (n = 36) ([Table 2](#)). The top ten research categories of the total number of articles were shown in [Fig. 1](#). The majority of the publications came from the United States (n = 402), distantly followed by England (n = 121), China (n = 118), and Germany (n = 67) ([Table 3](#)). The most common topic was vaccine design and development (n = 53) followed by clinical trials focusing on vaccine safety and efficacy (n = 21) and vaccine-associated challenges including SARS-CoV-2 variants and unusual severe complications (n = 18) ([Table 4](#)).

3. Characteristics of clinical trials and vaccines studied

21 clinical trials of the top 100 cited articles mainly focusing on the safety and efficacy of different COVID-19 vaccines against the virus and relative variants. [Table 5](#) summarized the vaccine types, number of participants, and primary clinical outcomes. There are 13 trials (59%) in 2020 and 9 studies in 2021 involving 14 phases 1/2 clinical trials and 7 phase 2/3 randomized controlled studies with ten different vaccines. Medians (range) of the number of participants and duration are 534 (10–43,548) persons and 28 (14–365) days, respectively. Most of these RCTs mainly focused on the neutralization of antibody responses and the occurrence of adverse events after vaccination. Two recent clinical trials evaluated the vaccine's safety and efficacy against virus mutations found in different variants. The rigorous demonstrations of the safety and efficacy of vaccines described in clinical trials provide the basis for the practical use of this public health measure in populations.

Research and technological breakthroughs in current mainstream vaccines could help end the ongoing coronavirus infections. Here, we further analyzed the eight vaccine types involved in the 21 clinical trials of the top 100 cited articles. Among these vaccine types, lipid nanoparticle-formulated, nucleoside modified RNA vaccine (BNT162b2 or BNT162b1) and recombinant adenovirus type-5 (26) vectored SARS-CoV-2 vaccine (Ad5 or Ad26) are most commonly studied. And then there is more research on the novel chimpanzee adenovirus-vectored vaccine (AZD1222) and mRNA-1273 vaccine type.

3.1. Co-citation feature analysis

The top five most co-cited references included Polack FP (2020) [54], Baden LR (2021) [6], Wrapp D (2020) [28], Hoffmann M (2020) [55], Walls AC (2020) [27]. The structure, function, and antigenicity of SARS-CoV-2 spike protein and the safety, and efficacy of antibodies were key considerations in these influential studies. [Fig. 2](#) visualized the detailed features of co-cited references and clustering results based on research interests.

Table 2
Top 10 Journals of the highly cited COVID-19 vaccine publications.

Journal	No. of articles	Total citations	Average citations	Impact factor (2022)
Nature	53	19,772	373	69.503
New England Journal of Medicine	53	28,787	543	176.077
Science	47	17,925	381	63.712
Cell	36	15,725	437	66.849
Nature Medicine	35	7329	209	87.239
Nature Communications	26	4672	180	17.694
Science Translational Medicine	20	1243	62	19.320
Clinical Infectious Diseases	17	1257	74	20.999
Cell Host Microbe	15	2587	172	31.315
Lancet	14	7382	527	202.728

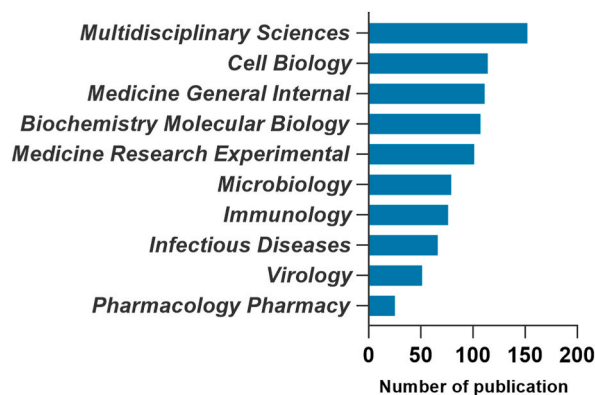


Fig. 1. The top ten study categories in terms of publications.

Table 3

Top 10 countries of the highly cited COVID-19 vaccine publications.

Country	No. of articles	Total of citations	Average citations
The United States	402	96,303	240
England	121	35,453	293
China	118	31,165	264
Germany	67	21,590	322
Italy	51	5154	101
Canada	46	6407	139
Israel	46	6817	148
Switzerland	40	7664	192
France	39	13,211	339
India	39	5085	130

Table 4

Main topics involved in the highly cited COVID-19 vaccine publications.

Topic	No. of articles
#1 Vaccine design and development	53
potential targets seeking	19
vaccine efficacy evaluation in the Nonhuman Primates model	13
novel antibodies pilot study	10
novel testing technique	6
kinetics of the neutralizing antibody response	5
#2 Safety and efficacy study of vaccine	21
phase 1/2 clinical trials	14
phase 3 clinical trials	5
large cohort study across diverse populations	1
infective mechanism of SARS-CoV-2	1
#3 Vaccine application-associated challenges	18
antibody resistance of SARS-CoV-2 variants	12
severe complications: unusual thrombotic events and vaccine breakthrough infection with virus variants	3
phase 3 RCT shows poor efficacy against virus variant	2
antibody-dependent enhancement (ADE)	1
#4 Vaccine improving	5
immunological memory	2
the predictive model of the efficacy of vaccines for SARS-CoV-2	1
genomic evidence for reinfection	1
sex considerations	1
#5 Attitudes toward potential SARS-CoV-2 vaccine	2
#6 Safety considerations for vaccinated healthcare workers	1

4. Discussion

This study first used citation analysis to identify the top publications in the COVID-19 vaccine domain. The number of citations a publication receives is representative of its impact in the field [56]. The identification and understanding of the characteristics of

Table 5
Important clinical trials to explore the effectiveness and safety of different COVID-19 vaccines.

Publication year	Vaccine studied	Phase	No. of subjects	Duration	Delivery Method	Primary Clinical Measure	[Ref.] NCT
2020	BNT162b2	III	43,548	21	IM	efficacy of the vaccine against laboratory-confirmed Covid-19 and safety	[26] 04368728
2020	mRNA-1273	I	75	28	IM	antibody responses and adverse events monitoring after vaccination	[32] N/A
2020	AZD1222	I/II	10	28	IM	assessment of efficacy and occurrence of serious adverse events (safety)	[35]] 04324606
2020	BNT162b2 and BNT162b1	I	75	21	IM	local and systemic reactions and adverse events between two vaccines	[36] N/A
2020	Ad5	I	195	28	IM	adverse events, safety and specific antibodies responses induced by vaccination	[41] 04313127
2020	BNT162b1	I/II	45	21	IM	safety, tolerability and immunogenicity evaluation of COVID-19 RNA vaccine	[42] 04368728
2020	mRNA-1273	I	40	28	IM	adverse events, safety and specific antibodies responses induced by vaccination	[43] 04283461
2020	Ad5	II	508	28	IM	neutralization antibody responses, incidence of adverse reactions	[44] 04341389
2020	WIV04 strain	I/II	330	41	IM	adverse reactions and the neutralizing antibody response	[45] N/A
2020	BNT162b1	I/II	60	30	IM	antibody and T cell responses after vaccination, safety	[46] 04380701
2020	NVX-CoV2373	I/II	131	35	IM	reactogenicity; laboratory values, safety, and IgG anti-spike protein response	[47] 04368988
2020	rAd26 and rAd5	I/II	76	42	IM	antigen-specific humoral immunity antibodies (ELISA) and safety	[48] 04436471*
2021	AZD1222	II/III	560	365	IM	Evaluation of efficacy, virologically confirmed COVID-19, and occurrence of serious adverse events (safety)	[49] 04400838
2021	mRNA-1273	III	30,420	28	IM	prevention of Covid-19 illness after second injection in health participants.	[6] 04470427
2021	AZD1222	III	23,848	14	IM	interim analysis of the safety and efficacy after a second dose of vaccine.	[9] 04324606*
2021	Ad26	III	19,630	28	IM	vaccine efficacy against moderate to severe-critical coronavirus disease 2019 and safety	[22] 04505722
2021	AZD1222	III	2026	35	IM	safety and efficacy of vaccine against laboratory-confirmed symptomatic coronavirus 2019 illness	[21] 04444674
2021	CoronaVac	I/II	744	28	IM	adverse reactions and seroconversion rates of neutralizing antibodies after injection	[50] 04352608
2021	Ad26	I/II	805	72	IM	safety and reactogenicity of different dose schedule	[51] 04436276
2021	BBIBP-CorV	I/II	640	28	IM	evaluation of vaccine safety and tolerability for variant	[52] N/A
2021	AZD1222	II/III	8534	14	IM	clinical efficacy of vaccine against variant (neutralizing antibody responses)	[53] 04400838

IM, intramuscular injections; BNT162b2(b1): lipid nanoparticle-formulated, nucleoside modified RNA vaccine; Ad5 (26), recombinant adenovirus type-5 (26) vectored SARS-CoV-2 vaccine; AZD1222, novel chimpanzee adenovirus-vectored vaccine, ChAdOx1 nCoV-19; NVX-CoV2373, recombinant severe acute respiratory syndrome coronavirus 2; WIV04 strain: an investigational inactivated whole-virus SARS-CoV-2 vaccine in China; CoronaVac: an inactivated vaccine candidate against SARS-CoV-2 (China); BBIBP-CorV: an inactivated SARS-CoV-2 vaccine in China; Ref., references; NCT, national clinical trial; *-presents two or more NCT number (showing the first one); N/A, not applicable.

highly cited articles in the COVID-19 vaccine field are of substantial importance to scientific workers medical professionals and the general public. First, vaccine manufacturers and researchers can determine clear study directions and current challenges they are facing thereby promoting vaccine design and improvement for emerging variants. Furthermore, policymakers can refer to the results of the study to develop local policies related to epidemic prevention and control and vaccination. Third, our study results help get information dissemination on SARS-CoV-2 and vaccine safety and efficacy to the public, which might be helpful for the general acceptance of vaccination. Finally, journal editors and reviewers can refer to our findings when critically evaluating scientific works submitted for publication.

Overall, most of the highly cited articles were about vaccine design, development, and evaluation of safety and efficacy studies (74%). In the early stage of the outbreak, research teams around the world almost focused on the potential targets for vaccine design and kinetics of the diverse neutralizing antibody responses. Accordingly, a body of phase 1/2 clinical trials have been conducted to evaluate the safety and effectiveness of novel vaccines. We also noticed that these relative studies were mainly published in 2020. Several vaccine application-associated challenges such as antibody resistance of new variants and unusual severe complications were subsequently found. At the same time, large and long-term clinical trials were carried out and reported. A series of highly cited studies provide a glimpse of the rapid development and evaluation of medical countermeasures around the world. The trends concluded from this cohort's highly cited articles furnish substantial confidence for future therapeutics for SARS-CoV-2 and diverse variants.

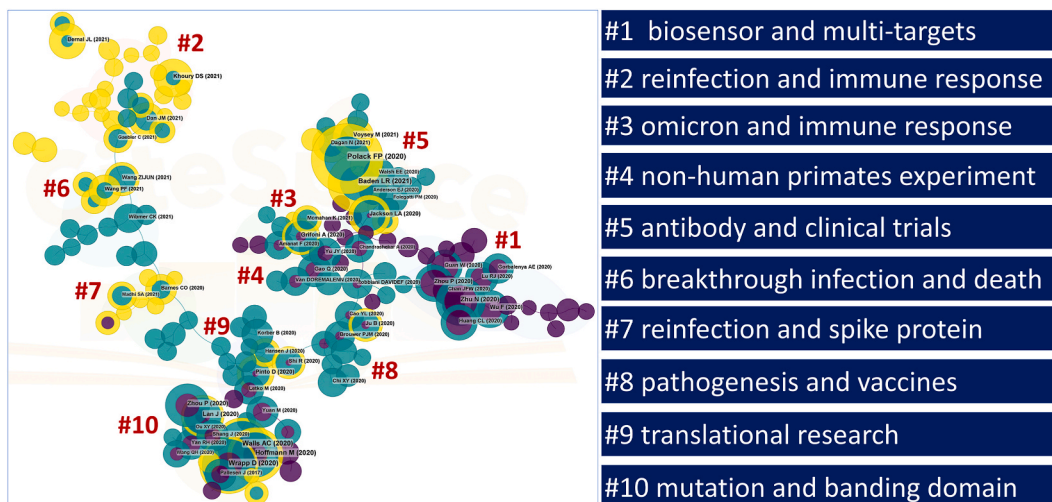


Fig. 2. Visualization map of the detailed features of co-cited references and clustering results based on research interests.

In this study, we also focused on the development of different vaccines and the evaluation of their safety and efficacy for population immunity. In 2020, researchers mainly focused on the small-scale participants and interim reports of phase 1 and phase 2 trials of the SARS-CoV-2 vaccine that primarily evaluate neutralization antibody responses and monitor adverse events after vaccination [32,35,36,41–48]. Recently, phase 3 trials were widely carried out to report the efficacy and longer-term adverse events in the larger population [6,9,21,22,53,49]. Many and large trials are ongoing. However, it is noteworthy that the emergency of virus mutations found in different variants represents a threat to the efficacy of the vaccine [53,52]. Emary KRW et al. conducted a phase 2/3 randomized controlled trial involving 8534 participants exploring clinical vaccine efficacy against symptomatic SARS-CoV-2 variant (B.1.1.7) and found the lower neutralizing antibody titers but sufficient clinical symptoms protection in B.1.1.7 lineage group [53]. In addition, it should be noted that large protection vaccine studies for further mutations in spike protein observed were still rare. In the future, continuing efforts to improve the effectiveness and safety of vaccines against new COVID-19 variants are necessarily needed.

The vaccines involved in these highly cited phase 2/3 trials were mainly lipid nanoparticle-formulated, nucleoside-modified RNA vaccine (BNT162b2 or BNT162b1) and recombinant adenovirus type-5 (26) vectored SARS-CoV-2 vaccine (Ad5 or Ad26). And then there is more research on the novel chimpanzee adenovirus-vectored vaccine (AZD1222) and mRNA-1273 vaccine type. According to the World Health Organization (<https://www.who.int/publications/m/item/draft-landscape-of-covid-19-candidate-vaccines>), these vaccines are gradually appearing in phase 4 clinical trials. There are currently 183 vaccines approved for clinical trials, but of these, few make it into Phase 4 clinical studies (Supplementary material). This study also found that these vaccines to be of value for research and application. This also illustrates the need for bibliometric analysis of highly cited articles related to the SARS-CoV-2 vaccines. Concerning the countries, the majority of the highly cited articles in the COVID-19 vaccine generated from the United States and China reflect both strong influences in this field. Another interesting finding from this study is the fact that the attitudes of the population toward a potential SARS-CoV-2 vaccine vary in the United States and China. Fisher KA et al. recruited approximately 1000 adults to evaluate their intent to be vaccinated against SARS-CoV-2 via a standard questionnaire. The results showed that about 30% of adults were unsure about receiving the vaccination and about 10% did not intend to be vaccinated [57]. Another same cross-sectional survey [58] involving 2058 adults was conducted in China by Wang JH et al. and their results revealed the same vaccine refusal proportion (10%) as the USA cohort but significantly higher acceptance of vaccination than the USA cohort (91.3% vs 57.6%). The main reasons for vaccination hesitancy include concerns about specific vaccines, antibody resistance to new mutant strains [1,59], anti-vaccine attitudes or lack of trust. Expanding vaccination coverage requires targeted, multi-pronged efforts.

Reinfection and its clinical effects cannot be neglected. With the opening of quarantine policies around the world, reinfection of the virus is expected. Clustering analysis based on research directions in this study showed that two of ten clusters involve reinfection and vaccine effectiveness. Recently, an article published in Nature Medicine showed that reinfection of the virus further increases the risks of death, hospitalization, and sequelae in multiple organ systems in the acute and post-acute phases [60]. This is a significant finding. Effective strategies for reinfection prevention are urgently needed to reduce the overall burden of death and disease due to SARS-CoV-2.

4.1. Limitations of the study

This study has some limitations. Citation analysis maybe not be able to thoroughly measure the impact of publications in a given field. The factors influencing the citation of an article include not only the quality but also other factors not considered in this study, such as self-citation. And obliteration by incorporation [61]. In addition, we determined the highly cited articles using searching topics that are highly dependent on the accuracy and comprehension of the keywords. Consequently, some influential and valuable articles

might not be searched because of the utilization of other words in their publication titles. Finally, the citation database bias. The citations of publications in this study were based on the internal calculating algorithm of the Web of Science that might differ from other databases such as Scopus, PubMed, and Google Scholar databases.

5. Conclusions

The development of vaccines and the evaluation of their safety and efficacy for population immunity has always been the subject of research. Clinical trials focusing on the safety and efficacy evaluation of diverse vaccines have flourished. Lipid nanoparticle-formulated, nucleoside-modified RNA vaccine and recombinant adenovirus type-5 (26) vectored SARS-CoV-2 vaccines are most commonly studied. Vaccine application-associated challenges mainly include antibody resistance of new variants and unusual severe complications. Currently, antibody resistance of emerging variants is the main vaccine application-associated challenge and the primary reason for vaccine hesitancy. Effective strategies for reinfection prevention are also urgently needed. The correlation between booster immunizations and reinfection still needs more real data studies to clarify to completely solve the problem of persistent infection.

6. Methods

6.1. Articles search and selection

On December 1, 2022, the Web of Science Core Collection database was utilized to generate relevant studies on the COVID-19 vaccine. The medical subject heading (MeSH) was used to design the search terms and topics in the database as follows: (TS = (SARS-CoV-2 Virus OR 2019 Novel Coronavirus OR SARS Coronavirus 2 OR 2019-nCoV OR COVID19 Virus OR Wuhan Coronavirus)) AND TS = (vaccine OR vaccines). The document type was set as "Articles" and the publications timespan was set as from January 1, 2020, to December 1, 2022. We believe that key information can only be obtained in the original studies in bibliometrics. This search yielded 10,876 original articles. These articles were then sorted by the number of citations and reviewed to identify if they were associated with the COVID-19 vaccine. Finally, we identified the 789 highly cited articles on the SARS-CoV-2 vaccine. The literature search and identification strategy were presented in [Table 6](#).

Here, the highly cited articles we refer to are determined by the Essential Science Indicators computing module in the Web of Sciences database. Two reviewers (Lihua Liu and Li Yan) independently conducted article identification and analysis. We reevaluated and discussed each other until consensus was achieved in cases of disagreement.

A COVID-19 vaccine article was defined as any publication that primarily focuses on vaccine design and development, vaccine-associated complications and challenges, clinical trials on the vaccines' safety and efficacy, and animal studies on antibody tests. Articles on drug therapy that were not considered to be in line with the scope of this study were excluded.

6.2. Data extraction and analysis

All of the highly cited publications were available online in the National Library of Medicine's MEDLINE database. The characteristics of every article including the publication year, number of citations, average citations, first author, journal sources, research categories (nonhuman primates model study, methodology, clinical trials or cross-sectional study), publication institutions, countries, and major topic were reviewed and extracted. CiteSpace (version 6.2. R2) was used for data visualization.

6.3. Statistical analysis

Descriptive statistics were used in this study. We selected the Kolmogorov-Smirnov method in SPSS (version 26.0, IBM, Armonk, NY, USA) to test the normality of continuous data. Use means and standard deviations (SDs) for normally distributed data and medians and ranges for data that are not normally distributed.

Author contributions

Lihua Liu conceived and designed the study. Li Yan performed the data preparation, analyzed, and interpreted the data collection using analysis tools. Lihua Liu and Li Yan wrote the paper. All authors read and approved the final manuscript.

Data availability statement

Data yielded in our study will be made available by the authors to any qualified researchers.

Institutional review board statement

Not applicable, because this article does not contain any studies with human or animal subjects.

Table 6
Literature search and identification strategies in Web of Science.

Search	Query	Results
#1	TS=(SARS-CoV-2 Virus OR 2019 Novel Coronavirus OR SARS Coronavirus 2 OR COVID19 Virus OR Wuhan Coronavirus OR 2019-nCoV)	61,474
#2	TS=(vaccine OR vaccines)	69,229
#3	#1 AND #2	10,876
#4	Publication: refined by "Article" Language: refined by "English"	7356
#5	Sort by citations (highest first): studies identified as highly cited papers were selected for analysis.	789

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Informed consent statement

Not applicable.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.heliyon.2023.e18540>.

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