A Bibliometric Analysis of Personal Protective Equipment and COVID-19 Researches

Yu Zhang¹, Man Hu²†, Junwu Wang¹, Pingchuan Wang¹, Pengzhi Shi², Wenjie Zhao², Xin Liu¹, Qing Peng¹, Bo Meng², Xinmin Feng¹ and Liang Zhang¹*

¹ Department of Orthopedics, Clinical Medical College of Yangzhou University, Yangzhou, China, ² Department of Orthopedics, Dalian Medical University, Dalian, China

COVID-19, which occurred at the end of December 2019, has evolved into a global public health threat and affects every aspect of human life. COVID-19's high infectivity and mortality prompted governments and the scientific community to respond quickly to the pandemic outbreak. The application of personal protective equipment (PPE) is of great significance in overcoming the epidemic situation. Since the discovery of severe acute respiratory coronavirus 2 (SARS-CoV-2), bibliometric analysis has been widely used in many aspects of the COVID-19 epidemic. Although there are many reported studies about PPE and COVID-19, there is no study on the bibliometric analysis of these studies. The citation can be used as an indicator of the scientific influence of an article in its field. The aim of this study was to track the research trends and latest hotspots of COVID-19 in PPE by means of bibliometrics and visualization maps.

Keywords: COVID-19, personal protective equipment, bibliometric, transmission, VOSviewer

INTRODUCTION

The 2019 coronavirus disease (COVID-19) pandemic, which occurred at the end of December 2019, was first reported in Wuhan, Hubei Province, China (1, 2). The main clinical manifestations are fever of unknown origin, fatigue, and dry cough. Severe patients can lead to acute respiratory distress syndrome and death, accompanied by interstitial alveolar injury (3). Etiology and gene sequence analysis showed that COVID-19 was caused by severe acute respiratory coronavirus 2 (SARS-CoV-2) syndrome, which is a new member of the coronavirus family (4–6).

COVID-19 has caused serious disruption around the world. Due to the constant variation of SARS-CoV-2, people are in a state of fear and uncertainty. COVID-19 is highly contagious, with respiratory droplets and contact transmission being the main routes of transmission (7–11). For infectious diseases, controlling the source of infection, cutting off the route of transmission, and protecting the susceptible population are the three key links of infection prevention and control. For infectious diseases which are highly, it is urgent to reduce the infection rate, thus, preventing infection and blocking transmission routes are the best way to achieve this goal. In addition to the fact that vaccines can greatly reduce the morbidity, mortality, and economic losses of the disease (12, 13), personal protective equipment (PPE) can also significantly reduce the risk of exposure to infection and pollutant surfaces, and the PPE can play an important role in reducing the infection rate.
Since the discovery of SARS-CoV-2, bibliometric analysis has been widely used in many aspects of the COVID-19 epidemic, such as vaccines (12, 13), AI technology (14), and public health surveillance systems (15). Similarly, it is widely used in clinical departments, such as rheumatology (16), medical imaging (17), diabetes (18), orthopedics (19), and urology (20). Although there are many reported studies about PPE and COVID-19, there is no study on the bibliometric analysis of these studies. Citations can be used as an indicator of the scientific influence of an article in its field (21, 22). Bibliometric analysis is an important tool to help quantify the number of articles in disciplines and can provide a comprehensive overview of the literature (23, 24).

In this study, bibliometric methods were used to analyze publications on PPE and COVID-19. This study was aimed to provide a general overview of studies on PPE and COVID-19.

MATERIALS AND METHODS

Search Methods

On 07 October 2021, the Web of Science (WOS) Core Collection database was used to identify documents on PPE and COVID-19. To ensure the breadth of the search scope, the search terms were constantly filtered. Finally, the keywords were established: TITLE = (Coronaviruses OR COVID-19 OR Coronavirus disease 2019 OR COVID-2019 OR 2019-nCoV OR nCov-2019 OR SARS-COV-2 OR Severe acute respiratory syndrome coronavirus 2 OR Novel Coronavirus) AND TITLE = (personal protective equipment OR gloves OR masks OR respirators OR goggles OR face shields OR gowns) AND Language = English AND Document type = (Article OR Review OR Letter OR Early Access OR ?Editorial Material) AND Time span = the end of December 2019 to 7 October 2021. The data were exported into Microsoft Excel 2016 and EndNote. Two duplicate articles were retrieved.

Data Extraction and Analysis

The number of citations, authors, institutions, published journals, document types, and countries were recorded. The HistCite Pro 2.1 (http://www.histcite.com) software was used for citation analysis. Key indicators included: Local Citation Score (LCS) is the number of times this article has been referenced in the current dataset; Global Citation Score (GCS) is the number of times this article has been cited by all references in the entire WOS database; Total Local Citation Score (TLCS) is the second sum of cited frequencies of documents in the current dataset; Total Global Citation Score (TGCS) is the sum of all references cited in WOS database. The current impact factor (IF) of the journals was obtained from the Journal Citation Reports (JCR) of WOS on October 07, 2021. VO S viewer software 1.6.16 (Van Eck and Waltman, Leiden University, Leiden, Netherlands) was used for network visualization analysis (25).

RESULTS

The initial search resulted in 1,590 documents on PPE and COVID-19 research and a total of 1,462 documents were included in the final analysis.

A total of 1,462 documents authored by 6,993 authors and published in 750 journals were included in the final analysis. The majority of the retrieved documents consisted of articles (n = 778, 53.2%), followed by letters (n = 301, 20.6%), and editorial material (n = 189, 12.9%) as shown in Table 1. The most prolific author was Macintyre CR (n = 9, 0.13%) as described in Table 2. Among the total authors, 35 authors published at least five documents about PPE and COVID-19. Bibliometric analysis of the top 10 most contributing countries was listed in Table 3, which showed their productivity and scientific influence. Of the total countries, four countries produced more than 100 documents. The USA was the most productive country with 463 (31.7%) published documents, followed by China (n = 162, 11.1%), the United Kingdom (n = 137, 9.4%), and India (n = 107, 7.3%). The leading journal was Plos ONE (n = 34; 2.3%, IF = 3.24), followed by International Journal of Environmental Research and Public Health (n = 30; 2.1%, IF = 3.39), and Infection Control and Hospital Epidemiology (n = 26; 1.8%, IF = 3.25) as described in Table 4. The most frequently used keywords were COVID (n = 1,235, 38.5%), and pandemic (n = 576, 17.9%) as presented in Table 5. The most prolific institution was Univ Toronto (n = 30) as described in Table 6. Among the total institutions, 39 institutions published at least nine documents about PPE and COVID-19.

Network Visualization Map of Co-authorship Country

Considering masses of countries, a minimum of five documents per country was fixed. Of the 94 countries, 55 countries satisfied this condition. Table 3 describes a complete picture of the academic performance of leading countries. The size of the circle represents the number of articles published by the country, and the larger the circle, the higher the country’s contribution to co-authorship. The thicker the lines between the two countries, the closer the cooperation exists between the two countries (Figure 1). The USA was the most productive country, with 463 published documents and total link strength (TLS) of 219, making it a country with the largest network of international cooperation. China ranked second in the number of published documents and third in TLS. The strongest country linkages were between the USA and Canada (n = 21).

Network Visualization Map of Keyword Analysis

The keyword analysis is one of the most important indicators of bibliometrics. According to co-occurrence analysis, the relationship of items is based on the number of publications in which they occur together (26). The co-occurrence network analysis tool was used to set the minimum number of occurrences to 10. Of the 3,061 keywords, 75 met the threshold. The keyword “COVID-19” (total link strength 1,382) appeared most, with 597
co-occurrences, followed by SARS-CoV-2 (occurrences = 165, TLS = 554, 11.7%), and PPE (occurrences = 175, TLS = 464, 9.8%; Figure 2).

**Network Visualization Map of Active Journals**

The minimum number of citations of a source was set at 200. Of the 11,711 sources, only 20 sources met the threshold. The New England Journal of Medicine was the leading source with the highest TLS 22,151 (citations = 775), followed by JAMA—Journal of the American Medical Association (TLS = 19,601, citations = 650), and Plos One (TLS = 17,525, citations = 543). The strongest link (1,070) was between the New England Journal of Medicine and the JAMA—Journal of the American Medical Association (Figure 3A). Two clusters of sources were identified by this analysis. Cluster 1, red color, included 14 journals closely

### TABLE 1 | Distribution of included publications by document type in COVID-19 and PPE.

| S. No. | Document type                  | Records | Percentage (%) | TLCS | TGCS |
|--------|--------------------------------|---------|----------------|------|------|
| 1      | Article                        | 778     | 53.2           | 741  | 6,240|
| 2      | Letter                         | 301     | 20.6           | 420  | 2,874|
| 3      | Editorial Material             | 189     | 12.9           | 324  | 3,039|
| 4      | Review                         | 106     | 7.3            | 271  | 1,991|
| 5      | Article; Early Access          | 67      | 4.6            | 0    | 50   |
| 6      | Editorial Material; Early Access | 8     | 0.5            | 0    | 2    |
| 7      | Letter; Early Access           | 8       | 0.5            | 0    | 2    |
| 8      | Review; Early Access           | 5       | 0.3            | 0    | 1    |

PPE, personal protective equipment; TLCS, total local citation score; TGCS, total global citation score.

### TABLE 2 | Top-10 most prolific authors in COVID-19 and PPE.

| Ranking | Author            | Records | Percentage (%) | TLCS | TGCS |
|---------|-------------------|---------|----------------|------|------|
| 1       | Macintyre CR      | 9       | 0.13           | 8    | 288  |
| 2       | Szarpak L         | 8       | 0.11           | 12   | 45   |
| 3       | Bialynicki BR     | 7       | 0.10           | 2    | 55   |
| 4       | Chou R            | 7       | 0.10           | 25   | 60   |
| 5       | Li J              | 7       | 0.10           | 5    | 32   |
| 6       | Smerika J         | 7       | 0.10           | 12   | 55   |
| 7       | Dana T            | 6       | 0.09           | 25   | 60   |
| 8       | Filipaik KJ       | 6       | 0.09           | 12   | 45   |
| 9       | Hamzavi IH        | 6       | 0.09           | 24   | 112  |
| 10      | Jungbauer R       | 6       | 0.09           | 25   | 60   |

PPE, personal protective equipment; TLCS, total local citation score; TGCS, total global citation score.

### TABLE 3 | Top-10 most productive countries in COVID-19 and PPE.

| Ranking | Country | Records | Percentage (%) | TLCS | TGCS |
|---------|---------|---------|----------------|------|------|
| 1       | USA     | 463     | 31.7           | 575  | 5,103|
| 2       | China   | 162     | 11.1           | 429  | 2,835|
| 3       | England | 137     | 9.4            | 278  | 2,086|
| 4       | India   | 107     | 7.3            | 43   | 349  |
| 5       | Italy   | 89      | 6.1            | 90   | 706  |
| 6       | Canada  | 87      | 6.0            | 254  | 1,513|
| 7       | Australia| 66     | 4.5            | 51   | 675  |
| 8       | Germany | 47      | 3.2            | 78   | 357  |
| 9       | Japan   | 47      | 3.2            | 15   | 226  |
| 10      | Spain   | 46      | 3.1            | 17   | 286  |

PPE, personal protective equipment; TLCS, total local citation score; TGCS, total global citation score.
TABLE 4 | Top-10 leading journals in COVID-19 and PPE.

| Ranking | Journals                                      | Records | Percentage (%) | TLCS  | TGCS  | IF (2020) | Quartile |
|---------|----------------------------------------------|---------|----------------|-------|-------|-----------|----------|
| 1       | Plos ONE                                     | 34      | 2.3            | 0     | 258   | 3.24      | 1        |
| 2       | International Journal of Environmental Research and Public Health | 30      | 2.1            | 0     | 207   | 3.39      | 2        |
| 3       | Infection Control and Hospital Epidemiology  | 26      | 1.8            | 10    | 185   | 3.25      | 2        |
| 4       | BMJ-British Medical Journal                  | 21      | 1.4            | 0     | 425   | 39.89     | 1        |
| 5       | Journal of Hospital Infection                | 21      | 1.4            | 63    | 298   | 3.93      | 1        |
| 6       | Annals of Internal Medicine                  | 18      | 1.2            | 87    | 286   | 25.39     | 1        |
| 7       | American Journal of Infection Control       | 17      | 1.2            | 18    | 90    | 2.92      | 1        |
| 8       | Science of The Total Environment             | 16      | 1.1            | 0     | 420   | 7.96      | 1        |
| 9       | Journal of The European Academy of Dermatology and Venereology | 15      | 1.0            | 31    | 113   | 6.17      | 1        |
| 10      | Scientific Reports                           | 12      | 0.8            | 0     | 34    | 4.38      | 1        |

PPE, personal protective equipment; TLCS, total local citation score; TGCS, total global citation score; IF, impact factor.

TABLE 5 | Top-10 frequently used words in COVID-19 and PPE.

| Ranking | Word               | Records | Percentage (%) | TLCS  | TGCS  |
|---------|--------------------|---------|----------------|-------|-------|
| 1       | COVID              | 1,235   | 38.5           | 1,351 | 10,836|
| 2       | Pandemic           | 576     | 17.9           | 583   | 4,924 |
| 3       | Mask               | 464     | 14.5           | 443   | 3,446 |
| 4       | Masks              | 423     | 13.2           | 736   | 4,859 |
| 5       | Protective         | 420     | 13.1           | 394   | 4,731 |
| 6       | Personal           | 400     | 12.5           | 379   | 4,672 |
| 7       | Face               | 397     | 12.4           | 687   | 5,078 |
| 8       | Equipment          | 394     | 12.3           | 369   | 4,629 |
| 9       | Use                | 226     | 7.0            | 378   | 2,500 |
| 10      | SARS               | 160     | 5.0            | 582   | 3,782 |

PPE, personal protective equipment; TLCS, total local citation score; TGCS, total global citation score.

in terms of scope. The New England Journal of Medicine was at the core of this cluster. Cluster 2, green color, including six sources and the American Journal of Infection Control was in the core. The areas of the red color in Figure 3B indicated active sources that have the highest rate of co-citation (i.e., New England Journal of Medicine).

Network Visualization Map of Co-authorship Institutions

In the visualization map, 116 institutes published more than five articles, and the cooperation network of institutions was shown in Figure 4. There were 388 links of collaboration with a TLS of 585. The University of Toronto had the highest number of links and the highest TLS (25 links with a TLS of 39).

DISCUSSION

The coronavirus disease, which occurred at the end of December 2019, has evolved into a global public health threat (27) and affects every aspect of human life. COVID-19’s high infectivity and mortality prompted governments and the scientific community to respond quickly to the pandemic outbreak. The previous literature on COVID-19 was mainly devoted to the use of vaccines (12, 13) and therapeutic drugs (28, 29). However, as the virus is still mutating, it is particularly important to block the route of transmission to prevent the further spread of the epidemic. The purpose of this study was to track the research trends and latest hotspots of COVID-19 in PPE by means of bibliometrics and visualization maps. Bibliometrics analysis is a form of statistical analysis of published articles (23, 24). Based on these technologies, we can analyze various aspects, such as countries, institutions, sources, authors, and journals. These technologies are widely used in different scientific fields, from micro (institutional level) to macro (global level), which can be evaluated qualitatively and quantitatively. The present study was the first bibliometric study to focus on COVID-19 and PPE research and visualization mapping. The results of this study were helpful to collate the data and easily obtain the maximum yield data of COVID-19 and PPE, as well as the current research, focuses on COVID-19 in PPE and other major bibliometrics information.

In the present study, a total of 1,462 documents on COVID-19 and PPE were analyzed. The most frequent keyword and author...
TABLE 6 | Top-10 most prolific institutions in COVID-19 and PPE.

| Ranking | Author                  | Records | TLCS | TGCS |
|---------|-------------------------|---------|------|------|
| 1       | Univ Toronto            | 30      | 26   | 224  |
| 2       | Harvard Med Sch         | 27      | 17   | 255  |
| 3       | Univ Hong Kong          | 22      | 251  | 1,098|
| 4       | Univ Milan              | 17      | 23   | 154  |
| 5       | Oregon Hlth and Sci Univ| 16      | 32   | 766  |
| 6       | Univ Penn               | 16      | 37   | 246  |
| 7       | Wroclaw Med Univ        | 16      | 20   | 136  |
| 8       | All India Inst Med Sci  | 15      | 1    | 31   |
| 9       | Stanford Univ           | 15      | 1    | 146  |
| 10      | Johns Hopkins Univ      | 14      | 0    | 143  |

PPE, personal protective equipment; TLCS, total local citation score; TGCS, total global citation score.

FIGURE 1 | Network visualization map of co-authorship country. A minimum of five documents per country was fixed. Of the 94 countries, only 55 meet the threshold. The size of the circle represents the number of articles published by the country, and the larger the circle, the higher the country's contribution to co-authorship. The more connections between the two countries, the stronger cooperation exists between the two countries.

Sharing very early information with countries, research institutes, government organizations, researchers, and the general public play a key role in the early stage of outbreaks and epidemics (30–32). According to this information, we can take various protective measures. In the early days of the COVID-19 outbreak, China began to share existing information about SARS-CoV-2 with other countries to study a variety of PPE, treatments, and vaccines.

The most prolific authors in COVID-19 and PPE research were from Australia (Macintyre CR). By analyzing the main authors in this field, we can identify the main contributors and look for opportunities for further cooperation. Among the types of documents, besides Articles, Letters, and Editorial Material attracted more attention. Most people thought that this was one of the most informative documents in the early days (12).

The impact factor of the top-10 journal ranged from 2.92 “American Journal of Infection Control” to 39.89 “BMJ-British Medical Journal”, of which eight journals were placed in Quartile 1 (Q1) and 2 in Quartile 2 (Q2). This finding showed that the
Zhang et al. PPE and COVID-19

FIGURE 2 | Network visualization map of keyword analysis. The co-occurrence network analysis tool was used to set the minimum number of occurrences to 18. Of the 3,061 keywords, 41 met the threshold. The larger the circle was, the words were used more frequently. Forty-one keywords classified in major four clusters.

FIGURE 3 | Visualization mapping of co-citation cited sources. (A) Network visualization map; (B) density visualization map. A minimum number of citations of a source: 200. Of the 11,711 sources, 20 sources met the threshold. For each of the 20 sources, the TLS with other sources was calculated. The sources with the greatest TLS were selected.

authors targeted top journals. The current analysis indicated that most of the publications on COVID-19 were published in influential and well-known journals. Many journals, which have special issues on COVID-19 have always been considered a priority and published in an open-access model (33). The USA was the highest productive country. According to the early bibliometric analysis, China was the main country of COVID-19, and the reason may be that this disease has first appeared in China. A few months later, there were a large number of COVID-19 cases in the United States, and the publishing
trend and COVID-19 trend transferred to the United States. The difference in the volume of contributions in each country can be attributed to the following factors: the wealth of the country, development level, population size, scientific capacity, and scientific infrastructure. Another major factor was related to the prevalence of COVID-19 in different countries. All these factors were related to the prevalence of epidemics, which was a major factor that cannot be ignored. This forced countries with high prevalence to strive to combat the impact of COVID-19's spread, and this analysis revealed the leading role played by the United States and China, which was due to COVID-19's high prevalence in these countries (34, 35).

In the visualization map of the institutions, the University of Toronto had the highest number of links and highest TLS. It was based on the two-dimensional space of cooperative relations between institutions. This cooperation was conducive to producing high-impact scientific research on the basis of complementary practice, experience, and skills (36). In this epidemic, cooperation between research centers around the world has a great advantage in fighting the epidemic (13, 37).

Limitations
Although bibliometrics is an effective method to evaluate article influence, there are still several limitations in our current research. First, only WOS was used to search the literature, not the existing Google academic, Medline, or other databases (38). The number of citations in the report may be slightly different. Second, English was included in the choice of language, which may lead to the omission of related articles in other languages (39). Third, the number of citations may be higher for the older research, but the older articles may not keep up with current research hotspots (40, 41). Finally, one of the reasons for a high number of citations may be self-citation, including authors citing their own articles and authors citing more articles from the journals they want to publish in (42). Further research is needed to analyze the frequency of self-citation and its influence on the article. Despite these limitations, bibliometric analysis is still an important tool to help quantify the number of articles in disciplines and provide a comprehensive overview of the literature. Our study is the first bibliometric analysis of COVID-19 and PPE research and visualization mapping. Moreover, our analysis can track the research trends and latest hotspots of COVID-19 in PPE.

CONCLUSION
This is the first bibliometric study to focus on COVID-19 and PPE research and visualization mapping, and this study provides detailed information on published literature and overall research perspective. The United States is the most productive country, and the University of Toronto is the most active institution. The most frequent keyword and author keywords' co-occurrence are COVID-19. The result is helpful for the funding agencies to evaluate the research trends of global COVID-19 and PPE. The application of PPE, by blocking the route of transmission, greatly reduced the prevalence of COVID-19, not only to protect themselves but also conducive to the health of others. The use of PPE is still a hot zone of future research.

DATA AVAILABILITY STATEMENT
The original contributions presented in the study are included in the article, further inquiries can be directed to the corresponding author.
ETHICS STATEMENT
Our study was a retrospective assessment of the public data, so the approval of the institutional review committee is not required.

AUTHOR CONTRIBUTIONS
YZ and MH: protocol/project development, data analysis, and manuscript writing. JW, PW, PS, BM, and XF: data collection or management and data analysis. WZ, XL, and QP: assist in the literature searching based on WOS and data analysis. LZ: protocol/project development, data analysis, and manuscript editing. All authors are agreed and approved the final manuscript for publication.

FUNDING
This study was funded by the Project on Maternal and Child Health Talents of Jiangsu Province (F201801).

REFERENCES
1. Li Q, Guan X, Wu P, Wang X, Zhou L, Tong Y, et al. Early transmission dynamics in Wuhan, China, of novel coronavirus-infected pneumonia. N Engl J Med. (2020) 382:1199–207. doi: 10.1056/NEJMoa2001316
2. Rodríguez-Morales AJ, MacGregor K, Kanagarajah S, Patel D, Schlenhaupf P. Going global - travel and the 2019 novel coronavirus. Travel Med Infect Dis. (2020) 33:101578. doi: 10.1016/j.tmaid.2020.101578
3. Yang X, Yu Y, Xu J, Shu H, Xia J, Liu H, et al. Clinical course and outcomes of critically ill patients with SARS-CoV-2 pneumonia in Wuhan, China: a single-centered, retrospective, observational study. Lancet Respir Med. (2020) 8:475–81. doi: 10.1016/S2216-2390(20)30079-5
4. Wu Y, Ho W, Huang Y, Jin DY Li S, Liu SL, et al. SARS-CoV-2 is an appropriate name for the new coronavirus. Lancet. (2020) 395:949–50. doi: 10.1016/S0140-6736(20)30557-2
5. Schoeman D, Fielding BC. Coronavirus envelope protein: current knowledge. Viril J. (2019) 16:69. doi: 10.1186/s12985-019-1182-0
6. Stadler K, Masignani V, Eickmann M, Becker S, Abrignani S, Klener H, et al. SARS–beginning to understand a new virus. Nat Rev Microbiol. (2003) 1209–18. doi: 10.1038/nrmicro775
7. Stadnytskiy V, Bax CE, Bax A, Anfrunud P. The airborne lifetime of small speech droplets and their potential importance in SARS-CoV-2 transmission. Proc Natl Acad Sci USA. (2020) 117:11875–7. doi: 10.1073/pnas.2006874117
8. Moore G, Rickard H, Stevenson D, Aranega-Bou P, Pitman J, Crook A, et al. Detection of SARS-CoV-2 within the healthcare environment: a multi-centre study conducted during the first wave of the COVID-19 outbreak in England. J Hosp Infect. (2021) 108:189–96. doi: 10.1016/j.jhin.2021.11.024
9. Morawska L, Tang JW, Bahnfleth W, Bluyssen PM, Boerstra A, Buonanno G, et al. How can airborne transmission of COVID-19 indoors be minimised? Environ Sci Pollut Res Int. (2021). doi: 10.1007/s11356-021-17800-z
10. Meyerowitz EA, Richterman A, Gandhi RT, Sax PE. Transmission of SARS-CoV-2 and other respiratory viruses: a systematic review and bibliometric analysis. J Infect Public Health. (2021) 14:72–3. doi: 10.5582/jiph/2020.01047
11. Ahmad T, Murad MA, Baig M, Hui J. Research trends in COVID-19. Ann Intern Med. (2021) 174:69–79. doi: 10.7326/M20-5008
12. Butnaf TC, Malekinejad M, Rutherford GW, Razani N. Outdoor transmission of SARS-CoV-2 and other respiratory viruses: a systematic review. Infect Dis J. (2021) 23:550–61. doi: 10.1093/infdis/jiaa742
13. Ahmad T, Murad MA, Baig M, Hui J. Research trends in COVID-19 vaccine: a bibliometric analysis. Hum Vacc Immunother. (2021) 17:2367–72. doi: 10.1007/2164555151.20188806
14. Xu Z, Qu H, Ren Y, Gong Z, Ri HJ, Zhang F, et al. Update on the COVID-19 vaccine research trends: a bibliometric analysis. Infect Drug Resist. (2021) 14:4237–47. doi: 10.2147/IDR.S357545
15. Wu Z, Xue R, Shao M. Knowledge graph analysis and visualization of AI technology applied in COVID-19. Environ Sci Pollut Res Int. (2021). doi: 10.1007/s11356-021-17800-z
16. Saad RK, Al Nsour M, Khader Y, Al Gunaid M. Public health surveillance systems in the eastern Mediterranean region: bibliometric analysis of scientific literature. JIMIR Public Health Surveil. (2021) 7:e32639. doi: 10.2196/32639
17. Pasin O, Pasin T. A bibliometric analysis of rheumatology and COVID-19 researches. Clin Rheumatol. (2021) 40:7475–40. doi: 10.1007/s10067-021-05844-y
18. Abuhammad RA, Ilushin MY, Youssef Ismail M, Alhargan A, Alghamdi A, Alzahrani AO, et al. Medical image processing and COVID-19: a literature review and bibliometric analysis. J Infect Public Health. (2022) 15:75–93. doi: 10.1016/j.jiph.2021.11.013
19. Patralekh MK, Iyengar KP, Jain VK, Vaishya R. Bibliometric analysis of COVID-19 related publications in Indian orthopaedic journals. J Clin Orthop Trauma. (2021) 22:101608. doi: 10.1016/j.jcot.2021.101608
20. Soytas M, Danacioglu YO, Boy MY, Horuz R, Albayrak S. COVID-19 and urology: a bibliometric analysis of the literature. Int J Clin Pract. (2021) 75:e14965. doi: 10.1111/i.jcp.14965
21. Ellegeard O, Wallin JA. The bibliometric analysis of scholarly production: how great is the impact? Scientometrics. (2015) 105:1809–31. doi: 10.1007/s11192-015-1645-2
22. Garfield E. Citations analysis as a tool in journal evaluation. Science. (1972) 178:471–9. doi: 10.1126/science.178.4060.471
23. Paladugu R, Schein M, Gardezi S, Wise L. One hundred citation classics in general surgical journals. World J Surg. (2002) 26:1099–105. doi: 10.1007/s00268-002-6376-7
24. Kavanagh RG, Kelly JC, Kelly PM, Moore DP. The 100 classic papers of general surgery. World J Surg. (2002) 26:1099–105. doi: 10.1007/s00268-002-6376-7
25. Synnestvedt MB, Chen C, Holmes JH. CitSpace II: visualization and knowledge discovery in bibliographic databases. AMIA Annu Symp Proc. (2005) 2005:724–8.
26. Zhang H. Challenges and approaches of the global governance of public health under COVID-19. Front Public Health. (2021) 9:727214. doi: 10.3389/fpubh.2021.727214
27. Wang M, Cao R, Zhang L, Yang X, Liu J, Xu M, et al. Remdesivir and chloroquine effectively inhibit the recently emerged novel coronavirus (2019-nCoV) in vitro. Cell Res. (2020) 30:269–71. doi: 10.1038/s41422-020-0282-0
28. Gao J, Tian Z, Yang X. Breakthrough: Chloroquine phosphate has shown apparent efficacy in treatment of COVID-19 associated pneumonia in clinical studies. Biosci Trends. (2020) 14:72–3. doi: 10.5582/bst.2020.01047
29. Nowak BM, Miedziarek C, Pelczyński S, Raymiki P. Misinformation, fears and adherence to preventive measures during the early phase of COVID-19 pandemic: a cross-sectional study in Poland. Int J Environ Res Public Health. (2021) 18:11266. doi: 10.3390/ijerph18221266
30. Li X, English AS, Kulich SJ. Anger among Chinese migrants amid COVID-19 discrimination: the role of host news coverage, cultural distance, and national identity. PLoS ONE. (2021) 16:e0259866. doi: 10.1371/journal.pone.0259866
31. Shahil Feroz A, Pradhan NA, Hussain Ahmed Z, Shah MM, Saleem S, et al. Perceptions and experiences of healthcare providers during COVID-19 pandemic in Karachi, Pakistan: an exploratory qualitative study. BMJ Open. (2021) 11:e048984. doi: 10.1136/bmjopen-2021-048984
32. Kambhampati SBS, Vaishya R, Vaish A. Unprecedented surge in publications related to COVID-19 in the first three months of pandemic: a bibliometric analytic report. J Clin Orthop Trauma. (2020) 11:S304–6. doi: 10.1016/j.jcot.2020.04.030
33. Ziyoud SH, Al-Jabi SW. Mapping the situation of research on coronavirus disease-19 (COVID-19): a preliminary bibliometric analysis during the early stage of the outbreak. BMC Infect Dis. (2020) 20:561. doi: 10.1186/s12879-020-05293-z
35. Zyoud SH, Zyoud AH. Coronavirus disease-19 in environmental fields: a bibliometric and visualization mapping analysis. *Environ Dev Sustain.* (2021) 23:8895–923. doi: 10.1007/s10668-020-01004-5

36. Havemann F, Heinz M, Kretschmer H. Collaboration and distances between German immunological institutes—a trend analysis. *J Biomed Discov Collab.* (2006) 1:6. doi: 10.1186/1747-5333-1-6

37. Triemstra JD, Haas MRC, Bhavsar-Burke I, Gottlieb-Smith R, Wolff M, Shelgikar AV, et al. Impact of the COVID-19 pandemic on the clinical learning environment: addressing identified gaps and seizing opportunities. *Acad Med.* (2021) 96:1276–81. doi: 10.1097/ACM.0000000000004013

38. Virk SS Yu E. The top 50 articles on minimally invasive spine surgery. *Spine.* (2017) 42:513–9. doi: 10.1097/BRS.0000000000001797

39. Zhao T, Shen J, Zhang J, Hu X, Morizane K, Huang Y, et al. Top 100 cited articles on spinal disc arthroplasty research. *Spine.* (2020) 45:1530–6. doi: 10.1097/BRS.0000000000003608

40. Gisvold SE. Citation analysis and journal impact factors—is the tail wagging the dog? *Acta Anaesthesiol Scand.* (1999) 43:971–3. doi: 10.1034/j.1399-6576.1999.431001.x

41. De la Garza-Ramos R, Benvenutti-Regato M, Caro-Osorio E. The 100 most-cited articles in spinal oncology. *J Neurosurg Spine.* (2016) 24:810–23. doi: 10.3171/2015.8.SPINE15674

42. Murray MR, Wang T, Schroeder GD, Hsu WK. The 100 most cited spine articles. *Eur Spine J.* (2012) 21:2059–69. doi: 10.1007/s00586-012-2303-2

**Conflict of Interest:** The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

**Publisher's Note:** All claims expressed in this article are solely those of the authors and do not necessarily represent those of their affiliated organizations, or those of the publisher, the editors and the reviewers. Any product that may be evaluated in this article, or claim that may be made by its manufacturer, is not guaranteed or endorsed by the publisher.

*Copyright © 2022 Zhang, Hu, Wang, Shen, Zhao, Shi, Zhang. This is an open-access article distributed under the terms of the Creative Commons Attribution License (CC BY). The use, distribution or reproduction in other forums is permitted, provided the original author(s) and the copyright owner(s) are credited and that the original publication in this journal is cited, in accordance with accepted academic practice. No use, distribution or reproduction is permitted which does not comply with these terms.*