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Monkeypox Virus and Current Trends: A Bibliometric Analysis of the Published Literature Based on VOSviewer

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Original Research

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Abstract

Objective: The World Health Organization declared the current monkeypox outbreak a public health emergency of international concern (PHEIC) on July 23, 2022, as it has posed a great threat to human health. This bibliometric analysis aimed to explore the current research hotspots focused on monkeypox.

Methods: A systematic search of the Web of Science Core Collection database was conducted for published articles on monkeypox from database inception to February 23, 2023. VOSviewer software was used for analysis and visualization of research results.

Results: A total of 1646 publications on monkeypox virus were included for bibliometric analysis. Results showed that (1) the number of publications about monkeypox virus increased significantly in 2022, (2) smallpox and monkeypox virus were popular research keywords, (3) the United States has made the most significant contribution to the study of monkeypox virus, (4) *Journal of Virology* was the most active journal in publishing articles about monkeypox, and (5) research themes mainly included the body's reaction after monkeypox infection, epidemiology, diagnosis, and pathological mechanisms.

Conclusions: Future research should focus on early sensitive diagnostic measures of monkeypox and the development of vaccines based on the characteristics of the virus. Study findings also provided key areas for public health experts to focus on and collaborate with policymakers.

The most recent report from the World Health Organization (WHO) showed that as of February 16, 2023, the monkeypox epidemic in 2022-23 had spread to 110 Member States across all 6 WHO regions, with a total of 85 860 laboratory-confirmed cases including 93 deaths.[1] Monkeypox is a viral zoonosis caused by the monkeypox virus (MPV) that is transmissible between animals and humans, as well as between humans for secondary transmission.[2,3] MPV is an enveloped double-stranded DNA virus with an approximate length of 197 kb, belonging to the genus *Orthopoxvirus* of the family Poxviridae.[4] Monkeypox is mainly transmitted through direct skin contact.[5] In humans, the most common monkeypox symptoms are fever, severe headache, muscle soreness, back pain, fatigue, and swollen lymph nodes, followed by or accompanied with a rash, typically lasting 2 to 3 weeks.[6–8] Most patients recover within a few weeks, but newborns, children, and those with immunodeficiency may become gravely ill or even die.[8]

On July 23, 2022, the WHO declared the current monkeypox outbreak a public health emergency of international concern (PHEIC), as it has posed a great threat to human health.[9] The spread of monkeypox has increased the burden of existing infectious diseases and placed significant strain on global health systems. In addition, measures taken to control the spread of the virus have had a large impact on daily life, the economy, and transportation.[9]

The outbreak of human monkeypox in numerous nations has sparked intense research interest. There has been a dramatic increase in the number of publications on monkeypox, providing information on epidemiology, prevention, vaccine development, and potential treatments, which may play a vital role in the fight against the monkeypox pandemic.

Bibliometrics, first proposed by American bibliographers in 1969, refers to the quantitative analysis of literature using methods such as mathematics and statistics.[10–12] Based on the construction of the citation graph, it can quantitatively analyze citation scientific publications.[10] In addition, VOSviewer software can be used to construct and visualize bibliometric networks.[13] This study aimed to conduct a comprehensive scientific quantitative evaluation of MPV literature to guide future research efforts.

Methods

Literature Search

All monkeypox-related literature was searched in the Web of Science (WoS) Core Collection from inception to February 23, 2023. According to the mesh and entry terms, search terms including "monkeypox virus" or "monkeypox viruses" or "monkeypoxvirus" or "monkeypoxviruses" or "monkey pox virus" or "monkey pox viruses" were used to gain complete access to relevant publications. All studies investigating MPV were enrolled in this analysis. No language restrictions existed.

Bibliometric Analytic Approach

Full records and cited references from the literature that met inclusion criteria that the publications involved participants who had monkeypox virus were included in this study and exported to a tab-delimited file. VOSviewer software (version 1.6.18, Leiden University, Leiden, Netherlands) was used for bibliometric analysis. The citation and the top 10 most active categories, including authors, countries, organizations, journals, research areas, and document types, were analyzed to determine the most recent research trends. Microsoft Excel 2016 was used to store and analyze the data of the included literature.

Results

Number and General Characteristics of the Literature

A total of 1646 publications were associated with the search terms in the WoS Core Collection from inception to February 23, 2023. Of these, 669 (40.64%) articles were published in 2022, whereas only 31 (1.88%) and 42 (2.55%) articles were published in 2021 and 2020, respectively. The number of research articles on MPV increased significantly in 2022. An evaluation of the annual distribution of publications is presented in Figure 1, and the frequency of occurrence of the keyword "monkeypox" by year is presented in Figure 2. The distribution trend reflected that there were relatively fewer studies on MPV before 2022, which might suggest that the virus was not a significant public health concern at that time.

Bibliometric Analysis of Keywords

Keywords (provided by the included articles) with at least three occurrences were analyzed. A sample of 761 keywords from a total of 4025 met this minimum threshold. In the network visualization of keywords, each circle represents a keyword and the lines between the circles represent the correlations between keywords. Specifically, the larger the circle, the higher the frequency of the keyword, and the shorter the distance between the two circles, the stronger the correlation between these two keywords. The keywords were grouped into 13 clusters by different colors. As shown in Figure 3, the most prevalent keyword was "monkeypox" (551 occurrences, total link strength 3847), which had a strong link to "orthopoxvirus". "Smallpox" (300 occurrences, total link strength 2628) and "monkeypox virus" (282 occurrences, total link strength 1896) were the other two most popular keywords (Figure 3A). Density visualization is provided to show the frequency of keywords that occurred more than 3 times, revealing that "monkeypox" and "infection" were the most frequently used terms (Figure 3B). The top 10 keywords are presented in Figure 3C.

The Most Active Authors, Organizations, and Countries

Table 1 lists the top 10 most active MPV publication authors, countries, and organizations. A total of 121 countries/regions and 2480 affiliations contributed scientifically. Inger K. Damon (Centers for Disease Control & Prevention, Poxvirus

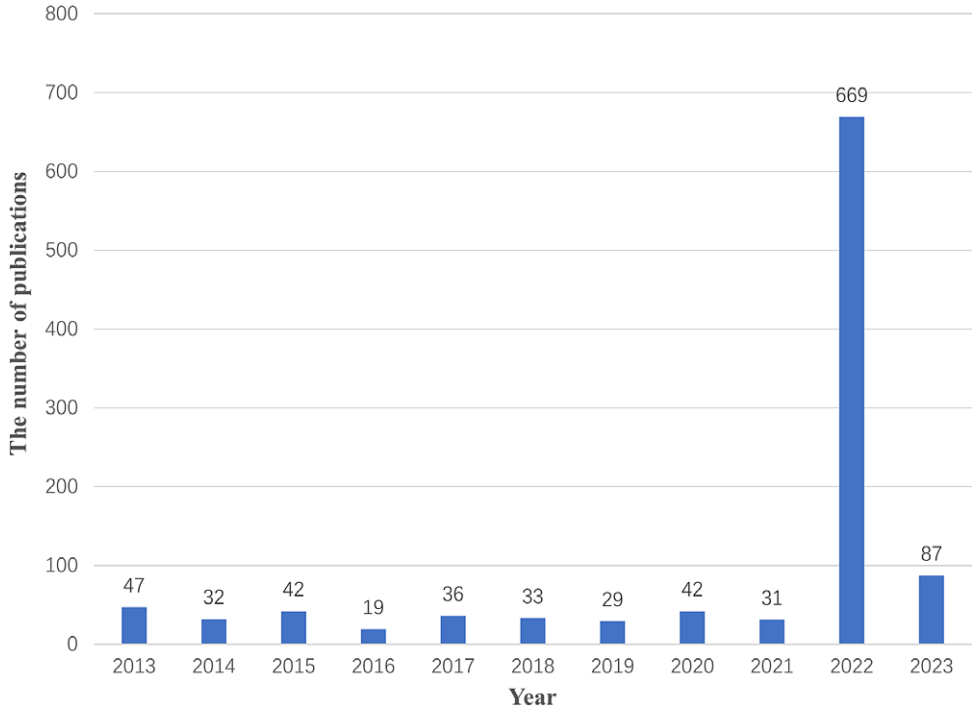

Figure 1. Annual distribution of publications, wherein publications about monkeypox virus increased significantly in 2022.

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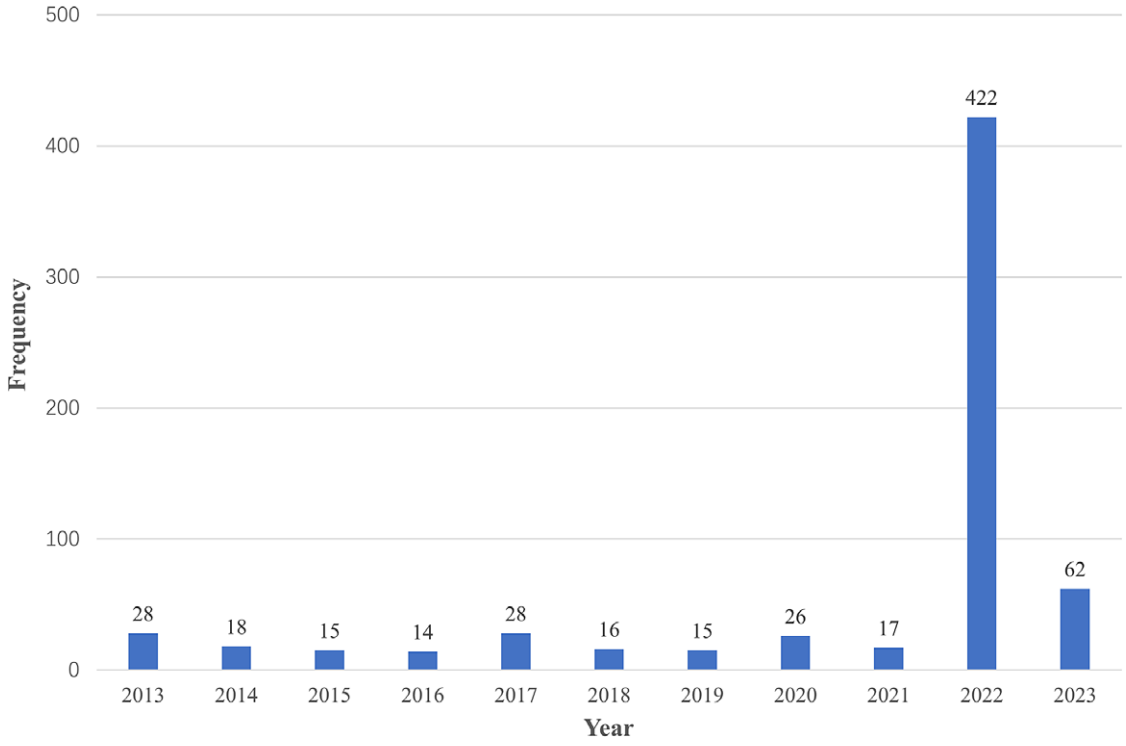

Figure 2. Frequency of occurrence of the keyword "monkeypox" by year.

Program, Atlanta, GA) was the top contributing author, with 75 publications and 4653 citations, although this author's articles were published before 2022. The other 2 of the top 3 most active authors were Mary G. Reynolds (total of 55 publications, 2710 citations) and Victoria A. Olson (total of 44 publications, 2314 citations). After 2022, they published one (total of 86 citations) and two articles (total of 86 citations), separately. The top two countries with the highest numbers of publications were the United States, with 764 publications (46.42%, with 24 532 citations) and Germany, with 133 publications (8.08%, with 4337 citations) with a wide disparity in the number of studies between the 2 countries. The top 3 affiliations with the highest numbers of publications were the Centers for Disease Control and Prevention (United States), with 187 publications and 8359 citations; the National Institutes of Health (NIH, United States), with 99 publications and 4606 citations; and the NIH National Institute of Allergy and Infectious Diseases (NIAID, United States), with 77 publications and 3023 citations.

The Most Active Journals, Document Types, and Research Areas

Table 2 lists the top 10 most active MPV publication journals, document types, and research areas. *Journal of Virology* had the highest number of both publications (54 [3.28%]) and citations (2343). Virology was, as expected, the largest research area, with 368 (22.36%) publications and 9858 citations. Research articles (1090, 66.22%), review articles (290, 17.62%), editorial materials (105, 6.38%), and letters (104, 6.32%) were the most popular document types. The article "The detection of monkeypox in humans in the Western Hemisphere", published in the *New England Journal of Medicine* in January 2004, and since the date of publication to the search date, has received the most citations (total of 479 times).

Bibliometric Analysis of Themes and Trend Topics

The bibliometric analysis of themes and trend topics is shown in Figure 4A, B. As indicated in Figure 4A, 5 themes of MPV studies were found. The red cluster focused on the theme of examining the body's reaction and challenges after infection with MPV. The green cluster investigated epidemiological characteristics of monkeypox. The yellow cluster investigated measures of diagnosis associated with the MPV. The blue cluster mainly examined characteristics and the pathogenic mechanism of MPV, and the purple cluster focused on the host range of the MPV. Figure 4B depicts the network map of trending topics according to the terms (extracted from titles and abstracts) used from inception to 2022. The indicator shifted from purple to yellow to display current publications, and some new subject words appeared in the recent period. This visualization demonstrated that research on MPV is gradually increasing.

Discussion

Due to the persisting prevalence of monkeypox, the number of scientific publications in this field has continued to rise, particularly in 2022. The importance of evaluating the quality of these publications and extracting useful information from them for future research cannot be overlooked. In the current studies, 1646 publications about monkeypox indexed in the WoS Core Collection database were analyzed. Three research areas were represented in the published literature: virology, immunology, and infectious diseases. The most frequently used keyword, "monkeypox" was closely related to "orthopoxvirus" and "smallpox." The United States has made the most outstanding contributions to this vital field.

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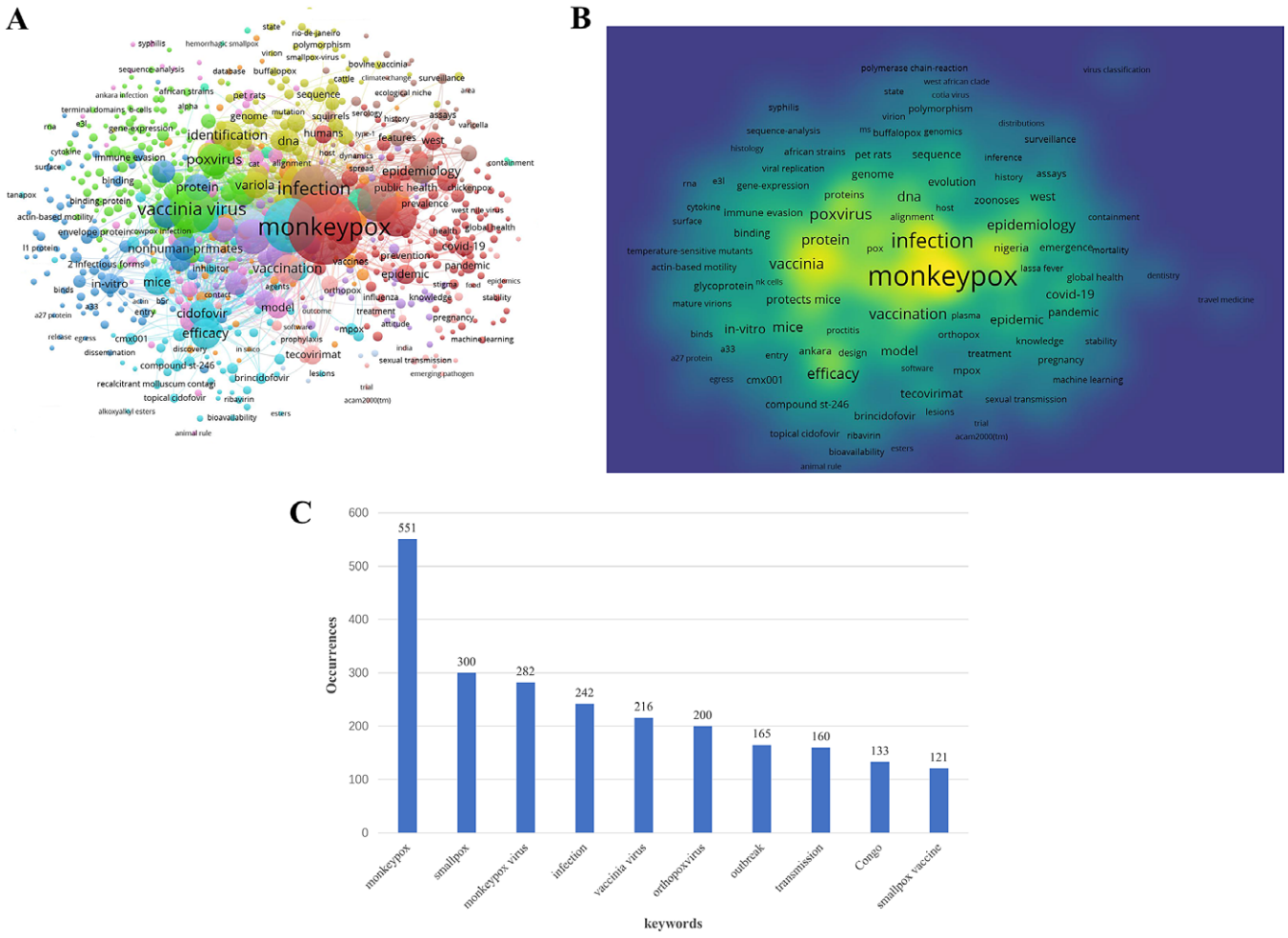

Figure 3. Bibliometric analysis of keywords in the included papers from the WOS Core Collection database. (**A)** Network visualization of keywords, with the most prevalent keyword being "monkeypox" (551 occurrences, total link strength 3847); **(B)** density visualization of keywords that occurred more than three times, with "monkeypox" and "infection" as the most frequently used terms; (**C)** bar chart of the top ten keywords.

Monkeypox is a rare infectious disease, first discovered in a laboratory monkey in 1958.[14] The first recorded human case was in 1970 in Zaire.[15]MPV occurred mainly in African countries before 2003. Since the outbreak of monkeypox in the United States in 2003, cases have emerged in many other countries outside Africa[16] and have continued to spread globally, predominantly in Europe and North America. The spike in the number of infectious cases may be related to a mutation making MPV more transmissible. WHO declared monkeypox a PHEIC in July 2022, indicating that global solidarity is needed to address its rapid spread. According to the case reports to date, the outbreak of monkeypox has been associated with close intimate contact, primarily involving men who have sex with men. In addition to the aforementioned direct contact form of transmission, airborne transmission is also a way by which the virus spreads.

The monkeypox epidemic is still raging throughout the world. This rapid global spread has heightened researchers' vigilance and led to the development of numerous effective strategies for combating the epidemic. With the highest number of published articles and citations, the *Journal of Virology* has become the most popular publication, demonstrating its great advantages.

Monkeypox is caused by the MPV. Both the MPV and smallpox virus belong to the orthopoxvirus family, and their typical clinical manifestations are similar.[2,3,17,18] Therefore, as the top 10 most frequently used keywords, "monkeypox" and "orthopoxvirus" were closely associated with "smallpox". In addition, many people are extremely concerned due to the outbreak of monkeypox and the lack of effective prevention and treatment methods. Therefore, "outbreak" and "smallpox vaccine" were another 2 top 10 keywords.

Most articles on monkeypox published in 2022 were written by American scholars. This is likely because the pandemic is mainly spreading in Europe and North America, particularly the United States, which has become one of the countries with the highest monkeypox infection rate worldwide.[19] The United States reported its first case of monkeypox on May 7, 2022, and by August 9, 2022, nearly 9500 confirmed cases had been reported. At the same time, on August 4, the United States government declared monkeypox a public health emergency.[19] In addition, the United States has a robust information and data management system.

With the in-depth study of monkeypox, more clinical studies have been carried out in other countries.[20,21] Current research focuses primarily on understanding the epidemiology and diagnosis of monkeypox, studying changes at the organ and cell levels, and exploring potential pathogenesis and treatment methods. For

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Table 1. The top ten most active authors, organizations, and countries of monkeypox virus publications

	Number of publications	Number of citations
Authors		
Damon, Inger K	75	4653
Reynolds, Mary G	55	2710
Olson, Victoria A	44	2314
Olson, Victoria A	43	1489
Karem, Kevin L	35	1255
McCollum, Andrea M	35	1326
Li, Yu	34	2213
Jarling, Peter B	31	1945
Shchelkunov, Sergei N	29	872
Meyer, H	26	1620
Organizations		
Centers for Disease Control and Prevention, USA	187	8359
National Institutes of Health, USA	99	4606
National Institute of Allergy Infectious Diseases	77	3023
University of California System	55	2267
UDICE French Research Universities	51	1027
Harvard University	45	830
State Research Center of Virology Biotechnology Vector	39	981
World Health Organization	38	2847
Ministry of Health	37	1316
Institute Nacional De Recherche Biomedical	35	1269
Countries		
United States	764	24532
Germany	133	4337
India	124	465
United Kingdom	104	3284
People's Republic of China	84	326
France	77	1622
Italy	72	1336
Canada	57	2417
Russia	53	137
Pakistan	53	1122

Table 2. The top ten most active journals, research areas, and document types of monkeypox virus publications

	Number of publications	Number of citations
Journals		
Journal of Virology	54	2343
Viruses Basel	54	994
Vaccine	47	1436
Journal of Medical Virology	44	394
Virology	43	1757
PLoS One	40	1014
Emerging Infectious Diseases	34	1866
Antiviral Research	27	833
Journal of Infectious Diseases	27	1066
American Journal of Tropical Medicine and Hygiene	25	734
Research areas		
Virology	368	9858
Infectious diseases	293	7435
Immunology	254	7747
Microbiology	232	6817
Public environmental occupational health	150	2560
General internal medicine	143	2017
Pharmacology and pharmacy	117	2565
Research in experimental medicine	104	2586
Biochemistry and molecular biology	100	2677
Science technology – other topics	84	3040
Document types		
Article	1090	29106
Review	290	6776
Editorial material	105	972
Letter	104	620

the diagnostic method of monkeypox, besides determining monkeypox-specific DNA sequences, AI-based detection is a valid method to identify this disease at the early stage, and AI-based diagnostic methods may be appropriate for mass screening.[22] Currently, the treatment for most patients is symptomatic, and there is no antiviral drug approved for monkeypox.[7,23] Three antivirals—tecovirimat, cidofovir, and brincidofovir—have been shown to be effective against monkeypox infection.[24,25] These antivirals, approved to treat smallpox, are expected to be potential options for treating monkeypox as well. However, none of these antivirals has been evaluated in randomized trials. Tecovirimat is the first choice for the treatment of monkeypox, and it has been approved by the European Medicines Agency (EMA) for monkeypox but not yet by the FDA.[26] Cidofovir has been shown to be effective against monkeypox in animal models, but its dose-dependent nephrotoxicity restricts its use in the clinic.[27] As an analogue of cidofovir, brincidofovir has decreased nephrotoxicity. However, it has the risk of derangement in liver function.[7] Consequently, effective treatment will undoubtedly become one of the primary concerns of future researchers. In addition, there are 2 main vaccines (the JYNNEOS and ACAM2000 vaccines) that can presently be used to prevent monkeypox, both of which have been proven to be 85% effective.[28,29] However, the supply of vaccines is severely limited at the moment, so further research and

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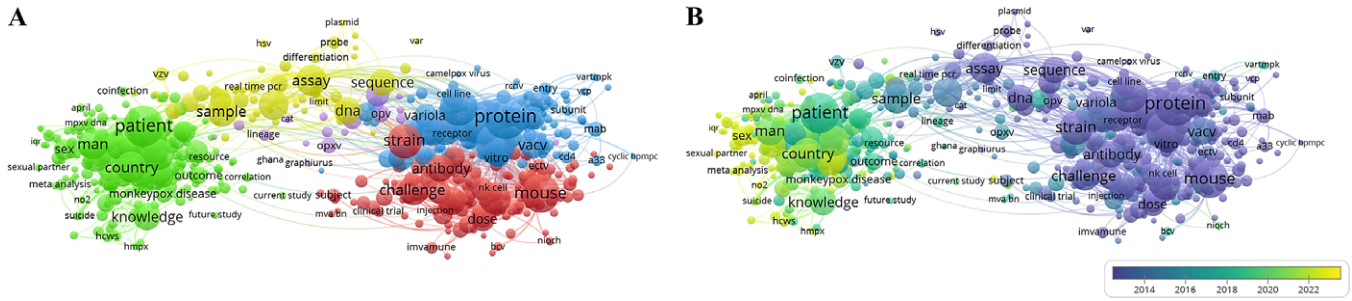

Figure 4. Bibliometric analysis of themes and trend topics. (**A)** Five themes of monkeypox virus studies were included, and nodes with different colors represent various research directions. The red cluster focused on the body's reaction and challenges after infection with monkeypox virus. The green cluster investigated the epidemiological characteristics of monkeypox. The yellow cluster investigated diagnostic measures associated with the monkeypox virus. The blue cluster examined characteristics and the pathogenic mechanism of monkeypox virus, and the purple cluster focused on the host range of the monkeypox virus; (**B)** network map of the trend topics according to the terms (extracted from titles and abstracts), with some new subject words appearing in 2022, indicating that research on the monkeypox virus is gradually increasing.

development of vaccines will also be a focus of future research. Finally, beyond vaccination, a comprehensive strategy to prevent monkeypox should be applied, including maintaining personal hygiene, avoiding contact with infected animals, controlling health-care environments, education and awareness, and early diagnosis and treatment.

In this study, the WoS Core Collection database was searched for publications on monkeypox, and VOSviewer was applied to conduct a quantitative analysis of the relevant literature to gain an objective and comprehensive understanding of the epidemic. However, there are some limitations in this research. First, only using the WoS Core Collection database to screen the literature may have caused some publications, which they might be included in other databases, to be excluded from our analysis. In addition, "grey" literature may hold significance in research, but this study mainly focused on publications that are widely recognized in academia; therefore, the "grey" literature, such as WHO's situation reports, will be included for more comprehensive analysis in a future study. Second, as time goes on, more articles may be published, and the number of articles included based on the search terms may be varied. In future reports, research results will be updated according to the latest number of articles, thereby improving the reliability of the study. Finally, the studies included were analyzed based on the citations rather than other evaluation methods, and thus, the collected literature was of variable quality. Impact Factor, CiteScore, Eigen Factor, and the h-index are significant indicators for evaluating the quality of literature. Therefore, future research may utilize evaluation criteria that include these indicators to control for the impact of the variable quality of literature on conclusions.

Conclusions

With the spread of the monkeypox epidemic, related publications showed a trend of rapid growth. The bibliometric analysis of monkeypox is particularly important for understanding the current situation and guiding future research directions. The current study found that the United States has played a crucial role in studying the monkeypox virus. Research topics have mainly involved bodily reaction after monkeypox infection, epidemiology, diagnosis, pathological mechanisms, and host range of monkeypox infection. Effective diagnostic methods, treatment schemes, and vaccine research are still the focus of future research.

Data availability statement. The corresponding author will supply the data for reasonable requests. Bo Jiao and Liyun Deng made equal contributions.

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Author contribution. BJ and CC designed this bibliometric analysis and constructed the search strategy. BJ and LYD completed the literature search and data collection. BJ and LYD performed the data synthesis and analysis. BJ, LYD, and YC were the major contributors to the draft writing. CC revised the manuscript critically. All authors have read and approved the final version.

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Competing interest. The authors declared they have no competing interests.

Ethical standard. Ethical approval is not required since all data were extracted from previously published studies.

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