Am J Transl Res 2022;14(5):2972-2987
www.ajtr.org /ISSN:1943-8141/AJTR0142082

Original Article

Mapping theme trends and recognizing hot spots in viral pneumonia: a bibliometric analysis of global research

Lixue Wu[1*], Hao Wu[1*], Tianle Ou[2*], Hao Huang[1], Liwei Duan[1], Wenfang Li[1#], Weiwei Jiang[1#]

[1]Department of Emergency and Critical Care Medicine, Changzheng Hospital, Naval Medical University, Shanghai, 200003, China; [2]College of Basic Medicine, Naval Medical University, Shanghai, 200433, China. [*]Equal contributors. [#]Equal contributors.

Received January 28, 2022; Accepted March 30, 2022; Epub May 15, 2022; Published May 30, 2022

Abstract: Background: The challenges that viral pneumonia poses to the global public health system remain daunting. In this study, an analysis of publications on viral pneumonia over the past two decades was conducted. Through this work, we hope to provide inspiration for future research on viral pneumonia. Methods: We extracted all of the English publications relevant to viral pneumonia published during 1999-2019 from Web of Science. GraphPad Prism, CiteSpace, and VOSviewer were used to collect and analyze the publication trends in related fields. Results: We identified 2,006 publications with 62,155 citations as of February 16, 2021. The United States accounted for the largest number of publications (34.2%), with the highest number of citations (27,616) and the highest h-index (78). China ranked second in the number of publications. Ctr Dis Control & Prevent proved to be the center of research cooperation. *Clinical Infectious Diseases* included the most papers published relating to the topic of viral pneumonia. Chan KH published the most papers in this field (25), while an article from Fouchier RAM presented the highest citation frequency (1,275). Conclusions: According to the bibliometric analysis database and related software results, the United States dominates the field of viral pneumonia research. The key term extracted by VOSviewer has shifted to "Diagnosis and management", indicating a new trend for viral pneumonia research.

Keywords: Publications, citation frequency, bibliometrics, viral pneumonia

Introduction

The morbidity of pneumonia has long been increasing in children and the elderly worldwide [1]. Although pneumonia can be triggered by a variety of microorganisms, the role of viral pathogens in causing pneumonia has been underestimated [2]. Respiratory viruses are an important cause of pneumonia in adults, while elderly people with underlying cardiopulmonary disease are more susceptible. In a study on the detection of pathogens in adults with community-acquired pneumonia, researchers followed 193 patients and found that 29 patients were infected with viruses, accounting for about 15% [3]. In adults, viral pneumonia is most commonly caused by influenza virus, and respiratory syncytial virus (RSV) is not uncommon [4]. The most frequently detected viruses in children with viral pneumonia are RSV (73.5%) and rhinovirus (24.3%) [5]. As well-known RNA viruses, coronaviruses (CoVs) were thought to be among the relatively harmless respiratory pathogens in the past. However, with the emergence of severe acute respiratory syndrome (SARS) and Middle East respiratory syndrome (MERS), CoVs have attracted attentions worldwide [6]. In January 2020, the global outbreak of novel coronavirus 2019-nCoV (officially named COVID-19) was announced as a public health emergency of international concern (PHEIC) by the WHO [7]. Pneumonia triggered by COVID-19 is developing into a global infectious disease, implying that more attention needs to be paid to viral pneumonia research.

Bibliometric research provides the overall situation of a research field through publication indicators such as journals, authors, institutions and countries, and determines the most influential research in the field [8]. Bibliometric mapping visualizes such data and enables a better understanding of it, while highlighting the most influential study in the area of interest

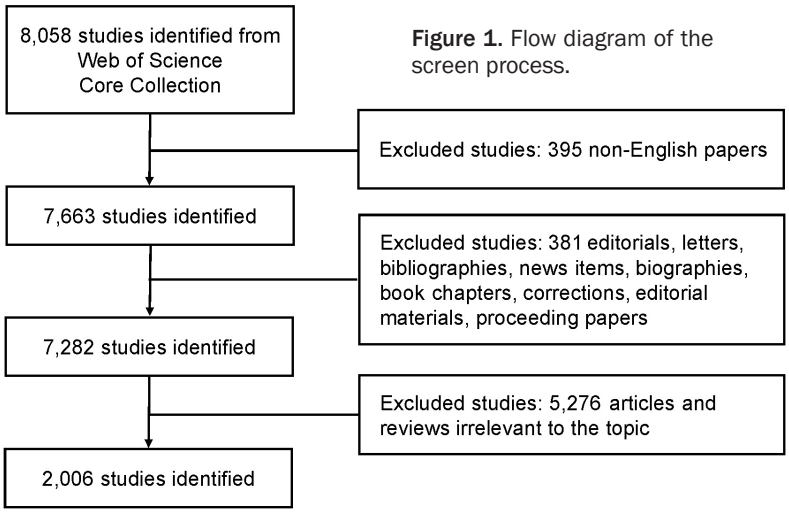

Figure 1. Flow diagram of the screen process.

[9]. Although bibliometric analyses have been conducted on pneumonia [10] as well as on viruses such as RSV and MERS-CoV [11], no bibliometric study has been done on viral pneumonia.

The present study aims to provide a comprehensive analysis of the current research status of viral pneumonia based on publications from the Web of Science (WOS). Bibliometric methods combining with two major software (VOSviewer and CiteSpace) and one Online Analysis Platform of bibliometric analysis were applied to discover the current trend of this research area and to predict potential hotspots in the future and provide an important reference for researchers in the future and an overall perspective for the study.

Materials and methods

Data sources and search strategies

Articles published from 1999-2019 were included in the present study. All publications were obtained from the online database Web of Science Core Collection.

The search process was finished on a single day, February 16, 2021, to avoid the bias introduced by rapid database renewal. The search strategy was set as follows: TS = (Viral AND pneumonia) OR (((Respiratory AND Syncytial AND Virus) OR (Influenza AND virus) OR (Rhinovirus)) AND (Pneumonia)) AND "Language = English". Only original articles and reviews using normal peer review processes were considered eligible. The detailed processes of enrollment and screening are shown in **Figure 1**.

Data collection

Two of the authors (WH and OTL) independently extracted the data of interest from all eligible publications, including the titles, keywords, publication dates, countries and regions, authors, institutions, published journals, sum of citations, h-index, etc. Microsoft Excel 2016 (Redmond, Washington, USA), GraphPad Prism 8.3 (GraphPad Prism Software Inc., San Diego, CA), CiteSpace version 5.6. R5 64 bit (Drexel University, Philadelphia, PA, USA), VOSviewer version 1.6.12 (Leiden University, Leiden, the Netherlands) and the Online Analysis Platform of Literature Metrology (http://bibliometric.com/) were used for the subsequent quantitative and qualitative analyses. The latest information on gross domestic product (GDP) and population was retrieved from the websites of the World Bank.

Bibliometric analysis

The Web of Science has been widely utilized in most bibliometric analyses, especially those focused on biomedical research. Relative research interest (RRI) was defined as the number of publications related to a specific research field divided by publications across all fields per year. The impact factor (IF) was obtained by examining Journal Citation Reports (JCRs) published in 2019. The h-index is a bibliometric measure that combines quantity (publications) and impact (citations). It allows us to objectively characterize the scientific output of a researcher. The h-index means that a scholar/country has published h papers, and each has been cited in other publications at least h times, which is better than other indicators considered (citation count, citations per paper, and paper count) in predicting future scientific achievement. The impact factors of all the journals are based on the 2019 Journal Citation Reports by Clarivate Analytics.

We utilized CiteSpace to represent bibliometric characteristics such as references, institutions, authors and terms by visualizing the links between the nodes in the map. This software is based on the co-citation analysis theory and pathfinder, minimum spanning trees algorithm to make a quantitative analysis of the literature in specific fields. Meanwhile, this software can also extract high-occurrence keywords to analyze potential research trends in future research. VOSviewer is the science-mapping software tool developed using the Java programming language, which is suitable for bibliometric mapping in an easy-to-interpret way. It can realize the construction and visualization of the keyword cooccurrence network in various fields. Map construction is based on the VOS mapping technique, which is based on a cooccurrence matrix, where VOS stands for the visualization of similarities. With zoom functionality, special labeling algorithms, and density metaphors, the graphical representation of bibliometric maps can be enhanced dramatically via multidimensional scaling.

Results

Contributions of countries to global publications

Our inclusion criteria were met by 2,006 articles dating from 1999-2019. The United States ranked first in the number of publications (686, 34.2%), followed by China (280, 14.0%) and Japan (147, 7.3%) (**Figure 2A**). Herein, a positive correlation was found between the rankings of the publications and the nations' GDPs. By calculating the number of papers per year, we found that the largest number of publications occurred in 2019 (164, 8.2%) (**Figure 2B**). When the number of all-field publications was considered, the global interest in this field, measured by the value of RRI, started to increase in 2003 and reached a 0.004% rate of growth in 2019, while two peaks (2011 and 2014) emerged in the curve during this progress (**Figure 2B**). The proportion of publications by Chinese researchers rose rapidly over the past 10 years. Notably, China (29, 26.1%) was fairly close to the United States (28, 25.2%) in the number of publications in 2018. This trend was maintained in 2019 with China (41, 25.0%) and the USA (43, 26.2%). Scientific research cooperation between countries worldwide is presented through the Online Analysis Platform of Literature Metrology in **Figure 3**.

Growth trends of the publications

The cumulative publication numbers for the world and the top 3 countries, as well as the corresponding model fitting curves, are shown in **Figure 4**. Based on these growth curves, by the year 2022, there should be an estimated 2,256 papers in this field: 758 from the United States, 363 from China, and 166 from Japan. We found that the growth of publications for the entire world was on a slow curve, which was also applicable to several major countries, such as the United States and Japan (**Figure 4B** and **4D**). The number of papers published by those countries per year has remained unchanged in recent years, while China showed an obviously faster growth curve in publications in this field compared to other countries (**Figure 4C**).

Institutions with research publications on viral pneumonia

The *Centers for Disease Control & Prevention* in the USA had the highest number of publications among institutions worldwide. Sixty-seven papers were from this institution, which accounted for 3.3% of all publications. Within the top 15 institutions in this field, there were 7 USA institutions, 4 Chinese, 2 Finland, 1 Netherlands and 1 Spain institution(s) (**Table 1**). As shown in maps generated by CiteSpace and VOSviewer, *Ctr Dis Control & Prevent* played the dominant role in this area, followed by *Univ Hong Kong, NIAID* and *Capital Med Univ* (**Figure 5A** and **5B**).

Journals with research publications on viral pneumonia

Approximately one-third of the papers within this scope were published in 20 journals (486, 24.23%). The number of papers published in *Clinical Infectious Diseases* (IF = 9.055) was the highest with 58 records. *PLOS One* (IF = 2.776) ranked second with 56 publications. The IF of journals ranking third and fourth was similar to that of *PLOS One*. The *American Journal of Respiratory and Critical Care Medicine* (IF = 16.494) and *The European Respiratory Journal* (IF = 11.807) had 51 and 48 publi-

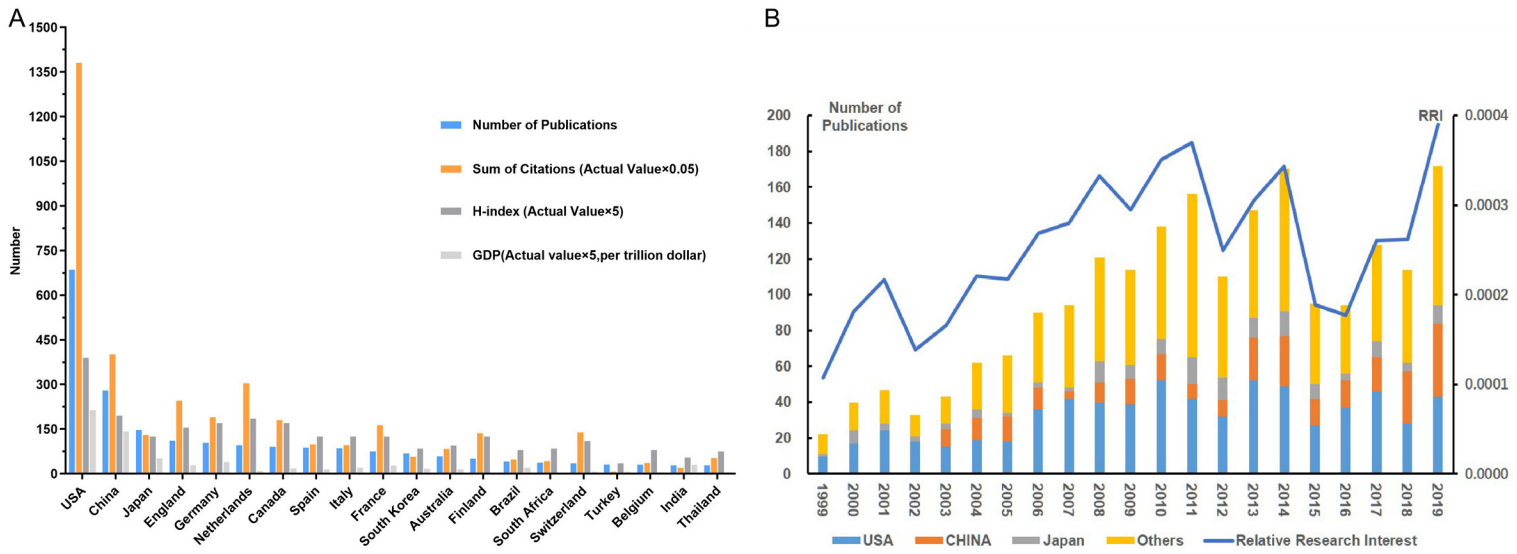

Figure 2. Contributions of different countries/regions to the research on viral pneumonia. A. The number of publications, citation frequency (×0.05), H-index (×5) and GDP (×5, per trillion dollar) in the top 10 countries or regions; B. The number of publications worldwide and the time course of the relative research interest in viral pneumonia.

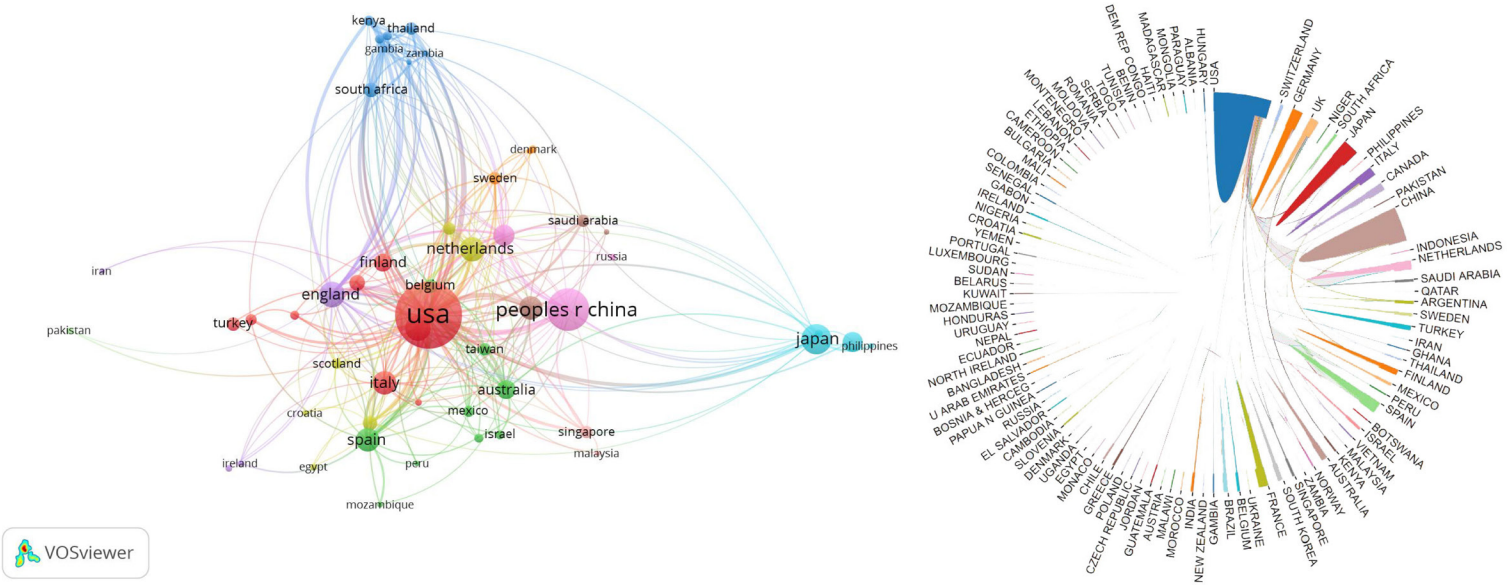

Figure 3. The network of cooperation among countries/regions in research on viral pneumonia. The cooperative relations between countries/regions were visualized.

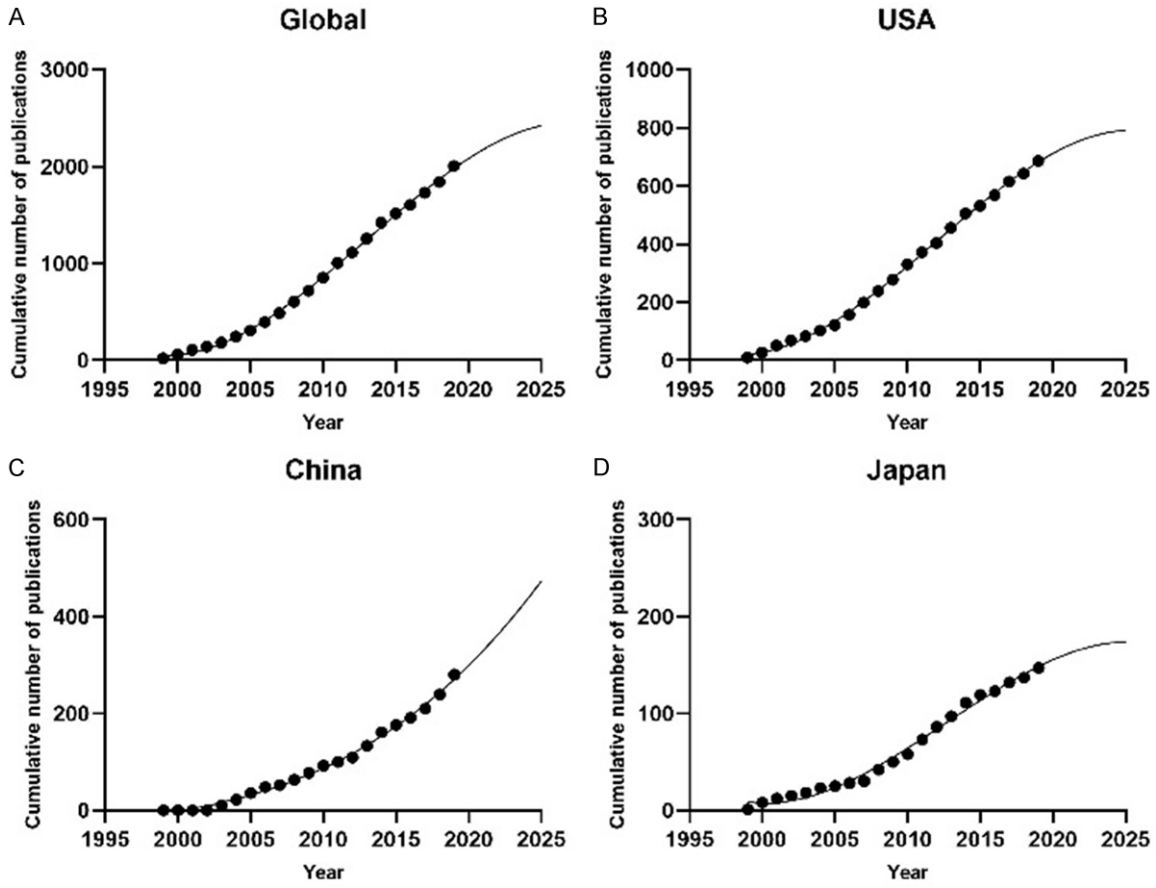

Figure 4. Model fitting curves for the growth trends in publications on viral pneumonia. A. Global; B. USA; C. China; D. Japan.

cations on viral pneumonia, respectively, ranking fifth and seventh in the number of publications. Other journals that had significant academic impact included the *Journal of The American Medical Association (JAMA)* and the *New England Journal of Medicine (NEJM),* each publishing 10 articles in this field. The top 10 journals with the most publications on viral pneumonia are listed in **Table 2**.

Authors with research publications on viral pneumonia

The top 10 authors published 282 papers accounting for 14.1% of all the literature in this research area. Yuen, K. -Y. from the University of Hong Kong published 42 papers related to viral pneumonia, ranking first in the number of publications. McCullers, Jonathan, A. published 37 papers and ranked second among all authors. As shown in **Table 3**, among the top 10 authors with the most publications on viral pneumonia, there were 4 authors from China, 4 from the USA, 1 from Spain and 1 from Finland. Notably, the citation frequency of all 3 authors from the University of Hong Kong in China exceeds 3,000 (**Tables 3** and **4**).

Analysis of the cooccurrence of keywords in the publications on viral pneumonia

We analyzed the keywords extracted from the 2,006 publications with VOSviewer. As shown in **Figure 6A**, 202 keywords (defined as terms that occurred more than 15 times within titles and abstracts in all papers) were identified and classified into 3 clusters: “Pathogenesis”, “Epidemiology” and “Diagnosis and management”. Within the “Pathogenesis” cluster, the following keywords were frequently mentioned:

Table 1. Top 15 institutes with most publications on viral pneumonia

Rank	Institution	Publications	Average citation per term	Country
1st	Centers for Disease Control & Prevention - USA	67	106.54	USA
2nd	University of Hong Kong	46	147.33	China
3rd	NIH National Institute of Allergy & Infectious Diseases	36	71.67	USA
4th	Capital Medical University	31	38.77	China
5th	University of Barcelona	30	26.4	China
6th	University of Washington	28	60.21	Spain
7th	Erasmus MC	26	138.85	Netherlands
8th	SUNY Stony Brook	24	12.46	USA
8th	University of Rochester	24	106	USA
8th	Vanderbilt University	24	64.5	USA
8th	Winthrop University Hospital	24	12.71	USA
9th	Northwestern University	23	26.13	USA
9th	University of Turku	23	27.91	Finland
10th	Turku University Hospital	22	87.41	Finland
10th	Chinese Academy of Medical Sciences	22	25.50	China

pneumonia (567), infection (351), influenza (199), and virus (154). In the "Epidemiology" cluster, the primary keywords were children (282), bronchiolitis (124), mortality (100), and tract infections (87). In the "Diagnosis and management" cluster, relevant keywords were also found, including community-acquired pneumonia (182), etiology (159), polymerase chain reaction (125), responses (81), and respiratory viruses (75).

As shown in **Figure 6B**, VOSviewer colored all keywords according to the average number of times the word appeared. Specifically, blue indicates that the word appeared relatively earlier, while yellow indicates a recent appearance. During the early stage of research on viral pneumonia, pneumonia (cluster 1, AAY = 2000.7) was the major topic in this field. More recently, research trends demonstrated that "infection" might be a new target in the studies on viral pneumonia (cluster 1, AAY = 2005.2). Within the first cluster ("Pathogenesis"), one of the newest words was "inflammation" (cluster 1, AAY = 2013.6), which occurred 34 times. In the second cluster ("Epidemiology"), "disease severity" (cluster 2, AAY = 2015.2) and "hospitalization" (cluster 2, AAY = 2013.8) were recently emerging words and appeared 22 and 29 times, respectively. For the third cluster ("Diagnosis and management"), "biomarkers" (cluster 3, AAY = 2015.6) rather than "community-acquired pneumonia" was noted as a new topic, which appeared 18 times. We extracted the top 25 keywords with the strongest citation bursts from the WOS data imported by CiteSpace for the analysis of the trends of the future research hotspots (**Figure 7**).

Discussion

The number of global publications on viral pneumonia has been continuously increasing over the past twenty years. Our data suggest that the keywords of the publications on viral pneumonia were classified into 3 clusters ("Pathogenesis", "Epidemiology" and "Diagnosis and management") by VOSviewer version 1.6.12. A research trend analysis indicated that the research on viral pneumonia has gradually transformed from pathogenesis into diagnosis and management (**Figure 6B**). Of the top 25 keywords with the strongest citation bursts, "bronchiolitis" and "acute respiratory syndrome" seemed to be classical research hotspots while "SARS" and "coronavirus" might indicate future trends.

Our results clearly demonstrated that the USA, China and Japan ranked first, second and third respectively, in terms of the number of publications on viral pneumonia among the top 20 countries with the most publications (**Figure 2A**). The close cooperation between the USA and other countries has contributed to the research of viral pneumonia and further scien-

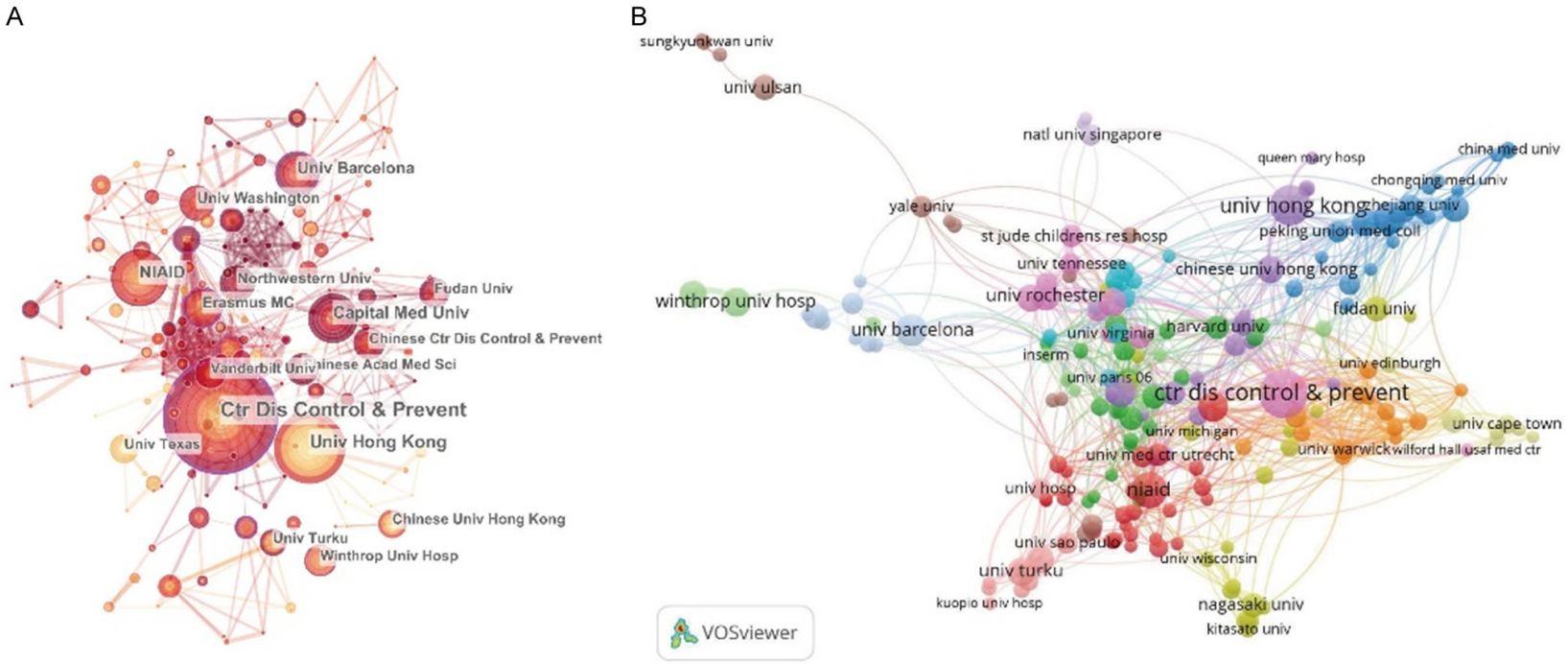

Figure 5. The distribution of institutions involved in research on viral pneumonia. A. The network of institutions by CiteSpace; B. The network of institutions by VOSviewer.

Table 2. Top 10 journals on viral pneumonia publications

SCR[a]	Journal	Contribution (%)	h-index	JIF[b]	Quartile in category[c]	OA[d] (yes/no)
1st	Clinical Infectious Diseases	58 (2.9)	36	8.313	Q1	Yes
2nd	PLOS ONE	56 (2.8)	22	2.740	Q1	Yes
3rd	Pediatric Infectious Disease Journal	54 (2.7)	29	2.126	Q2	No
4th	Journal of Clinical Virology	52 (2.6)	21	2.777	Q2	No
5th	American Journal of Respiratory and Critical Care Medicine	51 (2.5)	13	17.452	Q1	No
6th	Journal of Infectious Diseases	49 (2.4)	31	5.022	Q1	No
7th	European Respiratory Journal	48 (2.4)	12	12.339	Q1	No
8th	Journal of Virology	40 (2.1)	23	4.501	Q1	No
9th	BMC Infectious Diseases	39 (2.0)	17	2.688	Q2	Yes
9th	Journal of Medical Virology	39 (2.0)	18	2.021	Q2	No

SCR: standard competition ranking, IF: impact factor, OA: open access. [a]Equal journals have the same ranking number, and then a gap is left in the ranking numbers; [b]The JIF (journal impact factor) was reported according to the Journal Citation Reports (JCR) 2019; [c]Quartile in category was derived from a related field in the Journal Citation Reports (JCR) 2019; [d]Open access journals accelerate change and make the results of research available online for all to read and use.

Table 3. Top 10 authors with the most publications in the research scope of viral pneumonia

Author	Country	Affiliation	No. of Publications	No. of Citations
Yuen, K. -Y.	China	University of Hong Kong	42	4,479
McCullers, Jonathan A.	USA	Le Bonheur Children's Hosp	37	4,359
Chan, Kwok-Hung	China	University of Hong Kong	35	5,794
Peiris, J. S. Malik	China	University of Hong Kong	33	3,478
Falsey, Ann R.	USA	University of Rochester	30	2, 973
Rosenberg, Helene F.	USA	NIH National Institute of Allergy & Infectious Diseases (NIAID)	29	1,520
Torres, Antoni	Spain	University of Barcelona	23	430
Ruuskanen, Olli-Pekka	Finland	University of Turku	20	1,650
Wunderink, Richard G.	USA	Northwestern Memorial Hospital	17	82
Cao, Bin	China	Capital Medical University	16	316

Table 4. Top 10 most-cited papers related to viral pneumonia

Title	Corresponding authors	Journal	Publication Year	Total Citations	Corresponding authors' country
Isolation of a Novel Coronavirus from a Man with Pneumonia in Saudi Arabia	Fouchier, RAM	NEW ENGLAND JOURNAL OF MEDICINE	2012	1,275	Netherlands
A crucial role of angiotensin converting enzyme 2 (ACE2) in SARS coronavirus-induced lung injury	Jiang, CY	NATURE MEDICINE	2005	1,219	China
Pneumonia and Respiratory Failure from Swine-Origin Influenza A (H1N1) in Mexico	Perez-Padilla, R	NEW ENGLAND JOURNAL OF MEDICINE	2009	935	Mexico
Respiratory syncytial virus infection in elderly and high-risk adults	Falsey, AR	NEW ENGLAND JOURNAL OF MEDICINE	2005	933	USA
Clinical progression and viral load in a community outbreak of coronavirus-associated SARS pneumonia: a prospective study	Yuen, KY	LANCET	2003	826	China
Characterization and complete genome sequence of a novel coronavirus, coronavirus HKU1, from patients with pneumonia	Yuen, KY	JOURNAL OF VIROLOGY	2005	647	CHINA
Human metapneumovirus and lower respiratory tract disease in otherwise healthy infants and children	Crowe, JE	NEW ENGLAND JOURNAL OF MEDICINE	2004	592	USA
Severe Respiratory Disease Concurrent with the Circulation of H1N1 Influenza	Bertozzi, SM	NEW ENGLAND JOURNAL OF MEDICINE	2009	464	Mexico
Viral pneumonia	Ruuskanen, O	LANCET	2011	442	Finland
Detrimental contribution of the Toll-like receptor (TLR) 3 to influenza A virus-induced acute pneumonia	Si-Tahar, M	PLOS PATHOGENS	2006	341	France

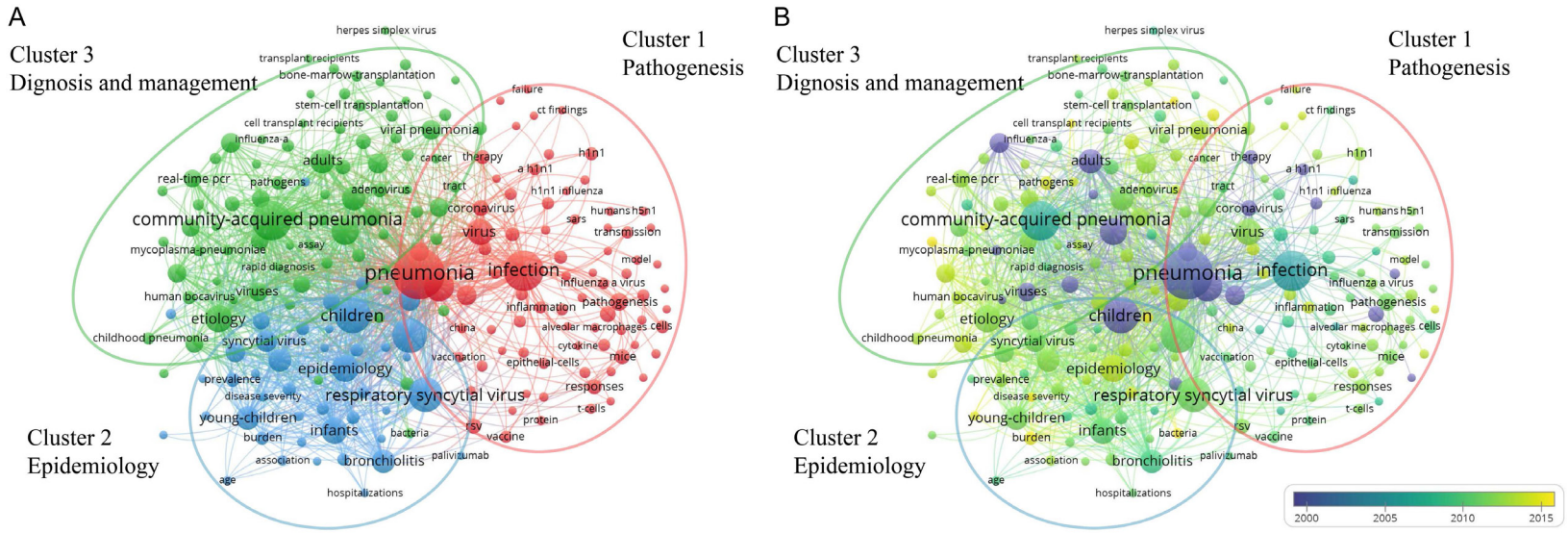

Figure 6. The co-occurrence analysis of all keywords in publications of viral pneumonia. A. Mapping of the keywords in the area of viral pneumonia. The words were divided into 3 clusters in accordance with different colors generated by default: “Pathogenesis” (right in red), “Epidemiology” (down in blue), and “Diagnosis and management” (left in green). Size of the circle represented the frequency of keywords; B. Distribution of keywords was presented according to the average time of appearance. The blue color represented early appearance and yellow color stands for late appearance. Two keywords were considered co-occurred if they both occurred on the same line in the corpus file. Smaller distance between two keywords indicated relatively higher co-occurrences of the keywords.

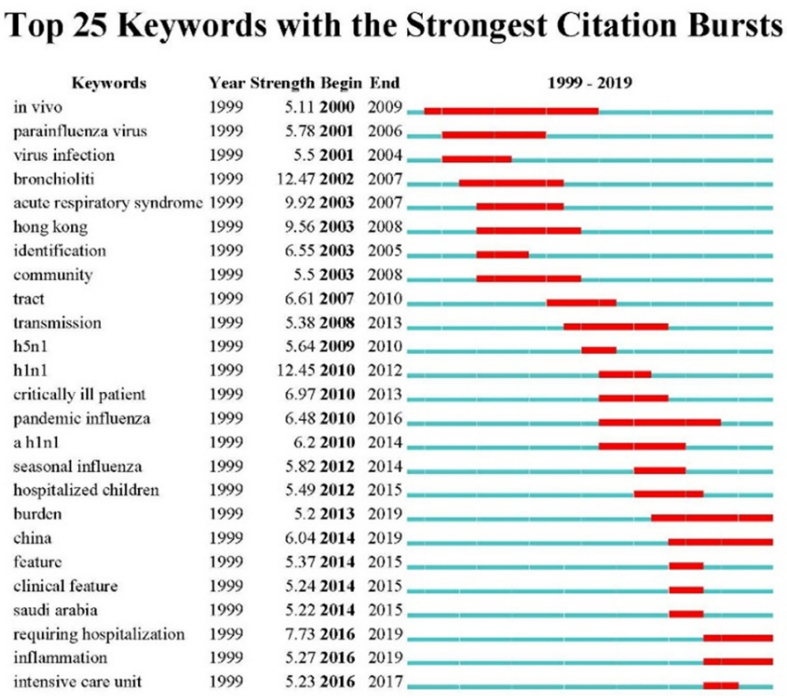

Figure 7. The top 25 keywords with the strongest citation bursts during 1999 to 2019. The extract keywords of burst detection were originated from CiteSpace.

tific research cooperation among countries (**Figure 3**). China has sustained rapid growth in the number of publications (**Figure 4**). China's contribution to this research field increased largely within a relatively short time. We predict that China will replace the USA in this research field in the near future. As the most populous country in the world, China has a large number of pneumonia patients. A systematic literature review reported that the prevalence of CAP in Chinese children < 6 months of age was 37.88%, which was the highest among 90 developing and newly industrialized countries [13]. In addition, the community outbreak of a novel coronavirus-associated severe acute respiratory syndrome in Guangdong, China, 2003 propelled Chinese researchers to explore the epidemiology, etiology and management of the disease [14]. In addition, China had a unique research direction advantage: traditional Chinese medicine, which dominated a part of the publications. For instance, Yinhuapinggan granule (YHPG), a Chinese medicinal granule, had protective effects on influenza viral pneumonia [15]. In the context of the recent breakout of the 2019 novel coronavirus (2019-nCoV)-infected pneumonia, traditional Chinese medicines such as Astragalus and Lianhua Qingwen capsules have been recommended for disease prevention and treatment [16].

Interestingly, the ranking of each country's publications was roughly consistent with their relative GDPs (**Figure 2A**). At the same time, we found that most of the top 20 countries in terms of publications were developed countries. Especially among the top ten countries in terms of publications, China was the only developing country. The incidence of viral pneumonia varies based on socioeconomic and sociocultural factors [17]. Risk factors for pneumonia-such as malnutrition, air pollution or tuberculosis-may occur more frequently in developing than in developed countries [18]. Therefore, developing countries likely have a larger population at high risk for viral pneumonia. Nevertheless, developing countries-though experiencing the most significant consequences of viral epidemics-cannot compete equally in viral pneumonia research due to the lack of funding and inadequate infrastructure. Similar gaps can also be found in other research fields [11].

Frequently cited papers usually have a high academic impact. Detailed information about the top 10 cited publications on viral pneumonia is listed in **Table 4**. Except for one basic research article, all the other publications were clinical studies published in high-IF journals. The rule that papers published in high-IF journals have the highest citations is also applicable for other diseases [23]. In turn, the articles cited most frequently help maintain the high IF of the journal [24]. "Isolation of a Novel Coronavirus from a Man with Pneumonia in Saudi Arabia" was cited 1,275 times, which was the most cited paper. This study was published in the *New England Journal of Medicine*, and the authors isolated an unknown coronavirus from the sputum of an old man who had acute pneumonia in Saudi Arabia [25], which was later named the Middle East respiratory syndrome coronavirus. The second most cited paper, with

935 citations, was the report of the clinical and epidemiologic characteristics of patients hospitalized for novel swine-origin influenza A (H1N1) virus (S-OIV) pneumonia [26]. The novelty and timeliness of the article determine whether it could be published in these high-IF journals, which promotes the rapid development of research to a certain extent. After the outbreak of the pandemic, many papers were published in a short time, including some articles in high-IF journals such as the New England Journal of Medicine [27] and Lancet [28]. These articles are likely to be frequently cited in the future.

Notably, *Clinical Infectious Disease* published 58 papers in the field, which was the most among all the journals. *PLOS One*, *Pediatric Infectious Disease Journal and Journal of Clinical Virology* were also major journals that published research on viral pneumonia. Thus, major developments within this field are likely to be presented in the aforementioned journals. Whether the journal is open access (OA) is an important factor for researchers to publish their papers. J. Gabrielle Breugelmans's [29] study indicated that there is a real, measurable citation advantage for publishing poverty-related disease papers in OA journals, which increases the scientific impact. However, researchers, especially those from low-income nations or countries, have limited budgets to pay for publication in renowned open-access journals [11], which increases the difficulties of their publication activities. To address this problem, broader waiver policies should be offered in the future.

To explore the research trend and the most recent hotspots, visualized mapping was applied by using VOSviewer. In the past two decades, the keywords were divided into 3 groups: "Pathogenesis", "Epidemiology" and "Diagnosis and management" (**Figure 6**). The pathogenesis of viral pneumonia is incompletely understood and cannot be unified due to its different etiologies. We found that the cooccurrence in the "Pathogenesis" cluster was not as close as that in the other clusters (**Figure 6A**), which may also be due to the difference in the causes of pneumonia. For example, MERS-CoV infects both humans and camels via the CD26 receptor on nonpiliated bronchial epithelial cells [30]. SARS-CoV pneumonia is related to immunopathologic injury, angiotensin receptor enzyme 2 (ACE-2) and CD209L, which have been found to be functional receptors for SARS-CoV [31]. Research progress on pathogenesis mainly relies on the development of basic research, while there was only one basic research article in the top 10 cited articles (**Table 4**), which revealed the detrimental effect of Toll-like receptor (TLR) 3 on influenza A virus-induced acute pneumonia [32]. The discrepancy between the importance of basic studies and its citation frequencies could be explained by the large differences between various types of viral pneumonia models, and that models are largely determined by pathogen-specific features of virulence, infection dose, transmission mode and other factors. Therefore, we could make use of murine acute lung infection models [33], perform a semiquantitative evaluation of that model through historical pathology, and combine model-specific pathology features with other factors to establish pathogen- and model-adapted criteria to promote pathogenesis and preclinical research.

In epidemiology studies, according to data from the World Health Organization (WHO), influenza occurs with an annual attack rate of 5%-10% in adults and 20%-30% in children [17]; 450 million cases of pneumonia are recorded, and approximately 4 million people die from this disease annually [1]. However, these data remain sparse, and there are no relatively accurate data for the morbidity and mortality of viral pneumonia. Due to the atypical clinical manifestations, the definition of viral pneumonia varies greatly, which increases the difficulty of cross study statistical analysis [11]. In addition, there are significant differences in the number of publications between developed and developing countries. Therefore, in epidemiological studies of viral pneumonia, more interventions should be applied in the data collection process through established monitoring systems, such as determining local morbidity and mortality, creating disease models and developing diagnostic criteria.

The diagnosis of viral pneumonia depends on laboratory tests of specimens from the upper/lower respiratory system. The detection methods include viral culture, immunofluorescence microscopy, measurement of antibodies in serum samples, etc. [1]. The introduction of polymerase chain reaction (PCR) into the diagnosis has increased our capability of detecting respiratory viruses. In general, PCR-based

methods are more sensitive than conventional diagnostic methods [1]. Symptomatic supportive care, especially respiratory support for patients with hypoxemia, is critical in the management of viral pneumonia [34]. The use of antibiotics and high-dose corticosteroids in viral pneumonia treatment is still controversial [35]. In clinical practice, the usage of antivirals (neuraminidase inhibitors and amantadine) is limited [36]. Further progress is needed in improving simple diagnostic procedures and finding more effective treatment options.

Of note, a gradual shift of focus from the "Pathogenesis" and "Epidemiology" clusters to the "Diagnosis and management" cluster appeared in the time-period map (**Figure 6B**), which predicted the demand and development of the research. In the exploration of the role of viruses in hospital-acquired and ventilator-associated pneumonia [37], a considerable number of cases indicated that the primary viral infection was followed by a secondary bacterial infection or a viral-bacterial coinfection [38]. Clinical evidence suggests that mixed infections cause more severe inflammatory reactions and clinical symptoms than viral or bacterial infections alone [1]. However, the clinical characteristics of viral and bacterial pneumonia are highly variable and sometimes overlap with each other [1], which makes the precise diagnosis of viral pneumonia quite challenging. Physicians relied on serologic tests to make diagnoses for a long time until the introduction of polymerase chain reaction (PCR) techniques [39]. In addition, radiographic and computed tomography (CT) patterns of patients can be used to classify viral families [40], which provides a new choice for the diagnosis of viral pneumonia. Future research, such as point-of-care lateral flow immunoassays combining the detection of IgM and IgG, which avoid false negative rates of testing, still need to be undertaken [41].

In the management of viral pneumonia, novel antiviral agents like small interfering RNAs such as cidofovir have been developed for treating viral infection [42]. A study discovered that an exchange protein directly activated by cyclic AMP can serve as a potential therapeutic target for resisting respiratory syncytial virus [43]. Controversial issues such as the prophylactic use of antibiotics and high doses of corticoids have also been explored. A study on 288 influenza A (H7N9) viral pneumonia cases showed that high-dose corticosteroids were associated with longer viral shedding and increased mortality [44]. In recent years, there have been many other similar clinical studies [45]. Clinical studies with higher quality and larger sample randomized controlled trials are expected to provide evidence-based practice for these controversial management issues in the future. Nonspecific treatment interventions are essential for preventing severe morbidity and mortality during outbreak, if there is no vaccine or specific antiviral drugs [12].

For the latest hotspot, "biomarkers" from the cluster "Diagnosis and management" appeared most recently (cluster 3, AAY = 2015.6) (Supplementary Materials). CAP is one of the most common infectious diseases caused by bacterial and viral pathogens [4]. Clearly, respiratory viruses can both cause pneumonia and predispose the patient to secondary infection with bacterial pathogens and coinfection [46]. Therefore, there is an urgent need for a more reliable and clear detection method to distinguish bacterial pneumonia from viral pneumonia. Furthermore, the choice of therapy and the need for hospitalization are determined by the causative agent and disease severity [47], which makes significant the prediction of the severity of viral pneumonia. Many recent studies have explored the possibility of using biomarkers in clinical practice. Xinge Yang's [48] research found that serum YKL-40 (a chitinase-like protein secreted by macrophages in the inflammatory response) levels on day 5 were a possible prognostic biomarker for viral pneumonia in children. Engelmann [49] found that Myxovirus resistance protein 1 (MxA), which inhibits the early phases of viral replication, may be a biomarker for viral infection and can be used to discriminate bacterial from viral infections with a high area under the curve (AUC; 0.89). Until now, in addition to the traditional biomarkers CRP and PCT, few biomarkers have been approved for clinical usage. However, with the development of new technologies-such as proteomics, metabolomics, and single-cell sequencing-in the search for new biomarkers, we believe that integrating the diagnosis and management of viral pneumonia will be largely improved in the near future. In this regard, searching for biomarkers with high sensitivity and specificity during the onset and course of viral pneumonia seems to be a promising future research direction and hotspot.

The top 25 keywords with the strongest citation bursts suggested that "bronchiolitis", "acute respiratory syndrome" and "Hong Kong" were traditional research hotspots. The reason "Hong Kong" attracted researchers' interest may be that it was once threatened by SARS, and related institutions further researched viral pneumonia. Meanwhile, "SARS" turned out to be a contemporary research focus for outbreaks of SARS in the past two decades. However, research on "coronavirus" seemed to stop the advancement at an early time, which may partly explain why great damage to the public health system was caused by COVID-19.

This bibliometric analysis investigated publications extracted from the Web of Science Core Collection database. The data analysis is comprehensive and objective. However, limitations are inevitable. Selection bias is unavoidable in the literature retrieval process with respect to manual screening. Due to our inclusion criteria, we used publications only in English, and may have excluded some important non-English studies related to viral pneumonia. In addition, the database continuously updates studies, so a slight discrepancy may exist between our bibliometric analysis results and the actual research situation. Owing to the worldwide increase in the investment in scientific research to tackle diseases, research on viral pneumonia will be further increased. Cooperation and information sharing between developed and developing countries are necessary. Based on our bibliometric analysis results, specifying the types of viral pneumonia and setting different coping strategies corresponding to different types of viral pneumonia would enhance the public health system's capability to respond to epidemics induced by viral pneumonia.

Conclusion

The USA was the most productive country in the research on viral pneumonia. The keywords extracted by VOSviewer gradually shifted from "Epidemiology" and "Pathogenesis" to "Diagnosis and management". The top 25 keywords included by the burst detection feature in CiteSpace indicated promising research hotspots, such as "SARS". However, research on "coronavirus" needs to be further advanced. Our study provided profound insights into the current status of viral pneumonia research, which might indicate its future trend for the preparation of resisting threats from viral pneumonia.

Acknowledgements

This research was financially supported by Three-Year Action Plan of Shanghai Public health system construction (GWV-10.1-XK24), Special diseases database constructive Program of Sepsis Cohort Research (Shanghai Shenkang Hospital Management Organization, SHDC2020CR6030-002), and The establishment of in vitro models of neural organs originated from human adipose-derived mesenchymal stem cells (Shanghai Municipal Science & Technology Commission, 19140901502).

Disclosure of conflict of interest

None.

Address correspondence to: Weiwei Jiang and Wenfang Li, Department of Emergency and Critical Care Medicine of Changzheng Hospital, Naval Medical University, Shanghai 200003, China. Tel: +86-02181885864; E-mail: 775249487@qq.com (WWJ); chzhedlwf@163.com (WFL)

References

[1] Ruuskanen O, Lahti E, Jennings LC and Murdoch DR. Viral pneumonia. Lancet (London, England) 2011; 377: 1264-1275.

[2] Angeles Marcos M, Camps M, Pumarola T, Antonio Martinez J, Martinez E, Mensa J, Garcia E, Peñarroja G, Dambrava P, Casas I, Jiménez de Anta MT and Torres A. The role of viruses in the aetiology of community-acquired pneumonia in adults. Antivir Ther 2006; 11: 351-359.

[3] Johnstone J, Majumdar SR, Fox JD and Marrie TJ. Viral infection in adults hospitalized with community-acquired pneumonia: prevalence, pathogens, and presentation. Chest 2008; 134: 1141-1148.

[4] Musher DM and Thorner AR. Community-acquired pneumonia. N Engl J Med 2014; 371: 1619-1628.

[5] Esposito S, Daleno C, Prunotto G, Scala A, Tagliabue C, Borzani I, Fossali E, Pelucchi C and Principi N. Impact of viral infections in children with community-acquired pneumonia: results of a study of 17 respiratory viruses. Influenza Other Respir Viruses 2013; 7: 18-26.

[6] Yin Y and Wunderink RG. MERS, SARS and other coronaviruses as causes of pneumonia. Respirology 2018; 23: 130-137.

[7] Zhou P, Yang XL, Wang XG, Hu B, Zhang L, Zhang W, Si HR, Zhu Y, Li B, Huang CL, Chen

HD, Chen J, Luo Y, Guo H, Jiang RD, Liu MQ, Chen Y, Shen XR, Wang X, Zheng XS, Zhao K, Chen QJ, Deng F, Liu LL, Yan B, Zhan FX, Wang YY, Xiao GF and Shi ZL. A pneumonia outbreak associated with a new coronavirus of probable bat origin. Nature 2020; 579: 270-273.

[8] Merigó JM, Gil-Lafuente AM and Yager RR. An overview of fuzzy research with bibliometric indicators. Applied Soft Computing 2015; 27: 420-433.

[9] Cobo MJ, López-Herrera AG, Herrera-Viedma E and Herrera F. Science mapping software tools: review, analysis, and cooperative study among tools. J Am Soc Inf Sci Technol 2011; 62: 1382-1402.

[10] Head MG, Fitchett JR, Newell ML, Scott JA, Harris JN, Clarke SC and Atun R. Mapping pneumonia research: a systematic analysis of UK investments and published outputs 1997-2013. Ebiomedicine 2015; 2: 1193-9.

[11] Brüggmann D, Köster C, Klingelhöfer D, Bauer J, Ohlendorf D, Bundschuh M and Groneberg DA. Respiratory syncytial virus: a systematic scientometric analysis of the global publication output and the gender distribution of publishing authors. BMJ Open 2017; 7: e013615-e013615.

[12] Chafekar A and Fielding BC. MERS-CoV: understanding the latest human coronavirus threat. Viruses 2018; 10: 93.

[13] DeAntonio R, Yarzabal JP, Cruz JP, Schmidt JE and Kleijnen J. Epidemiology of community-acquired pneumonia and implications for vaccination of children living in developing and newly industrialized countries: a systematic literature review. Hum Vaccin Immunother 2016; 12: 2422-2440.

[14] Zhong NS, Zheng BJ, Li YM, Poon, Xie ZH, Chan KH, Li PH, Tan SY, Chang Q, Xie JP, Liu XQ, Xu J, Li DX, Yuen KY, Peiris and Guan Y. Epidemiology and cause of severe acute respiratory syndrome (SARS) in Guangdong, People's Republic of China, in February, 2003. Lancet (London, England) 2003; 362: 1353-1358.

[15] Peng XQ, Zhou HF, Lu YY, Chen JK, Wan HT and Zhang YY. Protective effects of Yinhuapinggan granule on mice with influenza viral pneumonia. Int Immunopharmacol 2016; 30: 85-93.

[16] Jin YH, Cai L, Cheng ZS, Cheng H, Deng T, Fan YP, Fang C, Huang D, Huang LQ, Huang Q, Han Y, Hu B, Hu F, Li BH, Li YR, Liang K, Lin LK, Luo LS, Ma J, Ma LL, Peng ZY, Pan YB, Pan ZY, Ren XQ, Sun HM, Wang Y, Wang YY, Weng H, Wei CJ, Wu DF, Xia J, Xiong Y, Xu HB, Yao XM, Yuan YF, Ye TS, Zhang XC, Zhang YW, Zhang YG, Zhang HM, Zhao Y, Zhao MJ, Zi H, Zeng XT, Wang YY and Wang XH; the Zhongnan Hospital of Wuhan University Novel Coronavirus Management and Research Team; Evidence-Based Medicine Chapter of China International Exchange and Promotive Association for Medical and Health Care (CPAM). A rapid advice guideline for the diagnosis and treatment of 2019 novel coronavirus (2019-nCoV) infected pneumonia (standard version). Mil Med Res 2020; 7: 4-4.

[17] Jain S. Epidemiology of viral pneumonia. Clin Chest Med 2017; 38: 1-9.

[18] Arbo A, Lovera D and Martínez-Cuellar C. Mortality predictive scores for community-acquired pneumonia in children. Curr Infect Dis Rep 2019; 21: 10-10.

[19] Peiris JS, Chu CM, Cheng VCC, Chan KS, Hung IF, Poon LL, Law KI, Tang BS, Hon TY, Chan CS, Chan KH, Ng JS, Zheng BJ, Ng WL, Lai RW, Guan Y and Yuen KY; HKU/UCH SARS Study Group. Clinical progression and viral load in a community outbreak of coronavirus-associated SARS pneumonia: a prospective study. Lancet (London, England) 2003; 361: 1767-1772.

[20] Dawood FS, Jain S, Finelli L, Shaw MW, Lindstrom S, Garten RJ, Gubareva LV, Xu X, Bridges CB and Uyeki TM; Novel Swine-Origin Influenza A (H1N1) Virus Investigation Team. Emergence of a novel swine-origin influenza A (H1N1) virus in humans. N Engl J Med 2009; 360: 2605-2615.

[21] Assiri A, Al-Tawfiq JA, Al-Rabeeah AA, Al-Rabiah FA, Al-Hajjar S, Al-Barrak A, Flemban H, Al-Nassir WN, Balkhy HH, Al-Hakeem RF, Makhdoom HQ, Zumla AI and Memish ZA. Epidemiological, demographic, and clinical characteristics of 47 cases of Middle East respiratory syndrome coronavirus disease from Saudi Arabia: a descriptive study. Lancet Infect Dis 2013; 13: 752-761.

[22] Li Q, Guan X, Wu P, Wang X, Zhou L, Tong Y, Ren R, Leung KSM, Lau EHY, Wong JY, Xing X, Xiang N, Wu Y, Li C, Chen Q, Li D, Liu T, Zhao J, Li M, Tu W, Chen C, Jin L, Yang R, Wang Q, Zhou S, Wang R, Liu H, Luo Y, Liu Y, Shao G, Li H, Tao Z, Yang Y, Deng Z, Liu B, Ma Z, Zhang Y, Shi G, Lam TTY, Wu JTK, Gao GF, Cowling BJ, Yang B, Leung GM and Feng Z. Early transmission dynamics in Wuhan, China, of novel coronavirus-infected pneumonia. N Engl J Med 2020; 382: 1199-1207.

[23] Qu Y, Zhang C, Hu Z, Li S, Kong C, Ning Y, Shang Y and Bai C. The 100 most influential publications in asthma from 1960 to 2017: a bibliometric analysis. Res Med 2018; 137: 206-212.

[24] Chen LM, Liu YQ, Shen JN, Peng YL, Xiong TY, Tong X, Du L and Zhang YG. The 100 top-cited tuberculosis research studies. Int J Tuberc Lung Dis 2015; 19: 717-722.

[25] Zaki AM, van Boheemen S, Bestebroer TM, Osterhaus AD and Fouchier RA. Isolation of a novel coronavirus from a man with pneumonia

in Saudi Arabia. N Engl J Med 2012; 367: 1814-1820.
[26] Perez-Padilla R, de la Rosa-Zamboni D, Ponce de Leon S, Hernandez M, Quiñones-Falconi F, Bautista E, Ramirez-Venegas A, Rojas-Serrano J, Ormsby CE, Corrales A, Higuera A, Mondragon E and Cordova-Villalobos JA; INER Working Group on Influenza. Pneumonia and respiratory failure from swine-origin influenza A (H1N1) in Mexico. N Engl J Med 2009; 361: 680-689.
[27] Holshue ML, DeBolt C, Lindquist S, Lofy KH, Wiesman J, Bruce H, Spitters C, Ericson K, Wilkerson S, Tural A, Diaz G, Cohn A, Fox L, Patel A, Gerber SI, Kim L, Tong S, Lu X, Lindstrom S, Pallansch MA, Weldon WC, Biggs HM, Uyeki TM and Pillai SK; Washington State 2019-nCoV Case Investigation Team. First case of 2019 novel coronavirus in the United States. N Engl J Med 2020; 382: 929-936.
[28] Lu R, Zhao X, Li J, Niu P, Yang B, Wu H, Wang W, Song H, Huang B, Zhu N, Bi Y, Ma X, Zhan F, Wang L, Hu T, Zhou H, Hu Z, Zhou W, Zhao L, Chen J, Meng Y, Wang J, Lin Y, Yuan J, Xie Z, Ma J, Liu WJ, Wang D, Xu W, Holmes EC, Gao GF, Wu G, Chen W, Shi W and Tan W. Genomic characterisation and epidemiology of 2019 novel coronavirus: implications for virus origins and receptor binding. Lancet (London, England) 2020; 395: 565-574.
[29] Breugelmans JG, Roberge G, Tippett C, Durning M, Struck DB and Makanga MM. Scientific impact increases when researchers publish in open access and international collaboration: a bibliometric analysis on poverty-related disease papers. PLoS One 2018; 13: e0203156-e0203156.
[30] Drosten C, Kellam P and Memish ZA. Evidence for camel-to-human transmission of MERS coronavirus. N Engl J Med 2014; 371: 1359-1360.
[31] Frieman M, Yount B, Agnihothram S, Page C, Donaldson E, Roberts A, Vogel L, Woodruff B, Scorpio D, Subbarao K and Baric RS. Molecular determinants of severe acute respiratory syndrome coronavirus pathogenesis and virulence in young and aged mouse models of human disease. J Virol 2012; 86: 884-897.
[32] Le Goffic R, Balloy V, Lagranderie M, Alexopoulou L, Escriou N, Flavell R, Chignard M and Si-Tahar M. Detrimental contribution of the Toll-like receptor (TLR)3 to influenza A virus-induced acute pneumonia. PLoS Pathog 2006; 2: e53-e53.
[33] Dietert K, Gutbier B, Wienhold SM, Reppe K, Jiang X, Yao L, Chaput C, Naujoks J, Brack M, Kupke A, Peteranderl C, Becker S, von Lachner C, Baal N, Slevogt H, Hocke AC, Witzenrath M, Opitz B, Herold S, Hackstein H, Sander LE, Suttorp N and Gruber AD. Spectrum of pathogen- and model-specific histopathologies in mouse models of acute pneumonia. PLoS One 2017; 12: e0188251-e0188251.
[34] Aston SJ, Ho A, Jary H, Huwa J, Mitchell T, Ibitoye S, Greenwood S, Joekes E, Daire A, Mallewa J, Everett D, Nyirenda M, Faragher B, Mwandumba HC, Heyderman RS and Gordon SB. Etiology and risk factors for mortality in an adult community-acquired pneumonia cohort in Malawi. Am J Respir Crit Care Med 2019; 200: 359-369.
[35] Torres A, Chalmers JD, Cruz CSD, Dominedo C, Kollef M, Martin-Loeches I, Niederman M and Wunderink RG. Challenges in severe community-acquired pneumonia: a point-of-view review. Intensive Care Med 2019; 45: 159-171.
[36] Wong SS and Yuen KY. Antiviral therapy for respiratory tract infections. Respirology 2008; 13: 950-971.
[37] Dandachi D and Rodriguez-Barradas MC. Viral pneumonia: etiologies and treatment. J Investig Med 2018; 66: 957-965.
[38] Galván JM, Rajas O and Aspa J. Review of non-bacterial infections in respiratory medicine: viral pneumonia. Arch Bronconeumol 2015; 51: 590-597.
[39] Waterer GW. Diagnosing viral and atypical pathogens in the setting of community-acquired pneumonia. Clin Chest Med 2017; 38: 21-28.
[40] Koo HJ, Lim S, Choe J, Choi SH, Sung H and Do KH. Radiographic and CT features of viral pneumonia. Radiographics 2018; 38: 719-739.
[41] Li Z, Yi Y, Luo X, Xiong N, Liu Y, Li S, Sun R, Wang Y, Hu B, Chen W, Zhang Y, Wang J, Huang B, Lin Y, Yang J, Cai W, Wang X, Cheng J, Chen Z, Sun K, Pan W, Zhan Z, Chen L and Ye F. Development and clinical application of A rapid IgM-IgG combined antibody test for SARS-CoV-2 infection diagnosis. J Med Virol 2020; 92: 1518-1524.
[42] Doan ML, Mallory GB, Kaplan SL, Dishop MK, Schecter MG, McKenzie ED, Heinle JS and Elidemir O. Treatment of adenovirus pneumonia with cidofovir in pediatric lung transplant recipients. J Heart Lung Transplant 2007; 26: 883-889.
[43] Choi E-J, Ren Y, Chen Y, Liu S, Wu W, Ren J, Wang P, Garofalo RP, Zhou J and Bao X. Exchange proteins directly activated by CAMP and their roles in respiratory syncytial virus infection. J Virol 2018; 92: e01200-01218.
[44] Cao B, Gao H, Zhou B, Deng X, Hu C, Deng C, Lu H, Li Y, Gan J and Liu J. Adjuvant corticosteroid treatment in adults with influenza A (H7N9) viral pneumonia. Crit Care Med 2016; 44: e318-e328.

[45] Moreno G, Rodríguez A, Reyes LF, Gomez J, Sole-Violan J, Díaz E, Bodí M, Trefler S, Guardiola J and Yébenes JC. Corticosteroid treatment in critically ill patients with severe influenza pneumonia: a propensity score matching study. Intensive Care Med 2018; 44: 1470-1482.
[46] Bakaletz LO. Viral-bacterial co-infections in the respiratory tract. Curr Opin Microbiol 2017; 35: 30-35.
[47] Savvateeva EN, Rubina AY and Gryadunov DA. Biomarkers of community-acquired pneumonia: a key to disease diagnosis and management. Biomed Res Int 2019; 2019: 1701276.
[48] Yang X and Sheng G. YKL-40 levels are associated with disease severity and prognosis of viral pneumonia, but not available in bacterial pneumonia in children. BMC Pediatr 2018; 18: 381.
[49] Engelmann I, Dubos F, Lobert P-E, Houssin C, Degas V, Sardet A, Decoster A, Dewilde A, Martinot A and Hober D. Diagnosis of viral infections using myxovirus resistance protein A (MxA). Pediatrics 2015; 135: e985-e993.