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Review article

Research on coronavirus disease 2019 and the kidney: A bibliometric analysis

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ABSTRACT

Background: In addition to damage to the lungs, coronavirus disease 2019 (COVID-19) can damage multiple organs, including the kidney. Our purpose was to analyze the research hotspots and trends in COVID-19 and kidney diseases using bibliometrics to help clarify the development direction of this field.

Methods: We selected and extracted all relevant publications related to COVID-19 and the kidney from the Web of Science from December 1, 2019, to July 24, 2022. VOSviewer, RStudio, CiteSpace, and other software were used to visualize keywords, publishing trends, authors and their countries, and institutions in this field and perform the statistical analysis.

Results: A total of 645 articles published in 220 journals were included in this study. The United States and China contributed the most publications and were most active in international cooperation. In addition to COVID-19 and severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2), acute kidney injury (AKI), kidney transplant and mortality were the three keywords with the highest frequencies. In the initial stage of the COVID-19 outbreak, research focused on the clinical symptoms of COVID-19 and other macrocharacteristics, while in a later stage, the associations between SARS-CoV-2 infection and CKD and AKI, as well as the prognosis of patients with kidney disease or those who underwent kidney transplantation, gained more attention. The immune response and vaccines were also recent research hotspots.

Conclusions: This bibliometric analysis provides a comprehensive overview of research on COVID-19 and kidney disease, which has received continuous, global attention. AKI, CKD, kidney transplantation, immune response and vaccines are among the hotspots in this field.

1. Introduction

SARS-CoV-2, a virus containing single-stranded ribonucleic acid (RNA) genetic material that is spread mostly by respiratory droplets and direct contact, was initially reported in December 2019 and quickly became a global pandemic [1–3]. As of September 10,

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2022, more than 607 million people worldwide have been infected with SARS-CoV-2, with more than 6.51 million fatalities (https://coronavirus.jhu.edu/map.html), wreaking havoc on the health and societal development of the people. To date, COVID-19 has been shown to affect the lungs primarily, but extrapulmonary organs, such as the kidney, heart, and liver, can also be affected by SARS-CoV-2 in the context of the circulatory system and thus exhibit multiorgan clinical symptoms [4]. Recent pathological examinations of patients with COVID-19 and autopsy studies of those who died from the disease revealed an association between COVID-19 and kidney function [5].

Additionally, SARS-CoV-2 infection causes new kidney damage. AKI is a clinical syndrome characterized by a rapid decline in kidney function caused by a combination of factors and is a major complication in critically ill patients with COVID-19 [6]. The broad expression of angiotensin-converting enzyme 2 (ACE-2), a molecular receptor that enables SARS-CoV-2 infection of host cells in the proximal tubules and podocytes of the kidney, could be the cause of this kidney involvement [7,8]. Furthermore, the rapid and massive production of cytokines, such as granulocyte colony-stimulating factor, interleukins, and interferons, triggered by SARS-CoV-2 infection may lead to kidney impairment directly or indirectly via other organs [5]. However, SARS-CoV-2 infection makes it more challenging to treat and care for patients with end-stage renal disease and CKD, increasing the risk of mortality [9–12]. It should be highlighted that patients who undergo dialysis and a kidney transplant have a reduced vaccine response due to immunosuppression, which also increases the risk of COVID-19 infection in patients with CKD [13]. Some case studies have revealed AKI, proteinuria, edema, and hematuria following COVID-19 vaccination, with potential explanations such as podocyte injury, increased formation of antineutrophil cytoplasmic autoantibodies, and vaccine-induced thrombotic low platelet count [14,15]. Due to the complexity of the current research on COVID-19 and kidney-related disorders, it is imperative to identify the key problems and research priorities to guide future research.

Bibliometrics is a method of quantitative analysis of publications based on mathematics and statistics. It examines the quantitative relationships, distribution patterns, and laws of publication in a collection of published works as well as the internal organization and connections of the scientific literature to assess the current development trend and future research directions [16,17]. Therefore, this research was conducted to determine the progression of COVID-19 and kidney-related research based on the Web of Science (WOS) using bibliometrics and, on this basis, to identify new trends and hotspots in this field to identify paths for future research, as well as to draw the attention of clinical and scientific researchers in various countries to reduce the detrimental effects of COVID-19 on the population's physical and mental health.

2. Methods

2.1. Data sources and search strategy

The citation data for this bibliometric study were obtained from the Science Citation Index Expanded, the core collection of the WOS, which is widely regarded as one of the most accurate and complete sources of scientific investigation and evaluation with the highest quality index. The first case of COVID-19 was identified on December 1, 2019, globally. Therefore, we conducted a systematic online search on WoS for documents related to COVID-19 and kidneys published from December 1, 2019, to July 24, 2022 (the search process completion date), with publication categories limited to original research, reviews, systematic reviews, and meta-analyses, published in English-language. All searches were conducted on July 24, 2022, to avoid omissions due to rapid database updates.

The search strategy was as follows: TS = ("COVID-19″ OR "coronavirus disease 2019″ OR "disease 2019, coronavirus" OR "SARS coronavirus 2 infection" OR ″2019-nCov" OR ″2019 novel coronavirus" OR "SARS-CoV-2″ OR "severe acute respiratory syndrome coronavirus 2″ OR "coronavirus disease 19″ OR "coronavirus disease-19″ OR "SARS2″ OR "SARS-2″ OR "COVID-2019″ OR "COVID19″)) AND ALL = ("renal" OR "kidney" OR "nephr*" OR "uremi*" OR "glomerulonephritis".

Based on the above conditions, 6713 papers were identified. Two researchers (YW and TC) independently assessed titles, abstracts, keywords, and full texts when necessary to reject articles with poor relevance to our theme. Disagreements were resolved through discussion with another researcher (XZ), and ultimately, a total of 645 articles were included in our bibliometric study. The retrieved publications were exported as "plain text files" with "full records and cited references."

2.2. Bibliometric analysis

We adopted the categories of included articles as originally defined by the WOS (i.e., nephrology, infectious disease, etc.) and obtained a citation report from the database. The top 10 most-cited articles were referred to as highly cited articles. We calculated the adjusted annual average number of citations, which is the ratio of the overall number of citations to the year gap between the publication year and 2022 (i.e., adjusted numbers of citations in 2022, 2021, and 2020 were calculated by dividing the total number of citations by 1, 2, and 3, respectively). We then presented the number of articles published monthly.

For the published journals, we created a descending chart based on the Law of Bradford; that is, the journals were split into core, relevant, and irrelevant areas based on the number of papers published in them [18]. Using the R "Biblioshiny" package, we obtained H, G, and M indices and total citations. The H-index is an indicator based on the number of publications and citations; that is, there are H articles cited at least H times [19,20]. However, highly cited papers influence the H-index, so its derivative, the G-index, was used instead, which means that there are G articles that have a cumulative citation count of at least G^2 [21]. The M-index is another variant of the H-index that considers the existing length of the journals and shows the H-index for each year since its first publication [22]. CiteSpace's dual map overlay was used to show the distribution of disciplines and connections across magazines. The left side of the figure is the citation diagram, the right side is the cited diagram, and the curve is the citation line, fully displaying the citation

relationship. For cited images, the more papers published in a journal, the longer the vertical axis of the ellipse and the more authors there are, the longer the horizontal axis of the ellipse [23].

All the authors of the included articles were included in the analysis. Based on the hypothesis that all coauthors of the same article contribute to the article uniformly 1/n (where "n" is the total number of authors), we quantified the total contribution of a single author to the papers published in this field. Next, we calculated the H, G, and M indices, total citations, number of publications, and publication years. Furthermore, the author cooperative network and cocited author co-occurrence network were constructed using VOSviewer.

Similarly, we analyzed the countries and institutions of the included publications. Based on the nationalities of all the authors, we used CiteSpace to construct the national interactive network, which centrality represents the strength of the number of connections between a node and other nodes in the entire network [24]. And the R package "Biblioshiny" was used to construct the national cooperation map. We also visualized the number of multiple-country publications and single-country publications in the top 20 countries with the most corresponding authors. However, unlike their respective countries, many authors' affiliations are not unique. In this case, we only counted one of the authors' primary affiliations. Therefore, based on statistics from the WoS database, we presented the top 10 institutions and used a network map to analyze interagency cooperation.

In the current study, keyword analysis includes the keywords of the authors and keywords plus, which are words or phrases that frequently appear in the titles of the article's references rather than in the title of the article itself [25]. We standardized the keywords; that is, keywords with the same meaning were normalized and consolidated. For instance, coronavirus disease 2019 and COVID-19 were merged into COVID-19. We derived a co-occurrence diagram to reflect the frequency, timing, and correlation of the keywords. Additionally, for publications without the keywords of the author, we constructed a thematic map based on the keyword plus. CiteSpace was used to perform an analysis of keyword bursts, the blue line represents the timeline, and the red part above it represents the time when the keyword burst [24], including the start year, end year, and duration, aiming to detect the frequency of keywords and extract keywords with high-frequency changes in a specific period of time from a large number of subject words. The minimum duration of the outbreak in this study was set at one year. Furthermore, we used VOSviewer to color all keywords based on the average time of keyword occurrence to further analyze research hotspots over time.

3. Results

3.1. Publication characteristics and trends and citation analysis

In total, 645 papers were included in the bibliometric analysis (Fig. 1). These publications were classified into 55 research fields, including "Urology and Nephrology" (263, 40.775 %), "Medicine General Internal" (101, 15.659 %), and "Transplantation" (80, 12.403 %) (Fig. 2a). The monthly growth in the number of COVID-19 cases and kidney-related articles is presented in Fig. 2b. The first publication was published in March 2020. Since then, the number of publications (NPs) has gradually increased, especially since August 2020, and has remained at a high level for a long time.

The total cumulative number of citations for these publications was 13,426 (10,308 after removing self-citations), with an average of 20.28 citations per publication and an H-index of 55. As shown in Table 1, the publication with the highest total and average citations was the article entitled "Renal histopathological analysis of 26 postmortem findings of patients with COVID-19 in China", on the topic of direct evidence of SARS-CoV-2 invasion into kidney tissue. Based on both the total citations and the adjusted citation numbers that concern the publication years, the corresponding authors of these highly cited articles were mostly from China, the United States, and France.

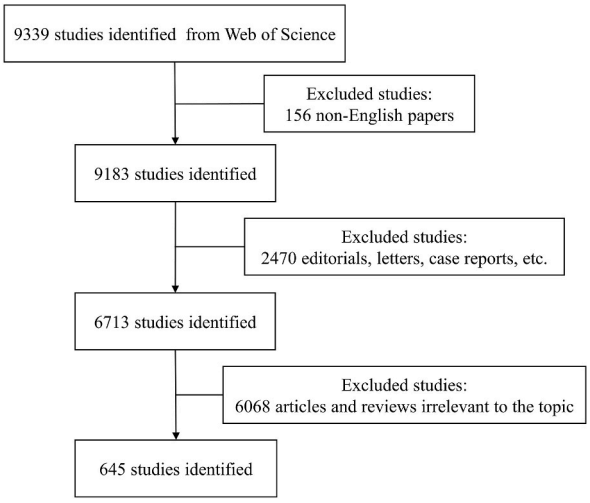

Fig. 1. Flow diagram of the article selection process used in the study.

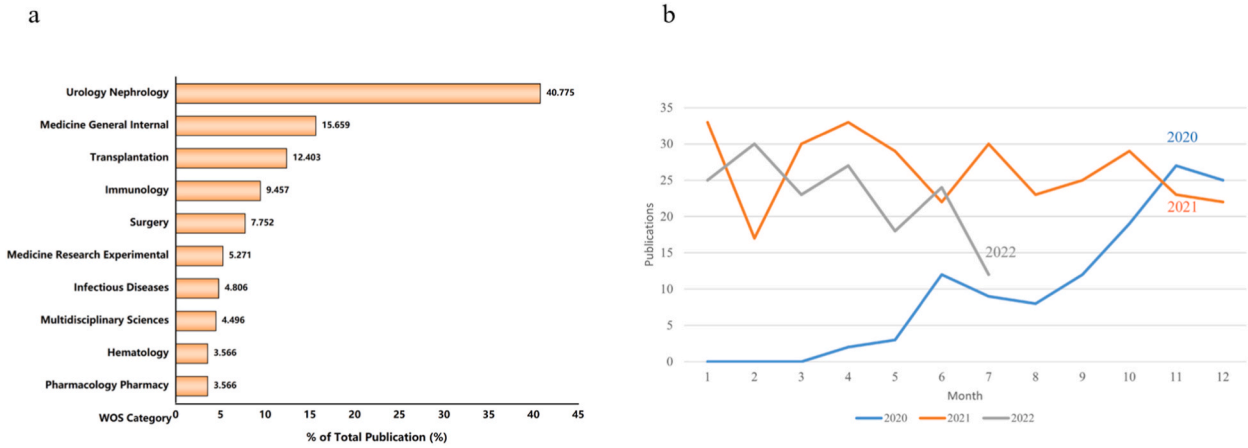

Fig. 2. (a). The top 10 research fields in the WOS category
(b). Monthly growth in the number of publications.

Table 1
The top 10 highly cited papers in COVID-19 and kidney-related fields.

Title	Corresponding Authors	Country of Corresponding Authors	Source Title	Publication Year	Total Citations	Average per Year
Renal histopathological analysis of 26 postmortem findings of patients with COVID-19 in China	Zhang, Chun	Peoples Republic of China	Kidney International	2020	922	307.33
Acute kidney injury in patients hospitalized with COVID-19	Jhaveri, Kenar D.	USA	Kidney International	2020	668	222.67
Renal involvement and early prognosis in patients with COVID-19 pneumonia	Xu, Gang	Peoples Republic of China	Journal of the American Society of Nephrology	2020	393	131
AKI in hospitalized patients with COVID-19	Nadkarni, Girish N.	USA	Journal of the American Society of Nephrology	2021	248	124
Coronavirus Disease 19 Infection Does Not Result in Acute Kidney Injury: An Analysis of 116 Hospitalized Patients from Wuhan, China	Gong, Zuojiong	Peoples Republic of China	American Journal of Nephrology	2020	227	75.67
Acute kidney injury in critically ill patients with COVID-19	Zafrani, Lara	France	Intensive Care Medicine	2020	222	74
Results from the ERA-EDTA Registry indicate a high mortality due to COVID-19 in dialysis patients and kidney transplant recipients across Europe	Massy, Ziad A.	France	Kidney International	2020	206	68.67
Ultrastructural Evidence for Direct Renal Infection with SARS-CoV-2	Jentzen, Jeffrey M.	USA	Journal of the American Society of Nephrology	2020	204	68
COVID-19 and kidney transplantation: Results from the TANGO International Transplant Consortium	Riella, Leonardo, V	USA	American Journal of Transplantation	2020	192	64
Reduced humoral response to mRNA SARS-CoV-2 BNT162b2 vaccine in kidney transplant recipients without prior exposure to the virus	Katchman, Helena	Israel	American Journal of Transplantation	2021	191	95.5

3.2. Analysis of the journals and authors

In total, 645 publications were published in 220 journals. However, there was a tendency to concentrate on specific factors. Fig. 3a depicts a descending graph based on Bradford's law, with the 12 journals that published the most articles located in the core source area of the graph. The three journals with the most publications were the Clinical Kidney Journal (n = 26, impact factor [IF] 2021 = 5.86), the Journal of Clinical Medicine (n = 24, IF 2021 = 4.964), and the Journal of the American Society of Nephrology (n = 21, IF 2021 = 14.978). Table 2 lists the top 10 journals in terms of the H-index and their G and M indices and total citations (TCs), indicating that the Journal of the American Society of Nephrology has a higher academic output with an appreciable volume of publications and

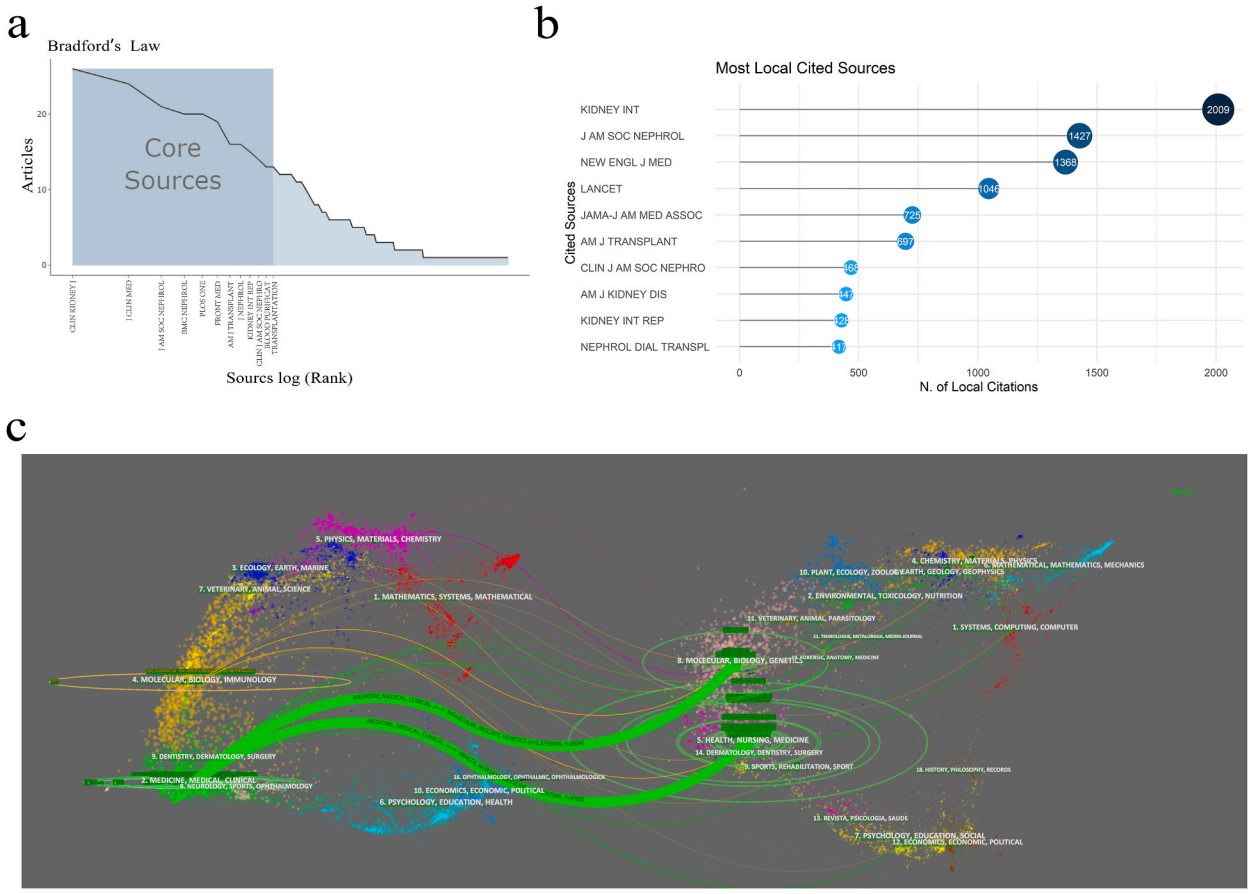

Fig. 3. (a). Core sources for COVID-19 and the kidney
(b). The top 10 most locally cited sources
(c). The dual-map overlay of journals on COVID-19 and kidney
(The journal on the right is cited by the journal on the left.) Each dot in the diagram represents a journal. The cluster of colored dots represents the classification of disciplines based on the journal title. The color path connecting them represents the mentioned relationship. The number of authors is represented by the horizontal axis of the ellipse at the start and end points, and the number of papers is represented by the vertical axis.

citations. Fig. 3b shows the reference sources of 645 publications, of which the kidney international journal (IF 2021 = 10.612) ranked first with 2009 times, followed by the Journal of the American Society of Neurology (1427 times, IF 2021 = 14.978) and the New England Journal of Medicine (1072 times, IF 2021 = 176.079).

In the dual map overlay (Fig. 3c), the two thick green paths show that the Molecular Biology and Genetics and Health, Nursing, and Medicine magazines often cited the research published in Medicine, Medical, and Clinical magazines. The track of the dual map overlay superposition of journals showed that COVID-19 and journals in kidney-related fields are relatively concentrated.

A total of 5126 authors were identified in publications related to COVID-19 and kidney disease. Fig. 4a shows the top 10 most

Table 2
The top 10 sources with the most publications.

Source	H-index	G-index	M-index	TC
Journal of the American Society of Nephrology	16	21	5.333	2113
American of Journal of Transplantation	12	16	4	966
Kidney International	11	12	3.667	2307
Nephrology Dialysis Transplantation	10	12	3.333	642
Kidney International Reports	9	15	3	465
PloS One	9	12	3	175
Clinical Journal of the American Society of Nephrology	8	14	2.667	266
Clinical Kidney Journal	8	16	2.667	269
Transplant Infectious Disease	8	11	2.667	134
Transplantation	8	13	2.667	258

TC: Total Citations.

prolific authors, producing 81 articles, accounting for 12.56 % of all publications, with JL publishing the most papers (12, 1.86 %). Among the top 10 authors, YC (1.06), JL (1.03), and YL (1.03) significantly contributed to the scientific output. The frequency distribution of scientific productivity is shown in Fig. 4b. Table 3 shows the top ten authors in terms of the H-index and G-index, M-index, TC, NP, and year of the first publication (PY-start). In the authors' collaboration network (Fig. 4c), clusters of the same color represent mutual cooperation. We found that Crespo M was associated with authors in both the green and orange clusters, which shows that this author was highly active and had a strong cooperative relationship with other authors. According to our cocitation analysis, 14 of the 10268 cocited authors were cited more than 100 times. Among them, YC and HS had the highest frequency of cocitations, indicating that their academic relationships were relatively close (Fig. 4d).

3.3. Analysis of countries, regions, and institutions

Researchers from 67 countries contributed 645 articles. Fig. 5a shows the top ten countries in terms of total NP and annual volume of publications, indicating that the top five countries are the United States (165, 18.39 %), the People's Republic of China (100, 11.15 %), Italy (60, 6.69 %), England (52, 5.80 %), and Turkey (41, 4.57 %). Fig. 5b and c shows the distribution and cooperation of countries; the United States had a better international cooperation network while publishing more papers than the other countries. However, cooperation between countries is generally not sufficiently close. Fig. 5d depicts the number of multi country publications (MCPs) and single-country publications (SCPs) in the top 20 countries with the most corresponding authors. The United States and China are among the best, and Israel has no international cooperation.

We counted 1583 institutions that contributed to this field. Table 4 lists the top ten institutions with the most publications, which contributed 202 articles (31.32 %), and it is obvious that Udice French Research Universities, located in France, published the most papers (4.34 %). Fig. 6a shows the publishing trends of the top 10 research institutions in the past three years, indicating that most institutions peaked in 2021, especially the Udice French Research Universities. However, there were similar number of publications by Harvard Medical School in 2021 as in 2022. Fig. 6b shows that Harvard Medical School, Hosp Del Mar, and the Icahn School of Medicine at Mount Sinai had many contacts with other institutions, and Radboud University Nijmegen showed tight collaboration

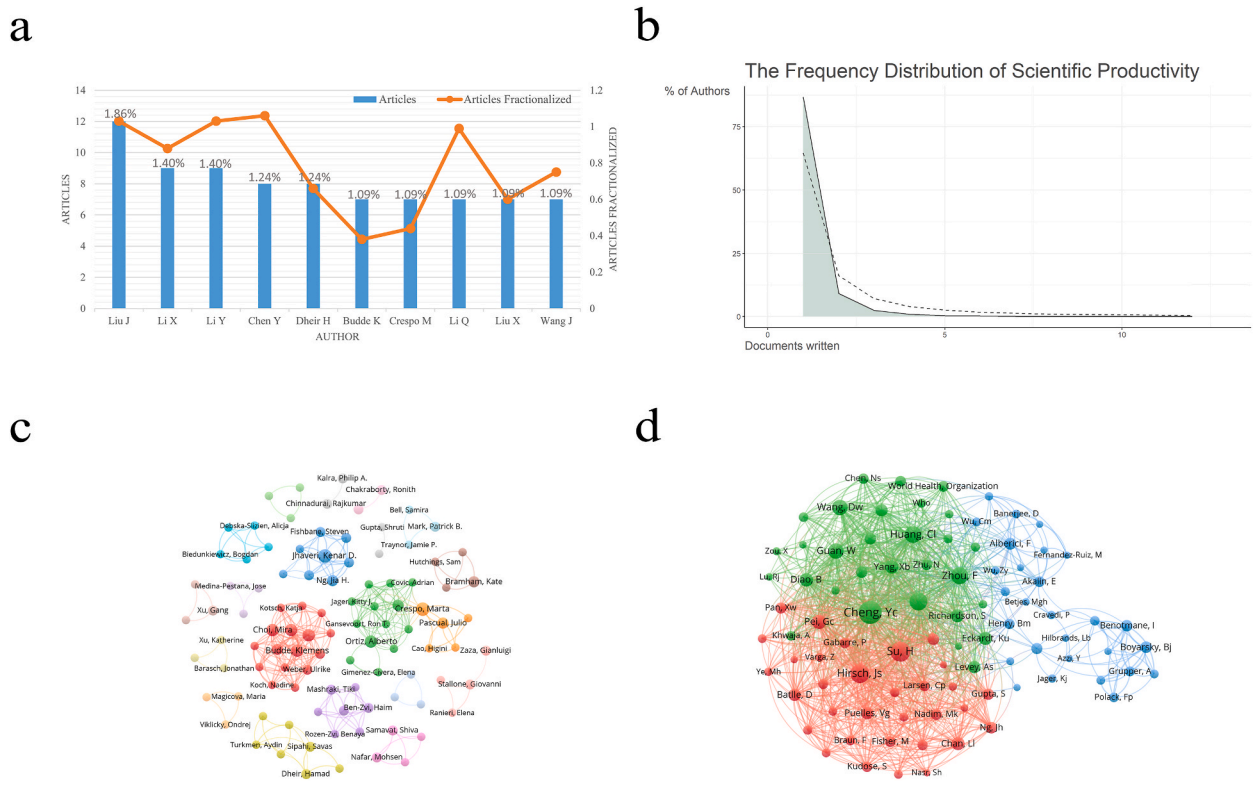

Fig. 4. (a). The top 10 most productive authors
(the blue columns represent the number of published papers, and the orange broken-line articles fractionalized represent the author's contribution to the literature collection in this field).
(b). The frequency distribution of scientific productivity.
(c). A cooperative network of authors.
(d). Cooperation network of cocited authors
(different color clusters represent the corresponding authors' research on similar topics.).

Table 3
H-index, G-index, M-index, TC, NP, and PY-start of the top 10 authors in the H-index.

Author	H-index	G-index	M-index	TC	NP	PY-start
LI X	7	9	2.333	423	9	2020
CRESPO M	6	7	2	135	7	2020
LIU L	6	6	2	583	6	2020
ZHANG Y	6	7	2	162	7	2020
BUDDE K	5	7	2.5	281	7	2021
CHEN X	5	6	1.667	99	6	2020
CHEN Y	5	8	1.667	192	8	2020
CRAVEDI P	5	6	1.667	323	6	2020
ISLAM M	5	5	1.667	271	5	2020
JHAVERI KD	5	5	1.667	945	5	2020

TC: Total Citations; NP: number of publications; PY-start: The year for the first publication.

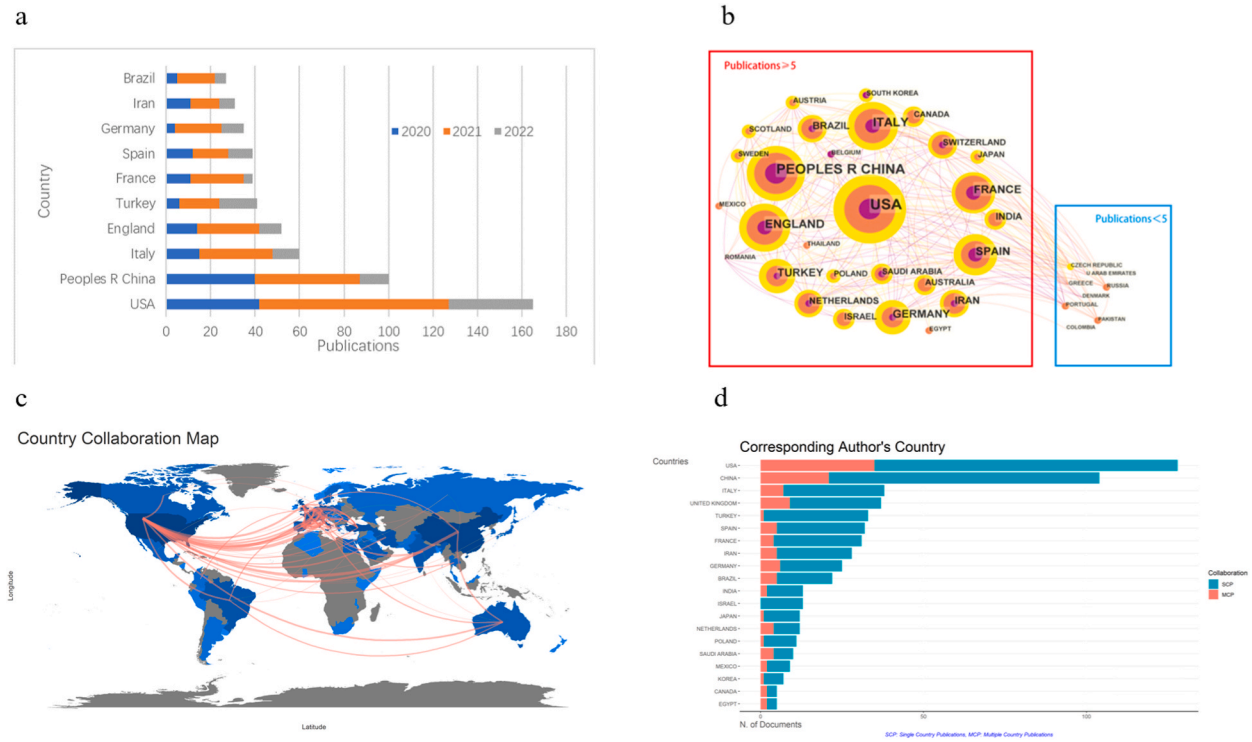

Fig. 5. (a). Countries with the top 10 articles published over the years.
(b). Map of national cooperation
(The size of the circle represents the number of articles published by the country, and the line represents the intensity of cooperation).
(c). Country collaboration map
(the color depths represent the number of documents, and the lines represent the intensity of cooperation).
(d). The number of MCPs and SCPs in the top 20 corresponding authors' countries.
(MCP: multicountry publication; SCP: single-country publication).

despite publishing relatively few papers.

3.4. Analysis of hotspots and frontiers

Keywords reflect the core content of an article. After using VOSviewer to evaluate the keywords, we discovered that COVID-19 (511 times), AKI (251 times), SARS-CoV-2 (166 times), kidney transplant (116 times), and mortality (112 times) were the top five keywords with the highest frequencies. Fig. 7 shows a network diagram of the 52 keywords with frequencies greater than 10. Clusters of the same color comprise a collection of closely related keywords that reflect the study topic to some extent, and our keyword co-occurrence analysis revealed five major clusters (red, yellow, blue, green, and purple). The main keywords in the red cluster were COVID-19, AKI, mortality, outcomes, and prognosis, which indicates that the focus was mainly on the association between COVID-19 and AKI and the prognosis of the disease. The keywords SARS-CoV-2, kidney disease, CKD, injury, and risk were the primary keywords in the

Table 4
The top 10 institutions with the most publications.

Rank	Insitiution	Country	Count (%)
1	Harvard University	USA	42 (2.65 %)
2	Udice French Research Universities	France	28 (1.77 %)
3	Institut National De La Sante Et De La Recherche Medicale Inserm	France	24 (1.51 %)
4	Assistance Publique Hopitaux Paris Aphp	France	21 (1.32 %)
5	Huazhong University Of Science Technology	Peoples R China	21 (1.33 %)
6	Icahn School Of Medicine At Mount Sinai	USA	18 (1.14 %)
7	University Of California System	USA	17 (1.07 %)
8	University Of London	England	16 (1.01 %)
9	Brigham Women S Hospital	England	15 (0.95 %)
10	Wuhan University	Peoples R China	14 (0.88 %)

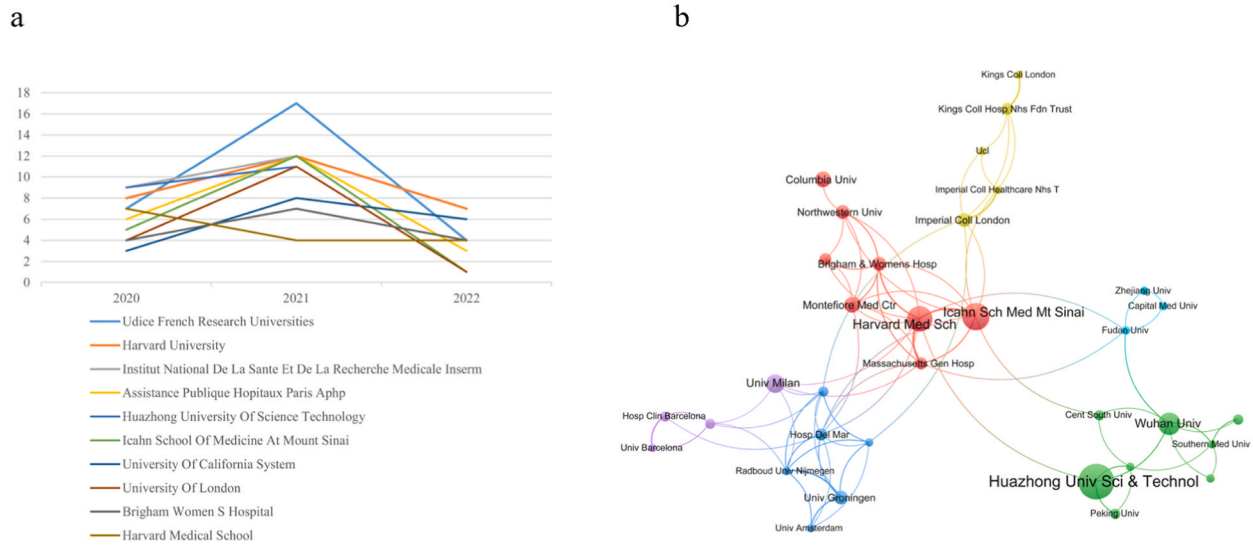

Fig. 6. (a). Top 10 research institutions publishing trends
The vertical axis represents the number of documents issued, and the horizontal axis represents the year.
(b). A collaborative network of research institutions
The size of the circle represents the number of documents sent, and the lines between organizations represent cooperative relationships.

yellow cluster, indicating that the cluster focused on the influence of SARS-CoV-2 infection on patients with CKD and its potential to further increase kidney injury. Infection, ACE-2 expression, inflammation, and receptors were the major keywords in the blue cluster. This cluster of studies focused on the potential mechanisms of kidney injury caused by COVID-19 infection, including the broad expression of the ACE-2 receptor in the kidney and an increased inflammatory response. The focus of the green cluster may be related to the immunosuppressed state of kidney transplant and dialysis patients, which affected the antibody titer of the novel coronavirus vaccine, based on keywords such as kidney transplant, hemodialysis, vaccination, and immunosuppression. “Hospitalized patients” and “clinical characteristics” were the emerging keywords in the purple cluster. This section may focus on explaining the clinical symptoms of COVID-19 and kidney disease in hospitalized patients. A thematic map of the keywords and their descriptions are shown in Supplementary Fig. 1.

Fig. 8a depicts CiteSpace’s burst analysis of keywords. However, the intensity of the keyword bursts was not significant because of the short span of the research years. The terms that continued to be popular in 2020 were pneumonia, clinical features, functional receptors, and kidney pathology, indicating that the focus of research in this phase was mostly on the clinical features and renal pathological changes in patients with COVID-19. Keywords that continued to be popular from 2021 to 2022 included dysfunction, infectious disease, kidney injury, cytokine storm, and T cell, which suggests that this stage of the study will focus on kidney injury and dysfunction as well as the involved immunological response. Fig. 8b shows the average time of keyword occurrence and the relationship between them. In the initial stage of COVID-19, research focused on the clinical symptoms of COVID-19 and other macrocharacteristics. Later, research was conducted on the associations between SARS-CoV-2 infection and CKD, AKI, and the prognosis of kidney disease in patients with COVID-19, including those who underwent kidney transplantation. Recent studies have focused on the correlation between kidney disease and COVID-19 vaccines.

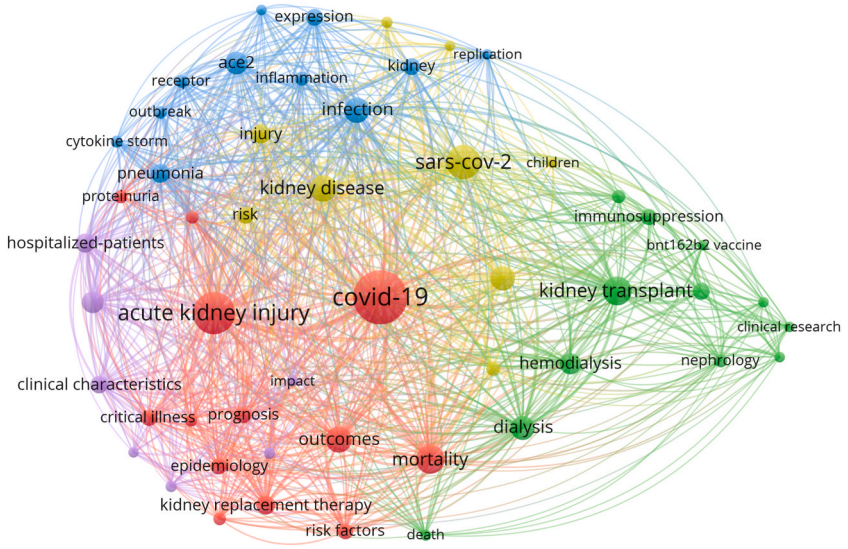

Fig. 7. Co-occurrence map of keywords.

a

Top 25 Keywords with the Strongest Citation Bursts

Keywords	Year	Strength	Begin	End	2020 - 2022
wuhan	2020	3.44	2020	2020	
pneumonia	2020	2.86	2020	2020	
clinical feature	2020	2.1	2020	2020	
functional receptor	2020	1.93	2020	2020	
renal pathology	2020	1.5	2020	2020	
computed tomography	2020	1.44	2020	2020	
acute kidney failure	2020	1.08	2020	2020	
acute respiratory distress syndrome	2020	1.02	2020	2020	
chronic renal failure	2020	0.96	2020	2020	
comorbidity	2020	0.96	2020	2020	
enzyme	2020	0.96	2020	2020	
in-hospital mortality	2020	0.96	2020	2020	
clinical research	2020	0.86	2020	2020	
renal failure	2020	0.86	2020	2020	
intensive care unit	2020	0.7	2020	2020	
kidney biopsy	2020	0.64	2020	2020	
inflammation	2020	0.59	2020	2020	
collapsing glomerulopathy	2020	0.59	2020	2020	
score	2020	0.53	2020	2020	
dysfunction	2020	1.5	2021	2022	
infectious disease	2020	1	2021	2022	
kidney injury	2020	0.83	2021	2022	
cytokine storm	2020	0.83	2021	2022	
t cell	2020	0.66	2021	2022	
proximal tubule	2020	0.66	2021	2022	

b

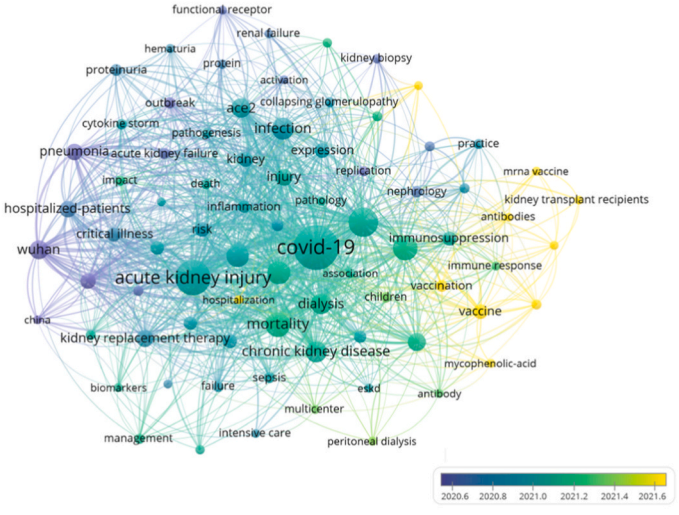

Fig. 8. (a). The top 25 keywords with the strongest citation bursts.
(b). A co-occurrence map of keywords.
The figure indicates the period of keyword occurrence from 2020 (blue) to 2021 (yellow) (the node size represents the frequency of keywords).

4. Discussion

4.1. General information

In this study, we analyzed 645 publications and found that the number of published articles in this field has increased annually in the past few years for the following reasons. First, COVID-19 has spread swiftly among people, and the population is generally susceptible, resulting in large-scale global dissemination [26]. The virus strain continues to mutate rapidly [27], resulting in its failure to be effectively controlled in a short period of time. Second, the interaction between SARS-CoV-2 infection and the kidney appears

relatively late in some aspects, such as COVID-19 vaccine-related kidney injury [28]. Third, kidney damage may have attracted the attention of researchers quite recently. Despite the rampant COVID-19 pandemic, all countries have made efforts to research COVID-19 and the kidneys and have achieved certain results. Among the top 10 countries in the world, six were developed countries, and four were developing countries, which shows that developed countries are slightly ahead of developing countries in this area of research. Generally, research on this topic is progressing, but there are still several issues to be addressed, as well as a lack of close international collaboration among authors, countries, and institutions. Considering the considerable global difficulties and tests posed by the COVID-19 pandemic, we believe that research on COVID-19 and the kidney should be continuous and more closely coordinated globally to address a series of challenging issues in this area as soon as possible.

4.2. The hotspots and frontiers

Based on keyword co-occurrence and thematic map analyses, we provided an overview of the research conducted on COVID-19 and kidney disease, and we discussed the changes and development of several research hotspots in this field.

In the early stage of the COVID-19 outbreak, AKI in patients was the earliest and most widespread concern [29]. According to statistics, more than 30–50 % of hospitalized patients with COVID-19 will develop to AKI, and the proportion of critically ill patients will be even greater [30,31,]. Only 30 % of patients recover their kidney function, and most have a poor prognosis [26,32]. This is related to various factors, such as inflammatory damage and immune disorders [33]. However, it is still controversial whether SARS-CoV-2 can directly infect the kidneys and cause AKI [34]. Although ACE-2 is highly expressed in the kidneys and mediates virus entry into host cells, related inhibitors cannot alter renal outcomes. Currently, the treatment of COVID-19-related AKI is mainly supportive [35], so we suggest that researchers should further investigate the mechanism of direct viral infection of the kidneys and, based on this, find a new drug that can directly target the virus and block its binding to renal cell receptors to prevent kidney damage, which is highly valuable.

In ongoing studies, investigators have found that underlying kidney diseases can also have a serious impact on SARS-CoV-2 infection. One study claimed that CKD is the strongest risk factor for critical illness after age [36]. Patients with CKD and COVID-19 are characterized by multisystemic organ failure, thrombosis, and an increased inflammatory response [37]. The risk of infection and severe disease increases as the estimated glomerular filtration rate decreases, with the highest risk in patients undergoing kidney replacement treatment, particularly in patients who have had kidney transplants [38], which is associated with large doses of immunosuppressive medications. One month after kidney transplantation, SARS-CoV-2 infection can quickly progress to a high risk [39]. Therefore, further clinical and basic research is needed to explore interactions and specific mechanisms between SARS-CoV-2 infection, CKD, and kidney transplantation, in addition to immunosuppression, to develop targeted drugs to accurately prevent further progression of kidney function. In addition, another aspect that needs to be emphasized is to strike a balance between using immunosuppressants to prevent rejection and preventing SARS-CoV-2 infection and postinfection treatment.

In the past few years, various COVID-19 vaccines have been studied. On the one hand, the excessive immune response triggered by vaccines can lead to kidney damage. On the other hand, due to immune disorders, the vaccine response in people with kidney disease decreases, and the immunogenicity of the vaccine decreases with the severity of kidney injury [40]. Therefore, accurately assessing an individual's immune status is a prerequisite for vaccination, and the development of vaccine types and doses suitable for different disease populations is also crucial. Significant efforts are still needed by researchers in the field of vaccines.

Our study has several strengths. To the best of our knowledge, we were among the first to use bibliometric analysis to analyze the research trends of the connection between COVID-19 and kidney-related diseases. Second, it summarized the conditions of the field's research and shifts in research hotspots. Third, it offered some suggestions for future research topics for researchers. However, our study had several limitations. On the one hand, after selection in accordance with our inclusion criteria, important articles published in languages other than English and publications not included in the Science Citation Index-Expanded were excluded, which could have affected the results. On the other hand, we only explored the relationship between COVID-19 and kidney-related diseases in terms of physiopathology, and the literature on kidney insufficiency caused by poor management of chronic diseases in epidemic situations was not included.

5. Conclusions

In the first three years following the outbreak of the COVID-19 pandemic, AKI, CKD, and kidney transplantation were prominent research foci in relation to COVID-19 and kidney health. Immune response and vaccines were emerging hotspots receiving more attention. National rankings of publication numbers should be interpreted with caution because only publications in English were included.

Ethics approval and consent to participate

Not applicable.

Consent for publication

Not applicable.

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Data availability statement

The original citation data used in this article were downloaded from Web of Science, an open public database at https://www.webofscience.com/.

CRediT authorship contribution statement

Yujiao Wang: Writing – original draft, Formal analysis, Data curation. **Tingting Chen:** Writing – original draft, Formal analysis, Data curation. **Chunyang Li:** Writing – review & editing. **Mei Qi:** Conceptualization. **Ping Fu:** Supervision. **Xiaoxi Zeng:** Conceptualization.

Declaration of competing interest

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

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Abbreviations

ACE-2	angiotensin-converting enzyme 2
AKI	acute kidney injury
CKD	Chronic Kidney Disease
COVID-19	coronavirus disease-2019
IF	impact factor
MCPs	NPs multicountry publications number of publications
PY-start	The year for the first publication
RNA	ribonucleic acid
SARS-CoV-2	Severe acute respiratory syndrome coronavirus 2
SCPs	single-country publications
TCs	Total Citations
WoS	Web of Science

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.heliyon.2024.e31749.

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