Systematic Reviews

RESEARCH

Open Access

The pyroptosis and fibrotic diseases: a bibliometric analysis from 2010 to 2024

Long Zhu[1†], Lijia Ou[2†], Binjie Liu[1], Yang Yang[1], Chang Su[3], Ousheng Liu[1] and Hui Feng[1*]

Abstract

Background Fibrosis is the ultimate, common pathological ending of most chronic inflammatory diseases and increases the chances of developing life-threatening illnesses. Pyroptosis, a newfound form of lytic programmed cell death initiated by the inflammasome, has received more and more attention because of its association with fibrotic diseases. Therefore, this study visualizes the connection between pyroptosis and fibrosis research through bibliometric methods, aimed at providing global research hits and tendencies in the field.

Methods We collected and analyzed the articles on pyroptosis and fibrosis from 2010 to 2024 via Web of Science. Visual data analysis was performed for countries, institutions, authors, references, and keywords in the field using VOSviewer, CiteSpace software, the "Bibliometrix" R package, the bibliometric website (https://bibliometric.com/), and Excel software. We analyzed the data by utilizing the bibliometric review method.

Results A total of 566 articles and reviews relating to pyroptosis and fibrosis were identified in the Web of Science. The number of publications in the domain has continued to grow since 2010. These scientific outputs were mainly from 129 countries/regions and 1919 institutions, particularly China ($n=423$) and the USA ($n=83$). More importantly, although China publishes a vast majority of articles, its centrality is lower than that of the USA (0.59 vs 0.61). Among the 3833 authors involved in this field, Feldstein, A. E. is the most prolific author. Shi, J. J. is the world's most-cited author among the 12,143 authors in these academic journals. *Frontiers in Immunology* was a prolific contributor, and *Nature* was the most frequently cited journal. After analysis, *Cleavage of GSDMD by inflammatory caspases determines pyroptotic cell death* were the top-cited articles. The analysis of keywords displayed that pyroptosis, fibrosis, and pathways were the main research hotspots and frontier directions in recent years.

Conclusion We analyzed the characteristics of published articles and drew a fundamental knowledge structure on pyroptosis and fibrosis research via bibliometric analysis. The potential mechanism between fibrosis and pyroptosis is deeply tied to the current moment. Our findings can help researchers make clear the research status and value of fibrosis and pyroptosis and provide new directions for future research as soon as possible.

†Long Zhu and Lijia Ou contributed equally to this work.

*Correspondence:
Hui Feng
fengh0929@csu.edu.cn
Full list of author information is available at the end of the article

Introduction

Fibrosis is not a disease but rather a dysregulation of a reparative or reactive process following tissue injury, resulting in a state caused by the accumulation of excessive collagen or extracellular matrix (ECM) during chronic diseases [20]. This fibrotic process has occurred in various tissues or organs such as the skin, liver, lung, kidney, and heart and become one of the major causes of morbidity and mortality, accounting for up to 45% of patients' deaths in Western world countries. Mechanistically, specific principles of fibrosis advancement concern the aggravation of chronic tissue injury, the ongoing inflammatory processes, massive production of myofibroblasts, and finally fibration of excess matrix scaffold [4, 55]. Despite the increasing development of novel diagnostic techniques and antifibrotic therapeutics, the prognosis of patients with fibrotic diseases is still rather poor. Therefore, a comprehensive and integrated understanding of critical fibrogenic molecular signals and cellular mechanisms in all kinds of organs is extremely significant for developing improved diagnosis and therapeutic approaches toward reversing the formation of fibrous tissue and scarring in fibrotic diseases.

Generally, fibrogenesis is caused by parenchymal cell destruction, in which cell death such as necrosis, apoptosis, pyroptosis, necroptosis, and ferroptosis plays a greatly important role. Among them, pyroptosis, a new form of pro-inflammatory programmed cell death, has caused widespread concern because of its association with fibrotic diseases. It was first discovered in 1986, when Friedlander treated mouse macrophages with lethal anthrax toxin, resulting in cell death and quick release of cell contents [13]. In 2001, Brennan, Cookson et al. first proposed the concept of pyroptosis to describe a mode of cell death in inflammatory cells that rely on caspase 1, which is a completely different mode of death from apoptosis [11]. During pyroptosis, the cell expands until the cell membrane bursts, causing the release of the cell's contents to activate a powerful inflammatory and immune response [27]. Activation of the inflammasomes can cause the maturation of caspase-1 or caspase-4/5/11 and then disintegrate gasdermin D to release its N-terminal domain, which can be combined in membrane lipids and perforate the cell membrane [45]. Currently, numerous research studies have manifested that pyroptosis is the intimate relationship between the occurrence and development of various fibrotic diseases, so a comprehensive understanding of the research status and hotspots in this field is contributing to providing new ideas for clinical prevention and treatment of fibrotic diseases.

The bibliometric, first proposed by Pritchard A in 1969 [39], is the quantitative method of academic literature that adopts statistics to introduce publishing statements and development trends and to evaluate the relationships between published articles [24]. Similar to epidemiology, scholars attempt to answer questions about a field according to data about publications (e.g., journal, topics, authors, research impact) in the same way that epidemiologists collect and analyze the databases for the patient or disease to explore the influence of the health of a population. With the development of bibliometric methods and analysis software, bibliometrics not only can provide the basis for promoting quantitative and scientific evaluation and management of academic periodicals but also can give a more reasonable and correct direction for the work of researchers in a field [7, 34].

Herein, we analyzed the literature characteristics and the mainstream direction of current research on pyroptosis and fibrosis in the last 15 years using bibliometric methods. The purpose of this study is to provide a comprehensive view of research on the association with pyroptosis and fibrosis to confirm the trend of annual publications, institutions, countries, the most prolific authors, institutions, and the most widely cited papers related to this topic and to lay a solid foundation for in-depth research of the field in the future.

Materials and methods

Inclusion and exclusion criteria

In our study, inclusion criteria were as follows: (1) Literature related to fibrosis and pyroptosis, (2) the language of the literature is English, (3) the types of literature searched include articles and reviews, and (4) bibliographic information must include title, author, country, institution, keywords, and references. The exclusion criteria were as follows: (1) Meeting papers, newspapers and books, etc., (2) literature with incomplete bibliographic information, and (3) duplicate publications.

Search strategy and data collection

Web of Science was chosen as the main database of our research, because it has a very comprehensive collection of scholarly journals and has been frequently used in past visual analytic studies [19, 56]. First, data were collected from the Web of Science Core Collection (WoSCC) database through the Science Citation Index Expanded (SCI-EXPANDED) and the Social Sciences Citation Index (SSCI). The search strategy was (TS = (Pyroptosis)) AND TS = (Fibrosis)). "Article" and "Review" were selected as Document Type. The language of literature was "English." The retrieval time was from 1 January 2010 to 14 September 2024. Literature was exported and saved as plain text files from Web of Science.

Data analysis

In our study, we have applied the review method of bibliometrics for the analysis, which is a quantitative statistical method that takes the representation of the scientific literature as the object of study and uses mathematical and statistical methods to describe, evaluate, and predict the current state of science and technology and development trends [36, 39]. Bibliometric analysis was performed by VOSviewer and CiteSpace v.6.3.R1 (64-bit) Basic, the "Bibliometrix" R package, and the bibliometric website (https://bibliometric.com/). The VOSviewer software tool embedded clustering algorithm helps researchers to construct and visualize co-occurrence networks of important information extracted from the scientific literature [49]. Using VOSviewer software, we analyze the distribution of information from different countries, institutions, authors, co-cited authors, journals, co-cited journals, and keywords. Meanwhile, CiteSpace, a Java-based bibliometric software developed by Prof. Chaomei Chen [38, 47], was applied to produce a timeline graph of keywords as well as to identify highly cited references and keywords that experienced a high citation burst during a specific period. Moreover, the Bibliometrix R package is a common bibliometric tool that collects core elements of the literature including title, abstract, author, reference, country, institution, and keywords and analyzes their interactions [3]. Furthermore, it was used to show the collaboration map of different countries on a world map. In addition, the online bibliometric website (https://bibliometric.com/) was used to visualize the international collaboration among countries. The exponential growth function in Excel was used to analyze the annual number of publications over the years of 2010–2024.

In the process of research, we need to clarify some concepts including the centrality index, co-cited authors/journals, co-citation publications, and the H-index. The centrality index describes the position, importance, and influence of an individual or organization in the social network in his research field, including degree centrality, closeness centrality, and betweenness centrality. Intermediate centrality is used in this study, which refers to the number of times that this node, as an intermediate bridge, links the other two nodes on the shortest path. The larger the value, the more times it appears on the shortest path in the overall network and the greater the influence and importance in the cooperative network [8, 35]. Co-cited authors/journals are two or more authors/journals that are simultaneously cited in one or more subsequent papers. Co-citation publications mean that two or more publications are cited by one or more articles at the same time. The H-index is a quantitative indicator that can be used to estimate the quantity and level of a certain researcher's academic output. Citation burst is a concept that can be used to identify hot topics, referring to articles that experience a spike in citations after publication, which typically indicates a high level of scholarly attention to the topic in question.

Results

Study selection

All publications selected for inclusion in the study were obtained from WoSCC, and 583 publications were obtained by searching for the keywords "Pyroptosis" and "Fibrosis." Then, 576 publications were obtained by filtering the publications with the types of article and review. After screening the publications in languages other than English, 573 publications were obtained. Finally, by setting the screening time period from 2010 January 01 to 2024 September 14, we obtained 566 eligible publications. After using CiteSpace software and manually excluding irrelevant literature, literatures meeting the criteria were stored in the format of download_txt to VOSviewer, the Literature Metrology Online Analysis Platform (https://bibliometric.com), Bibliometrix, and CiteSpace to carry out bibliometric analysis (Fig. 1).

The trend of publications outputs

According to the data retrieved from WoSCC, there were 566 publications in the field of pyroptosis and fibrosis between 2010 and 2024, including 437 (77.21%) articles and 129 (22.79%) reviews. The increasing number of annual publications over time clearly reflected the research of the field at various times and showed the research tendency at a particular stage. As shown in Fig. 2, the number of publications related to pyroptosis and fibrosis was from a period of stability to a rapidly increasing stage in the last 15 years. Among them, the number of articles in the domain did not exceed 10 in total from 2010 to 2014, indicating that the research in this field had less academic attention in this period. Significantly, since 2018, there has been a fast-growth trend in the number of related articles in this area, to more than 200, indicating that the research on the relationship between pyroptosis and fibrosis has gradually attracted the attention of scholars around the world.

The performance of countries, regions, and institutions

According to the data retrieved from the WoSCC database, 129 countries/regions and 1919 institutions had published literature on this topic in total. The top 10 most productive countries, regions, and institutions are presented in Table 1 and Fig. 3. China contributed to the most publications ($n=423$), followed by the USA ($n=83$), Germany ($n=20$), South Korea ($n=14$), and Spain ($n=14$). The total number of articles published in China represented about 74% of all publications in the

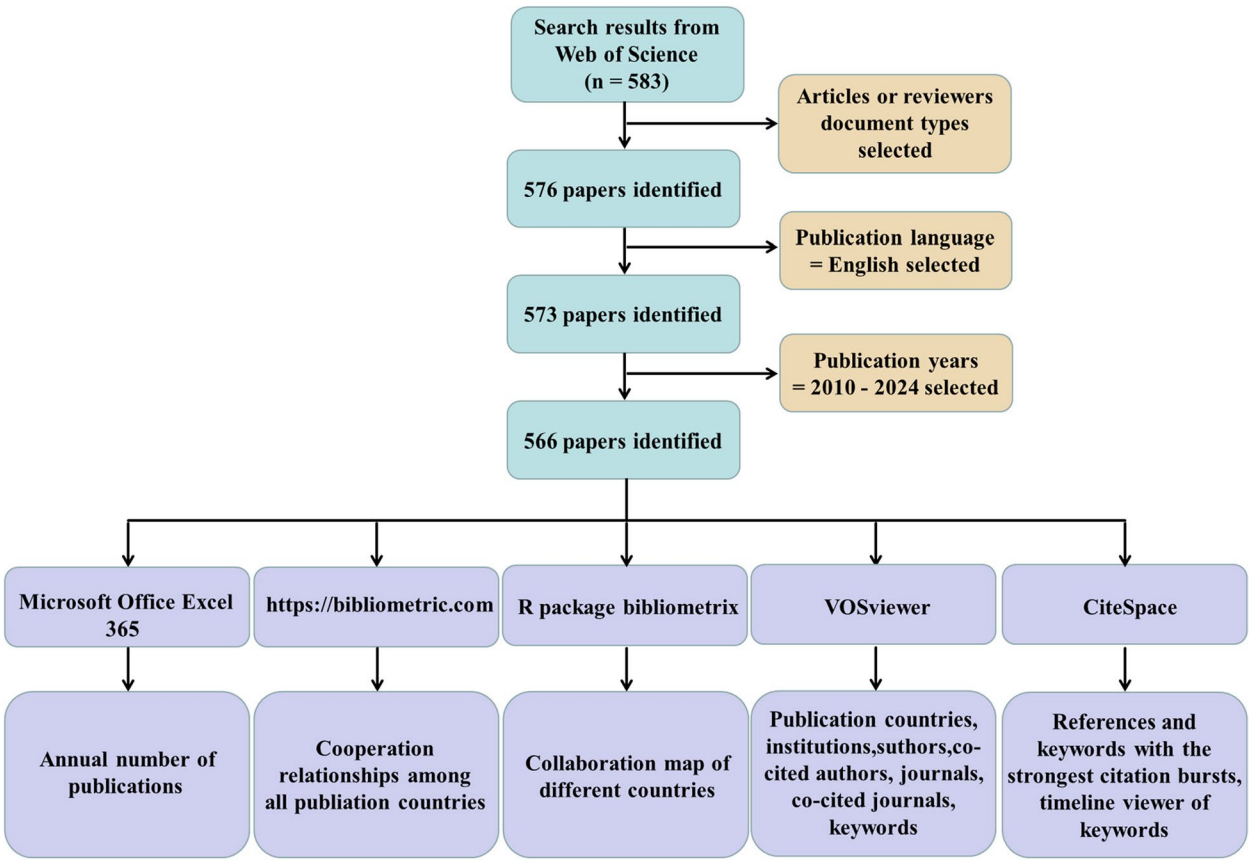

Fig. 1 Flowchart of bibliometric analysis on pyroptosis and fibrosis from 2010 to 2024

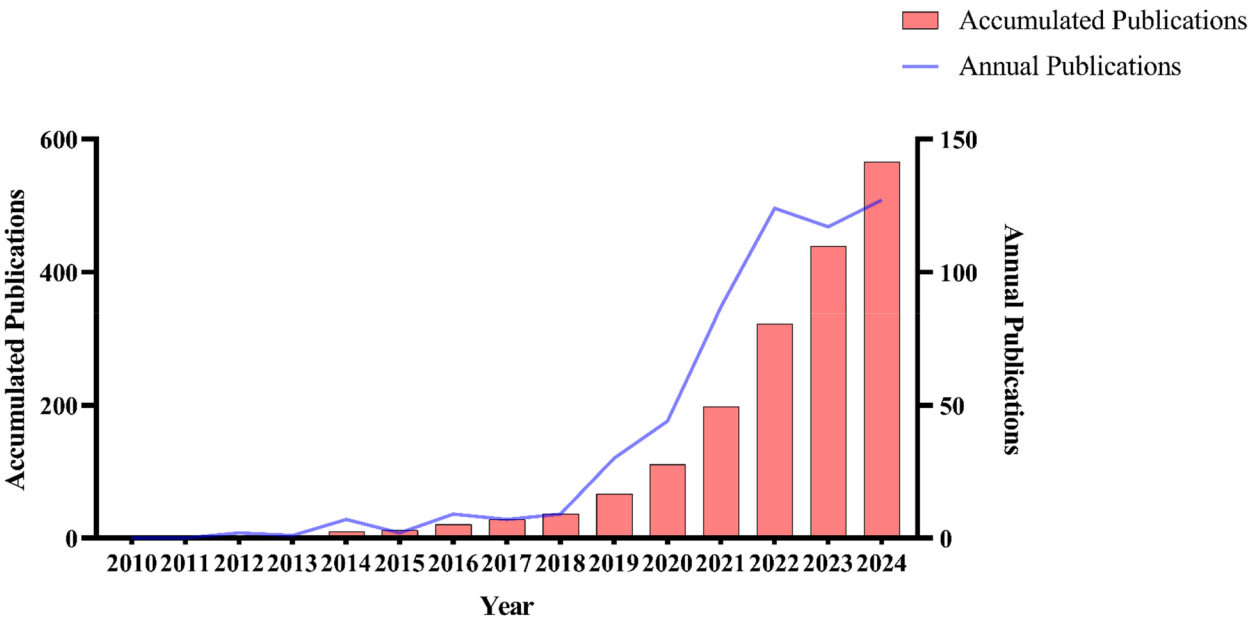

Fig. 2 The temporal distribution of publications on pyroptosis and fibrosis over 2010 ~ 2024

Table 1 Top 10 countries/regions and institutions in pyroptosis and fibrosis research

Rank	Country/region	Article count	Centrality	First published year	Institution	Article count	Citations	First published year
1	China	423	0.59	2014	Harbin Med. Univ	19	608	2018
2	USA	83	0.61	2012	Fudan Univ	19	355	2020
3	Germany	20	0.06	2013	Nanjing Med. Univ	18	488	2018
4	South Korea	14	0.01	2016	Nanjing Univ. Chinese Med	17	393	2019
5	Spain	14	0.17	2017	Zhejiang Univ	17	234	2018
6	India	12	0.06	2019	China Med. Univ	15	206	2020
7	Japan	11	0.09	2014	Cent. South Univ	14	298	2020
8	Canada	9	0.19	2012	Southern Med. Univ	14	200	2019
9	Egypt	9	0.26	2020	Capital Med. Univ	13	247	2019
10	Mexico	9	0.10	2012	Univ. Calif. San Diego	13	1498	2014

field. The cooperative relationships with different countries or regions are displayed in Fig. 3. Centrality was used to measure the importance of nodes in a collaboration network, and it was clear that the USA (centrality = 0.61) took center stage of the network, followed by China (centrality = 0.59) and Egypt (centrality = 0.26). The cooperation relationships between countries on a chordal graph and the world map are shown in Fig. 3B and C, and the USA had the most vigorous cooperation with other countries or regions, especially China.

As for institutions, 1919 institutions were published in this field, and 9 of the top 10 institutions were dominated by Chinese. Among them, the top three institutions were Harbin Medical University ($n = 19$), Fudan University ($n = 19$), and Nanjing Medical University ($n = 18$). More importantly, except the University of California, San Diego among the top 10 institutions published an article in 2014, the rest of the publications were published after 2018, indicating that the research in this field had been gradually paid attention to by more and more researchers after 2018. In addition, we found that among the top 10 most productive institutions in the domain, the top 3 cited institutions were the University of California San Diego ($n = 1498$), Harbin Medical University ($n = 608$), and Nanjing Medical University ($n = 488$). Therefore, although Harbin Medical University was the most productive institution, the University of California, San Diego was the most-cited institution. From the network of major institutional relationships and cooperation (Fig. 4), it can be found that the cooperation among institutions was mainly centered on Nanjing Medical University, Harbin Medical University, Southern Medical University, and Fudan University. Although the University of California, San Diego was in the top 10 in terms of academic output in this field, it did not collaborate frequently with other institutions and was therefore not included in the network.

Authors and co-cited authors

Based on VOSviewer, the results of the bibliometric analysis manifested that 3833 authors participated in the research of pyroptosis and fibrosis. Table 2 displayed the specific information of the top 10 authors with the most productive and co-cited authors, including the main authors, the number of literatures, the number of citations, and the average citations, affiliations, and H-index of productive authors. The top 3 authors with the most documents were Feldstein, A. E. ($n = 11$), followed by Tao, H. ($n = 7$), and Hoffman, H. M. ($n = 6$). The top 3 authors with the highest H-index were Feldstein, A. E. (72), Hoffman, H. M. (58), and Pelegrin, P. (57). In Table 2, Shi, J. J. was the most co-cited author with 211 citations, followed by Wree, A. (199) and Kayagaki, N. (122). Generally, the co-citation frequency of an author is higher, and the academic relationship with other authors in the field is closer. Besides, the visual analysis from Fig. 5A and B revealed the cooperative network relationship between the authors and the co-cited authors. The cooperative networks between authors were divided into clusters of different colors according to the closeness of their ties. The co-cited authors were divided into four clusters represented by three colors (red, blue, and green), and the authors in each cluster are closely related. Feldstein, A. E. made important contributions in this field, as he was not only the author with the most publications and the highest H-index but also he was in the top 3 in terms of average citations per publication.

Productive journals and co-cited journals

A total of 255 journals and 3147 co-cited journals participated in the publications of research on pyroptosis

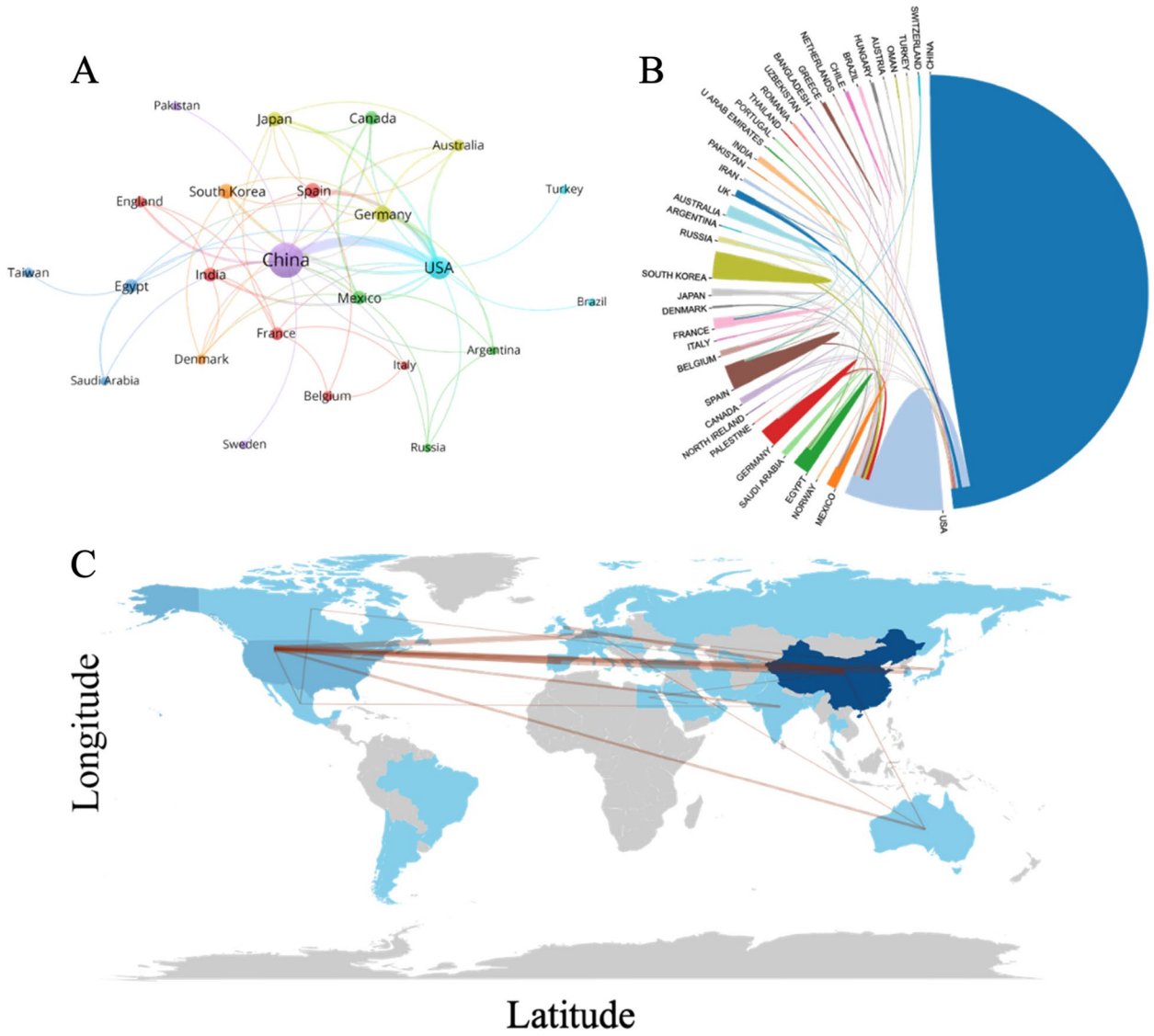

Fig. 3 **A** Analysis of distribution and cooperation between the major countries of publication. **B** Network mapping of cooperation relationships among the main countries. **C** Visualization of global mapping of publications and collaboration relationship

and fibrosis from 2010 to 2024. Details of the top 10 journals in terms of the number of publications and the top 10 co-cited journals in terms of the number of citations are shown in Table 3. The top 3 journals with the largest number of publications were *Frontiers in Immunology* ($n=19$), *International Journal of Molecular Sciences* ($n=18$), and *Fronters in Pharmacology* ($n=16$). According to the standards of Journal Citation Reports 2023 (JCR 2023), the IFs of the journals ranged from 2.9 to 6.9, with an average of 4.95, and 100% of the top 10 most published journals were distributed in Q1 and Q2. Among them, the 2023 impact factor of *Biomedicine & Pharmacotherapy* was the highest ($IF=6.9$), followed by *Ecotoxicology and Environmental Safety* ($IF=6.2$) and *International Immunopharmacology* ($IF=5.8$). Moreover, among the top 10 co-cited academic journals, the highest-cited journal was *Nature* ($n=1116$), followed by *Hepatology* ($n=813$) and *Journal of Hepatology* ($n=735$). Three journals in this area of research had an impact factor greater than 20, and *Nature* had the highest impact factor ($IF=50.5$). The top 10 co-cited journals were sorted into Q1 and Q2 regions based on the JCR standard. Significantly, *Nature*, *Cell*, *Hepatology*, and *Journal of Hepatology* were SCI's top international academic journals in various fields. The network visualization

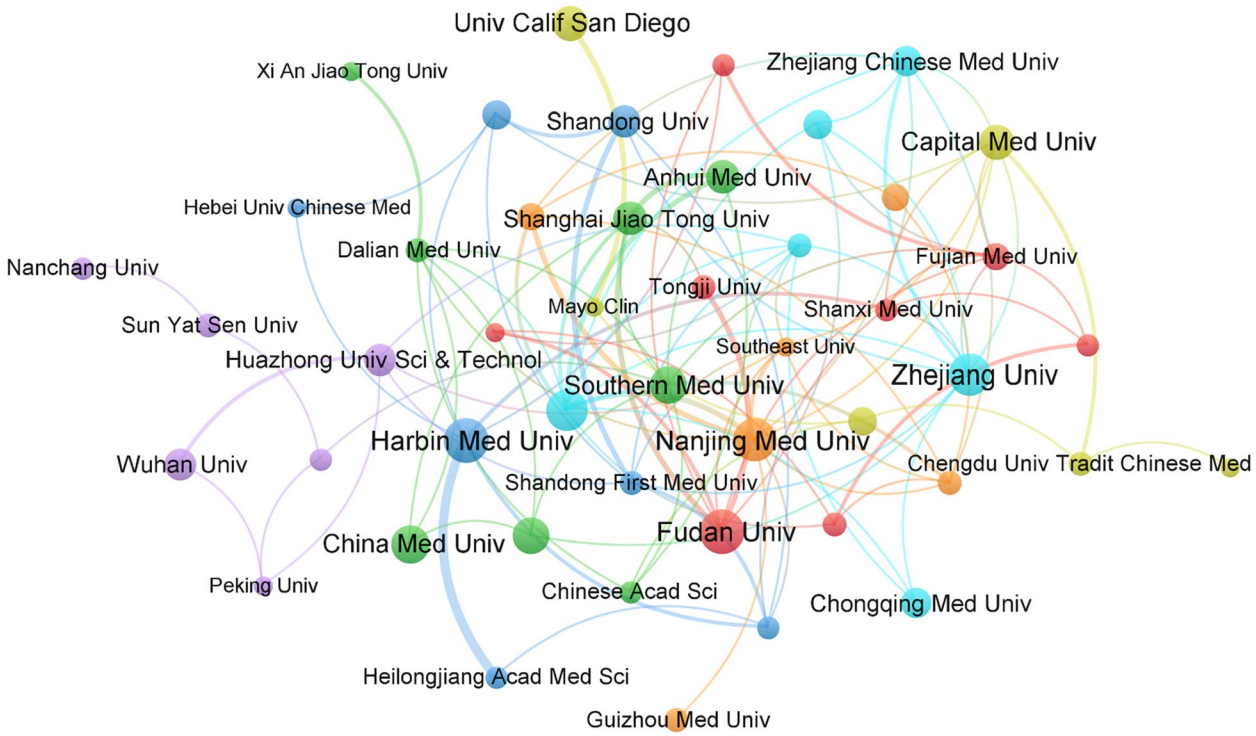

Fig. 4 Analysis of distribution and cooperation between the major institutions of publications

Table 2 Top 10 authors and co-cited authors related to pyroptosis and fibrosis

	Author	Documents	Citations	Average citations	Affiliation	H-index	Co-cited author	Co-citations
1	Feldstein, A. E	11	1331	121	University of California San Diego	72	Shi, J. J	211
2	Tao, H	7	76	10.86	Anhui Medical University	10	Wree, A	199
3	Hoffman, H. M	6	1062	177	University of California San Diego	58	Kayagaki, N	122
4	Li, Y	6	395	65.83	Helmholtz-Center for Infection Research	42	Liu, X	91
5	Pelegrin, P	6	546	91	Biomedical Research Institute of Murcia	57	Zhang, Y	91
6	Zhang, L	6	229	38.16	Jinan University	14	Mridha, A. R	85
7	Zhou, Y	5	234	46.8	Soochow University	8	Broz, P	83
8	Zhang, J	5	177	35.4	Shanghai Jiao Tong University	5	Gaul, S	75
9	Liu, Q	5	139	27.8	University of California, San Francisco	20	Man, S. M	73
10	Li, H	5	132	26.4	Shandong University	1	Lamkanfi, M	72

of journals and co-cited journals was evaluated by VOSviewer software (Fig. 6A, B), the division of highly productive journals and co-cited journals were divided into five different colored clusters, and the journals in the same-colored cluster had a strong correlation. With this visual analysis, it is possible to observe more directly that *Frontiers in Pharmacology* have a strong collaborative relationship with *Frontiers in Immunology* and *International Immunopharmacology*.

Co-cited references and references burst

CiteSpace was utilized for the co-cited references and reference bursts related to pyroptosis and fibrosis research. Table 4 presented some detailed information about the top 10 most co-cited articles in this research area, including title, number of citations, first author, centrality, and journal. Of these publications, *Cleavage of GSDMD by inflammatory caspases determines pyroptotic cell death* was the most cited reference. Additionally, 9 of the 10

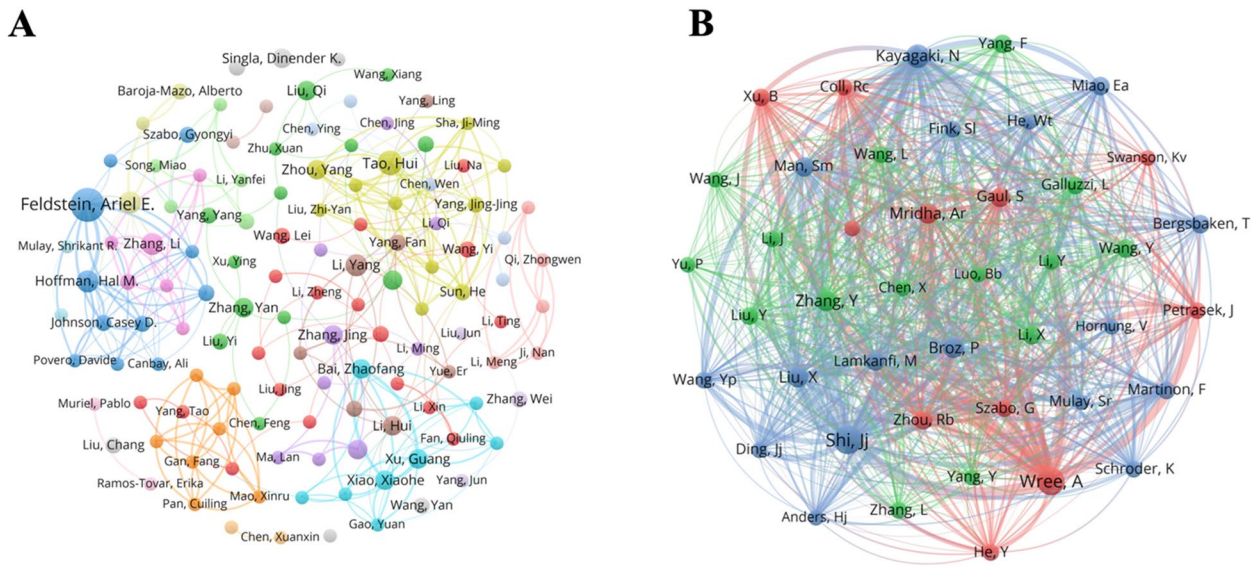

Fig. 5 Visualization diagrams of the distribution of **A** the authors and **B** the co-cited authors involved in research on pyroptosis and fibrosis

Table 3 Top 10 journals and co-cited journals related to fibrosis and pyroptosis

Rank	Journal	Count	IF (2023)	JCR (2023)	Co-cited journal	Citation	IF (2023)	JCR (2023)
1	*Frontiers in Immunology*	19	5.7	Q1	*Nature*	1116	50.5	Q1
2	*International Journal of Molecular Sciences*	18	4.9	Q1	*Hepatology*	813	12.9	Q1
3	*Frontiers in Pharmacology*	16	4.4	Q1	*Journal of Hepatology*	735	26.8	Q1
4	*International Immunopharmacology*	16	5.8	Q1	*Cell Death and Disease*	669	8.1	Q2
5	*Biomedicine and Pharmacotherapy*	14	6.9	Q1	*Cell*	542	45.5	Q1
6	*Journal of Inflammation Research*	13	4.2	Q2	*Frontiers in Immunology*	538	5.7	Q1
7	*Cells*	11	5.1	Q2	*International Journal of Molecular Sciences*	507	4.9	Q1
8	*PLOS One*	11	2.9	Q1	*PLOS One*	446	2.9	Q1
9	*Scientific Reports*	11	3.8	Q1	*Journal of Immunology*	460	3.6	Q2
10	*Ecotoxicology and Environmental Safety*	11	6.2	Q1	*Proceedings of the National Academy of Sciences of the United States of America*	458	9.4	Q1

most cited references in the field of pyroptosis and fibrosis research were published in Q1 and three in *Nature*, most of which were published after 2014. Based on these popular references, it can also be found that NLRP3 and inflammasome are frequent terms in this field. As displayed in Fig. 7, There were the top 25 references with the strongest citation bursts. And among these publications, all references' citation burstness appeared from 2012 to 2024. It is worth noting that 5 references were in burstness until 2024. As for the strongest burstness, an article entitled "Inflammatory caspases were innate immune receptors for intracellular LPS" with a strength of 13.79 came out in *Nature* by Shi, J. J. et al. in 2015. Furthermore, its citation burstness was from 2016 to 2020.

Frequency of keyword occurrence and clustering analysis

The frequency of keyword occurrence in the research of pyroptosis and fibrosis from 2010 to 2024 was analyzed and visualized by VOSviewer and CiteSpace. According to Table 5, the top 5 keywords included pyroptosis (332), fibrosis (198), activation (153), NLRP3 inflammasome (147), and inflammation (117). The co-occurrence network visualization of these keywords is shown in Fig. 8. Node size represents the frequency of the keyword, while the distance between nodes reflects the strength of their cooperative relationship. All keywords were divided into six clusters, and the more closely related keywords were assigned to the same cluster, indicating the critical topics in the domain of pyroptosis and fibrosis research.

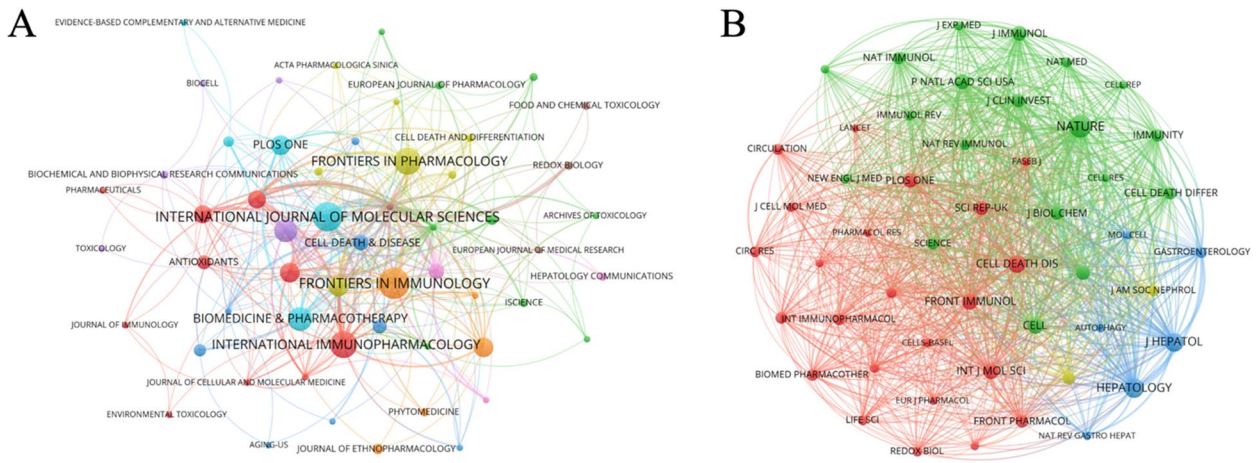

Fig. 6 Network visualization graphs of distribution and connection of **A** the journals and **B** co-cited journals on the studies of pyroptosis and fibrosis

Table 4 Top 10 co-cited references related to fibrosis and pyroptosis

Rank	References	Citations	First author	Affiliation	Journal	Publication year
1	Cleavage of GSDMD by inflammatory caspases determines pyroptotic cell death	112	Shi, J. J	Beijing Stanford University School of Humanities and Science	*Nature*	2015
2	NLRP3 inflammasome activation results in hepatocyte pyroptosis, liver inflammation, and fibrosis in mice	109	Wree, A	University of California San Diego	*Hepatology*	2014
3	NLRP3 inflammasome blockade reduces liver inflammation and fibrosis in experimental NASH in mice	84	Mridha, A	University of Sydney	*J Hepatol*	2017
4	Pyroptosis: gasdermin-mediated programmed necrotic cell death	78	Shi, J. J	Beijing Stanford University School of Humanities and Science	*Trends Biochem Sci*	2017
5	Hepatocyte pyroptosis and release of inflammasome particles induce stellate cell activation and liver fibrosis	75	Gaul, S	University of California San Diego	*J Hepatol*	2021
6	Inflammasome-activated gasdermin D causes pyroptosis by forming membrane pores	68	Liu, X	Harvard Medical School	*Nature*	2016
7	Pyroptosis: host cell death and inflammation	64	Bergsbaken, T	Rutgers University Biomedical & Health Sciences	*Nat Rev Microbiol*	2009
8	Caspase-11 cleaves gasdermin D for noncanonical inflammasome signalling	63	Kayagaki, N	Genentech Physiol Chem Dept	*Nature*	2015
9	Gasdermin D plays a key role as a pyroptosis executor of nonalcoholic steatohepatitis in humans and mice	58	Xu, B	Nanjing University	*J Hepatol*	2018
10	Gasdermin D is an executor of pyroptosis and required for interleukin-1β secretion	45	He, W. T	Scripps Research Institute	*Cell Res*	2015

As shown in Fig. 8, we can view green, red, orchid, blue, yellow, and purple clusters. Green clustering keywords were powerfully relevant to pyroptosis and liver fibrosis, such as "NLRP3 inflammasome," "oxidative stress," "liver fibrosis," and "hepatocyte pyroptosis." Red clustering keywords were associated with the pathogenesis of fibrosis, including "fibrosis," "inflammasome," "pathogenesis," and "gasdermin D." The keywords for the orchid cluster

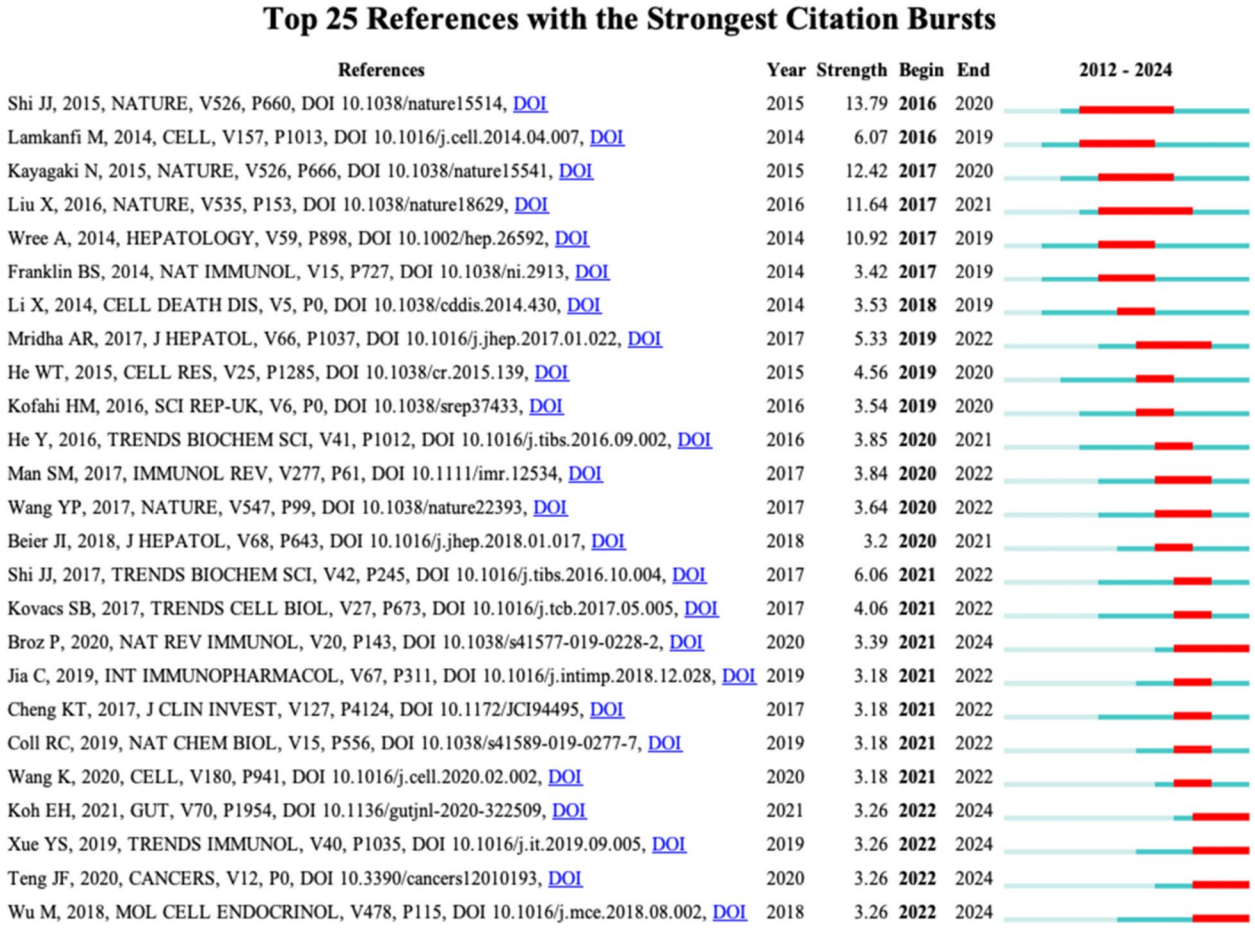

Fig. 7 CiteSpace visualization map of the top 25 references with the strong citation bursts involved in fibrosis and pyroptosis research

focused on the relationship between pyroptosis and cardiac fibrosis, including "pyroptosis," "dysfunction," and "cardiac fibrosis." The blue keyword cluster was in connection with pulmonary fibrosis harbored "inflammation," "mechanism," and "pulmonary fibrosis." The yellow keyword cluster was dominated by different modes of cell death, such as "apoptosis" and "necroptosis." Furthermore, the keywords for the purple cluster were mainly linked to autophagy in the development of fibrosis, consisting of "activation," "expression," and "autophagy." As shown in Fig. 8B, we presented the top 15 keywords with the most robust citation bursts. Among them, caspase 1 was the keyword with the strongest citation burst (strength = 4.06). Before 2016, the research hotspots were mainly concentrated on inflammation, cell death, and caspase 1 activation. However, after 2016, researchers put more effort into NLRP3, fatty liver disease, and therapy. The keyword "pathway" remained a buzzword between 2022 and 2024, suggesting that it is of great significance to explore the mechanism of pyroptosis and potential biomarkers for the diagnosis and treatment of fibrosis. Figure 8C displays the development and transformation of keywords in each cluster. It enables us to better realize the changes of a particular topic in one research field over time and understand promptly the field's development and frontiers.

Table 5 Top 10 keywords related to fibrosis and pyroptosis

Rank	Keyword	Occurrence
1	Pyroptosis	332
2	Fibrosis	198
3	Activation	153
4	NLRP3 inflammasome	147
5	Inflammation	117
6	Apoptosis	108
7	Oxidative stress	87
8	Cell death	73
9	Injury	67
10	Expression	66

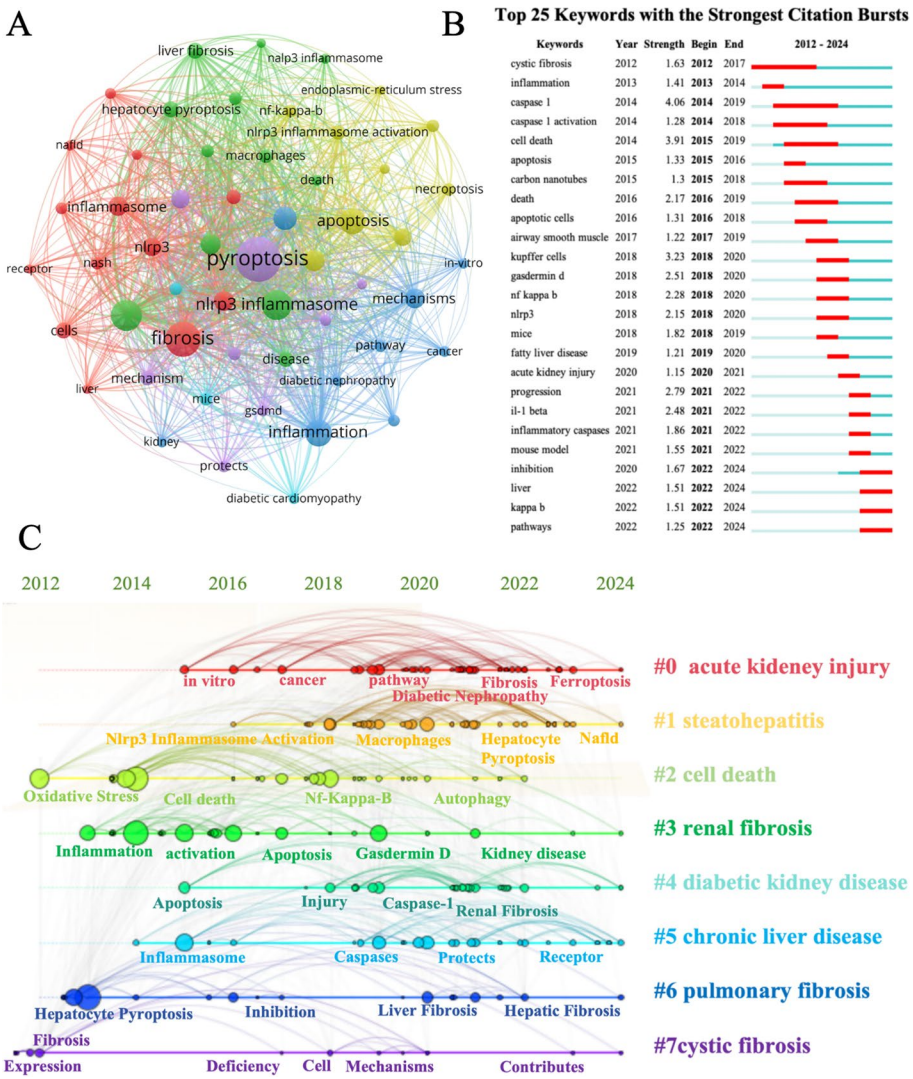

Fig. 8 **A** Visualization graph of keywords co-occurrence network and clusters in pyroptosis and fibrosis research. **B** CiteSpace visualization map of the top 25 keywords with the strongest citation bursts involved in pyroptosis and fibrosis. **C** Clustering analysis of keywords timeline viewer on pyroptosis and fibrosis

Discussion

Fibrotic diseases, characterized by the progressive pathological deposition of fibrotic tissue in multifarious organs, constitute one of the most significant causes of disability and death worldwide [52]. They have protean clinical features and can occur in virtually all organs, including the cardiac, pulmonary, pancreatic, kidney, liver, skin, and eye [2, 10, 14, 17, 25, 29, 44, 48]. The fibrogenic progress is a continuous and circulating developing process. Namely, primary organ injury occurs under various stimuli, and related fibrogenic effector cells are sustainably activated and reproduce abundant extracellular matrix protein and cytokines, etc. [6, 30]. This chain of dynamic events causes the formation of organ scars, further promotes the progression of organ fibrosis, and ultimately leads to organ dysfunction and even failure. Therefore, prevention and treatment of fibrosis are of decisive significance for the prognosis of fibrotic diseases, which need more attention and concern.

Bibliometric analysis is an effective and efficient method of literature analysis, which can capture the features and hotspots of publications and contribute to researchers promptly understanding an unfamiliar territory [38]. In this paper, through adopting Web of Science data and bibliometric methods, we have taken scientific papers as an important form of research output to comprehensively sort out and describe the

research output model, academic influence, national and regional distribution, international cooperation, and other aspects of this field from the perspective of pyroptosis and fibrosis. Although this quantitative analysis cannot provide a comprehensive understanding of the details of research on pyroptosis and fibrosis, it can reveal the current research status and development trends of pyroptosis and fibrosis research based on several characteristics.

Numerous studies have confirmed that pyroptosis can regulate inflammatory damage, signal transduction, and cell growth to affect the pathological process of fibrotic diseases [45]. However, research on the mechanism of pyroptosis in fibrotic diseases is still in its infancy. According to the data in the WoSCC database from 2010 to 2024, 566 articles have been published in this domain by 3833 researchers in 129 countries/regions. Since one article was published in this field from 2000 to 2010, the period chosen for this paper was from 2010 to 2024. It can be seen from Fig. 2 that the quantity of papers in this area has gradually increased over the past 15 years, especially in the period from 2018 to 2024, demonstrating that the studies of pyroptosis have captured more and more attention of scholars worldwide in the progression of fibrotic diseases. Analyzing the distribution of countries, regions, and institutions in Table 1 and Fig. 3, we found that the correlative research of pyroptosis and fibrosis across different countries or regions has been unbalanced. Among them, China was the world leader in terms of the number of publications, indicating China has a growing respect for exploring the function and mechanism of pyroptosis in fibrotic diseases and had a significant increase in the disciplinary output in this field. However, the centrality of China (centrality = 0.59) was less than that of the USA (centrality = 0.61), which implied that the USA occupies a more important position in international cooperation and is more influential in the field. Abundant and influential papers are more readily available through cooperation between countries or regions.

In terms of author publications and co-citation data in Table 2 and Fig. 5, Feldstein, A. E. was the author with the highest number of publications, while Tao, H., Hoffman, H. M., Li, Y., Pelegrin, P., and Zhang, L. from different countries rank next, indicating that these authors had a strong interest in this field. Professor Feldstein, A. E. had published 11 papers focused primarily on the relationship between pyroptosis and liver fibrosis, 3 of which investigated that the NLRP3 (NOD-, LRR-, and pyrin domain-containing protein 3) inflammasome causes and exacerbates the progression of liver fibrosis via activating pyroptosis [16, 22, 53]. Professor Feldstein, A. E. also discovered that SMS1(sphingomyelin synthase 1) mediated hepatocyte pyroptosis through a novel DAG-PKCd-NLRC4 axis and is expected to be a therapeutic target for nonalcoholic steatohepatitis (NASH) [26]. The remaining three papers reviewed research advances between inflammation, pyroptosis, and liver fibrosis in alcoholic and nonalcoholic liver diseases [1, 37, 54]. Besides, Tao, H. studied more on the relationships between fibrosis and pyroptosis in diabetic fibrosis, especially the connection between the regulation of various RNAs and fibrosis in diabetic cardiomyopathy. The research found that an upregulated miR-21 passenger strand (miR-21-3p) could promote cardiac fibroblast pyroptosis and fibrosis in a diabetic cardiomyopathy model by downregulating its target androgen receptor [43]. It was also revealed that methylation of DNMT3A reduced the expression of lncRNA Neat1 and promoted cardiac fibroblasts pyroptosis and cardiac fibrosis [12]. Moreover, it can be seen in Fig. 6 and Table 4 that the top-ranked co-cited author was Shi, J. J. with 211 citations. An article published by Shi, J. J. et al. in 2015 was at the top of the co-cited references (112 citations) and first elaborated that inflammatory caspase-stimulated cleavage of GSDMD plays a key role in pyroptosis as well as inflammation-induced fibrosis [42]. Additionally, according to the journals and co-cited journals in Table 3, the journal with the most publications about pyroptosis and fibrosis was *Frontiers in Immunology* ($n = 19$), followed by *International Journal of Molecular Sciences* ($n = 18$), and *Frontiers in Pharmacology* ($n = 16$), indicating that publications in this field were highly relevant to inflammation and immunology. The co-cited journals like *Nature* (1116), *Hepatology* (813), and *Journal of Hepatology* (735) are extremely influential in the medical field, and citing these articles also enhances the credibility of the publications.

NLRP3 inflammasomes have become hotspots and have played a crucial role in the field of pyroptosis and fibrosis in recent years. In terms of keywords in Table 5 and Fig. 8, whether it is the frequency of keyword occurrences, the number of citation bursts the timeline graphs, and inside the most cited publications, NLRP3 has a dense occurrence. According to Table 4, 3 of the top 10 publications in total citations were related to NLRP3. NLRP3 inflammasome, an essential member of the NLRs family, is the most important component of pattern recognition receptors (PRRs) and can be activated via multiple pathways to mediate pyroptosis [51]. In the classic pathway of pyroptosis, NLRP3 oligomerization is caused by the treatment of cells by lipopolysaccharide (LPS) (or other toll-like receptor ligands) with one of pathogen-associated molecular patterns (PAMPs)/damage-associated molecular patterns (DAMPs) [5, 46]. The adapter apoptosis-associated speck-like protein containing a CARD (ASC) and

effector caspase-1 are recruited downstream through PYD-PYD and CARD-CARD interactions to assemble into the NLRP3 inflammasome [9, 32]. The inflammasome serves as a platform that induces caspase-1 to cleave the substrates pro-IL-1β and pro-IL-18, as well as the pore-forming protein gasdermin D, thus leading to pyroptosis [21], whereas in the nonclassical pathway it has been found that NLRP3 inflammasome may be activated by caspase-11 directly sensed by caspase-11 after infection by gram-negative bacteria to activate IL-1β, IL-18, and gasdermin D, leading to pyroptosis [23, 41, 42]. In 2014, Were, Alexande directly pointed out the critical effect of NLRP3 inflammasome in liver fibrosis and pyroptosis. In mice with elevated NLRP3 expression, the number of pyroptosis-associated characteristic caspase-1 and PI double-positive cells was significantly increased. The hepatic stellate cell (HSC), strongly associated with the development of hepatic fibrosis, was activated, and collagen deposition appeared in the liver [53]. NLRP3-mediated cell death was inhibited by blockade of caspase-1 and inhibition of gasdermin D activation, suggesting that pyroptosis may be the main mode of NLRP3-mediated cell death. Whereas mice undergo fibrosis in the presence of Nlrp3KI CreA, this was due to phagocytosis of extracellular NLRP3 inflammatory vesicle particles by hepatic stellate cells, leading to increased IL-1β secretion and α-SMA expression [15]. Meanwhile, in 2014, Luo, B. B. et al. found that silencing NLRP3 in H9c2 cardiomyocytes was enabled to inhibit pyroptosis and ameliorated myocardial inflammation and fibrosis in a diabetic cardiomyopathy fibrosis model [33]. And in 2019, Qiu, Z. et al. found that lipopolysaccharide (LPS) activates the NLRP3 inflammasome in H9C2 cardiomyocytes by upregulating ROS production to induce further pyroptosis as well as fibrosis in their study of exacerbated I/R injury in diabetes [40]. In addition, NLRP3 plays a bridging function in kidney fibrosis. In 2014, Lorenz, G. et al. reviewed NLRP3 inflammasome in the kidney through activation of IL-1β, IL-18, and pyroptosis leading to renal inflammation and fibrosis [31]. And Krishnan, S. M. et al. in 2019 found that NLRP3 inhibitor MCC950 effectively inhibited inflammation and fibrosis in the kidney [28]. In unilateral ureteral occlusion, both NLRP3 and caspase-1 expression were significantly elevated, while renal fibrosis was reduced in the NLRP3 − / − condition [18, 50]. Finally, in the lung, NLRP3 also plays a central function in pyroptosis and fibrosis. In a mouse silicosis model, researchers found that bone marrow MSC treatment reduced the expression of NLRP3; cleaved caspase-1, IL-1β, and IL-18; inhibited pyroptosis; and attenuated lung fibrosis [57]. Overall, NLRP3 plays an important associative role between pyroptosis and fibrosis in different organs, indicating the close correlation between NLRP3 inflammasome, fibrosis disease, and pyroptosis.

As the first bibliometric analysis of pyroptosis in fibrotic diseases, this research is of great importance, but some limitations should be taken into account when analyzing these results. Firstly, all publications were searched using the Web of Science database with an authoritative and extensive database containing a vast majority of papers in the field, and some publications were omitted because they were not included in this database. Secondly, due to a continuously updated process of research in this field, recent articles will inevitably continue to be published, but not included in this paper after the search has been completed in the period. Finally, the bibliometric analysis tools do not introduce more analysis that reflects the quality indicators of the articles, which can also make the results not comprehensively and effectively reflect the critical authors or publications in the field. Despite the limitations mentioned above, we are of the opinion that this study can prove the overall progress and tendency of relevant research on the effect of pyroptosis in the development of fibrosis. Moreover, it provides significant insights and a ponderable reference for researchers to acquire objective data in fibrosis and pyroptosis research.

Conclusion

In summary, this study is the first bibliometric analysis based on the results of VOSviewer and CiteSpace exploring the contributions of countries, institutions, journals, authors, references, and keywords to analyze the research status and trends on pyroptosis and fibrosis for the past 15 years. The most publications and the top 10 research institutions in this domain were mainly from China. Feldstein, A. E. was the academic authority in this area in terms of the number of publications. *Frontiers in Immunology was* the journal with the most publications in this field, while *Nature* was the journal with the most citations. Research directions are mainly concerned with the mechanisms of pyroptosis in fibrotic diseases. These findings will enable researchers to better seek capable researchers to look for academic collaboration and exchange with authoritative scholars in the field, to keep abreast of present directions, and to explore future developing perspectives in pyroptosis and fibrotic diseases research.

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s13643-024-02703-0.

Supplementary Material 1.

Acknowledgements
Not applicable.

Authors' contributions
All authors listed have made a substantial, direct, and intellectual contribution to the work and approved it for publication.

Funding
This work was supported by the National Key R&D Program of China (2022YFC2402900), the National Natural Science Foundation of China (81700988), and the Provincial Natural Science Foundation of China (2021JJ40903) from the Central South University.

Data availability
Not applicable.

Declarations

Ethics approval and consent to participate
Not applicable.

Consent for publication
Not applicable.

Competing interests
The authors declare that they have no competing interests.

Author details
[1]Academician Workstation for Oral-Maxillofacial and Regenerative Medicine, Hunan 3D Printing Engineering Research Center of Oral Care, Hunan Clinical Research Center of Oral Major Diseases and Oral Health, Xiangya Stomatological Hospital, Xiangya School of Stomatology, Central South University, Changsha, Hunan 410008, China. [2]State Key Laboratory of Oral Diseases, Research Unit of Oral Carcinogenesis and Management, National Clinical Research Center for Oral Diseases, West China Hospital of Stomatology, ChineseAcademy of Medical Sciences, Sichuan University, Chengdu, Sichuan 610041, China. [3]Department of Histology and Embryology, Xiangya School of Medicine, Central South University, Changsha, Hunan, China.

Received: 12 July 2024 Accepted: 29 October 2024
Published online: 13 November 2024

References

1. Alegre F, Pelegrin P, Feldstein AE. Inflammasomes in liver fibrosis. Semin Liver Dis. 2017;37(2):119–27. https://doi.org/10.1055/s-0037-1601350.
2. Andrews JP, Marttala J, Macarak E, Rosenbloom J, Uitto J. Keloids: the paradigm of skin fibrosis - pathomechanisms and treatment. Matrix Biol. 2016;51:37–46. https://doi.org/10.1016/j.matbio.2016.01.013.
3. Aria M, Cuccurullo C. Bibliometrix: an R-tool for comprehensive science mapping analysis [Article]. J Informet. 2017;11(4):959–75. https://doi.org/10.1016/j.joi.2017.08.007.
4. Artlett CM. Inflammasomes in wound healing and fibrosis. J Pathol. 2013;229(2):157–67. https://doi.org/10.1002/path.4116.
5. Bauernfeind FG, Horvath G, Stutz A, Alnemri ES, MacDonald K, Speert D, Fernandes-Alnemri T, Wu J, Monks BG, Fitzgerald KA, Hornung V, Latz E. Cutting edge: NF-kappaB activating pattern recognition and cytokine receptors license NLRP3 inflammasome activation by regulating NLRP3 expression. J Immunol. 2009;183(2):787–91. https://doi.org/10.4049/jimmunol.0901363.
6. Bonnans C, Chou J, Werb Z. Remodelling the extracellular matrix in development and disease. Nat Rev Mol Cell Biol. 2014;15(12):786–801. https://doi.org/10.1038/nrm3904.
7. Boyack K. W., Klavans R. Creation of a highly detailed, dynamic, global model and map of science. J Assoc Inf Sci Technol. 2014;65(4):670–85.
8. Brandes U. A faster algorithm for betweenness centrality [Article]. J Math Sociol. 2001;25(2):163–77. https://doi.org/10.1080/0022250x.2001.9990249.
9. Cai X, Chen J, Xu H, Liu S, Jiang QX, Halfmann R, Chen ZJ. Prion-like polymerization underlies signal transduction in antiviral immune defense and inflammasome activation. Cell. 2014;156(6):1207–22. https://doi.org/10.1016/j.cell.2014.01.063.
10. Chanda D, Otoupalova E, Smith SR, Volckaert T, De Langhe SP, Thannickal VJ. Developmental pathways in the pathogenesis of lung fibrosis. Mol Aspects Med. 2019;65:56–69. https://doi.org/10.1016/j.mam.2018.08.004.
11. D'Souza CA, Heitman J. Dismantling the Cryptococcus coat. Trends Microbiol. 2001;9(3):112–3. https://doi.org/10.1016/s0966-842x(00)01945-4.
12. Ding JF, Zhou Y, Xu SS, Shi KH, Sun H, Tu B, Song K, Xuan HY, Sha JM, Zhao JY, Tao H. Epigenetic control of LncRNA NEAT1 enables cardiac fibroblast pyroptosis and cardiac fibrosis. Eur J Pharmacol. 2023;938: 175398. https://doi.org/10.1016/j.ejphar.2022.175398.
13. Friedlander AM. Macrophages are sensitive to anthrax lethal toxin through an acid-dependent process. J Biol Chem. 1986;261(16):7123–6.
14. Friedlander M. Fibrosis and diseases of the eye. J Clin Invest. 2007;117(3):576–86. https://doi.org/10.1172/jci31030.
15. Gaul S, Leszczynska A, Alegre F, Kaufmann B, Johnson CD, Adams LA, Wree A, Damm G, Seehofer D, Calvente CJ, Povero D, Kisseleva T, Eguchi A, McGeough MD, Hoffman HM, Pelegrin P, Laufs U, Feldstein AE. Hepatocyte pyroptosis and release of inflammasome particles induce stellate cell activation and liver fibrosis [Article]. J Hepatol. 2021;74(1):156–67. https://doi.org/10.1016/j.jhep.2020.07.041.
16. Gaul S, Leszczynska A, Alegre F, Kaufmann B, Johnson CD, Adams LA, Wree A, Damm G, Seehofer D, Calvente CJ, Povero D, Kisseleva T, Eguchi A, McGeough MD, Hoffman HM, Pelegrin P, Laufs U, Feldstein AE. Hepatocyte pyroptosis and release of inflammasome particles induce stellate cell activation and liver fibrosis. J Hepatol. 2021;74(1):156–67. https://doi.org/10.1016/j.jhep.2020.07.041.
17. Ginès P, Krag A, Abraldes JG, Solà E, Fabrellas N, Kamath PS. Liver cirrhosis. Lancet. 2021;398(10308):1359–76. https://doi.org/10.1016/s0140-6736(21)01374-x.
18. Guo H, Bi X, Zhou P, Zhu S, Ding W. NLRP3 deficiency attenuates renal fibrosis and ameliorates mitochondrial dysfunction in a mouse unilateral ureteral obstruction model of chronic kidney disease. Mediators Inflamm. 2017;2017:8316560. https://doi.org/10.1155/2017/8316560.
19. He X, Xu S, Tang L, Ling S, Wei X, Xu X. Insights into the history and tendency of liver transplantation for liver cancer: a bibliometric-based visual analysis. Int J Surg. 2024;110(1):406–18. https://doi.org/10.1097/js9.0000000000000806.
20. Henderson NC, Rieder F, Wynn TA. Fibrosis: from mechanisms to medicines. Nature. 2020;587(7835):555–66. https://doi.org/10.1038/s41586-020-2938-9.
21. Jorgensen I, Rayamajhi M, Miao EA. Programmed cell death as a defence against infection. Nat Rev Immunol. 2017;17(3):151–64. https://doi.org/10.1038/nri.2016.147.
22. Kaufmann B, Kui L, Reca A, Leszczynska A, Kim AD, Booshehri LM, Wree A, Friess H, Hartmann D, Broderick L, Hoffman HM, Feldstein AE. Cell-specific deletion of NLRP3 inflammasome identifies myeloid cells as key drivers of liver inflammation and fibrosis in murine steatohepatitis [Article]. Cell Mol Gastroenterol Hepatol. 2022;14(4):751–67. https://doi.org/10.1016/j.jcmgh.2022.06.007.
23. Kayagaki N, Stowe IB, Lee BL, O'Rourke K, Anderson K, Warming S, Cuellar T, Haley B, Roose-Girma M, Phung QT, Liu PS, Lill JR, Li H, Wu J, Kummerfeld S, Zhang J, Lee WP, Snipas SJ, Salvesen GS, Dixit VM. Caspase-11 cleaves gasdermin D for non-canonical inflammasome signalling. Nature. 2015;526(7575):666–71. https://doi.org/10.1038/nature15541.
24. Khalil GM, Crawford CA. A bibliometric analysis of US-based research on the behavioral risk factor surveillance system. Am J Prev Med. 2015;48(1):50–7. https://doi.org/10.1016/j.amepre.2014.08.021.

25. Kisseleva T, Brenner D. Molecular and cellular mechanisms of liver fibrosis and its regression. Nat Rev Gastroenterol Hepatol. 2021;18(3):151–66. https://doi.org/10.1038/s41575-020-00372-7.
26. Koh EH, Yoon JE, Ko MS, Leem J, Yun JY, Hong CH, Cho YK, Lee SE, Jang JE, Baek JY, Yoo HJ. Sphingomyelin synthase 1 mediates hepatocyte pyroptosis to trigger non-alcoholic steatohepatitis. Gut. 2021;70(10):1954–64. https://doi.org/10.1136/gutjnl-2020-322509.
27. Kovacs SB, Miao EA. Gasdermins: effectors of pyroptosis. Trends Cell Biol. 2017;27(9):673–84. https://doi.org/10.1016/j.tcb.2017.05.005.
28. Krishnan SM, Ling YH, Huuskes BM, Ferens DM, Saini N, Chan CT, Diep H, Kett MM, Samuel CS, Kemp-Harper BK, Robertson AAB, Cooper MA, Peter K, Latz E, Mansell AS, Sobey CG, Drummond GR, Vinh A. Pharmacological inhibition of the NLRP3 inflammasome reduces blood pressure, renal damage, and dysfunction in salt-sensitive hypertension [Article]. Cardiovasc Res. 2019;115(4):776–87. https://doi.org/10.1093/cvr/cvy252.
29. Liu M, de Juan L, Abad B, Cheng K. Cardiac fibrosis: myofibroblast-mediated pathological regulation and drug delivery strategies. Adv Drug Deliv Rev. 2021;173:504–19. https://doi.org/10.1016/j.addr.2021.03.021.
30. Long Y, Niu Y, Liang K, Du Y. Mechanical communication in fibrosis progression. Trends Cell Biol. 2022;32(1):70–90. https://doi.org/10.1016/j.tcb.2021.10.002.
31. Lorenz G, Darisipudi MN, Anders HJ. Canonical and non-canonical effects of the NLRP3 inflammasome in kidney inflammation and fibrosis [Review]. Nephrol Dial Transplant. 2014;29(1):41–8. https://doi.org/10.1093/ndt/gft332.
32. Lu A, Magupalli VG, Ruan J, Yin Q, Atianand MK, Vos MR, Schröder GF, Fitzgerald KA, Wu H, Egelman EH. Unified polymerization mechanism for the assembly of ASC-dependent inflammasomes. Cell. 2014;156(6):1193–206. https://doi.org/10.1016/j.cell.2014.02.008.
33. Luo BB, Li B, Wang WK, Liu XJ, Xia YF, Zhang C, Zhang MX, Zhang Y, An FS. NLRP3 gene silencing ameliorates diabetic cardiomyopathy in a type 2 diabetes rat model [Article]. Plos One. 2014;9(8). https://doi.org/10.1371/journal.pone.0104771.
34. Medina C, Leeuwen T. Seed journal citation network maps: a method based on network theory. J Am Soc Inform Sci Technol. 2012;63(6):1226–34.
35. Mirakyan M. ABCDE: Approximating Betweenness-Centrality ranking with progressive-DropEdge. PeerJ Comput Sci. 2021;7: e699. https://doi.org/10.7717/peerj-cs.699.
36. Montazeri A, Mohammadi S, P, M. H., Ghaemi, M., Riazi, H., & Sheikhi-Mobarakeh, Z. Preliminary guideline for reporting bibliometric reviews of the biomedical literature (BIBLIO): a minimum requirements. Syst Rev. 2023;12(1):239. https://doi.org/10.1186/s13643-023-02410-2.
37. Osna NA, Eguchi A, Feldstein AE, Tsukamoto H, Dagur RS, Ganesan M, New-Aaron M, Arumugam MK, Chava S, Ribeiro M, Szabo G. Cell-to-cell communications in alcohol-associated liver disease. FrontPhysiol. 2022;13. https://doi.org/10.3389/fphys.2022.831004.
38. Pan X, Yan E, Cui M, Hua W. Examining the usage, citation, and diffusion patterns of bibliometric mapping software: a comparative study of three tools [Article]. J Informet. 2018;12(2):481–93. https://doi.org/10.1016/j.joi.2018.03.005.
39. Pritchard A. Statistical bibliography or bibliometrics. J Doc. 1969;25:348.
40. Qiu Z, He Y, Ming H, Lei S, Leng Y, Xia ZY. Lipopolysaccharide (LPS) aggravates high glucose-and hypoxia/reoxygenation-induced injury through activating ROS-dependent NLRP3 inflammasome-mediated pyroptosis in H9C2 cardiomyocytes. J Diabetes Res. 2019;2019(1):8151836. https://doi.org/10.1155/2019/8151836.
41. Ramirez MLG, Poreba M, Snipas SJ, Groborz K, Drag M, Salvesen GS. Extensive peptide and natural protein substrate screens reveal that mouse caspase-11 has much narrower substrate specificity than caspase-1. J Biol Chem. 2018;293(18):7058–67. https://doi.org/10.1074/jbc.RA117.001329.
42. Shi J, Zhao Y, Wang K, Shi X, Wang Y, Huang H, Zhuang Y, Cai T, Wang F, Shao F. Cleavage of GSDMD by inflammatory caspases determines pyroptotic cell death. Nature. 2015;526(7575):660–5. https://doi.org/10.1038/nature15514.
43. Shi P, Zhao XD, Shi KH, Ding XS, Tao H. MiR-21-3p triggers cardiac fibroblasts pyroptosis in diabetic cardiac fibrosis via inhibiting androgen receptor. Exp Cell Res. 2021;399(2): 112464. https://doi.org/10.1016/j.yexcr.2020.112464.
44. Singh VK, Yadav D, Garg PK. Diagnosis and management of chronic pancreatitis: a review. JAMA. 2019;322(24):2422–34. https://doi.org/10.1001/jama.2019.19411.
45. Song Z, Gong Q, Guo J. Pyroptosis: mechanisms and links with fibrosis. Cells. 2021;10(12):3509. https://doi.org/10.3390/cells10123509.
46. Sutterwala FS, Ogura Y, Szczepanik M, Lara-Tejero M, Lichtenberger GS, Grant EP, Bertin J, Coyle AJ, Galán JE, Askenase PW, Flavell RA. Critical role for NALP3/CIAS1/cryopyrin in innate and adaptive immunity through its regulation of caspase-1. Immunity. 2006;24(3):317–27. https://doi.org/10.1016/j.immuni.2006.02.004.
47. Synnestvedt MB, Chen C, Holmes JH. CiteSpace II: visualization and knowledge discovery in bibliographic databases. AMIA Annu Symp Proc. 2005;2005:724–8.
48. Tang PM, Nikolic-Paterson DJ, Lan HY. Macrophages: versatile players in renal inflammation and fibrosis. Nat Rev Nephrol. 2019;15(3):144–58. https://doi.org/10.1038/s41581-019-0110-2.
49. van Eck NJ, Waltman L. Citation-based clustering of publications using CitNetExplorer and VOSviewer. Scientometrics. 2017;111(2):1053–70. https://doi.org/10.1007/s11192-017-2300-7.
50. Vilaysane A, Chun J, Seamone ME, Wang W, Chin R, Hirota S, Li Y, Clark SA, Tschopp J, Trpkov K, Hemmelgarn BR, Beck PL, Muruve DA. The NLRP3 inflammasome promotes renal inflammation and contributes to CKD. J Am Soc Nephrol. 2010;21(10):1732–44. https://doi.org/10.1681/ASN.2010020143.
51. Wang L, Hauenstein AV. The NLRP3 inflammasome: mechanism of action, role in disease and therapies. Mol Aspects Med. 2020;76: 100889. https://doi.org/10.1016/j.mam.2020.100889.
52. Weiskirchen R, Weiskirchen S, Tacke F. Organ and tissue fibrosis: molecular signals, cellular mechanisms and translational implications. Mol Aspects Med. 2019;65:2–15. https://doi.org/10.1016/j.mam.2018.06.003.
53. Wree A, Eguchi A, McGeough MD, Pena CA, Johnson CD, Canbay A, Hoffman HM, Feldstein AE. NLRP3 inflammasome activation results in hepatocyte pyroptosis, liver inflammation, and fibrosis in mice [Article]. Hepatology. 2014;59(3):898–910. https://doi.org/10.1002/hep.26592.
54. Wree A, Holtmann TM, Inzaugarat ME, Feldstein AE. Novel drivers of the inflammatory response in liver injury and fibrosis [Review]. Semin Liver Dis. 2019;39(3):275–82. https://doi.org/10.1055/s-0039-1685515.
55. Wynn TA. Cellular and molecular mechanisms of fibrosis. J Pathol. 2008;214(2):199–210. https://doi.org/10.1002/path.2277.
56. Zhang X, Yi K, Xu JG, Wang WX, Liu CF, He XL, Wang FN, Zhou GL, You T. Application of three-dimensional printing in cardiovascular diseases: a bibliometric analysis. Int J Surg. 2024;110(2):1068–78. https://doi.org/10.1097/js9.0000000000000868.
57. Zhao Q, Hao C, Wei J, Huang R, Li C, Yao W. Bone marrow-derived mesenchymal stem cells attenuate silica-induced pulmonary fibrosis by inhibiting apoptosis and pyroptosis but not autophagy in rats. Ecotoxicol Environ Saf. 2021;216: 112181. https://doi.org/10.1016/j.ecoenv.2021.112181.

Publisher's Note