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ORIGINAL ARTICLE

Visual analysis of subarachnoid hemorrhage research hotspots based on CiteSpace and VOSviewer: A retrospective study

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Abstract

OBJECTIVE: To analyze the hotspots and frontiers in the field of subarachnoid hemorrhage using the bibliometrics method and providing references for academic research.

METHODS: All published studies related to subarachnoid hemorrhage published in the Web of Science core database from 1 January 2016 to 25 September 2021 were retrospectively identified using VOSviewer and CiteSpace software. Visualization VOSviewer and CiteSpace software were used to perform statistical and cluster analyses on authors, countries, institutions, keywords, and co-cited documents. Knowledge graphs were drawn.

RESULTS: A total of 7151 research papers related to subarachnoid hemorrhage were included for analysis. The number of papers on subarachnoid hemorrhage research showed an upward trend. The leading countries in subarachnoid hemorrhage research were the United States, China, and Japan. In addition, the Harvard Medical School, the Mayo Clinic, and the Capital Medical University were leading authorities subarachnoid hemorrhage research. The common keywords formed 7 clusters. There were 13 clusters of citations.

CONCLUSIONS: Research hotspots and directions in subarachnoid hemorrhage research were identified, such as cerebral aneurysm, early brain injury, vasospasm, and prognosis model.

INTRODUCTION

Subarachnoid hemorrhage (SAH) is a serious condition in which blood leaks into the space between the brain and the thin membrane that covers the brain (i.e., the subarachnoid space). Typically, a SAH manifests abruptly with a severe state, high mortality rate, and high disability rate. Ruptured intracranial aneurysms are the primary reason for SAH in most cases (75%–85%), while the worldwide occurrence of intracranial aneurysms is estimated to be approximately 6% (Achrén *et al.* 2022). The clinical presentation of SAH is variable, but typically includes an intense headache, nausea, vomiting, meningeal irritation, and altered consciousness. Blood enters the subarachnoid space when a cerebrovascular rupture develops, leading to elevated intracranial pressure and further impairing normal brain function. Untreated SAH is potentially fatal if not treated promptly (Cheng *et al.* 2021; Medeiros *et al.* 2022; Callen *et al.* 2023). Current research has primarily concentrated on the brain damage that initially occurs following SAH and the development of prediction models. This research has significantly enhanced our understanding of the early detection of SAH. In recent years bibliometric analysis has gained popularity as a method for assessing the contributions of authors, journals, organizations, and countries, as well as identifying trends and hotspots in specific research areas. Bibliometrics efficiently analyzes various aspects of the literature, such as publication time, country/region, research direction, publishing institutions, and journals. Bibliometrics helps track the development of cutting-edge issues in a specific discipline or field, identify research hotspots, and stay current with the latest progress. Bibliometrics also aids scholars in gaining a macroscopic understanding of relevant research.

Bibliometrics uses specific software for the purpose of visual analysis. VOSviewer is a software program created by van Eck and Waltman from the Leiden University Center for Science and Technology Studies in 2009. VOSviewer is written in the JAVA programming language and is primarily designed for visually analyzing scientific information using book data (Eck & Waltman, 2010). CiteSpace is a visual analysis software created by Professor Chen Chaomei, an American researcher. CiteSpace has been extensively utilized in information science, computer science, medicine, and various other sectors, including neuroscience research (Fei *et al.* 2023). A scientific knowledge graph analysis on the research status and frontiers in the field of SAH was performed in the current study by combining the above two methodologies. This analysis serves as the basis for future research on related concerns of SAH. Bibliometric analysis is highly beneficial when applied to the field of SAH. Liang *et al.* (2023) did a comprehensive search and analysis of papers and related information on delayed cerebral ischemia (DCI) after SAH in the Web of Science Core Collection from 2013–2022. The researchers utilized VOSviewer software to do a comprehensive analysis and visualization of the collected data, unveiling the current research status, focal points, and emerging trends in the field of DCI. The scope of the research was restricted to the specific

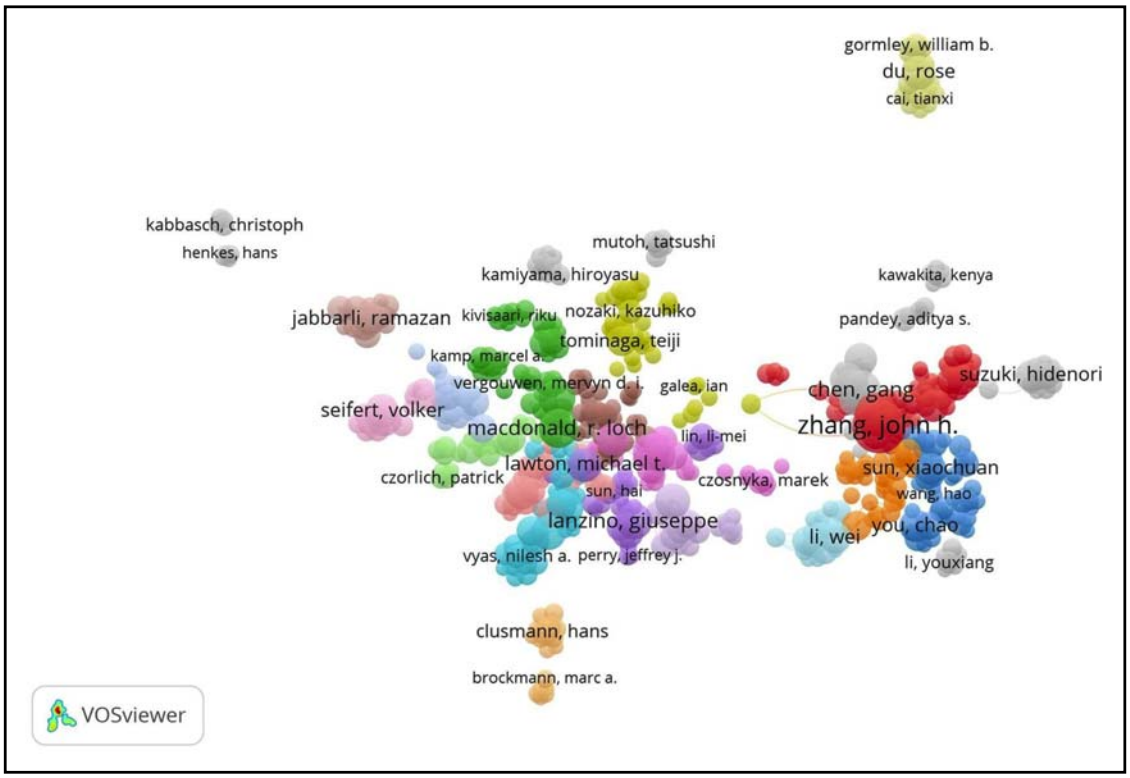

Fig. 1. Cluster analysis of authors by VOSviewer.

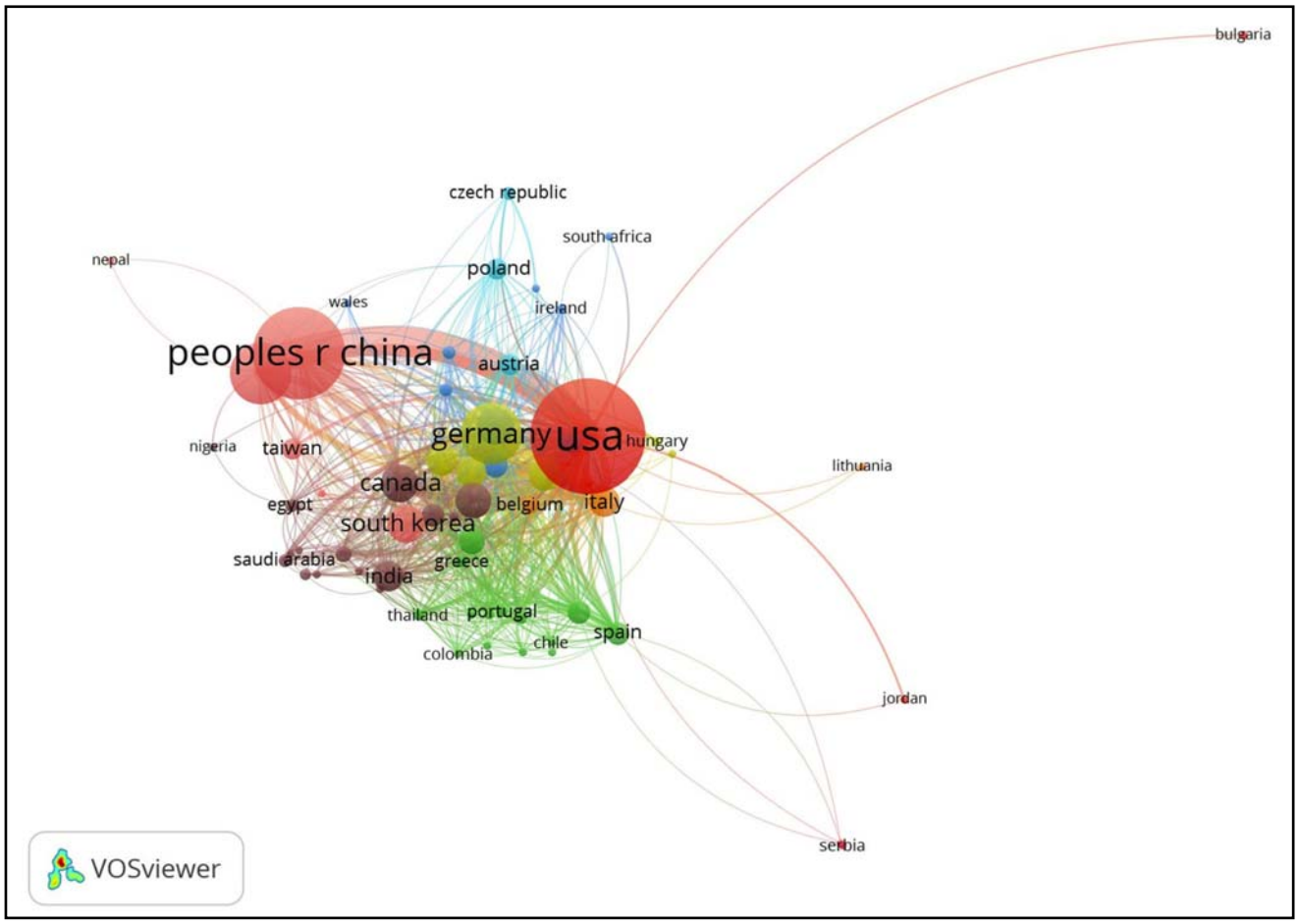

Fig. 2. Co-occurrence mapping of issuing countries.

categories of "DCI" "delayed ischemic neurological deterioration," and "delayed cerebral infarction," as well as search terms in the titles related to "DCI." This deliberate selection excluded a significant number of publications that primarily focused on SAH.7 The focus of SAH tendencies warrants continued investigation.

The current study utilized the commonly used bibliometric analysis tools, CiteSpace and VOSviewer, to thoroughly investigate the field of SAH. The analysis was performed on publications obtained from the Web of Science Core Collection between 2016 and 2021, using the search term "subarachnoid hemorrhage." Specifically, the analysis identified the focal points and patterns in the domain of SAH between 2016 and 2021.

MATERIALS AND METHODS

Source of Materials

The ethical approval for this retrospective study was waived by the Institutional Ethical Review Board of PLA 960th Hospital because this study did not involve with humans or animals.

The data for this study were retrospectively retrieved from the Web of Science Core Collection database using the theme word "subarachnoid hemorrhage." The time limit was set from 2016–2021, with a cut-off date of 25 September 2021. A total of 10,157 references were retrieved. The literature type was limited to articles, excluding duplicates, reviews, and conference abstracts. The language was limited to English. A total of 7151 articles were exported in the form of "full records and cited references" and downloaded and saved as plain text files. These files were then imported into VOSviewer and CiteSpace 5.7 R5 software for analysis.

Statistical Analysis

Statistical analysis of the included literature was performed using VOSviewer and CiteSpace 5.7 R5 software. Knowledge maps were drawn based on the analysis results of parameters, such as authors, countries and institutions, journals, keywords, and co-cited literature. Through interpretation of frequency, clustering, burstiness, and other aspects, a comprehensive understanding of the research status, hotspots, and development trends in this field was obtained.

RESULTS

Basic Analysis

Publication of papers reflects research achievements and the distribution characteristics of the annual publication volume are important for evaluating the research

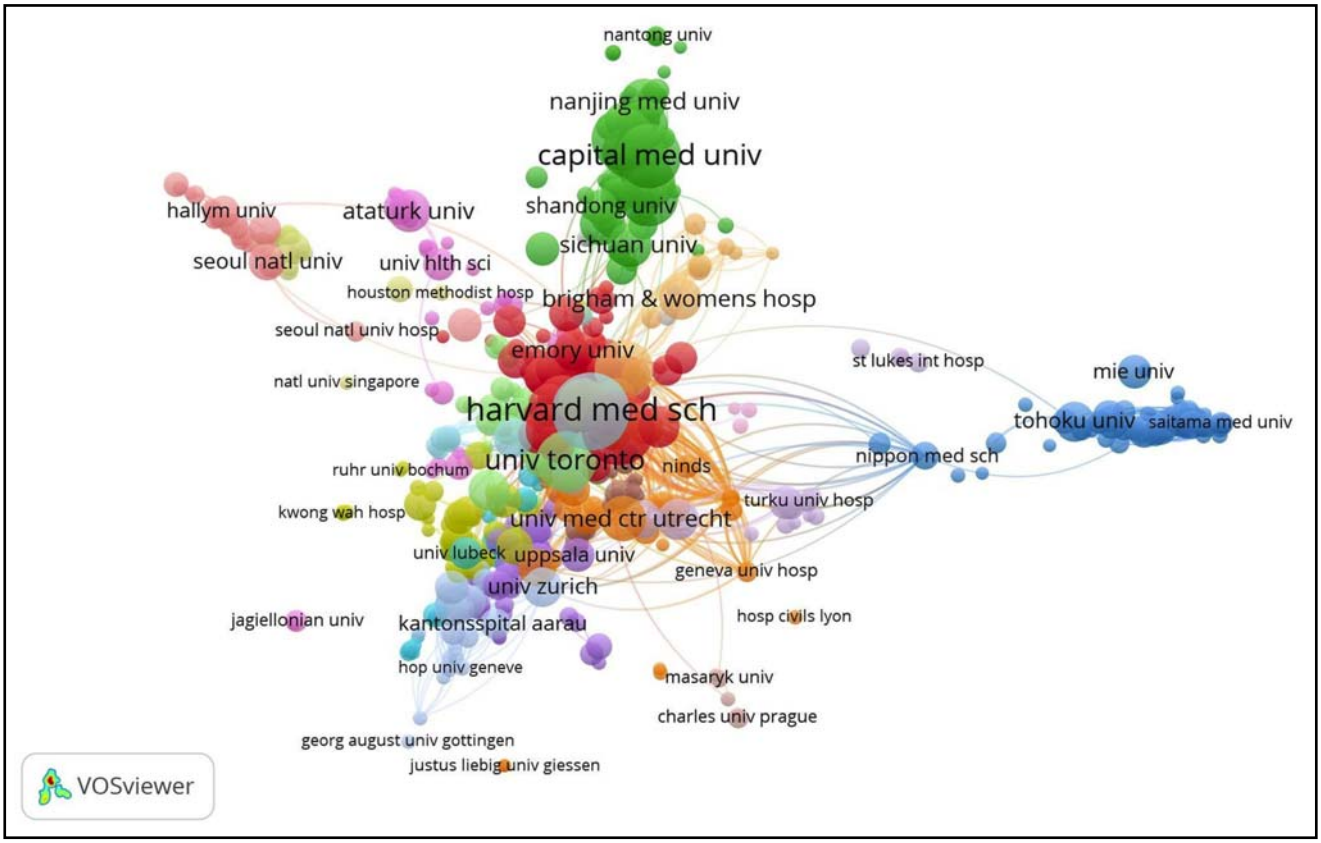

Fig. 3. Co-occurrence mapping of research institutions.

status and progress in a specific field. In the past 5 years the number of articles on SAH has stabilized at >1000 per year: 1141 articles in 2016, 1273 articles in 2017, 1307 articles in 2018, 1234 articles in 2019, 1340 articles in 2020, and 856 articles in 2021(data recorded up to September). There was a slight decrease in 2019 (1234 articles). The statistics for 2021 only covered the period up to September and do not represent a decline in the annual publication volume. From 1141 articles published in 2016 to 1340 articles in 2020, there was an increasing publication volume trend year-after-year.

Tab. 1. Top 10 research institutions with the highest number of publications on subarachnoid hemorrhage

Rank	Institution	Number of publications
1	Harvard Medical School	167
2	Mayo Clinic	150
3	Capital Medical University	118
4	Zhejiang University	113
5	University of Toronto	103
6	Loma Linda University	98
7	Massachusetts General Hospital	97
8	Soochow University	78
9	Johns Hopkins University	73
10	University of California at San Francisco	72

Distribution of Authors

A total of 29,195 authors were counted in VOSviewer. The author with the highest number of publications was John H Zhang (80 articles), followed by Tang Jiping (52 articles), Chen Gang (45 articles), MacDonald Loch (44 articles), and Aydin Murat Demir (41 articles). According to Price's law, one-half of the papers are written by a group of high-production authors in the same subject area. The number of this author set is approximately equal to the square root of the total number of authors. The minimum number of publications for a core author is 7, according to the following formula: $Mp=0.749\times\sqrt{Npmax}$, where Npmax is the number of papers published by the author with the highest productivity (Huang *et al.* 2024). There were 686 authors with >7 publications, accounting for 2.35% of the total number of publications (686/29,195). Therefore, the minimum number of author citations was set to 7 for cluster analysis and 25 research groups were identified (Figure 1). John H Zhang, who holds a position at Loma Linda University (Loma Linda, CA, USA), is the author with the highest number of publications. His research focuses on the protection of early brain injury in SAH and the role and changes of cortical inhibition.

Tab. 2. Top 10 journals publishing research on subarachnoid hemorrhage

Rank	Journal	Number of publications	2020 IF (country)
1	World Neurosurgery	725	1.829 (USA)
2	Journal of Neurosurgery	218	3.968 (USA)
3	Neurocritical Care	197	2.72 (USA)
4	Stroke	169	7.19 (USA)
5	Journal of Stroke & Cerebrovascular Diseases	167	0 (USA)
6	Acta Neurochirurgica	128	1.817 (Austria)
7	Journal of Neurointerventional Surgery	115	4.460 (England)
8	Neurosurgery	114	4.853 (USA)
9	Journal of Clinical Neuroscience	106	1.760 (Scotland)
10	Frontiers in Neurology	98	2.889 (Switzerland)

Distribution of Countries and Institutions

Analysis of countries was performed in VOSviewer by selecting the network node, "country." One hundred twelve countries were involved and the system defaulted to include countries with >5 publications, resulting in a final count of 67 countries (Figure 2). The top 5 countries were the United States (2059), China (1383), Japan (671), Germany (658), and Canada (270).

By selecting the network node, "institute," 5671 institutions were identified and 690 institutions with >5 publications were counted. The top 10 institutions with respect to publication volume are listed in Table 1. Six of the top 10 institutions were from the United States, which is one of the factors contributing to the United States leading among institutions in this field. Three institutions are from China (Capital Medical University, Zhejiang University, and Soochow University). Figure 3 is a clustering map of the publishing institutions, in which the size of the nodes reflects the number of publications and the lines connecting the nodes indicate collaborative relationships.

Statistics on Publishing Journals

A total of 6851 articles specifically related to SAH were published in 756 journals. Table 2 lists the top 10 journals that have published the most research findings on SAH. Notably, six of these journals are from the United States, establishing the leading position of the United States in this field of neuroscience.

Keyword Statistics

Among the 16,480 keywords analyzed, 498 had a frequency of >20. After merging similar keywords, the top 10 keywords were as follows: SAH (4240 occurrences); intracranial aneurysm, including aneurysm, cerebral aneurysm, aneurysmal subarachnoid hemorrhage (2495 occurrences); vasospasm, including cerebral vasospasm (1102 occurrences); stroke (798 occurrences); risk, including risk factor

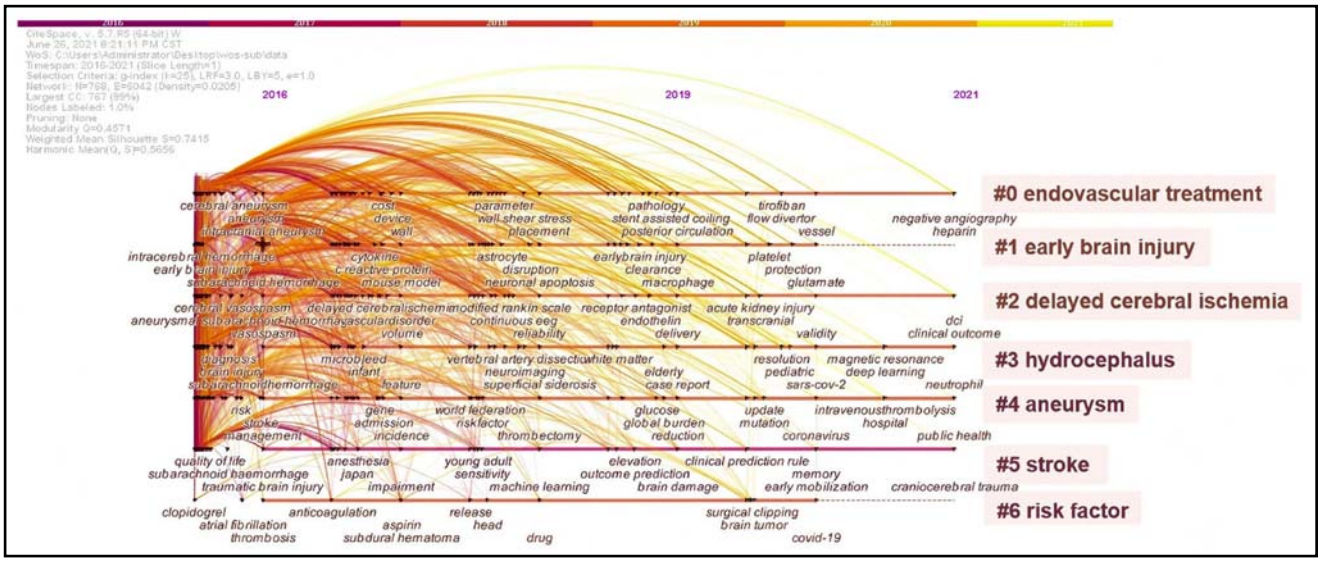

Fig. 4. Time-series mapping of keyword clustering.

Tab. 3. Results of keyword burst analysis

Keywords	Year	Strength	Begin	End	2016-2021
Gender	2016	5.08	2016	2017	
Clinical article	2016	4.85	2016	2018	
Ventriculostomy	2016	4.44	2016	2017	
Spinal cord injury	2016	4.41	2016	2017	
In vivo	2016	4.17	2016	2017	
Ruptured cerebral neurysm	2016	4.12	2016	2017	
Japan	2016	4.77	2017	2018	
Aneurysm surgery	2016	4.49	2017	2018	
Moyamoya disease	2016	4.49	2017	2018	
randomized trial	2016	4.21	2017	2018	
Neuronal apoptosis	2016	8.25	2018	2019	
Signaling pathway	2016	4.31	2018	2019	
Elderly	2016	5.68	2019	2021	
Macrophage	2016	5.01	2019	2021	
Reduction	2016	5.01	2019	2021	
Posterior circulation	2016	4.34	2019	2021	
Stent-assisted coiling	2016	4.34	2019	2021	
Brain damage	2016	4.34	2019	2021	
Global burden	2016	4.01	2019	2021	

(1060 occurrences); traumatic brain injury (409 occurrences); early brain injury (388 occurrences); mortality (387 occurrences); DCI (386 occurrences); and inflammation (343 occurrences).

Keyword Clustering

Using the log-likelihood ratio algorithm, CiteSpace grouped similar, related, and thematic keywords together. The primary metrics for evaluating clustering are the modularity value (Q-value) and the mean silhouette value (S-value). A Q-value > 0.3 indicates a significant clustering structure, while an S-value > 0.7 suggests a convincing clustering and an S-value > 0.5 is considered reasonable. In this analysis a total of 7 keyword clusters were obtained with a Q-value of 0.45 and an S-value of 0.74, indicating a convincing clustering that reflects the main research content and directions (Figure 4). The clusters are labeled as follows: #0 endovascular treatment; #1 early brain injury; #2 DCI; #3 hydrocephalus; #4 aneurysm; #5 stroke; and #6 risk factor.

Burst Analysis of Keywords

Using burst detection technology, CiteSpace analyzed the changes in the popularity of keyword co-occurrences and identified 19 burst keywords (Table 3). The keywords that remained popular in 2021 included elderly, macrophage, reduction, posterior circulation, stent-assisted coiling, brain damage, and global burden.

Analysis of Cited Documents

The number of "co-citations" of a document can reflect the key points, hot topics, and recognition in a field, while changes in the number of co-citations can indicate the frontiers of the discipline. Using CiteSpace to conduct a network analysis of cited documents (Figure 5), the reference with the largest node size and the highest citation frequency was Connolly (Connolly *et al.* 2012), which involves the American Heart Association/American Stroke Association's Guidelines for Healthcare Professionals in the Treatment of Aneurysmal Subarachnoid Hemorrhage.

Clustering the cited documents (N%100%, log-likelihood ratio algorithm) yielded a Q-value of 0.64 and an S-value of 0.8, indicating a convincing clustering result. Thirteen clusters were formed (Figure 6), including #0 aneurysmal subarachnoid hemorrhage, #1 intracranial aneurysm, #2 early brain injury, #3 unruptured intracranial aneurysm, #4 angiogram-negative subarachnoid hemorrhage, #5 intracerebral hemorrhage, #6 mechanical thrombectomy, #7 blister aneurysm, #8 spreading depolarization, #9 new mechanism, #10 shunt-dependent hydrocephalus, #11 human intervention-free clinical diagnosis, and #12 COVID-19 patient.

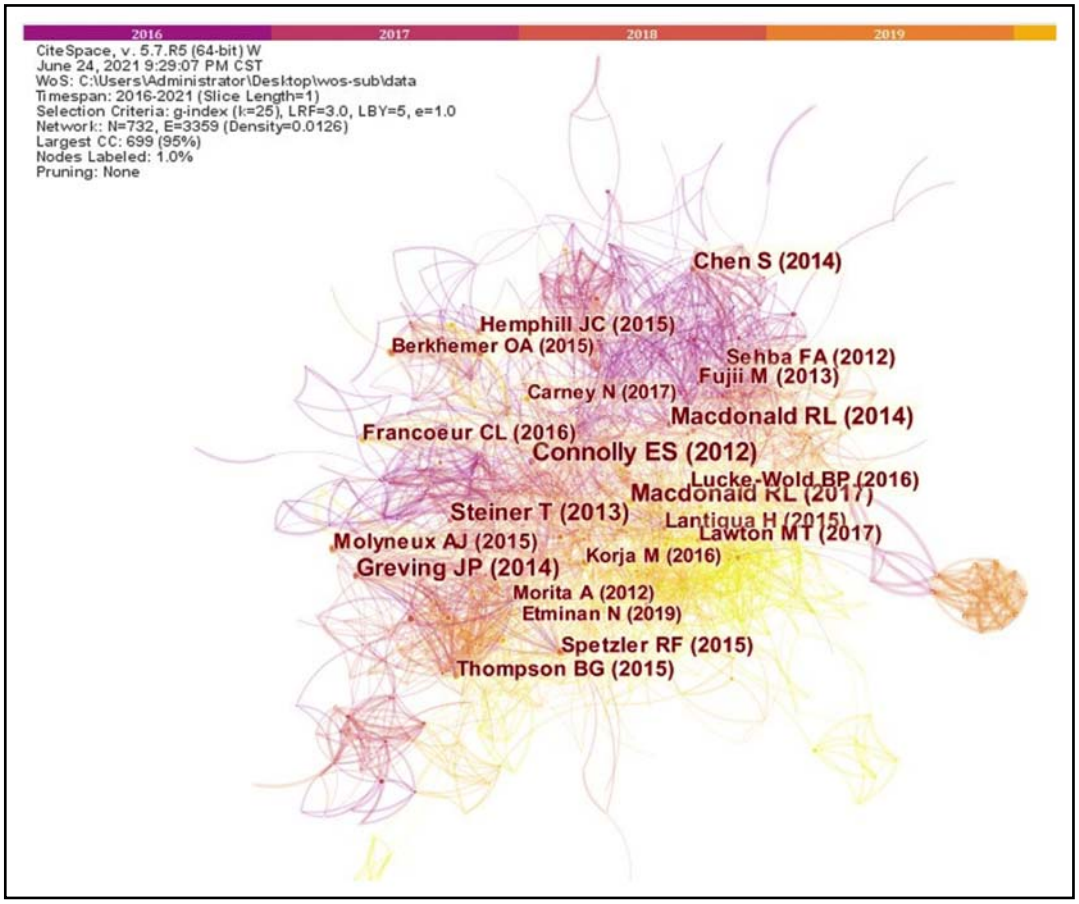

Fig. 5. Co-occurrence map of cited references.

DISCUSSION

Increasing Attention in the Field of SAH Research

A visual analysis of pertinent SAH literature in the Web of Science database was performed utilizing the bibliometric visualization analysis software of CiteSpace and VOSviewer. The results revealed that from 2016–2021 research growth in SAH has been rapid with > 1000 SCI publications produced annually on this issue. The number of publications has been increasing year-after-year, demonstrating that this discipline remains a hot issue of interest with great development potential. China is second in the number of published articles in this field with 4 of the top 10 research institutions. This finding illustrates the influence and voice of China in this sector. As one of the countries with a high incidence of SAH, lowering the morbidity and limiting bad outcomes is clinically significant.

Frontiers and Hotspots in SAH Research

Hotspot keywords include SAH, intracranial aneurysm, stroke, vasospasm, risk factors, traumatic brain injury, early brain injury, mortality, and delayed cerebral hemorrhage. Keyword burst analysis in 2021 showed that the elderly, macrophages, reduction, posterior circulation, stent-assisted coil embolization, brain damage, and global burden of disease were hot subjects. Each cluster was formed of many closely related words, numbered from 0–6. The smaller the number, the more keywords included in the cluster. The seven thematic keywords for keyword clustering are as follows: endovascular treatment; early brain injury; DCI; hydrocephalus; aneurysm; stroke; and risk factors. CiteSpace groups closely relates keywords through algorithms and assigns a value to each keyword, selecting the keyword with the largest value as the label for that cluster. Endovascular treatment is the largest clustering label, covering phrases, such as SAH, endovascular surgery, prediction, animal models, hydrocephalus, coils, stents, and stent retrievers. Rupture of aneurysms is the primary cause of SAH. Endovascular therapy is one of the most active research fields. Analyzing the larger nodes in the timeline graph, which represent more frequently cited and classic literature, Dengler *et al.* (2019) observed that the mortality and rupture rates of intracranial aneurysms treated surgically or endovascularly were lower than those treated conservatively after observing the natural history and 1-year mortality rates of 581 patients with giant intracranial aneurysms. A 10-year follow-up of the British aneurysm trial demonstrated that the health-related quality of life following endovascular coil embolization was higher than after surgical clipping and had an essential role in long-term therapy adjustments for life years (Hua *et al.* 2021).

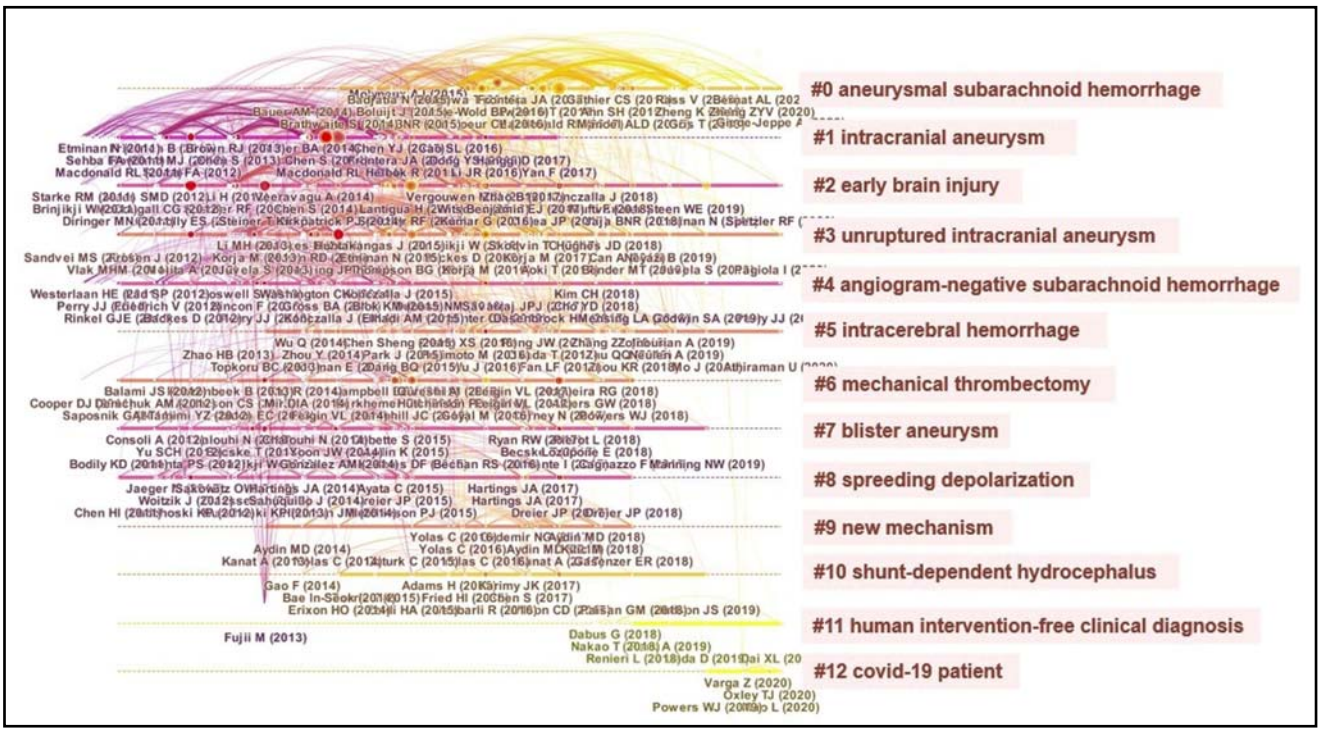

Fig. 6. Time-series mapping of co-cited reference clustering.

The cited literature constituted 13 clusters, which can be considered as the research hotspots in the field of SAH in recent years. Three classic texts (Chen *et al.* 2014; Macdonald, 2014; Spetzler *et al.* 2015) and six recent hot documents (Galea *et al.* 2017; Jaja *et al.* 2018; Etminan *et al.* 2019; Spetzler *et al.* 2019; van der Steen *et al.* 2019) were identified from the timeline chart of the cited literature. Chen *et al.* (2014) recommended use of the terms, "early brain injury" and "delayed brain injury," according to the time evolution of brain injury produced by SAH. The most common referenced reference is the review study published by Macdonald *et al.* in 2014 (2014), which discussed delayed neurologic decline after SAH. The pathophysiology of DCI is multifaceted, involving angiographic vasospasm, cortical spreading ischemia, microthrombosis, and microvascular constriction. Factors, such as the volume, density, and duration of SAH, early brain injury, diminished cerebral oxygen and glucose delivery, and the presence of hypertension, all raise the risk of DCI. Treatments include nimodipine, balloon angioplasty or vascular angioplasty, and induced hypertension. Spetzler *et al.* (2015) conducted a 6-year randomized controlled research comparing surgical clipping with endovascular coil embolization for the management of aneurysmal SAH. Coil embolization appears to have more lasting advantages in the treatment of posterior circulation aneurysms but there is no meaningful difference between the two procedures in the treatment of anterior circulation aneurysms. Although the rate of re-treatment is greater after embolization, there is no return of bleeding within 6 years after surgery. However, in a 10-year follow-up study by Spetzler *et al.* in 2020 (2019), there was no difference in clinical outcomes between the two groups of patients with anterior circulation aneurysms but the clipping surgery cohort showed better outcomes with respect to rebleeding, re-treatment, and aneurysm occlusion compared to the endovascular embolization group. Indeed, this document drew significant attention. Other popular articles include a meta-analysis published by Etminan *et al.* in 2019 (2019), which was mentioned 138 times and involved 75 studies from 32 countries. The global incidence of SAH and its reduction reveal significant regional differences connected to the decline in blood pressure and smoking prevalence. Van *et al.* (2019) conducted a comprehensive review and meta-analysis in 2019 that predicted DCI after SAH using radiologic scales and showed a strong link between the modified Fisher scale and DCI. Jaja *et al.* (2018) published the development and validation of a prediction model for the outcomes of aneurysmal SAH in 2018, which reliably assessed the outcomes of patients treated for aneurysmal SAH caused by intracranial aneurysm rupture under various circumstances. In 2017 Galea *et al.* (2017) published the determinants of prognosis in patients with aneurysmal SAH and observational results from a multicenter dataset. Al-Mufti *et al.* (2018) proposed a new technique for the treatment of refractory vasospasm after aneurysmal SAH. Vasospasm is a significant cause of DCI and carries a poor prognosis. Nimodipine remains an important component of first-line treatment. Refractory vasospasm requires rescue operations, such

as angioplasty. Intrathecal injection of anti-spasmodic medicines or insertion of implants that can maintain local concentration levels are potential novel therapeutics (Al-Mufti *et al.* 2018).

Limitations

The shortcoming of this study is that the analysis was based on data in the Web of Science database, which may overlook some publications that are only included in other databases, such as Pubmed, Medline, and CNKI. Second, the time period of the included literature was 2016–2021, which is not current. The exclusion of articles written in languages other than English leads to linguistic bias.

CONCLUSION

Through bibliometric analysis of important literature on SAH in the past 5 years, current research was shown to focus on endovascular therapy, early brain injury, delayed cerebral hemorrhage, model prediction, later complications, and clinical efficacy in the field of SAH. The authors from USA and China warrant attention. It is advised that future studies involving this subject can be undertaken in areas, such as endovascular treatment, early brain injury, delayed cerebral bleeding, and prediction models. Additionally, emphasis should focus on the studies undertaken by Chinese authors.

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CONSENT FOR PUBLICATION

Not applicable.

DATA AVAILABILITY STATEMENT

The datasets generated during and/or analysed during the current study are available from the corresponding author on reasonable request.

AUTHORS' CONTRIBUTIONS

Zhenqiang Hao: Conceptualization, Methodology, Data curation, Data analysis, Writing original draft, Review & editing.

Peigang Lu: Methodology, Data curation, Data analysis, Review & editing, Visualization, Project administration.

Bo Li: Conceptualization, Methodology, Software, Resources, Data curation, Review & editing.

All the authors have approved the final draft for submission.

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