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Research hotspots and trends of multimodality MRI on vascular cognitive impairment in recent 12 years

A bibliometric analysis

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Abstract

Background: Multimodality magnetic resonance imaging (MRI) is widely used to detect vascular cognitive impairment (VCI). However, a bibliometric analysis of this issue remains unknown. Therefore, this study aimed to explore the research hotspots and trends of multimodality MRI on VCI over the past 12 years based on the Web of Science core collection using CiteSpace Software (6.1R2).

Methods: Literature related to multimodality MRI for VCI from 2010 to 2021 was identified and analyzed from the Web of Science core collection database. We analyzed the countries, institutions, authors, cited journals, references, keyword bursts, and clusters using CiteSpace.

Results: In total, 587 peer-reviewed documents were retrieved, and the annual number of publications showed an exponential growth trend over the past 12 years. The most productive country was the USA, with 182 articles, followed by China with 134 papers. The top 3 active academic institutions were Capital Medical University, Radboud UNIV Nijmegen, and UNIV Toronto. The most productive journal was the *Journal of Alzheimer's Disease* (33 articles). The most co-cited journal was *Neurology*, with the highest citations (492) and the highest intermediary centrality (0.14). The top-ranked publishing author was De Leeuw FE (17 articles) with the highest intermediary centrality of 0.04. Ward Law JM was the most cited author (123 citations) and Salat Dh was the most centrally cited author (0.24). The research hotspots of multimodal MRI for VCI include Alzheimer disease, vascular cognitive impairment, white matter intensity, cerebrovascular disease, dementia, mild cognitive impairment, neurovascular coupling, acute ischemic stroke, depression, and cerebral ischemic stroke. The main frontiers in the keywords are fMRI, vascular coupling, and cerebral ischemic stroke, and current research trends include impact, decline, and classification.

Conclusions: The findings from this bibliometric study provide research hotspots and trends for multimodality MRI for VCI over the past 12 years, which may help researchers identify hotspots and explore cutting-edge trends in this field.

Abbreviations: ASL = arterial spin labeling, DTI = diffusion tensor imaging, fMRI = functional magnetic resonance imaging, MRI = magnetic resonance imaging, MRS = magnetic resonance spectroscopy, rs-fMRI = rest state fMRI, VCI = vascular cognitive impairment.

Keywords: bibliometric analysis, CiteSpace, MRI, vascular cognitive impairment, Web of Science database

1. Introduction

Vascular cognitive impairment (VCI), which ranges from subjective cognitive decline to vascular dementia, is the second most common form of dementia after Alzheimer disease.[1,2] Its prevalence is estimated from 1% to 1.5% among people over 65 years of age globally,[3] and its incidence increases with age. Presently, the available treatments for this disorder include mizagliflozin,

M-HX, AL, R-XG, X-LL, and Q-HZ contributed equally to this study.

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folic acid, repetitive transcranial magnetic stimulation, acupuncture, and Chinese herbal medicine.[4–8]

In recent years, with the rapid development of neuroimaging, a variety of studies have utilized multimodality magnetic resonance imaging (MRI) to explore brain structure, function, and metabolism in patients with cognitive dysfunction and to provide important evidence for its pathogenesis, including functional MRI (fMRI),[9–11] 3-dimensional arterial spin labeling,[12,13] diffusion tensor imaging (DTI),[14–17] magnetic resonance spectroscopy (MRS),[18,19] susceptibility weighted imaging,[20–22] rest state fMRI (rs-fMRI),[23–25] and magnetic resonance perfusion weighted imaging.[26] Although previous reviews have addressed the imaging research on VCI, few studies have investigated its research hotspots and trends.[16,27]

Bibliometric analysis is utilized to explore and analyze collaborations among core researchers, institutions, and countries from large volumes of scientific documents using statistical and mathematical methods. The analyses from the retrieved literature of specific domains, topics, and disciplines present the research trends with keywords, journals, cited references, academic institutions, and countries at the general level. At an advanced level, it also investigates hotspots and trends using the bibliographic newwork of co-occurrence analysis, co-citation analysis, keyword bursts, and collaboration networks.[28] The CiteSpace software is a visual software developed by Professor Chaomei Chen based on the Java language environment and citation analysis theory. It can display the associated literature data using a mapping knowledge network and help scholars fully understand research hotspots and trends.

To the best of our knowledge, no published bibliometric study has explored multimodality MRI for VCI. Thus, the present bibliometric analysis was designed to analyze the academic output in the domain of multimodality MRI on VCI to investigate its research hotspots and trends within the past 12 years.

2. Methods

2.1. Ethic statement

Ethical approval is not required for this study because it is conducted based on secondary data.

2.2. Data acquisition

Eligible studies were retrieved from the WOS core collection from January 2010 to November 2021, with bibliographic indices: SCI-Expanded, Social Sciences Citation Index, arts and humanities citation index, conference paper citation index-science, publications from the Science Citation Index database, conference proceedings citation index-social science and humanities, book citation index-science, book citation index-social science and humanities, and emerging source citation index; literature type: Vehicle OR Review, language: English. The detailed search strategy is presented in Table 1.

2.3. Analysis tool

We used Microsoft Excel 97 to calculate the number of annual publications, and a total of 587 articles were identified. We performed a bibliometric analysis to identify hotspots in the research domain by mapping countries/regions, institutions, authors, keywords, co-cited references and co-cited journals with nodes and links using CiteSpace 5.8.R1 software (Drexel University, Philadelphia, PA).[29] In accordance with the definition of CiteSpace, each node in the map indicates an author, reference, or country, and the connection between nodes indicates that represents a collaboration or co-citation. Cluster analysis refers to the statistical technique used to explore knowledge structures and research hotspots by analyzing keyword bursts, which are considered predictors of research frontiers.

The CiteSpace parameters were set as follows: Time Slicin: 2010 to 2021, Years Per Slice (1); text processing: term source (title, abstract, author keywords, keywords plus); term type; network configuration parameters: node type selected keywords for co-occurrence network analysis, author, institution for cooperative network analysis, and link selection criteria by default; pruning parameters and function area: pathfinder, cited-journals analysis by pathfinder, pruning sliced networks, and pruning the merged networks were selected for keyword co-occurrence analysis.

3. Results

3.1. General information

A total of 606 related articles were initially retrieved for this study. There were 587 records after duplicates removed. Then, we included a total of 587 full-text articles and analyzed those studies through annual publications and trend, countries/regions, analysis of institutions, journals and cited journals, authors, research hotspots and trends, co-cited authors, keywords co-occurrence and clustering, co-cited reference, and keyword bursts.

3.2. Analysis of annual publications and trend

The annual number of publications on multimodality MRI for VCI is presented in Figure 1A. In addition to a significant decrease in 2018, this number has increased annually since 2010, with a fitting curve index of $y = 2E{-}68e^{0.0793x}$ (Fig. 1B).

3.3. Analysis of countries/regions

A co-occurrence map of the countries was generated using CiteSpace (Fig. 2). A total of 55 countries/regions contributed to this topic, and 272 collaborations were identified between these countries/regions, with 918 relevant published articles on multimodality MRI for VCI.

The top 10 countries/regions are listed in Table 2. The USA had the highest number of publications (182), followed

Table 1

Detailed search strategy.

Set	Result	Search query
#1	171,286	Functional magnetic resonance imaging OR fMRI OR 3D-arterial spin labeling OR 3D-ASL OR diffusion tensor imaging OR DTI OR magnetic resonance spectroscopy OR MRS OR susceptibility weighted imaging OR SWI OR rest state functional magnetic resonance imaging OR rs-fMRI OR magnetic resonance perfusion weighted imaging OR MR PWI
#2	9106	Vascular Cognitive Impairment*OR Vascular Cognitive Dysfunction*
#3	606	#1AND#2 REFINING ELIMINATION engineering electrical electronic or optics or public environmental occupational health

3D-ASL = 3-dimensional arterial spin labeling, DTI = diffusion tensor imaging, fMRI = functional magnetic resonance imaging, MR PWI = magnetic resonance perfusion weighted imaging, MRS = magnetic resonance spectroscopy, rs-fMRI = rest state fMRI, SWI = susceptibility weighted imaging.

by China (145), and the UK (68) ranked second and third, respectively. According to centrality, Canada (0.13) ranked first, followed by South Korea (0.12) and the UK (0.10), with a higher centrality indicating a deeper research influence of the corresponding country/region. This suggests that Canada has the highest international recognition rate for multimodality MRI for VCI. Although these 3 countries published a relatively low number of articles, their impacts were much higher.

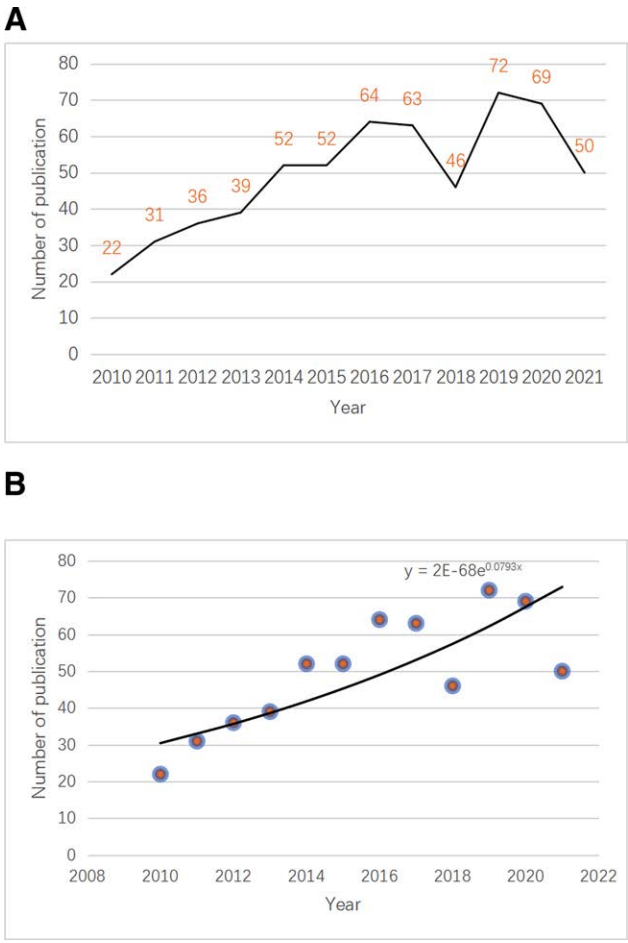

Figure 1. Number of annual publications.

3.4. Analysis of institutions

A co-occurrence map of institutions focusing on multimodality MRI for VCI was generated using CiteSpace (Fig. 3). A total of 346 nodes and 625 links were identified. Each node indicates an institution and its size corresponds to the number of publications. Links between nodes represent collaboration, with a wider link indicating a tighter collaboration.

The top 10 research institutions in the field of multimodality MRI for VCI are listed in Table 3. The top institution with the most publications was Capital Medical University with 21 articles, followed by Radboud University Nijmegen, and the University of Toronto with 18 articles, respectively. According to centrality, the top institution was the German Center for Neurodegenerative Diseases, DZNE (0.38), followed by the University of California, San Francisco (0.22), and Karolinska Institute (0.16).

3.5. Analysis of journals and cited journals

A total of 587 articles related to multimodality MRI for VCI were published in 221 journals. We summarized the top 10 journals in terms of the most published articles in Table 4, and all of them ranked at the Q1 and Q2 levels, with an average impact factor of 5.608. In terms of the number of publications, the *Journal of Alzheimer's Disease* (33 articles), *Frontiers in Aging Neuroscience* (32 papers) and *PLOS One* (24 publications) were the top 3 journals. The top 10 most frequently cited journals are listed in Table 5. 7/10 of the top cited journals ranked Q1, and 3/10 ranked Q2, with an average impact factor of 10.902. Neurology ranked first in terms of citations (492) and agency centrality (0.14).

A co-cited journal map was generated using CiteSpace (Fig. 4). There were 474 nodes and 2147 links. Each node represents a co-cited journal, and the links between the nodes indicate the co-citation frequencies of these journals. A larger node indicates a higher frequency of co-cited journals. Neurology is,

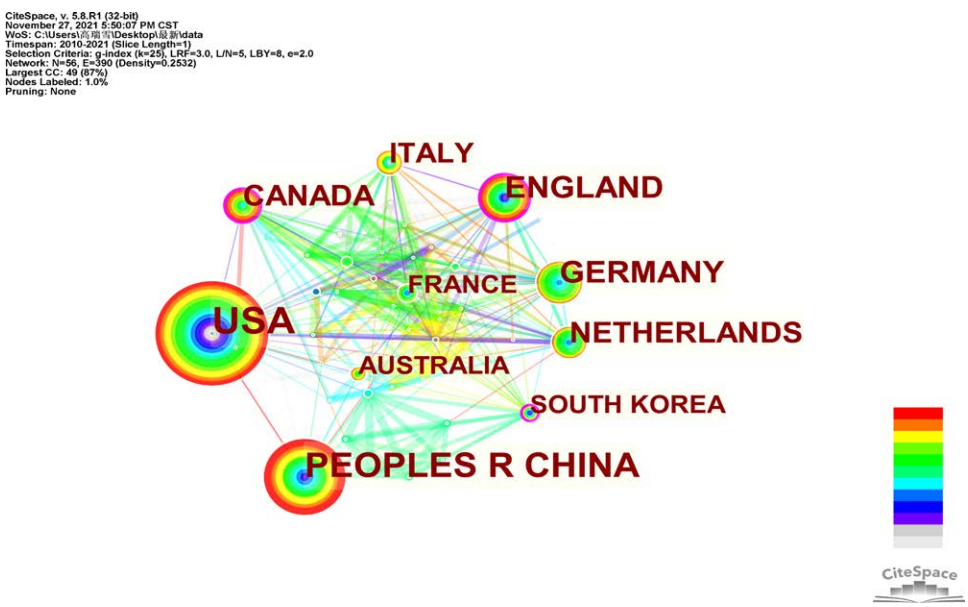

Figure 2. National cooperative network analysis.

therefore, considered the most influential journal in the field of multimodality MRI for VCI.

3.6. Analysis of authors

A co-occurrence map of the authors was generated using CiteSpace (Fig. 5). There are 410 nodes and 710 links. Each node represents an author and its size is proportional to the number of publications, with a larger node presenting more publications. The links between nodes indicate cooperation, with wider links signifying closer collaboration.

The top 10 most productive authors and the highest centrality of multimodality MRI for VCI are listed in Table 6. The most productive author was De Leeuw FE (11 articles). This was followed by Markus HS (9 papers), Zhou Y (8 articles) and Tuladhar AM (8 articles), Dichgans M (6 articles), Duering M (6 articles), Norris DL (6 articles), Wang Y (6 articles), Xu Q (6 articles), and Na DL (6 articles). Benno Gesierich and De Leeuw FE had the highest centrality of 0.04.

3.7. Research hotspots and trends

The research hotspots of this study refer to a large number of publications or issues on multimodality MRI for VCI that have been investigated over the past 12 years. We explored research hotspots and trends through co-cited authors, co-cited references, and keyword co-occurrence and clustering.

Table 2

Top 10 countries with the largest number of publications.

Ranking	Country	Frequency	Centrality
1	USA	182	0.09
2	Peoples R China	145	0.04
3	England	68	0.10
4	Germany	61	0.09
5	Netherlands	56	0.08
6	Canada	52	0.13
7	Italy	47	0.09
8	France	31	0.05
9	Australia	28	0.01
10	South Korea	28	0.12

3.8. Analysis of co-cited authors

A network of co-cited authors was generated using CiteSpace (Fig. 6). A total of 532 nodes and 1755 links were identified. The co-cited authors of multimodality MRI on VCI are presented in Table 7. The most co-cited author was Ward Law (123 times), followed by Fazekas F and Smith SM (122 times). Salat DH (0.24) was the top author with the highest centrality, followed by Hanyu H (0.23) and Jack CR (0.20).

3.9. Analysis of keywords co-occurrence and clustering

A map of keyword co-occurrence of multimodality MRI on VCI is generated by CiteSpace in Figure 7, involving 470 nodes and 1780 links. Each node represents the frequency of the keywords, and a link implies keyword co-occurrence, with a larger node suggesting more frequencies and a wider link implying more keyword co-occurrence. The top 10 frequencies of keyword co-occurrence are presented in Table 8. The most frequent keyword was Alzheimer's disease (276 times), followed by VCI, white matter hyperintensity, cerebrovascular disease, dementia, MRI, mild cognitive impairment, risk factors, DTI, and brain. Among the top 10 co-occurrence keywords, cerebral blood flow and mild cognitive impairment had a centrality of more than 0.1.

A map of the keyword clusters of multimodality MRI for VCI is shown in Figure 8. After log-likelihood test (LLR) cluster analysis, a total of 13 keyword clusters were identified, including "fMRI," "neurovascular coupling," "acute ischemic stroke," "depression," "diffusion tensor imaging," "DTI," "cerebral amyloid angiopathy," "cerebral microbleeds," "cognitive performance," "arterial spin labeling," "Alzheimer disease," "white matter integrity," and "cerebral blood flow" (Table 9). Each circle represents a cluster, with Q = 0.7348 (>0.3) indicating a substantial cluster structure, and S = 0.8836 suggesting high clustering consistency and good homogeneity (Table 9).

3.10. Analysis of co-cited reference

The top 5 co-cited references and centrality are listed in Tables 10 and 11, respectively. The most frequently co-cited article by Wardlw JM (2013) was published in *Lancet Neurol*,[30] which provides standard and new progress in neuroimaging in image data collection, analysis, and reporting of cerebral small vessel diseases

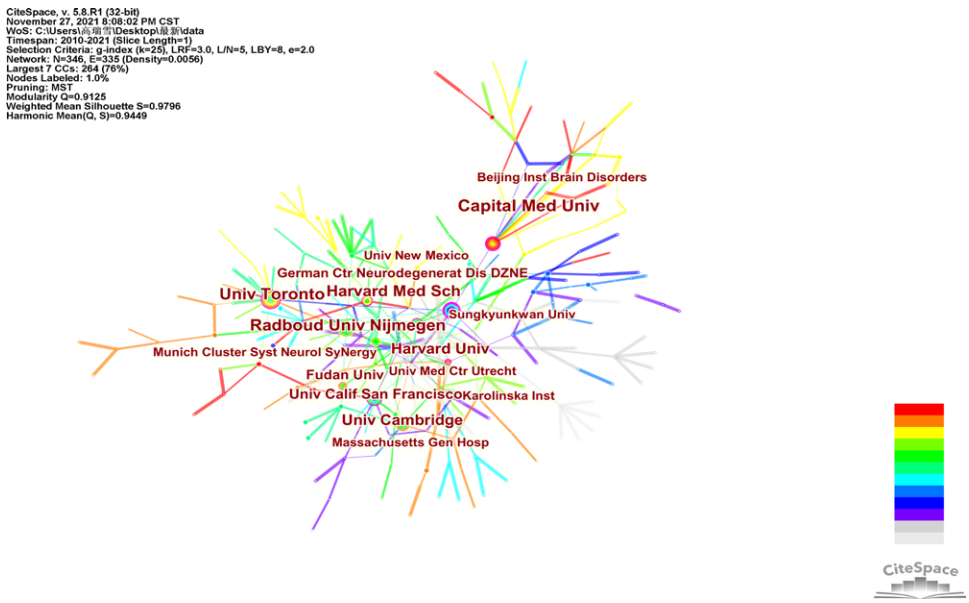

Figure 3. Institution collaboration network analysis.

Table 3

Top 10 institutions with the largest number of publications.

Ranking	Institution	Frequency	Centrality
1	Capital Medical University	21	0.11
2	Radboud University Nijmegen	18	0.03
3	University of Toronto	18	0.10
4	Harvard Medical School	16	0.13
5	University of Cambridge	15	0.05
6	Harvard University	14	0.05
7	University of California, San Francisco	11	0.22
8	Fudan University	10	0.00
9	German Center for Neurodegenerative Diseases, DZNE	9	0.38
10	Karolinska Institute	8	0.16

Table 4

Top 10 journals with the largest number of publications.

Ranking	Journal	Frequency	IF (2020)*	Quartile in category (2020)
1	*Journal of Alzheimer's Disease*	33	4.472	Q2
2	*Frontiers in Aging Neuroscience*	32	5.750	Q1
3	*PLOS One*	24	3.240	Q2
4	*Journal of Cerebral Blood Flow and Metabolism*	21	6.200	Q1
5	*Stroke*	17	7.914	Q1
6	*Neurobiology of Aging*	16	4.673	Q2
7	*Frontiers in Neurology*	15	4.003	Q2
8	*Neurology*	14	9.910	Q1
9	*Human Brain Mapping*	13	5.038	Q1
10	*Neuroimage-clinical*	13	4.881	Q2

IF = impact factor.

*IF in category according to Journal Citation Reports (2020).

Table 5

Top 10 cited journals with the largest number of publications.

Ranking	Journal	Frequency	Centrality	IF (2020)*	Quartile in category (2020)
1	*Neurology*	492	0.14	9.910	Q1
2	*Stroke*	446	0.02	7.914	Q1
3	*Neuroimage*	421	0.02	6.556	Q1
4	*Neurobiology of Aging*	341	0.03	4.673	Q2
5	*Brain*	334	0.09	13.501	Q1
6	*Lancet Neurology*	322	0.01	44.182	Q1
7	*Journal of Neurology, Neurosurgery, and Psychiatry*	293	0.00	10.154	Q1
8	*PLOS One*	274	0.01	3.240	Q2
9	*Archives of Neurology*	271	0.05	4.419	Q1
10	*Journal of Alzheimer's Disease*	271	0.01	4.472	Q2

IF = impact factor.

*IF in category according to Journal Citation Reports (2020).

and neurodegeneration (Table 11). The top co-cited reference with the highest centrality by Barkhof F was published in *Radiology*.[31] This study investigated the rs-fMRI of its primary imaging method, changes in the resting brain network with age, and the resting brain network of cognitive disorders, mental disorders, and dementia. It also summarizes the advantages and limitations of rs-fMRI and provides suggestions for its future development.

3.11. Analysis of keyword bursts

The keyword bursts of multimodality MRI on VCI are presented in Figure 9. The analysis reflects the research hotspots and trends during different periods. Keyword bursts began in 2010 with "fractional anisotropy" up to 2013, with strong bursts of 3.71. This keyword burst was the earliest burst time, with a relatively longer duration and stronger intensity. This indicates that "fractional anisotropy" is an earliest hotspot in this field. The keyword with the strongest citation burst was "magnetic resonance spectroscopy" with 4.9, and the longest duration one was "hippocampus" with 4 years. Of these keyword bursts, impact, decline, and classification all appeared in 2019 and last to the present, exerting current research hotspots and trends.

4. Discussion

This study analyzed data from associated papers on multimodality MRI for VCI in the WOS core collection database. We retrieved literature from 2010 to 2021, analyzed data with a visual knowledge map using CiteSpace software, and summarized general information, research hotspots, and trends of multimodality MRI on VCI.

4.1. General information for multimodality MRI on VCI

In terms of annual publications of multimodality MRI on VCI, the number of published articles in this field is increasing

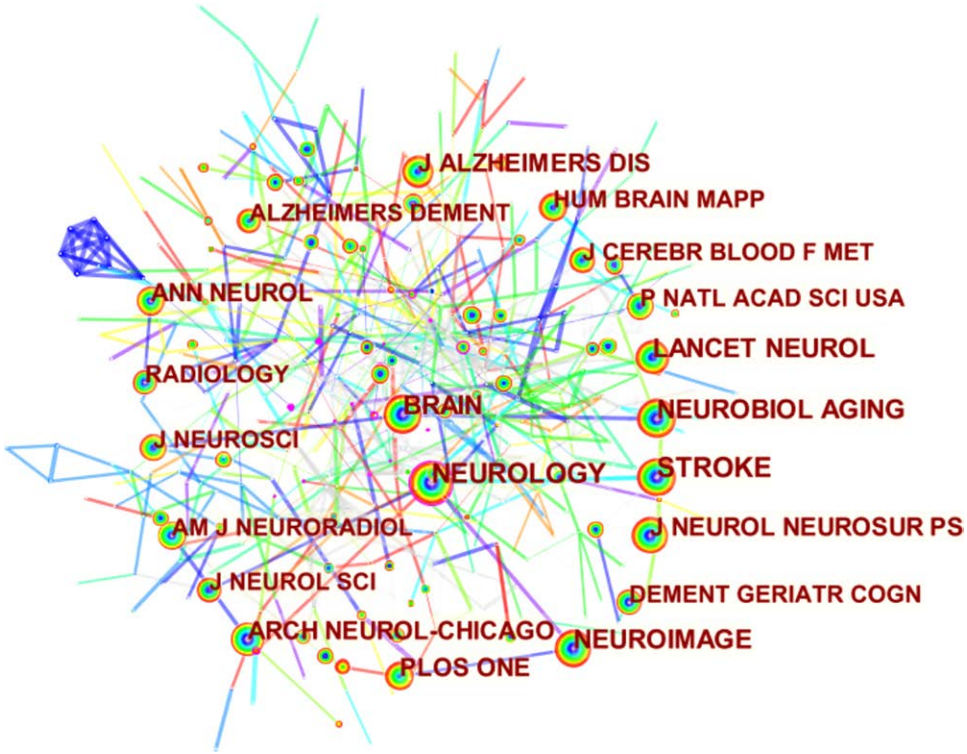

Figure 4. Co-cited journal network analysis.

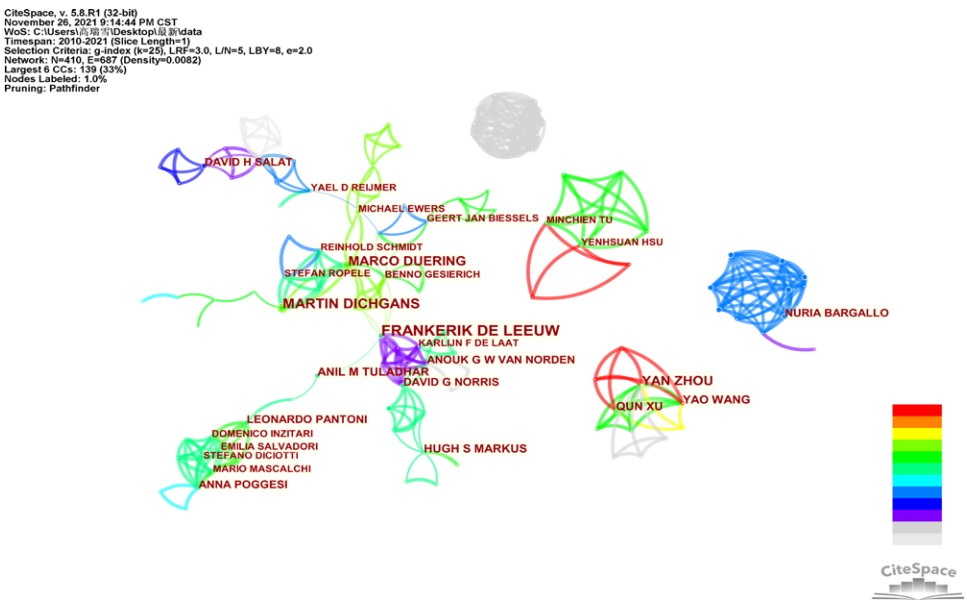

Figure 5. Author collaboration visualization network analysis.

annually, with an average of number of 58.7 papers annually. This indicates that such hotspots are still rising, and scholars are increasingly focusing on this issue. Among them, the USA has the most publications, followed by China, with collaboration between countries. Canada, South Korea, and the UK were the most influential countries in this research field.

The most productive institution regarding multimodality MRI for VCI was Capital Medical University in China, followed by Radboud University Nijmegen in the Netherlands and the University of Toronto in the UK, with more collaboration between the institutions. The most influential institution was the German Center for Neurodegenerative Diseases, DZNE, followed by the University of California and San Francisco in the USA, and Karolinska Institute in Sweden. The most productive and influential institutions were universities, which attached great importance to the collaboration with other institutions.

From the authors' point of view, research on multimodality MRI for VCI in this field has built groups, but there has been less cooperation among them. Among these groups, De Leeuw FE and Wardlaw JM had a greater impact on basic research on cerebrovascular disease.[30] Collaborations are helpful for knowledge exchange and resource sharing in the field for the further development of multimodality MRI for VCI. Thus, it

Table 6

Top 10 authors with the largest number of publications.

Ranking	Frequency	Author	Ranking	Centrality	Author
1	11	De Leeuw FE	1	0.04	De Leeuw FE (11)
2	9	Markus HS	2	0.04	Benno Gesierich (4)
3	8	Zhou Y	3	0.03	Alexander Leemans (3)
4	8	Tuladhar AM	4	0.03	Marco Duering (8)
5	6	Dichgans M	5	0.02	Marco Pasl (2)
6	6	Duering M	6	0.02	Anand Vlswanathan (3)
7	6	Norris DL	7	0.02	Yael D Reijmer (4)
8	6	Wang Y	8	0.02	Leonardo Pantoni (5)
9	5	Xu Q	9	0.02	Anil M Tuladhar (6)
10	5	Na DL	10	0.01	Alexander Thiel (1)

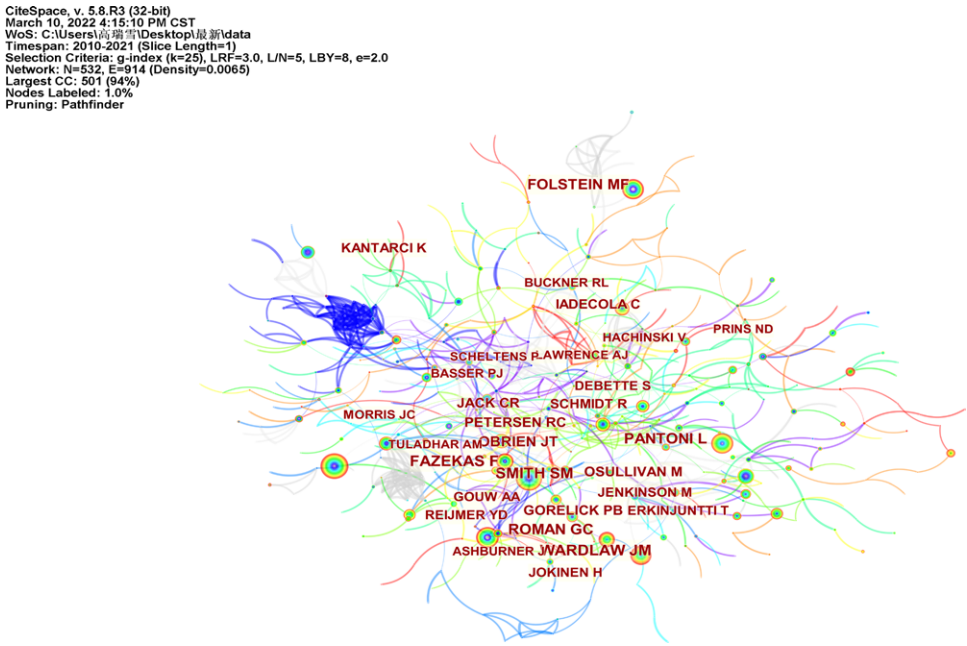

Figure 6. Co-cited author collaboration visualization network analysis.

Table 7

Top 10 cited authors with the largest number of publications.

Ranking	Frequency	Cited author	Ranking	Centrality	Cited author
1	123	Wardlaw JM	1	0.24	Salat DH
2	122	Fazekas F	2	0.23	Hanyu H
3	122	Smith SM	3	0.20	Jack CR
4	111	Roman GC	4	0.18	Bastos-LEITE AJ
5	109	Pantoni L	5	0.18	Chao LL
6	93	Folstein MF	6	0.15	Awad IA
7	81	Obrien JT	7	0.14	Hachinski VC
8	75	Petersen RC	8	0.13	Alsop DC
9	75	Osullivan M	9	0.13	Dickerson BC
10	72	Gorelick PB	10	0.13	Gouw AA

is essential to establish cooperative networks among authors, institutions, and countries.

The journal with the most publications was the *Journal of Alzheimer's Disease* and the journal with the highest centrality was *Neurology*. Both journals focus on neuroscience and neurology research fields. Papers published in *Neurology* have focused on stroke and cognitive impairment over the past 2 years.[32] Studies on Alzheimer disease have focused on its association with Alzheimer disease.

4.2. Research hotspots and trends of multimodality MRI on VCI

This study discusses the hotspots and trends of multimodality MRI for VCI from the perspectives of co-cited authors, co-cited references, keyword co-occurrence and clusters. Some research findings can be used to investigate the main focus area of authors in this field by reading and analyzing literature with higher citation frequency and centrality.

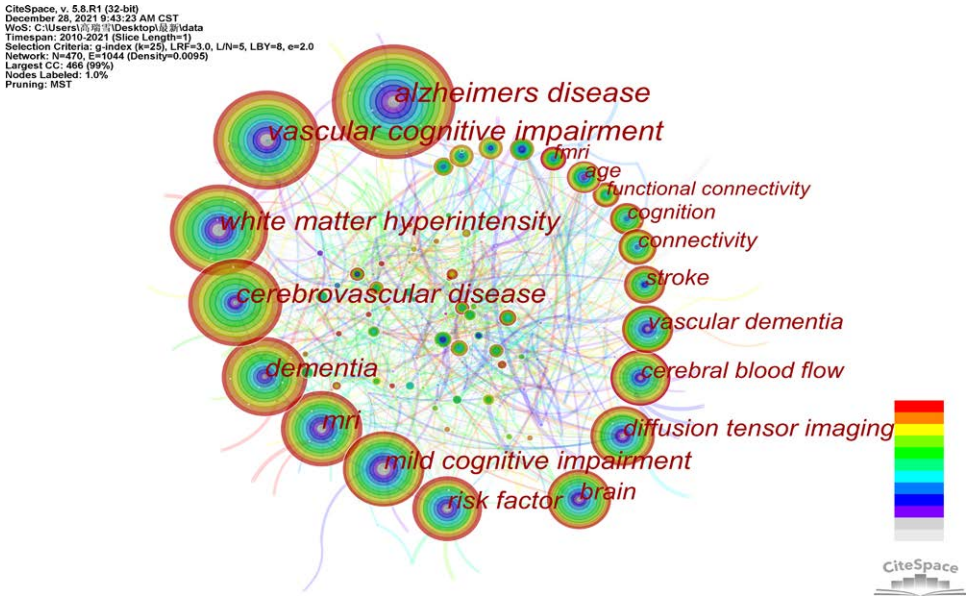

Figure 7. Keyword co-occurrence visualization network analysis.

Table 8

List of co-occurrence keywords.

Ranking	Frequency	Keyword	Centrality	Ranking	Centrality	Keyword	Frequency
1	276	Alzheimer's disease	0.01	1	0.13	Cerebral blood flow	88
2	249	Vascular cognitive impairment	0.02	2	0.10	Mild cognitive impairment	157
3	206	White matter hyperintensity	0.03	3	0.08	Older adult	25
4	195	Cerebrovascular disease	0.04	4	0.08	Magnetic resonance spectroscopy	38
5	179	Dementia	0.02	5	0.08	Age	54
6	162	MRI	0.04	6	0.08	Brain	105
7	157	Mild cognitive impairment	0.10	7	0.06	Default mode network	18
8	120	Risk factor	0.04	8	0.06	Blood pressure	23
9	105	Diffusion tensor imaging	0.06	9	0.06	Atrophy	26
10	105	Brain	0.08	10	0.06	Diffusion tensor imaging	105

MRI = magnetic resonance imaging.

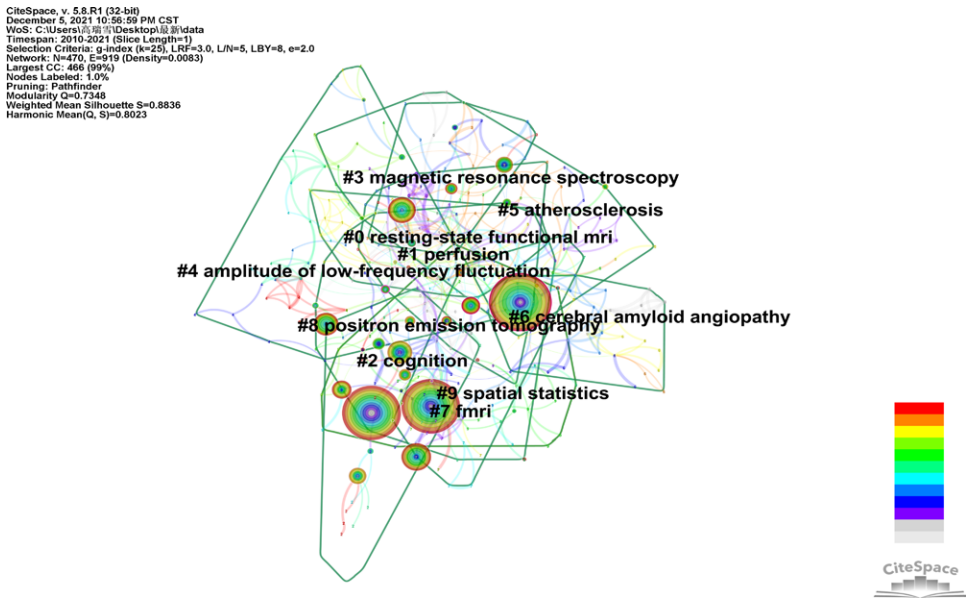

Figure 8. Keyword cluster network analysis.

Table 9

List of keyword clusters.

Cluster no.	Scale	Contour value	Year	Label (LLR)
#0	51	0.718	2012	fMRI (17.1, 1.0E–4)
#1	43	0.753	2018	Neurovascular coupling (14.35, 0.001)
#2	42	0.702	2015	Acute ischemic stroke (11.95, 0.001)
#3	41	0.740	2016	Depression (25.57, 1.0E–4)
#4	41	0.849	2012	DTI (16.19, 1.0E–4)
#5	40	0.714	2016	DTI (13.04, 0.001)
#6	40	0.715	2014	Cerebral amyloid angiopathy (14.38, 0.001)
#7	38	0.717	2013	Cerebral microbleeds (15.69, 1.0E–4)
#8	35	0.712	2012	Cognitive performance (17.39, 1.0E–4)
#9	32	0.561	2015	Arterial spin labeling (8.95, 0.005)
#10	31	0.796	2012	Alzheimer's disease (22.47, 1.0E–4)
#11	19	0.718	2014	White matter integrity (11.25, 0.001)
#12	13	0.753	2012	Cerebral blood flow (12.41, 0.001)

DTI =diffusion tensor imaging, LLR = log-likelihood test, fMRI =functional magnetic resonance imaging.

Table 10

Cited reference with top 5 centrality.

Ranking	Cited reference	Representative author	Centrality	Journal	Publication year
1	Resting-state functional MR imaging: a new window to the brain	Barkhof F	0.37	*Radiology*	2014
2	Pathoconnectomics of cognitive impairment in small vessel disease: a systematic review	Dey AK	0.25	*Alzheimers Dement*	2016
3	ASL perfusion MRI predicts cognitive decline and conversion from MCI to dementia	Chao LL	0.25	*ALZ DIS ASSOC DIS*	2010
4	Diffusion tensor changes in patients with amnesic mild cognitive impairment and various dementias	Chen TF	0.15	*Psychiat Res-Neuroim*	2009
5	Age-related myelin breakdown: a developmental model of cognitive decline and Alzheimer disease	Bartzokis G	0.13	*Neurobiol Aging*	2004

Table 11

Top 5 cited reference with highest frequency.

Ranking	Cited reference	Representative author	Frequency	Journal	Publication year
1	Neuroimaging standards for research into small vessel disease and its contribution to ageing and neurodegeneration	Wardlaw JM.	91	*Lancet Neurol*	2013
2	Vascular contributions to cognitive impairment and dementia: a statement for healthcare professionals from the American Heart Association/American Stroke Association	Gorelick PB	48	*Stroke*	2011
3	Cerebral small vessel disease: from pathogenesis and clinical characteristics to therapeutic challenges	Pantoni L	36	*Lancet Neurol*	2010
4	Structural network efficiency is associated with cognitive impairment in small vessel disease	Lawrence AJ	27	*Neurology*	2014
5	The diagnosis of dementia due to Alzheimer's disease: recommendations from the National Institute on Aging-Alzheimer's Association workgroups on diagnostic guidelines for Alzheimer's disease	McKhann GM	27	*Alzheimers Dement*	2011

Wardlaw JM was the most frequently cited author and De Leeuw FE was the most influential author. They were in the same group and focused on basic research on cerebrovascular disease. Their most frequently cited reference, entitled "Neuroimaging standards for research into small vessel disease and its contribution to ageing and neurodegeneration" was published in *Lancet Neurol*.[30] The Wardlaw JM group provided important insights into the precursors of Alzheimer disease by identifying more precisely the neurobiological underpinnings of cognitive decline in aging populations. They utilized magnetic resonance structural imaging and magnetic resonance diffusion imaging to study the aging of specific regions of the brain network that connect the gray matter volume (nodes) and white matter connectivity (edges). It has been suggested that the senility-sensitive network in the human structural connectivity group is associated with cognitive decline later in life.[33] In a recent study, cerebral small vessel disease related cognitive impairment affected all major areas of cognitive function, and was not limited to executive function and reaction speed. At the same time, low education level is also a risk factor for vascular cognitive dysfunction.[34] De Leeuw FE used structural network efficiency to predict cognitive decline in cerebrovascular disease and proposed the comprehensive efficiency, feature path length, and binary local efficiency of DTI to show the highest predictive strength of baseline efficiency measures for cognitive impairment.

Highly cited literature has a high reference value. All highly cited references in this study were published in well-known international journals, which have high academic status and international influence. According to the 5 top cited articles reported the neuroimaging criteria for small vessel diseases,[30] effects of vascular factors on cognitive impairment and dementia,[35] etiology, pathogenesis, and treatment of cerebral small vessel diseases,[36] structural network of VCI,[37] and diagnostic criteria for Alzheimer disease.[38] According to the top centrality

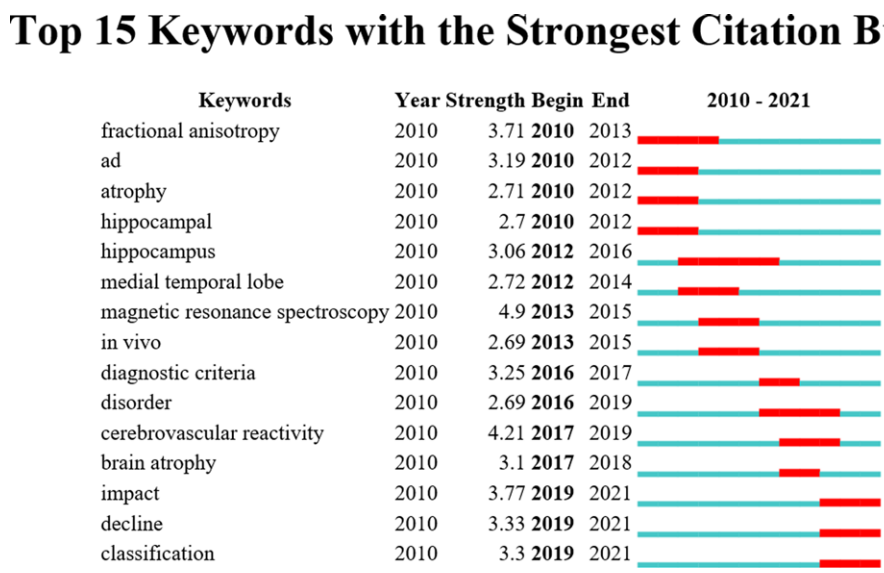

Figure 9. Network analysis of keyword bursts.

of the cited references, they focused on VCI research by multifocused rs-MRI,[31,39] arterial spin labeling (ASL) perfusion MRI,[40] and DTI.[41]

According to the analysis of keyword co-occurrence and cluster, the imaging techniques for VCI based on multimodal MRI are mainly fMRI, DTI, arterial spin labeling, and MRS. Research has focused on Alzheimer disease, VCI, white matter hyperintensity, cerebrovascular disease, dementia, mild cognitive impairment, neurovascular coupling, acute ischemic stroke, depression, and cerebral amyloid angiopathy. VCI is closely associated with Alzheimer disease, mild cognitive impairment, acute and chronic stroke, depression, leukoencephalopathy and cerebrovascular disease. Risk factors, such as age and blood pressure, are also hotspots in this field. The development of fMRI has promoted research progress in cognitive dysfunction neuropathology, and has become a research hotspot in recent years. Damage to the white matter network is an important mechanism of cognitive dysfunction in patients with cerebrovascular disease.[42] FMRI was used to explore neurologic factors in patients with mild VCI, which indicated abnormal activity in each brain region.[43] In other study, DTI and ASL imaging were used to investigate white matter diffusion and cortical perfusion in patients with VCI, with accuracy of identifying small vessel disease subtype markers of 72.57%.[44] A previous study utilized MRS to longitudinally track neurochemical metabolic disorders of gray matter associated with working memory and to regulate neurochemical metabolism by optogenetics for targeted treatment of VCI induced by chronic cerebral ischemia.[45] The hotspots study focuses on exploring the neuropathological changes of VCI by fMRI, DTI, ASL, and MRS. A large number of clinical or experimental studies have been carried out for the early detection, prevention and treatment of diseases to provide convincing imaging evidence.

4.3. Trends for MRI research on VCI

In terms of keyword bursts, this study explored the global trends and frontiers of multimodality MRI on VCI. The top 5 strongest citation bursts of keywords were MRS, cerebrovascular reactivity, impact, fractional anisotropy, and decline. In recent years, studies have increasingly used DTI, MRS, and other imaging techniques to detect the neurovascular pathology of VCI and participate in targeted therapy.[45] Over the past 2 years, it has become a global trend to explore the factors that influence cognitive decline to identify the disease as early as possible, and timely prevention has been a frontier topic of research in recent years.

4.4. Limitation

This study used the CiteSpace software to conduct a bibliometric analysis of the literature on multimodality MRI for VCI. It only retrieved and analyzed data from publications in the WOS core collection because of the restriction of CiteSpace. In addition, research over the past 12 years may not have fully explored the development of VCI based on multimodality MRI.

5. Conclusion

This study summarizes the general information, research hotspots, and trends of multimodality MRI for VCI over a period of 12 years. The present study shows that multimodality MRI research still has great growth-promoting potential in this area, and the collaboration between international institutions and authors needs to be strengthened. The focus and trend of research mainly involve the neurovascular pathology of cognitive impairment with multimodality imaging; in particular, the white matter integrity of the brain is detected by DIT imaging technology. This has become a research trend in the field of VCI.

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