Original Article

The use of cardiac magnetic resonance in hypertrophic cardiomyopathy over the past 10 years [2013–2023]: a CiteSpace-based bibliometric analysis

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Background: Hypertrophic cardiomyopathy (HCM) is a common genetic cardiac disorder characterized by the hypertrophy of a segment of the myocardium. Cardiac magnetic resonance (CMR) has been widely used in the assessment of HCM. However, no bibliometric assessment has been conducted on the progress of research in this field. This study thus aimed to examine the current state of research into the application of CMR in HCM and the hotspots and trends that have emerged in this field over the past decade.

Methods: A systematic search was conducted on the Web of Science regarding CMR in the assessment of HCM. The databases were searched from 2013 to June 2023. CiteSpace is an application that can be used to characterize the underlying knowledge of the scientific literature in a given field. We used it to analyze the relationship between publication year and country, institution, journal, author, bibliography, and keywords in the field of CMR for the assessment of HCM.

Results: A total of 1,427 articles were included in the analysis. In the assessment of HCM, the findings from the past decade have consistently demonstrated a progressive rise in the quantity of articles pertaining to CMR. The country with the largest number of publications was the United States [310], and the institution with the greatest number of publications was the University College London [45]. The analysis of keywords revealed the diagnosis and management of HCM with CMR to be the current research focus and emerging trend within this academic field.

Conclusions: This study used a novel approach to visually analyze the use of CMR in HCM assessment. The current research trajectory in CMR consists of the diagnosis and management of patients with HCM. Although most studies confirmed the indispensability of CMR in the assessment of HCM, larger-scale cohorts are still needed to more comprehensively evaluate the role of CMR in the differential diagnosis, pre- and post-treatment assessment, and long-term management of patients with HCM.

Keywords: Cardiac magnetic resonance (CMR); hypertrophic cardiomyopathy (HCM); bibliometric analysis; CiteSpace

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Introduction

Hypertrophic cardiomyopathy (HCM), a fairly common genetic cardiac disorder, has an approximate occurrence rate of 1 in 500 individuals in the general adult population and is characterized by the hypertrophy of a segment of the myocardium (1). Patients with HCM may remain clinically asymptomatic for long periods. The primary clinical presentations include exertional dyspnea, chest pain, syncope, and palpitations, which are potentially linked to ventricular and supraventricular arrhythmia and usually occur several years after electrocardiographic (ECG) or echocardiographic evidence of left ventricular (LV) hypertrophy is first detected. As the disease progresses, patients become prone to heart failure, atrial fibrillation (AF), and sudden cardiac death (SCD) (2-4). HCM brings about significant challenges to the patient's daily life and considerable difficulties and costs to the family and society.

The identification of family members with HCM has been facilitated by the presence of an inherited predisposition. Furthermore, family history plays a crucial role in informing the judicious selection of subsequent diagnostic examinations. ECG stands out as the most sensitive test for detecting HCM, exhibiting abnormal findings in over 90% of cases (5). Screening echocardiography is recommended as the initial diagnostic test due to its affordability although its specificity is limited. Echocardiography is required for all patients who are suspected of having HCM, but it has a lower sensitivity than does cardiac magnetic resonance (CMR) and may fail to detect apical hypertrophy. As a result, the incidence of HCM has been historically underreported (6,7). CMR can detect apical HCM that has been missed via ultrasound due to its multiplanar and multisequence capabilities. Moreover, late gadolinium enhancement (LGE) sequences with injected contrast can identify morphologically similar cardiomyopathies, such as Anderson-Fabry disease, based on the typical enhancement pattern of HCM (8). CMR is not only applied in the diagnosis and differential diagnosis of HCM (9,10) but is also a crucial tool for informing the risk stratification and prognosis of patients (11-13).

Bibliometric analysis, a statistical and quantitative tool, has gained prominence across various research domains as a means to evaluating the countries, institutions, journals, authors, and keyword patterns linked to distinct publication types. For example, Khan *et al.* conducted a bibliometric analysis of the top 100 most cited articles in cardiovascular magnetic resonance (14). Additionally, Cuocolo *et al.* conducted a study on authorship in CMR imaging studies (15). Literature regarding CMR for the assessment of HCM is typically in the form of retrospective analyses, literature reviews, or meta-analyses. Therefore, an examination of the current state of research in the use of for HCM, along with the related hotspots and trends, is lacking.

We thus performed a bibliometric here analysis to identify the current research trends and hotspots in the field of CMR assessment for HCM. The objective of this study was to provide a comprehensive analysis of the temporal evolution of research hotspots and dynamic frontiers in this field, with the aim of acquiring key references and quantitative and objective data.

Methods

Data source and search strategy

The Web of Science database was searched from 2013 to June 2023 with the following search method: Topic Search (TS) = (Hypertrophic cardiomyopathy) AND (((TS=(Cardiac)) OR TS = (Heart)) OR TS= (Cardiovascular)) AND TS = (Magnetic resonance). The data were analyzed between June 2023 and July 2023.

Inclusion and exclusion criteria

The selection process involved identifying relevant studies on CMR for HCM by reviewing the titles and abstracts of articles and reviews. Study types such as letters and conference abstracts were excluded from consideration. Additionally, only publications in the English language were included. Ultimately, a total of 1,427 records (1,029 original studies and 398 reviews) were identified for the final analysis.

Analysis method

CiteSpace was employed for the purpose of examining the scholarly literature in order to characterize the

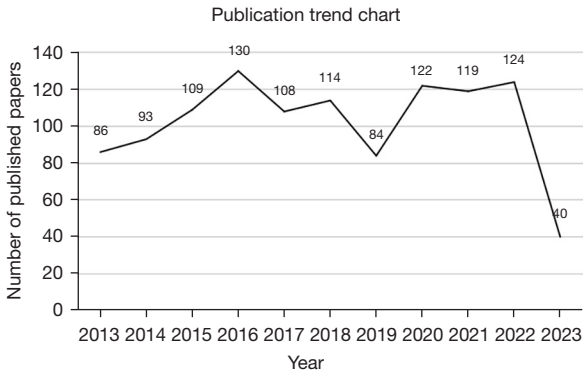

Figure 1 Number of articles published.

configuration of scientific knowledge. This software employs Java programming language to complete a visual examination of scientific references. By employing co-occurrence and cocitation analysis on an extensive corpus of reference data within a specific research domain, the software objectively and quantitatively scrutinizes and forecasts research frontiers and development patterns (16,17). We used CiteSpace 5.8. R3 software to retrieve studies, configuring the "time slice" value to 1 year (18,19). The node types for co-occurrence analysis were chosen based on country, keyword, and category, while cocitation analysis was performed for references and journals.

Interpretation of visual map recognition applications

The concept of tree ring history can be applied to the citation record of a specific scholarly article. The magnitude of the rings symbolizes the frequency of citations received by the paper, while the hue of the citation ring signifies the chronological occurrence of the citations. Furthermore, the thickness of a ring is directly proportional to the quantity of citations within the corresponding temporal interval (20).

In the collaboration graph, the nodes and connections depict various entities, such as authors, institutions, and countries/regions. The size of the nodes corresponds to the quantity of papers published by these entities, while the connections signify the intensity of their collaborative relationships. Similarly, in the network graph, the nodes represent words and scientific categories, with their size indicating their frequency and the lines symbolizing the strength of co-occurrence. Finally, in the cocitation analysis, the nodes' size reflects the number of citations a given article has received, while the lines represent the cocitations between them.

Centrality serves as a crucial metric for assessing the significance of keywords. Centrality values surpassing 0.1 indicated central nodes, and these were considered to have heightened importance and influence in our study. These central nodes are visually distinguished by purple circles. Notably, nodes surrounded by purple circles exhibit higher centrality (0.1), while nodes surrounded by red circles indicate greater burst intensity (18).

Results

Analysis of post volume

A comprehensive search on the Web of Science yielded a total of 1,427 articles, encompassing various literature types such as original studies and reviews. The distribution of specific articles published annually can be observed in *Figure 1*. As of writing, the year 2023 has not yet ended, and the analysis found that the number of publications in this field maintained a steady upward trend from 2013 to 2022 (R^2=0.2669). These results suggest that CMR has received the bulk of researcher attention as a complementary and alternative noninvasive evaluator for HCM, and many studies have been included in guidelines for the diagnosis and management of patients with HCM.

Journal and citation analysis

Among the 1,427 articles published between 2013 and 2023, the journals with the most publications (11 articles each) were *European Heart Journal-Cardiovascular Imaging*, *International Journal of Cardiology*, *International Journal of Cardiovascular Imaging*, *Journal of Magnetic Resonance Imaging*, and *Journal of the American College of Cardiology* (Figure S1). Among the top 10 most cited journals, *Circulation* was the most cited journal with 975 citations, followed by *Journal of the American College of Cardiology* with 969 citations and *European Heart Journal* with 814 citations (*Table 1*).

The analysis of bursts in cited journals identified cardiovascular journals that exhibited research hotspots (*Figure 2*). A journal cocitation analysis of references cited by 1,427 studies published in the 2013–2023 period found that among the oldest journals, *Journal of the American College of Cardiology* and *American Journal of Roentgenology* showed bursts in 2013, while *JACC-Clinical Electrophysiology* had the longest burst from 2019 to 2023. *ESC Heart Failure*, *Heart Failure Reviews*, *Insights Imaging*, and *Cardiothoracic Radiology* also demonstrated recent bursts.

Table 1 Top 12 journals with the most publications and the most citations

Rank	Journal	Count	IF	JCR	Cocited journal	Cocitations	IF	JCR
1	*European Heart Journal-Cardiovascular Imaging*	11	9.131	Q1	*Circulation*	975	39.918	Q1
2	*International Journal of Cardiology*	11	4.039	Q2	*Journal of the American College of Cardiology*	969	27.206	Q1
3	*International Journal of Cardiovascular Imaging*	11	2.316	Q3	*European Heart Journal*	814	35.855	Q1
4	*Journal of Magnetic Resonance Imaging*	11	5.119	Q1	*American Journal of Cardiology*	641	3.133	Q3
5	*Journal of the American College of Cardiology*	11	27.203	Q1	*JACC Cardiovascular Imaging*	606	16.051	Q1
6	*American Journal of Cardiology*	10	3.133	Q3	*Journal of Cardiovascular Magnetic Resonance*	594	6.903	Q1
7	*JACC Cardiovascular Imaging*	10	16.051	Q1	*Heart*	592	7.365	Q1
8	*Circulation Cardiovascular Imaging*	9	8.589	Q1	*New England Journal of Medicine*	505	176.077	Q1
9	*Heart*	9	7.365	Q1	*Circulation-Cardiovascular Imaging*	482	8.589	Q1
10	*Journal of Cardiovascular Magnetic Resonance*	9	6.903	Q1	*European Heart Journal-Cardiovascular Imaging*	384	9.131	Q1
11	*Journal of the American Heart Association*	9	6.106	Q1	*Journal of the American Society of Echocardiography*	383	7.723	Q2
12	*Echocardiography-A Journal of Cardiovascular Ultrasound and Allied Techniques*	8	1.874	Q4	*International Journal of Cardiology*	361	4.039	Q2

IF, impact factor; JCR, journal citation report.

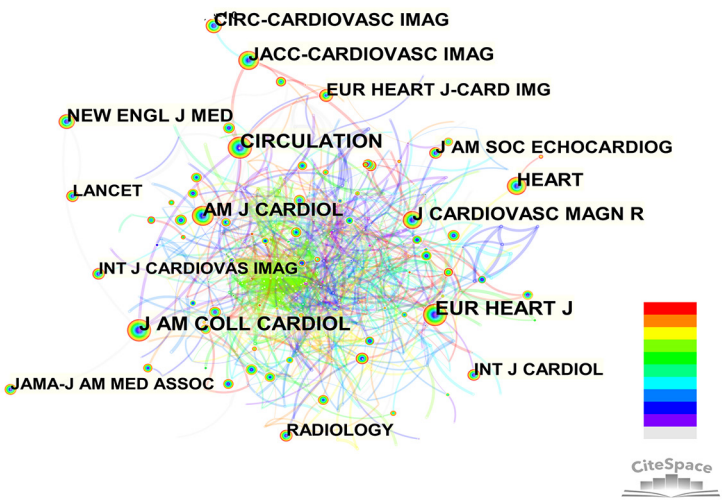

Figure 2 Top 25 cited journals with the strongest citation centrality.

The double-graph superposition graph of 1,427 studies in Figure S2 shows that the most common citations in journal were focused on the field of cardiology. As the quantity of papers published in journals increases, the longitudinal axis of the ellipse on the left side of the graph exhibits a corresponding elongation. Similarly, an increase in the number of authors is associated with a lengthening of the horizontal axis (18).

The 1,427 included studies were from the fields related to cardiovascular systems and cardiology, radiology, nuclear medicine and medical imaging, general and internal medicine, medicine, general and internal, peripheral vascular disease, multidisciplinary science, science and technology, research and experimental medicine, engineering, and pediatrics, among others (Figure S3).

Based on the references of the 1,427 included studies, 14 cited references were used to generate a common reference cluster for the landscape displayed in the Figure S4. A cocitation network was constructed by selecting the initial 100 references with the highest number of citations per year. Upon synthesizing the annual network, it was determined that the network comprised a cumulative count of 330 references and 733 nodes. The cluster studies were subsequently categorized into 14 distinct groups, denoted as group numbers 0–13. Each cluster was assigned a label based on the title, keywords, and subject words found in the citation references and abstracts that pertained to the cluster citation (Figure S4) (18).

Analysis of 1,427 representative cited references

The analysis of content and perspective encompassed the reference information of the 1,427 cited sources, which is succinctly summarized in *Table 2*. Through a systematic review, Maron *et al.* observed that over the course of more than five decades, HCM has undergone a significant transformation from being a rare and predominantly incurable condition to becoming a common but treatable genetic disorder. This shift has been accompanied by the development of management strategies that offer the potential for improved quality of life and extended lifespan, thereby allowing individuals with HCM to have realistic aspirations for restored well-being and increased longevity (21).

The article by Guttmann *et al.* is widely recognized and had a high citation rate in our analysis. It provides a critical assessment of the existing literature pertaining to AF and thromboembolism in HCM and details the findings of a meta-analysis aimed at determining the prevalence and incidence of these conditions. The results indicated that AF is frequently observed in HCM and is linked to a heightened risk of thromboembolism. Although left atrial dimension and age have been identified as independent factors associated with AF, the existing literature lacks sufficient evidence to establish reliable clinical instruments for predicting the occurrence of AF or thromboembolism. Guttmann *et al.*'s paper further reports that the majority of available data suggest anticoagulation for patients with AF as the favored approach. However, the scope of this review is limited to studies specifically investigating AF, stroke, or thromboembolism as primary or secondary outcomes. It is important to note that other observational cohort studies addressing different aspects of the disease may include data on the prevalence of AF (22).

Maron *et al.* (23) examined the risk stratification and outcomes in older adult patients with HCM. They found that individuals with HCM who live beyond their sixth decade of are unlikely to experience disease-related morbidity or mortality, such as sudden death, even if they have the conventional risk factors. Consequently, these findings do not advocate for the implementation of proactive defibrillator implantation in older adult patients with HCM. Instead, it is evident that the survival of older patients is predominantly influenced by other comorbidities, both cardiac and noncardiac, and not HCM itself (23).

Maron *et al.* (24) found evidence suggesting that the current management strategies and treatment interventions for sudden death prevention, such as the use of implantable cardioverter-defibrillators (ICDs), can substantially modify the clinical trajectory of the disease. As a result, the mortality rate related to the condition has decreased to 0.5% per year, allowing for prolonged survival in a sizable, longitudinally evaluated adult cohort with HCM (24).

Delcrè *et al.* (25) introduced a straightforward scoring system to assess the extent of ECG abnormalities in patients with HCM. Their study, conducted on a sizable HCM population, demonstrated a direct correlation between the quantity and severity of ECG abnormalities and the phenotypic manifestation observed through CMR. Delcrè *et al.* point out that while the identification of false-negative ECG results remains a challenge in HCM screenings, the presence of a normal ECG effectively excludes the presence of severe LV hypertrophy. This finding suggests potential implications for the long-term monitoring of patients with HCM and their family members (25). Therefore, researchers should focus on the potential use of CMR in the

Table 2 Five representative studies on cardiac magnetic resonance in hypertrophic cardiomyopathy in the citations of the included 1,427 studies

Study	Citations, n	Design or type of article	Sample size	Intervention	Outcomes	Highlights
Maron BJ (21)	536	Review	11,370 studies	Review	–	The prevalence of HCM, once considered a rare and largely incurable condition, has undergone a significant transformation, emerging as a common but treatable genetic disorder. This transformation has been paralleled by the emergence of management strategies that empower individuals to realistically pursue a regained quality of life and an extended lifespan
Guttmann OP (22)	409	Systematic Review	33 studies	Review	–	AF is prevalent in HCM and is closely linked to a heightened risk of thromboembolism
Maron BJ (23)	344	Research Article	428 patients	428 consecutive HCM patients presenting at ≥60 years of age	(I) Non-HCM-related mortality; (II) HCM-related mortality/ adverse events (embolic stroke, progressive heart failure, heart transplantation for end-stage disease, postoperative complications, arrhythmic SD events)	The advanced age of HCM is inversely related to the disease-related risk; non-HCM-associated cardiac death poses a greater threat to long-term survival than does HCM alone, underscoring the importance of attention to the overall clinical environment with aggressive identification of coexistent disease
Maron BJ (24)	202	Research Article	1,000 patients	1,000 consecutive HCM patients obtained by hospital visit or systematic telephone contact	Sudden cardiac death, advanced (end-stage) heart failure without transplant, advanced (end-stage) heart failure without transplant and prior ICD intervention, embolic stroke, posttransplant deaths and nonfatal HCM-related major events	There is a need to identify with greater precision patients with HCM who benefit from specific therapeutic modalities and to define the optimal timing for various interventions
Delcrè SD (25)	183	Research Article	257 patients	257 patients with definite diagnosis of HCM	Four classes of ECG score and CMR findings	A simple scoring system for the quantification of ECG abnormalities in patients with HCM is proposed

HCM, hypertrophic cardiomyopathy; AF, atrial fibrillation; SD, sudden death; ICD, implantable cardioverter-defibrillator; ECG, electrocardiography; CMR, cardiac magnetic resonance.

assessing of cardiac damage and dysfunction and develop more accurate management methods to reduce the risk of AF and SCD in patients with HCM.

Keyword analysis

The keyword co-occurrence graph in Figure S5 consists of 213 nodes and 279 lines. The 5 most commonly used keywords were "cardiovascular magnetic resonance", "diagnosis", "hypertrophic cardiomyopathy", "task force", and "late gadolinium enhancement". The top 5 keywords in terms of centrality were "guideline", "American college", "sudden death", "cardiology", and "echocardiography". We plotted the top 25 keywords from 2013 to 2023 (*Figure 3*). Emergent words are keywords that are often used within a certain period of time. The top 5 most emergent keywords were "management", "European association", "delayed enhancement", "coronary artery disease", and "prevention".

Three stages of keywords

Figure 3 shows the beginning and end years of the popular

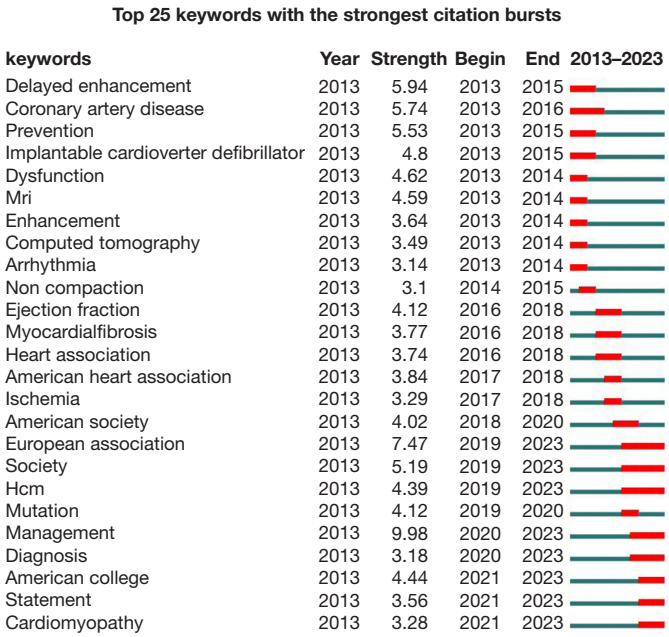

Figure 3 The top 25 most cited keywords. The blue section represents the years from 2013 to 2023, and the red section represents the start and end years.

Table 3 The centrality of the keywords

Rank	Centrality	Frequency	Keywords
1	0.17	16	Classification
2	0.17	7	Hypertension
3	0.15	18	Adult
4	0.15	12	Insight
5	0.14	25	Abnormality
6	0.13	13	Diffuse myocardial fibrosis
7	0.11	31	Outcome
8	0.11	14	Event
9	0.11	11	Cardiac troponin T
10	0.11	8	Alcohol septal ablation
11	0.10	41	Society
12	0.10	17	Computed tomography
13	0.10	7	Myectomy
14	0.09	18	Prognosis
15	0.09	17	Gene
16	0.09	11	2-dimensional strain
17	0.09	6	Perfusion
18	0.09	6	ECG
19	0.09	2	2-dimensional echocardiography
20	0.09	2	Severity

ECG, electrocardiography.

keywords. The analysis of the year the keyword started points to two important observations: (I) in the first stage, "delayed enhancement" [2013–2015] was the popular keyword, suggesting primarily that delayed gadolinium enhancement is an important prognostic marker in HCM. (II) In the second stage, "ejection fraction" [2016–2018] and "ischemia" [2017–2018] were the most popular keywords. The primary focus of papers that included these keywords was to reveal the significant association between heart failure and mortality in patients diagnosed with HCM. Patients with systolic dysfunction [left ventricular ejection fraction (LVEF) <50%] are at a high risk of heart failure-related death and SCD (26). (III) In the third stage, "management" [2020–2023], "diagnosis" [2020–2023], and "cardiomyopathy" [2021–2023] emerged as the most frequent keywords. The findings demonstrate that CMR plays occupies an additional role in both diagnosing and managing patients with HCM, thereby offering potential benefits in reducing the risk of sudden death for these individuals.

Centrality is the key criterion for measuring a node's presence in a graph in a network. Through the calculation of a research keyword's centrality (>0.1), 20 high centrality keywords (*Table 3*) were identified. These represent the current state of research into CMR for HCM, with

Table 4 Keywords clustering table

Clustering number	S	Clustering tags
#0	0.942	European Association (9.74, 0.005); management (8.26, 0.005); echocardiography (6.27, 0.05); American Society (5.83, 0.05); myocardial strain (5.1, 0.05)
#1	0.852	Right ventricle (13.83, 0.001); dilated cardiomyopathy (9.99, 0.005); hypertrophic cardiomyopathy (7.57, 0.01); cardiomyopathy dilated (6.91, 0.01); sudden cardiac death (6.9, 0.01)
#2	0.943	Fibrosis (17.12, 1.0E–4); quantification (12.35, 0.001); extracellular volume (10.12, 0.005); gadolinium (8.64, 0.005); texture analysis (8.64, 0.005)
#3	0.807	European Society (13.29, 0.001); cardiology (12.59, 0.001); obstructive cardiomyopathy (9.9, 0.005); guideline (8.21, 0.005); delayed enhancement (5.92, 0.05)
#4	0.943	Left ventricular noncompaction (12.84, 0.001); cardiovascular abnormalities (9.34, 0.005); amyloid heart disease (7.39, 0.01); ventricular (7.39, 0.01); phenotypic variability (7.39, 0.01)
#5	0.988	Delayed enhancement (30.44, 1.0E–4); late gadolinium enhancement (16.2, 1.0E–4); cardiac MR imaging (6.78, 0.01); international society (6.78, 0.01); multidetector computed tomography (6.78, 0.01)
#6	0.947	risk (25.22, 1.0E–4); myocardial fibrosis (13.53, 0.001); HCM (10.55, 0.005); death (7.64, 0.01); sudden death (7.05, 0.01)
#7	0.913	Prevalence (28.88, 1.0E–4); diagnosis (22.79, 1.0E–4); sex (11.84, 0.001); disarray (8.67, 0.005); ECG (8.67, 0.005)
#8	0.749	disease (15.11, 0.001); association (9.07, 0.005); mutation (6.99, 0.01); strain (6.71, 0.01); utility (5.33, 0.05)
#9	0.932	Pregnancy (34.75, 1.0E–4); shared decision-making (28.94, 1.0E–4); rhythm monitoring (28.94, 1.0E–4); exercise stress testing (28.94, 1.0E–4); occupation (28.94, 1.0E–4)
#10	0.990	Exercise (10.61, 0.005); athlete's heart (9.66, 0.005); sarcomeres (9.5, 0.005); echocardiography (7.06, 0.01); genetic testing (6.73, 0.01)

MR, magnetic resonance; HCM, hypertrophic cardiomyopathy; ECG, electrocardiography.

topics of heightened focus being the classification of and hypertension in patients with HCM, research methods for randomized controlled experiments, and the systematic evaluation of CMR evaluation for HCM, among others.

Keyword cluster analysis

In order to further characterize the knowledge network structure of the research on CMR for HCM and the combination categories of different keywords, we selected the log-likelihood ratio clustering method to cluster the included keyword maps and form 10 categories (Figure S6, *Table 4*). The modularity Q value of 0.7776 suggests that the community structure of clustering is statistically significant, as values greater than 0.3 indicate significance. Additionally, the average contour value S of 0.9179, exceeding the threshold of 0.7, provides further evidence that the clustering results are convincing. Each color block represents a cluster, and the nodes in the color block belong to the cluster range. When the evaluation index of the keyword clustering visualization atlas, Q, is greater than 0.3, this indicates a significant clustering structure within the network. The Q value of the key cluster visualization atlas in this study was 0.7776, and the keyword cluster analysis formed 11 cluster results. Clustering labels represent the distribution of the main research contents in this field.

Analysis of authoritative authors, institutions, and countries

Author analysis

By analyzing the authors, we can identify the major research trends, cores researchers, collaboration networks, and other relevant data in this field. Through the analysis of 1,427 pieces of literatures, 253 nodes and 495 lines were identified, and the network connection density was 0.0155 (Figure S7). The author co-occurrence chart in Figure S7 shows the most prolific authors and coauthors and their connections; a connection between nodes can illustrate authors' joint publication. Among the authors identified, Maron MS was

Table 5 Core author rank table

Rank	Author	Count
1	Martin S. Maron	29
2	Barry J. Maron	18
3	Shihua Zhao	17
4	Harry Rakowski	17
5	Carolyn Y. Ho	15
6	Stefan Neubauer	13
7	James C. Moon	13
8	Shubin Qiao	12
9	Theodore P. Abraham	11
10	David A. Bluemke	10
11	Jiansong Yuan	10
12	Sanjay K. Prasad	10
13	Dudley J. Pennell	9
14	Iacopo Olivotto	9
15	Yucheng Chen	8
16	Andris H. Ellims	7
17	Andrew J. Taylor	7
18	Perry Elliott	7
19	Jingang Cui	7
20	Jie Wang	7
21	Arnon Adler	7
22	Gianluca Pontone	6
23	Yan Zhang	6
24	Christopher M. Kramer	6
25	Erwan Donal	6
26	Fenghuan Hu	6
27	Raymond Y. Kwong	6
28	Jiayu Sun	5
29	Andreas Greiser	5
30	Betty Raman	5
31	Christopher Semsarian	5
32	Steve R. Ommen	5
33	Yuchi Han	5
34	Sharlene M. Day	5
35	Franco Cecchi	5
36	Camillo Autore	5
37	Roxana Mehran	4
38	Hugh Watkins	4
39	Anita Deswal	4
40	Seema Mital	4
41	Christina Y. Miyake	4
42	Lauren L. Evanovich	4
43	John U. Doherty	4
44	Prem Soman	4
45	Jose A. Joglar	4
46	Michael A. Burke	4

the most prolific author with 29 publications. According to Price's law, the number of papers published by the least productive author among core authors is equal to 0.749 times the number of papers published by the most prolific author, and the specific formula is as follows:

$$M \approx 0.749\sqrt{n_{max}} \quad [1]$$

where, M is the number of papers published by the least productive authors of the core authors, and n_{max} is the number of papers published by the most productive authors. From 2013 to 2023, the number of core authors in the field of CMR for HCM was at least 4, with a total of 59 core authors (*Table 5*), accounting for 23.32% of the total number of authors, and 416 articles were published, accounting for 46.3% of the total number of papers. The number of core authors did not reach 50% of the total number of published papers, so a core author team has not yet been formed.

Cited authors of the 1,427 cited references

Among all cited authors, the most cited author was Maron BJ (536 times), followed by Elliott PM (409 times) and Maron MS (344 times). All three authors are leading experts in their respective fields (Table S1).

Country and institutional analysis

A national distribution map was generated. A total of 232 countries were involved in the research of CMR for HCM (Figure S8), with the United States [310] accounting for a

majority of the total number of articles published in this field. China [152], England [152], Italy [116], and Germany [110] all published more than 20 articles each, indicating that they all made significant contributions to the research in this field.

A total of 163 nodes and 198 lines were generated in the distribution map of institutions, and 163 institutions participated in the research of CMR for HCM (Figure S9). The top 5 institutions in terms of the number of publications were University College London, Brigham and Women's Hospital, Sichuan University, the University of Oxford, and the Chinese Academy of Medical Sciences and Peking Union Medical College (Table S2). The top 10 institutions in terms of centrality were Brigham and Women's Hospital, Duke University, the Chinese Academy of Medical Sciences and Peking Union Medical College, University College London, the University of Oxford, Imperial College, The National Institute of Health and Medical Research, the University of Pennsylvania Johns Hopkins University School of Medicine, and the University of Rennes 1. The institution with the highest centrality, Brigham & Women's Hospital, emerged as a significant institution in our analysis, warranting further investigation in the context of CMR for HCM research. Notably, numerous institutions in the United States, China, England, and other countries have made substantial contributions to the research on CMR for HCM as evidenced by their prolific publication output and centrality.

Discussion

To the best of our understanding, this study represents the first bibliometric analysis conducted on CMR for HCM. We obtained 1,427 papers published from 2013 to 2023 through the Web of Science and analyzed them with CiteSpace to identify the research hotspots in the research of CMR for HCM. We believe that this study provides comprehensive analysis of the relevant fields in the research of this field and serves as an adequate reference.

In bibliometric analysis, annual publication volume can be used as a metric for discerning the most influential countries/regions, institutions, authors, and journals in a given field. In our analysis, the number of publications showed a stable upward trend from 2013 to 2016 and except for a slight decline in 2019, remained at a high level from 2016 to 2022. The annual number of publications was stable at around 110–130 papers per year. On August 25, 2023, the European Society of Cardiology (ESC) released the 2023 ESC Guidelines for the Management of Cardiomyopathies (27), which included the latest guidelines on HCM. The new edition of the guidelines comprehensively updated the diagnosis and management of HCM to facilitate its use in daily clinical decision-making. Therefore, it can be expected that after the introduction of these new management guidelines, the research on HCM will increase and change. For one, it will strengthen the mechanistic exploration of the HCM pathogenic gene mutations, myocardial ischemia, and cardiac electrophysiological abnormalities, among other aspects; for another, it will focus on the practical exploration of individualized management, multidisciplinary cooperation, and remote monitoring, among other aspects related to patients with HCM.

In terms of journal distribution, the most prolific journal weas *European Heart Journal-Cardiovascular Imaging*. Among the top 12 journals, Q1 accounted for 66.7%, Q3 16.7%, Q2 8.3%, and Q4 8.3%. Journals with a high impact factor, such as *Lancet* (21) and *Circulation* (23), have published articles on this topic. This indicates that the relevant research in HCM has great clinical value and has been the subject of high-quality literature.

As it relates to the author analysis, the author with the most publications in this field in recent years was Maron MS from Tufts Medical Center of Boston. Professor Maron indicated that CMR enables more accurate measurement of LV wall thickness, even in regions of the chamber that are not consistently visualized with echocardiography. This leads to improved diagnosis and a better understanding of the various patterns of hypertrophy observed in this disease. Additionally, CMR can identify specific imaging markers that are associated with an increased risk of sudden death, such as LV apical aneurysms, diffuse late gadolinium enhancement (indicating myocardial fibrosis), and end-stage systolic dysfunction caused by extensive scarring (28). This provides favorable evidence for the noninvasive assessment of cardiac impairment due to HCM. From the perspective of centrality, there was little cooperation and communication among the top-ranked authors. In the future, collaboration should be strengthened to further promote research and development in this field.

In the country and institution analysis, the United States, China, and England were at the top in terms of the number of publications and citations. Moreover, the amount of literature from the United States was equal or greater to that of China and England combined. In addition, the institutions with the greatest number of publications were University College London, Brigham & Women's Hospital,

and Sichuan University, which are located in England, the United States, and China, respectively, indicating that these three countries are the largest contributor and world leaders in the study of CMR for HCM. The country with the highest centrality was Canada, indicating that research into CMR for HCM has been paid greater attention to in Canada, which is conducive to information sharing and plays a vital role in the developing this field. Nevertheless, in general, cooperation and exchange between countries was found to be relatively limited. Therefore, it is imperative that international collaboration among organizations across various nations be enhanced to foster the worldwide advancement of the noninvasive assessment of HCM through CMR.

In terms of keywords, the 5 most commonly used keywords were "cardiovascular magnetic resonance", "diagnosis", "hypertrophic cardiomyopathy", "task force", and "late gadolinium enhancement". The top 5 key words in terms of centrality were "classification", "hypertension", "adult", "insight", and "abnormality". This indicates that research into CMR assessment for HCM mainly focuses on differential diagnosis and aid management decisions at present (29) or more generally, reducing the risk of complications such as sudden death and AF in patients with HCM. Regarding keyword emergence, in recent years, individualized treatment and long-term management have become the hotspots in HCM research. The importance of treatment and long-term management of HCM lies in effectively controlling symptoms, improving myocardial ischemia and diastolic dysfunction, reducing ventricular outflow tract obstruction, preventing SCD and other cardiovascular events, and improving the prognosis and survival rate of patients (30,31).

An increasing number of studies have shown that CMR allows for the noninvasive risk stratification of patients with HCM and the identification of high-risk patients to guide aggressive clinical treatment and improve their quality of life. The management strategies still need be improved through rigorous basic experimental design and clinical research. The advantages of our study are apparent, as our findings provide a comprehensive and accurate bibliometric reference for scholars and hotspots in this field.

Nevertheless, this study is subject to certain limitations. To begin, our analysis solely relied on data obtained from the Web of Science, potentially introducing language and publication biases. In addition, most studies on CMR for HCM are single-center studies. All of these factors may affect the results. Multicenter, large-sample studies that use consistent methods are still needed to analyze the efficacy and accuracy of CMR in the noninvasive assessment of HCM. We expect CMR to become a more popular and globally accepted method for evaluating HCM.

Conclusions

This study offers significant empirical evidence that can facilitate potential collaboration among researchers and institutions and has also identified prominent themes and emerging patterns in the field of CMR for HCM. Although CMR holds promise as an effective tool for evaluating HCM, its application needs to be further confirmed through additional empirical research.

Acknowledgments

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Footnote

Conflicts of Interest: All authors have completed the ICMJE uniform disclosure form (available at https://qims.amegroups.com/article/view/10.21037/qims-23-1080/coif). The authors have no conflicts of interest to declare.

Ethical Statement: The authors are accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

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Supplementary

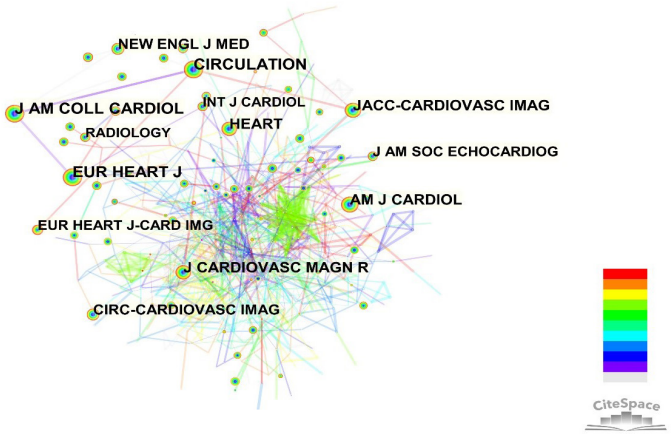

Figure S1 Co-occurrence map of cited journals.

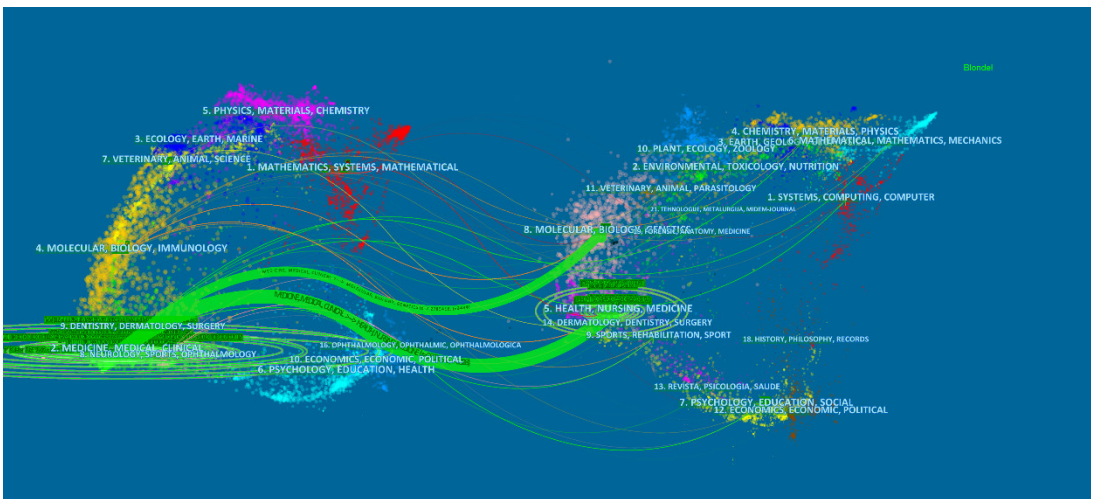

Figure S2 Double-image superposition. Double image overlay visualization of citing and cited journals. The curve is the citation line, which starts from the 16 fields of citing journals on the left and points to the 21 fields of cited journals on the right, completely showing the origin and origin of citation.

https://dx.doi.org/10.21037/qims-23-1080

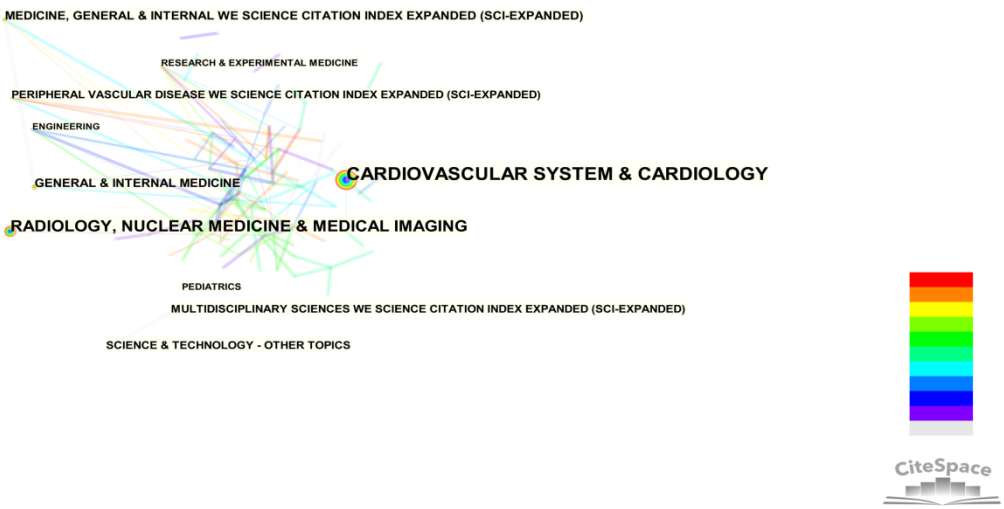

Figure S3 Journal source co-occurrence chart.

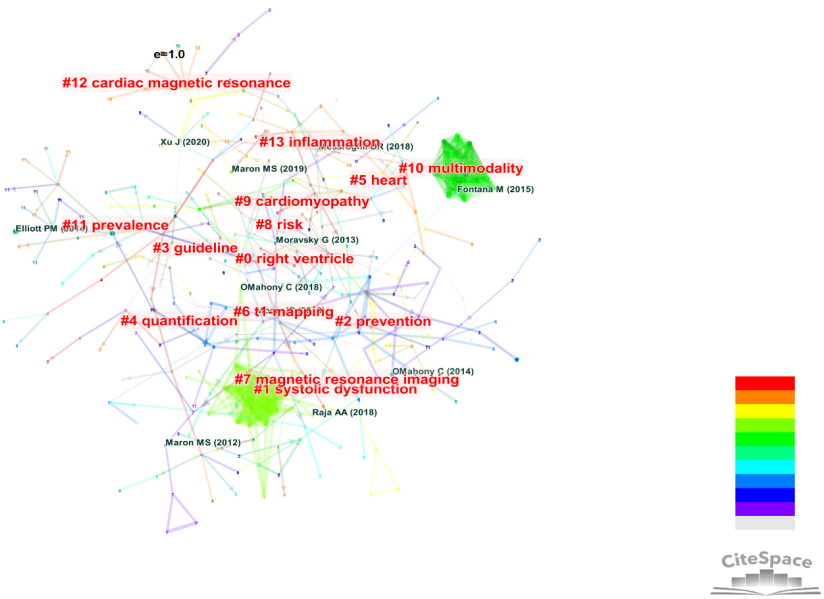

Figure S4 Analysis of cited references in keyword clustering. Based on the references of 1,427 included studies, 14 cited references were used to generate a common reference cluster for the landscape displayed in the figure. A cocitation network was constructed by selecting the initial 100 references with the highest number of citations per year. Upon synthesizing the annual network, it was determined that the network comprised a cumulative count of 330 references and 733 nodes. The cluster studies were subsequently categorized into 14 distinct groups, denoted as groups number 0–13. Each cluster was assigned a label based on the title, keywords, and subject words found in the citation reference and abstracts that pertain to the cluster citation.

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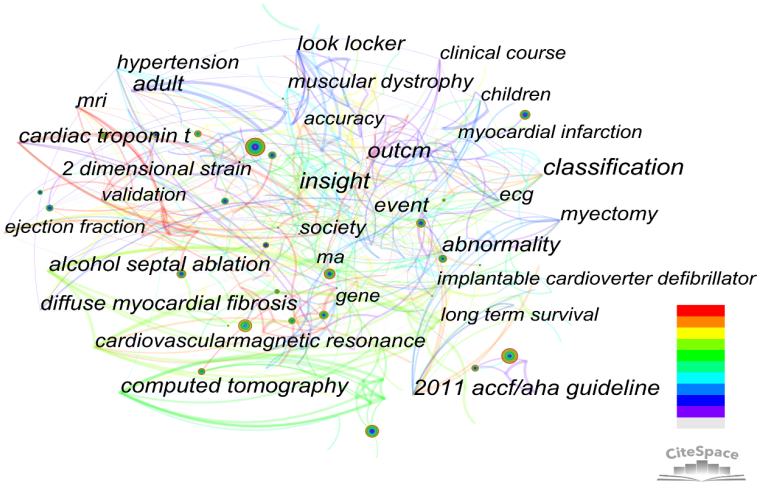

Figure S5 Keyword co-occurrence diagram.

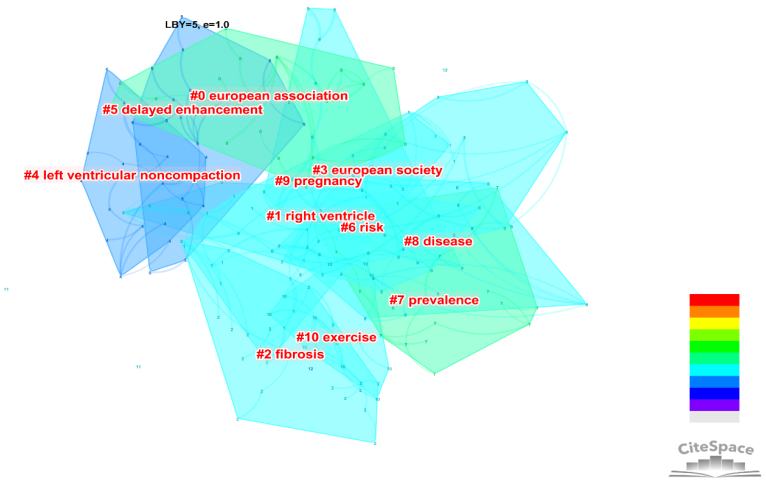

Figure S6 Keyword clustering graph.

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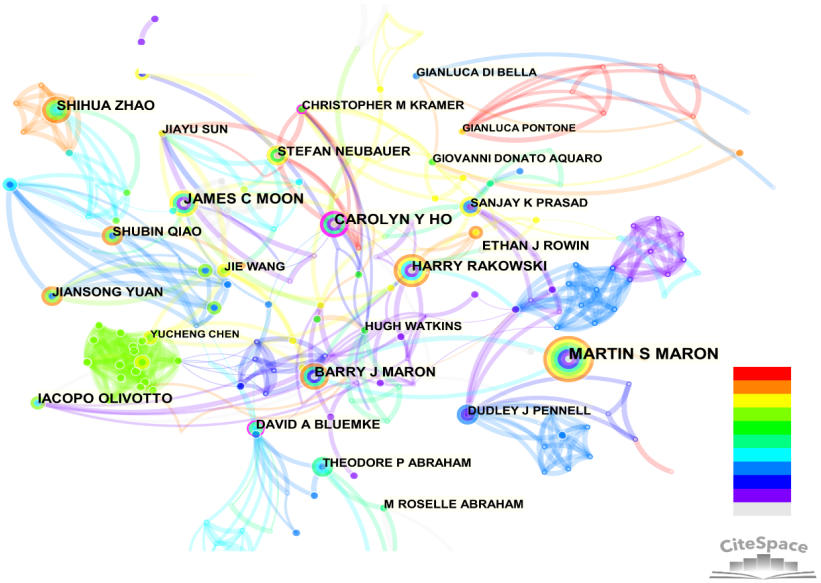

Figure S7 Author co-occurrence network diagram.

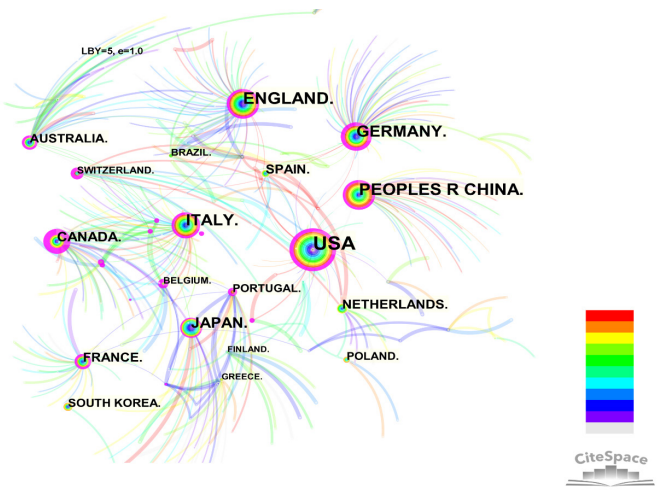

Figure S8 Country co-occurrence network diagram.

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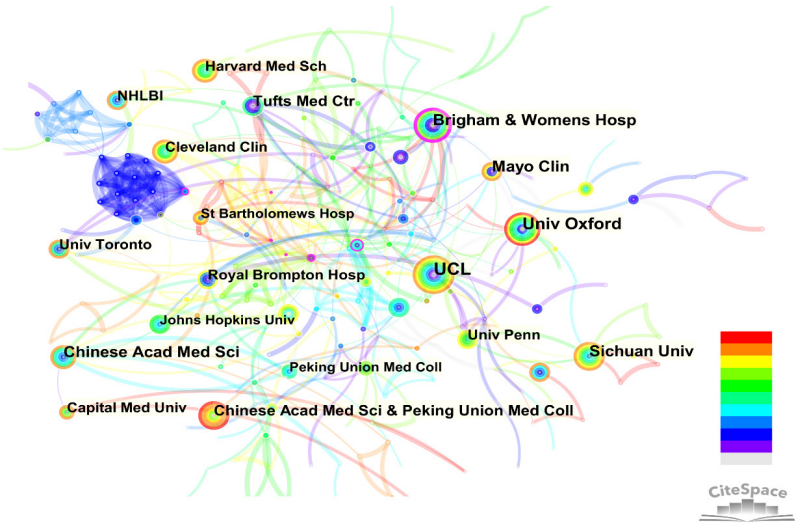

Figure S9 Institutional co-occurrence network diagram.

Table S1 Top 10 authoritative authors in cited references

Rank	Count	Centrality	Year	Author
1	536	0.01	2013	Maron BJ
2	409	0.22	2013	Elliott PM
3	344	0.00	2013	Maron MS
4	316	0.00	2013	Gersh BJ
5	202	0.00	2015	Chan RH
6	191	0.07	2013	Moon JCC
7	183	0.11	2013	Olivotto I
8	171	0.13	2013	Ohanlon R
9	161	0.00	2013	Nagueh SF
10	158	0.01	2013	Lang RM

Table S2 Top 5 countries and institutions

Rank	Country	Publications, n	Centrality	Institutions	Publications, n	Centrality
1	USA	310	0.54	University College London	45	0.16
2	China	152	0.29	Brigham & Women's Hospital	32	0.54
3	England	151	0.85	Sichuan University	30	0.06
4	Italy	116	0.18	University of Oxford	28	0.16
5	Germany	110	0.32	Chinese Academy of Medical Sciences & Peking Union Medical College	27	0.01

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