

RESEARCH ARTICLE

Research Hotspots and Trends in Home-Based Cardiac Rehabilitation: A Bibliometric Visualization Analysis

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Abstract

Objective: This research was aimed at determining research hotspots and major topics in the field of international home-based cardiac rehabilitation (HBCR) over the past 20 years, and exploring future trends in HBCR.

Methods: A total of 757 research articles from 2002 to 2022, with themes of home-based cardiac rehabilitation, were included in the core collection database of Web of Science. CiteSpace software was used for literature metrology and visualization analysis.

Results: (1) The total number of research articles on HBCR is increasing. (2) Research hotspots in HBCR include the effectiveness of rehabilitation after coronary heart disease or heart failure; quality of life; mental health; and home rehabilitation after COVID-19. (3) Research trends in HBCR include wearable intelligent technology; telerehabilitation; lifestyle interventions; and home-based rehabilitation prescriptions for exercise, nutrition, psychology and continuous management.

Conclusion: The effects of HBCR have been continuously verified. Research has focused primarily on secondary prevention and rehabilitation after coronary heart disease and heart failure. More attention must be paid to improving patients' quality of life by HBCR. Telerehabilitation based on wearable intelligent technology, home-based lifestyle interventions and continuous management are future trends of HBCR development.

Keywords: Home based cardiac rehabilitation; CiteSpace; Bibliometrics; Visualization; COVID-19; Telerehabilitation; lifestyle interventions

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Introduction

Cardiovascular disease is the disease with the highest mortality and disability rate [1]. Cardiac rehabilitation is a prevention and treatment system that integrates cardiovascular medicine, sports medicine, nutrition medicine, behavioral

medicine and psychosomatic medicine [2]. Many authorities have developed guidelines on cardiac rehabilitation as a class Ia recommendation for prevention and treatment [2–4]. Use of the center-based cardiac rehabilitation (CBCR) model remains low [3]. Home-based cardiac rehabilitation (HBCR) was proposed in 1987 and has continually been demonstrated to be an effective alternative method [5, 6]. To identify hotspots and research trends, and their implications regarding HBCR, we conducted a systematic bibliometric analysis.

Method

This study used the core collection of the Web of Science (including the SCIE, SSCI, A&HCI, ESCI, CPCI-S, CPCI-SSH, BKCI-S, BKCI-SSH, CCR and IC databases) as the research database. For all articles, the database included full records and references, such as the title, abstract, keywords, author information, institute information and contents. The retrieval keywords were home based cardiac rehabilitation OR cardiac telerehabilitation OR mobile cardiac rehabilitation OR telehealth cardiac rehabilitation. The time span of publication was from January 1, 2002, to December 31, 2022. The retrieval date was April 1, 2023, and 1178 articles were retrieved. After exclusion of literature that did not contain all the necessary data, a total of 757 articles were obtained (Figure 1).

CiteSpace R6.2.2 (hereafter referred to as CiteSpace) was used for literature analysis visualization. CiteSpace software, developed by Chaomei Chen, is used to identify scientific documents and display the research development trends and dynamics, mainly by analysis of co-cited networks. CiteSpace uses clustering analysis as the underlying algorithm and independently performs visual analysis of literature research [7, 8]. The processing procedure is displayed below.

First, the collected data are formatted. The literature is processed with a function to eliminate duplicates in CiteSpace. The time slice is 1 year in length. The log-likelihood ratio algorithm is used for clustering, to summarize the clustering statistic results as rigorously as possible by using the log-likelihood

ratio as a standard. Two view modes, Timeline and Cluster, were used.

After obtaining non-repetitive standardized data, we used CiteSpace software to conduct visual analysis of 757 HBCR theme documents in the core collection of Web of Science. The main research countries and institutions, research authors, cited journals and authors and co-occurrence of key words were summarized. The results enabled an in-depth understanding of HBCR and drawing of preliminary conclusions.

Results

HBCR Research Status

The number of articles on the topic of HBCR was determined to analyze the activity and potential for field research, thereby reflecting the influence of HBCR research. The number of research publications in 2002–2022 was measured and presented as a histogram (Figure 2).

From 2002 to 2022, the annual number of HBCR articles presented a general growth trend. The number of articles in 2022 was more than eight times that in 2002, thus reflecting the increasing attention paid to HBCR by researchers worldwide.

Based on the statistical summary of the literature on HBCR in the past two decades, the main countries conducting related research were selected. These included the United States (156), the U.K. (113), Canada (69), Australia (68), the Netherlands (40) and China (37) (Figure 3).

Each individual entry with blue background represent a country or region of clustering results, and entries beginning with #0, #1, etc. indicated research topics in those countries or regions. The pictures subsequently drawn with CiteSpace were similar.

The United States was the country with the most publications in the field of HBCR, accounting for 21.6% of the total number of publications in the past two decades. The joint theme and country network map indicated that the studies in countries including the United States, China and Australia focused on acute myocardial infarction, whereas those in countries including Canada, the U.K. and Denmark

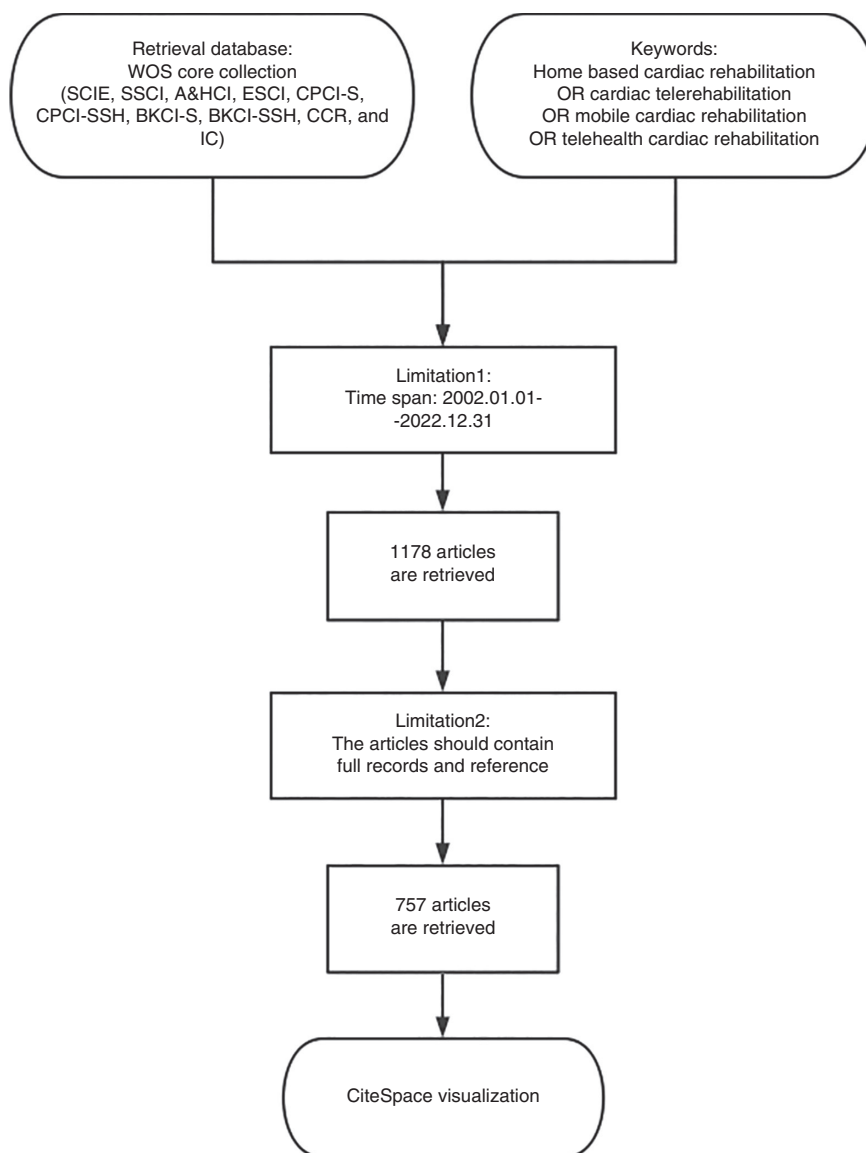


Figure 1 Flowchart of Literature Search and Analysis.

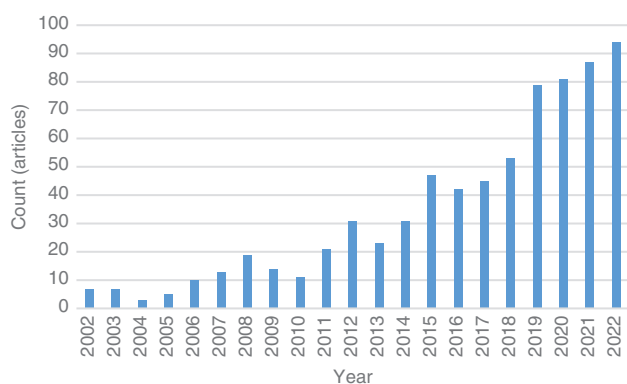


Figure 2 Number of HBCR Documents Published each Year from 2002 to 2022 in the Core Collection of WOS.

focused on heart failure. The studies in countries including Poland and Greece focused on home-based telemonitored cardiac rehabilitation. The reason for the different themes in these countries might have been that the institutions and authors working on cardiopulmonary rehabilitation in those countries might possibly have been working on related topics for a long time and consequently published more literature in the field, thus also reflecting the coherence of scientific research.

CiteSpace software was used to visualize and analyze the main research institutions, as displayed in a timeline view (Figure 4).

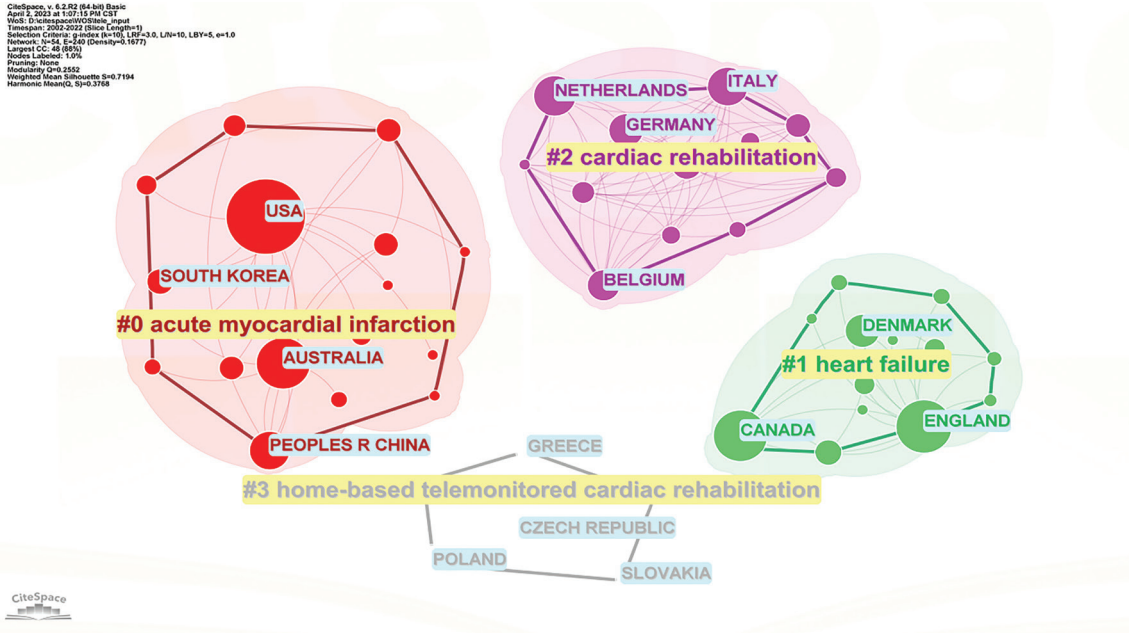


Figure 3 Major Countries or Regions Conducting Research in HBCR from 2002 to 2022.

The top five research institutions with the most articles on HBCR were the US Department of Veterans Affairs (United States, 41 articles, starting in 2014), the University of Toronto (Canada, 25 articles, starting in 2003), Institute of Cardiology (Poland, 25 articles, starting in 2009), University of Health Network (Canada, 21 articles, starting in

2012) and University of Exeter (United Kingdom, 17 articles, starting in 2007).

The different institutes focused on different topics of research. The University of York and University of Exeter focused on studies on HBCR in patients with heart failure, whereas the University of Toronto and University of Health Network focused

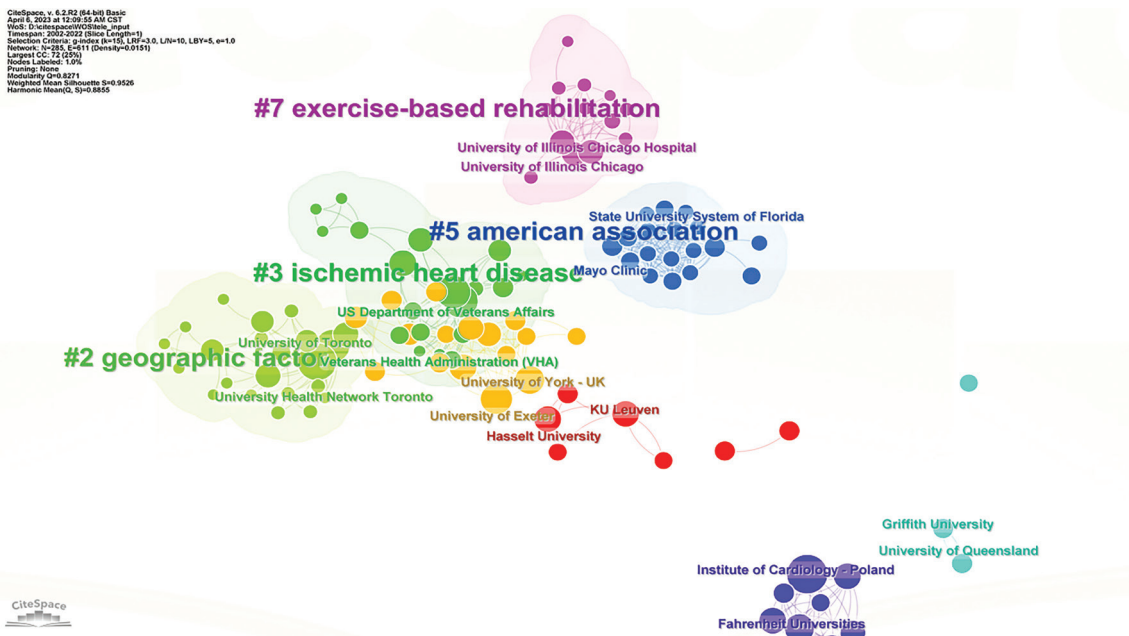


Figure 4 Main Institutions Performing HBCR Subject Research in the WOS Core Collection from 2002 to 2022.

Table 1 Summary of Research Directions in Home-Based Cardiac Rehabilitation Research Coverage.

No.	Research Direction	Counts (articles)
1	Exercise Rehabilitation	517
2	Behavior (smoking cessation)	124 (44)
3	Nutrition and Dietetics	77
4	Medicine Prescription and Medication	63
5	Mental Health	36

on geographical factors in HBCR. University of Illinois Chicago and University of Illinois Chicago Hospital performed studies on exercise-based rehabilitation, and the US Department of Veterans Affairs and VHA focused on ischemic heart disease.

The main research directions in HBCR were found to include exercise rehabilitation (517 articles), behavior (124 articles, including 44 articles on smoking cessation), nutrition dietetics (77 articles), medicine prescription and medication (63 articles), and mental health (36 articles) (Table 1).

The journal, article quantity, 5 year JCR impact factors and relevant information retrieved on the subject of HBCR are summarized in Table 2 below.

As shown in Table 2, the main journals included *J Cardiopulm Rehabil Prev*, *Eur J Prev Cardiol* and *BMJ OPEN*. These journals have high recognition in the HBCR field.

The major cited journals reflect which journals are cited most and can be used to summarize the major research topics. The statistical results are displayed in Figure 5.

As shown in Figure 5, studies on mental health cited primarily *Cochrane Db Syst Rev* and *Heart*,

and studies on heart failure tended to cite *J Am Coll Cardiol* and *Int J Cardiol*. Articles on low-intensity home-based walking programs cited mainly *Med Care* and *Arch Phys Med Rehab*, whereas articles associated with shirt-based ECG usually cited *Heart Lung* and *Mayo Clin Proc*.

According to the literature statistics, the main researchers in the field of HBCR include Piotrowicz (Warsaw Institute of Cardiology, 26 articles), Dendale (Jessa Hosp, 15 articles), Grace (University of Toronto–Institute of Rehabilitation, 16 articles), Taylor (University of Exeter, 15 articles) and Jolly (University of Birmingham, 12 articles). The results indicated that the researchers with high activity in the past 20 years are concentrated at the Warsaw Institute of Cardiology in Poland and the University of Toronto in Canada.

Through clustering analysis of the authors, we discovered the main authors in research studies on various topics. The results were visualized in CiteSpace (Figure 6).

According to the visualization results, some studies were identified to have played important roles in this field. HBCR's effectiveness, adoption and deficiencies have long been a research focus. In 2002, Arthur HM et al. conducted a randomized controlled trial on the rehabilitation of patients with coronary artery disease after coronary artery bypass grafting. The study indicated that home-based rehabilitation has favorable effects and paid formal attention to HBCR stage [9].

Another notable topic of HBCR is technology-based telerehabilitation, including home based telemonitored Nordic walking training and technology enabled cardiac rehabilitation platforms [10]. Frederix et al. have proposed a home based telemonitoring rehabilitation program using

Table 2 Main Journal Publications in the Core Collection of HBCR Subject Literature in WOS from 2002 to 2022.

No.	Journal	Count (articles)	5-year Impact Factor as of April 2023
1	Journal of Cardiopulmonary Rehabilitation and Prevention	38	2.931
2	European Journal of Preventive Cardiology	28	6.886
3	BMJ Open	23	3.587
4	Journal of Medical Internet Research	15	7.68
5	BMC Cardiovascular Disorders	14	2.644

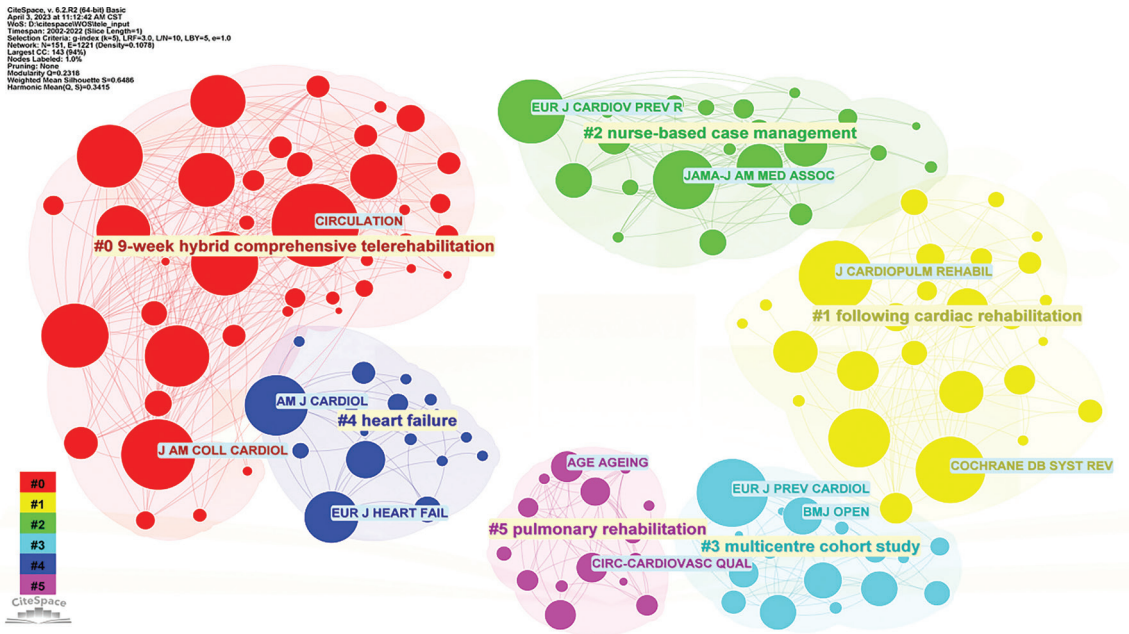


Figure 5 Major Cited Journals in the HBCR Field, Analyzed by CiteSpace.

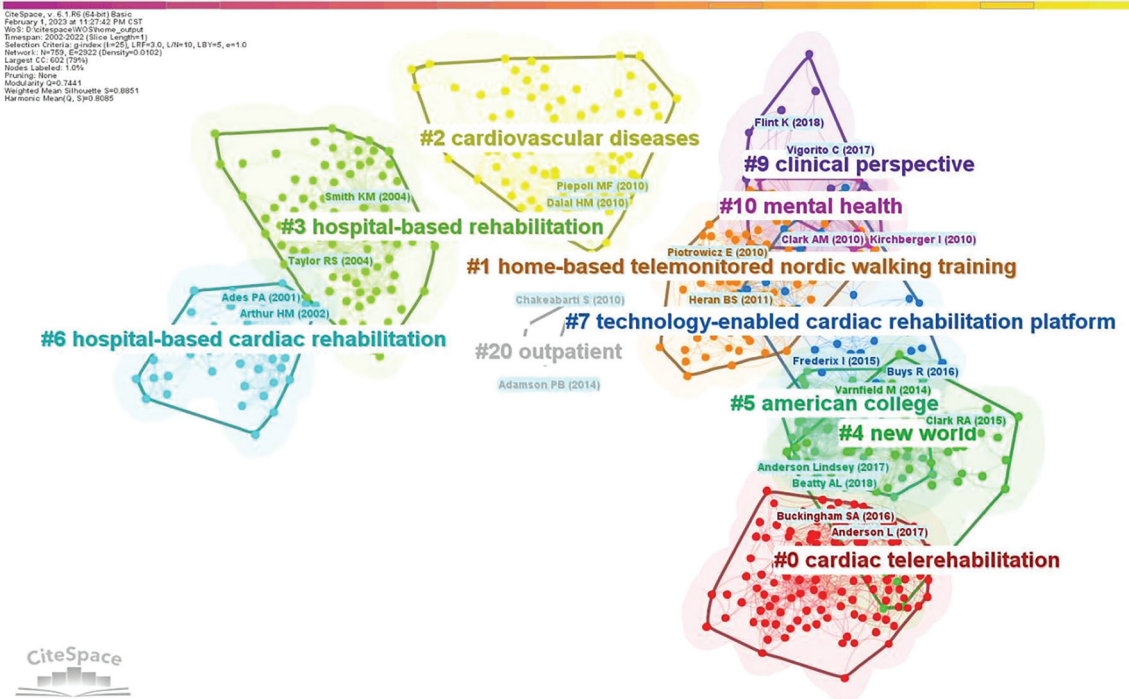


Figure 6 CiteSpace Visualization Results of Cited Authors and Subject Clustering Analysis.

semi-automated interaction to encourage patients and convey prescriptions [11].

Additionally, mental health is also worthy of focus. In long-term rehabilitation, patients’ emotional state and enthusiasm may be challenged. In HBCR, mental factors include a lack of encouragement,

company of wardmates and monitoring by physicians. Clark et al. have described mental health in home based interventions in a meta-analysis in 2010. Interventions focusing on depression, a risk factor in the cardiovascular disease rehabilitation process, was significantly compared with usual care but not

with CR [12]. Piotrowicz et al. have compared the mental and physical health scores between home-based telemonitored cardiac rehabilitation and standard cardiac rehabilitation [13], and found that home-based rehabilitation had better performance than standard care, in terms of mental health.

Research Hotspots

Research hotspots in HBCR were indicated by keyword cluster co-occurrence analysis of the literature. The major keywords, as computed by CiteSpace, were statistically summarized (Table 3, sorted by count).

To accurately determine the data obtained from keyword cluster analysis of literature research in the past 20 years, we performed CiteSpace visualization to obtain Figure 7 (some keywords that substantially overlap in the figure and emerged in Table 3 were deleted by default).

The visualization of keyword cluster analysis results for HBCR in the past 5 years revealed keywords including mobile health, percutaneous coronary intervention, exercise-based cardiac rehabilitation and Tai Chi. The University of Birmingham published relevant studies in 2007 and 2009 analyzing the rehabilitation of patients with coronary heart disease and myocardial infarction. The results indicated that HBCR can achieve favorable rehabilitation effects. Considering transportation costs, the difference of average cost of CBCR and HBCR is not significant [6, 14].

Table 3 Overview of Coexistence Analysis Results of Keywords in CPET Subject Research from 2002 to 2022.

No.	Keyword	Count	Occurrence year
1	Cardiac Rehabilitation	327	2002
2	Quality of Life	167	2002
3	Physical Activity	147	2006
4	Heart Failure	102	2008
5	Association	47	2015
6	Wearable Technology	36	2016
7	Telerehabilitation	12	2017
8	Mobile Health	6	2019
9	Cardiac Telerehabilitation	6	2019
10	Cardiorespiratory Fitness	10	2020

Additionally, with the rapid development of information and wearable technology, rehabilitation at home may be increasingly chosen. HBCR with wearable or intelligent devices was reported in 36 articles after 2016. Wearable technology is widely used in telemonitoring devices or telerehabilitation. To date, contactless monitoring technologies have been used in HBCR or other home rehabilitation to increase patient comfort.

The number of publications listed in Figure 2 indicates how HBCR has grown since 2019. HBCR regulation, programs and recommendations are urgently needed. Since the 21st century, many countries or authorities have issued relevant consensus statements. Moreover, greater recognition worldwide could further HBCR establishment.

HBCR Program

The American Association of Cardiovascular and Pulmonary Rehabilitation proposed a detailed HBCR plan for patients in 2017. The plan divides HBCR into three stages. The first stage includes patient evaluation, mobilization, risk factor identification, education and promotion of outpatient CR. The second stage includes physical activity, adjustment of risk factors, nutrition guidance, psychosocial adjustment, recovery of previous activities and improvements in quality of life. A 6-minute walk test is required before the start, to evaluate and formulate exercise prescriptions. The third stage is a long-term maintenance plan, including a follow-up call every month or every 2 months, which can last as long as 1 year after discharge [15].

The European Association for Cardiovascular Prevention and Rehabilitation proposed an HBCR program including seven parts: patient assessment, physical activity counseling, exercise training, diet/nutrition counseling, weight control management, blood lipid management, blood pressure monitoring, smoking cessation and psychosocial management [16]. The efficacy, compliance and sustainability of mobile cardiac rehabilitation have been validated by EU-CaRE [17].

In 2014, Chinese physician Hu Dayi proposed drug, exercise, nutrition, psychological, smoking cessation and alcohol restriction prescriptions (Abbreviated five prescriptions) for HBCR [18, 19]. Meanwhile, Hu has proposed “Promote

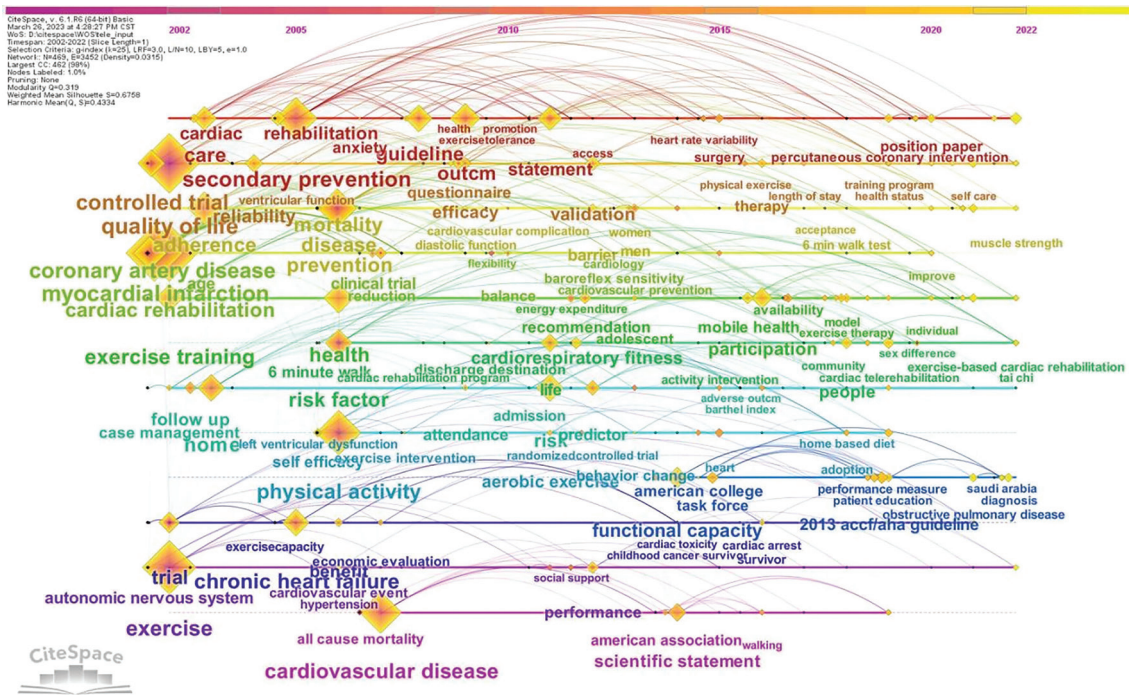


Figure 7 CiteSpace Keywords of Research on HBCR, in Highest Frequency Timeline View from 2002 to 2022.

community and home based cardiac rehabilitation, Implement five prescription services.” The cardiovascular medicine should be transferred from a focus on disease treatment to a focus on people’s health [20]. In 2017, Ding et al. explored the effects of HBCR on health behaviors and risk factors among Chinese patients with acute coronary syndrome, and indicated the feasibility and effectiveness of HBCR [21]. In 2022, a consensus of experts in home-based rehabilitation of patients with cardiovascular disease in China has indicated that the core components of HBCR include exercise prescription, nutrition intervention, sleep management, psychological rehabilitation and CVD risk factor management [22].

Most international authoritative cardiac research and rehabilitation organizations have developed HBCR programs for cardiovascular diseases, such as coronary heart disease revascularization and myocardial infarction. The revision, verification and extension of such procedures have been a focus in HBCR research in the past 20 years.

Effects of COVID-19

With the international COVID-19 pandemic, cardiac rehabilitation in hospitals became more

difficult, thus increasing the need for HBCR and telerehabilitation [23]. Some researchers have proposed that guidelines for Virtual Cardiac Rehabilitation should be launched and established as soon as possible [24, 25]. Moreover, COVID-19 has also been suggested to have led to faster development and application of telerehabilitation technology: “COVID-19 provides an opportunity to ‘reshape the implementation of home-based cardiac rehabilitation’.” [26] For both external reasons (the environment of the COVID-19 pandemic) and internal reasons (inability to treat patients in hospitals or CR centers), HBCR programs may be launched after their efficacy is validated.

Discussion

From a health environment perspective, the outbreak of COVID-19 in 2019 has accelerated the development HBCR. According to the results of CiteSpace, HBCR based on wearable devices, artificial intelligence and telerehabilitation may be future development trends. In addition lifestyle interventions and home-based rehabilitation prescriptions for exercise, nutrition, psychology and

continuous management have been areas of focus that may persist in the future.

HBCR with Wearable Devices

Research on HBCR has gradually inclined toward CR, with the integration of various electronic technologies. Simple HBCR has been reported to have poor compliance, because patients lack motivation to exercise, and updating of rehabilitation prescriptions has been hindered. In this case, physicians' encouragement, guidance and real-time monitoring of relevant data, such as troponin levels, may be important.

In 2022, Antonio et al. compared the cardiorespiratory function recovery of patients with cardiovascular disease undergoing wearable sensor-assisted HBCR and normal CBCR. Wearable sensor-assisted HBCR significantly improved cardiorespiratory function [27]. Wearable devices, the main method used in home and portable rehabilitation plans, have been studied and designed for use in cardiac rehabilitation, and have been demonstrated to be safe and effective. In addition, the efficacy of telerehabilitation plans equipped with different electronic devices and information technologies, including wearable devices, for patients with cardiovascular diseases is also being intensively verified.

HBCR with Intelligent Telerehabilitation

Kikuchi et al. have studied the effect of HBCR with a comprehensive telerehabilitation platform. The results have shown that HBCR with a comprehensive telerehabilitation platform significantly enhances patients' participation and cardiopulmonary function, and may provide an alternative choice for patients who cannot participate in CBCR because of geographical or social accessibility limitations, or physical barriers [28].

As indicated by recent studies, HBCR can inspire the enthusiasm among patients and increase participation. Meanwhile, cardiopulmonary exercise testing, including exercise monitoring and guidance, is also an important HBCR method [29, 30]. Existing studies have demonstrated that a telerehabilitation platform may include smartphone apps, wearable body parameter real-time monitoring devices or

exercise trackers, thus resulting in substantial positive effects in HBCR for cardiovascular patients. Increasing the applications of electronic technology in telerehabilitation may be necessary for HBCR in the future, and is a predicted development path for HBCR.

HBCR Exercise Prescription and Lifestyle Interventions

Exercise training, an important part of HBCR prescription, traditionally includes various forms of aerobic fitness, including walking, running or swimming, as well as muscle strength training to improve exercise tolerance. Tai Chi, an aerobic exercise, considers exercise intensity, range of activity, and ease and flexibility of movements. It can improve cardiorespiratory function, balance and posture stability, and aid in fall prevention and stress reduction. Tai Chi is cost-effective and conducive to a lifestyle of health-associated behavior practice, and therefore is an effective exercise prescription for HBCR [31, 32].

Further study of the mechanism and effect of exercise prescription and lifestyle interventions in improving patients' cardiopulmonary function and other indicators may be a future trend in HBCR combined with traditional Chinese medicine. HBCR can be established, and an integrated service for lifestyle interventions and rehabilitation prescriptions for exercises, nutrition, psychology and continuous management can be realized, through 5G and smartphone apps. Another trend in HBCR might be efficiently combining lifestyle interventions and HBCR.

Limitations

The main limitations of this study include the following: (1) The literature analyzed in this study was from the core collection of Web of Science. Literature in other databases was not included, thus potentially limiting the results. (2) This bibliometric analysis focused on systematic analysis of knowledge units of the literature (e.g., keywords, authors, institutions and volume of publications). The hotspots and trends in the development of HBCR involve procedural effectiveness, accessibility, and

details of rehabilitation techniques, which require analysis of key elements of the literature. Although this study performed necessary analysis of the important literature, it may also have a limitation of incompleteness.

Conclusion

The above analysis of the current research status, research hotspots and trends in HBCR in the past 20 years indicated continuous research verification of the effects of HBCR. The main research focuses were the secondary prevention and rehabilitation of coronary heart disease and heart failure. Increasing attention is being paid to improving patients' quality of life by HBCR. Telerehabilitation based on wearable intelligent technology and home-based lifestyle interventions are expected to become future development trends in HBCR.

Data Accessibility

The data acquired and used in this article are all available.

Ethics Statement

This study is not a clinical trial and does not require ethical approval.

Author Contribution

Li Jianchao: Conceptualization, formal revision. Zhao Yu: Data acquisition and extraction, original draft. Tao Chunjing: Draft editing. Zhang Sisi: Data acquisition and review. Ding Rongjing: Review. All authors have approved the final version of the manuscript.

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Conflict of Interest

The authors declare that there are no potential conflicts of interest.

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