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Research Paper

Identification of Emerging Topics and Technologies in Cardiovascular Systems

Reza Karimi[1], **Akram Mehrandasht**[2*], **Mohammad Reza Nasiri**[2]

1. Department of Knowledge and Information Science, Faculty of Literature and Human Sciences, University of Qom, Qom, Iran.
2. Spiritual Health Research Center, Qom University of Medical Sciences,Qom, Iran.

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ABSTRACT

Background and Aim: Identifying the topic trends in cardiac systems is a crucial tool for decision-makers in various health fields. This research aimed to identify the topical trends and changes in this field over the past three decades and to validate emerging topics and technologies in the field of cardiac systems based on reliable databases.

Materials and Methods: Using the subject–action–object (SAO) technique, keywords in the field of cardiac systems were identified from different sources, including expert interviews. Search strategies were developed based on cardiac system subject areas. Search strategies were developed based on cardiac system subject areas. Relevant data were extracted from the USPTO, PATENTSCOPE, Espacenet, FPO and Lens databases based using a checklist developed by the researcher, and finally processed and analyzed by Rapidminer software, version 9 and R text mining software, version 4.4.

Results: Out of 883 patents in the heart system field, 1611 cases were extracted and classified according to international patent classification (IPC) subject categories. Over the review period, the "devices-find-use" category was the most frequent, while "determine-beat-data" was the least frequent, with 35 cases in the database. Citation trends for patent registrations in cardiac systems have evolved, with 1960 marking a notable turning point in citation activity in this area.

Conclusion: This article showed that diseases are discovered using diagnostic methods and systems, and according to monitoring systems and emergency responses, deaths caused by diseases can be reduced.

*** Corresponding Author:**
Akram Mehrandasht, PhD.
Address: *Spiritual Health Research Center, Qom University of Medical Sciences, Qom, Iran.*
Phone: *+98 (919) 3850934*
E-mail: *mrnasiri1989@gmail.com*

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Introduction

Research is one of the vital activities of universities and research institutions, which can be a basis for reaching a developed and healthy society for the people of the country [1]. Therefore, knowing and evaluating research and technology products is essential for planners, policy-makers, and researchers [2].

System biology models life in the form of biological networks and develops methods to decipher the secrets hidden within them [3]. It seems that if the mission of biology is to understand the nature of life, the biological system puts this science on the right path to achieve its goal, which includes the nervous system, heart, and blood circulation; in this article, the focus is on the cardiovascular system [4].

Recent advances in medical sciences have played a crucial role in improving the lives of people, especially patients. However, the entry and application of new health technologies face several challenges, including the lack of a roadmap, government support for health technology development and uncertainties regarding the overarching scientific framework. These vital obstacles hinder progress. Some of these emerging technologies have created tremendous changes in health, including patient-centered care systems, digital twins, wearable technologies, etc. [5].

These emerging technologies can greatly change the quality, accessibility, and efficiency of health services. Recognizing these technologies can help improve, diagnose, treat, prevent, and care for patients, which leads to increased interaction and cooperation between health service providers and patients [5].

Identifying technological and subject trends in the field of cardiac systems is a crucial tool for decision-makers to predict and identify new technologies and emerging issues in this field. Due to the short life cycles of rapidly evolving technologies, it is often challenging to assess the current state of a given technology. The growth and development of technology are dependent on knowledge and non-coded information, and it can be concluded that the life of technologies is multifaceted and depends on different knowledge bases. Therefore, three branches—identifying, reviewing, and discovering technologies—are used to identify and extract information [6].

Achieving insights into emerging technologies using the subject-action-object (SAO) method [7] is not straightforward. However, unlike other text mining methods, semantic analysis is based on the problem-solving theory, allowing for the identification of technologies within a specific field. This results in structured data about technologies that include the topic of technology (noun phrase), function (current phrase), and purpose (noun phrase) [7]. This structure clarifies the relationships between various semantic phrases and addresses specific problems. The topic indicates the type of technology, while the combination of function and purpose shows the nature of the problem that needs to be solved [8].

The past three decades have seen the identification and validation of emerging topics and technologies in the field of cardiac systems based on valid databases from the ESA and patent databases. Therefore, this research was conducted to identify the trends, changes, and developments in this field over the last three decades and to identify and validate emerging topics and technologies in cardiac systems based on valid databases from ISA and patent databases.

Materials and Methods

This research employed text mining based on SAO techniques for identifying and trending emerging technologies in cardiovascular systems. The research population was the patents of this field in the relevant government sites in developed countries [7].

Using the SAO technique (Figure 1), all the keywords in the subject area of cardiac systems were identified from various sites and through interviews with experts in the subject area. Search strategies were then developed based on these keywords, and relevant data were extracted from the Lens database according to a checklist created by the researcher that aligned with the research objectives. Finally, the data were processed and analyzed by text mining in Python software. The search was conducted on February 5, 2023, using the term “cardiovascular system” in active patents, focusing on those with titles and abstracts.

The research method for identifying and trending emerging issues in the subject area of cardiac systems was scientometrics based on lexical co-occurrence, citation analysis, and inclusion techniques. The research population for this method included the scientific outputs in the field, specifically patents indexed in the ISI database. In this method, all keywords related to cardiac systems are identified from different sites and through expert interviews. Search strategies are created based on

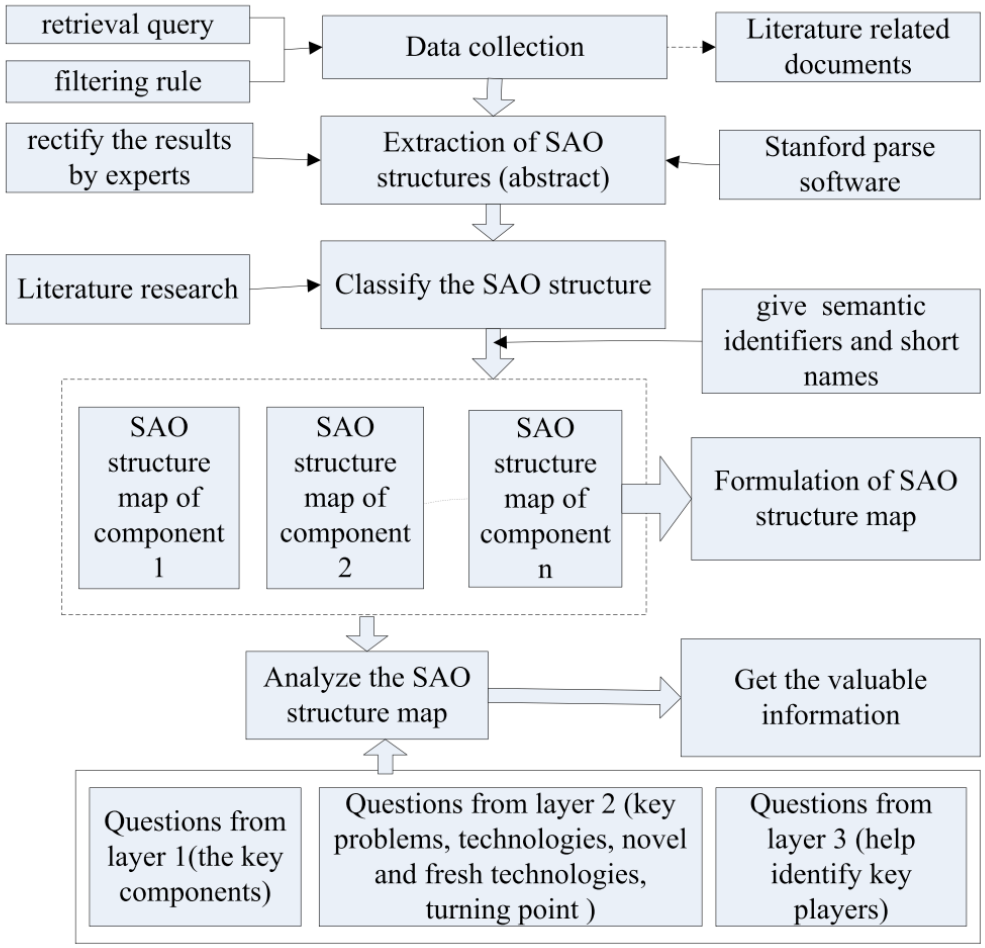

Figure 1. The specific process to construct the SAQ structure map and mine the valuable information

the subject areas of biological systems, and related data from the ISI database are transferred to Excel software as a plain text file for compilation. Excel, NetDraw and USENET were used to analyze and prepare the data, as well as to find trends and changes in topics. BibExcel software, was used to prepare the symmetric matrix.

Results

As shown in Table 1, out of 883 patents related to the cardiovascular system, 1611 cases of SAO were extracted. The Table shows the highest and lowest frequencies. This subject classification study was based on the international patent classification (IPC) categories. This classification provides an independent language using symbols and is a practical model in this field. Among the frequencies observed during the studied years, the "devices-find-use" category, with 35 cases, was the most frequent, while "determine-beat-data" was the least frequent in the database.

Using natural language processing methods in Python software, patents were extracted from the titles and abstracts based on the SAO method, which captures three key components: Subject, application and objective. This technique is effective for extracting key information from texts, especially in language processing and data analysis. In the field of patents, this method can help identify and extract the main components of an invention.

Using this method, it is possible to systematically extract key information from patents and achieve a better understanding of new innovations and techniques in the field of cardiac systems. This can help researchers and developers identify new trends and leverage past experiences.

Table 1. Frequency of SAO cases of patents

No.	Cases of SAO
35	Devices-find-use
31	Invention-provides-devices
24	Contraction-deposit-blood
22	Method-comprises-steps
17	Invention-provides-compounds
16	Invention-provides-compositions
11	Invention-provides-method
10	Model-discloses-device
10	Novel-has-effect
9	Disclosure-uses-data
9	Invention-provides-compound
9	Which-comprises-body
9	Method-uses-algorithm
8	Detection-provides-guidance
8	Invention-provides-methods
7	Device-obtains-data
7	Device-has-processor
7	Calcification-includes-calcification
7	Signal-comprises-sequence
7	Pulse-represents-wave
7	Determine-beat-data

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In Table 2, the frequency of patents over several years, without any restrictions on the years of patent examination, indicates that the active patents with titles and abstracts include only one patent in 2003, which represents the lowest frequency, while 2021 has the highest frequency with 92 patents in the subject area of cardiovascular systems.

After the necessary examinations of patents and categorizing them, all patents were divided into five clusters using the bibliometrix library in R software based on words and keywords. Each cluster was formed of ten sub-clusters and the relationships between the clusters are shown in Table 3. The term “devices-find-use” appears most frequently in the first cluster, with seven occurrences.

The dominant terms in cluster 1 include devices-find-use, contraction-deposit-blood, invention-provides-devices, and method-comprises-steps. The subject of this cluster focused on diagnostic methods and systems for diseases, emphasizing practical applications and components of various inventions.

The dominant terms in cluster 2 were method-comprises-steps, device-obtains-data, determine-beat-data, and device-has-processor. This cluster addressed monitoring systems and emergency responses, highlighting terms such as methods, monitoring systems, and emergency responses. Both clusters used the term “method-comprises-steps”. This indicates a conceptual correlation

Table 2. Frequency of patents per year

No.	Publication Year
1	2003
16	2004
7	2005
12	2006
22	2007
18	2008
26	2009
30	2010
31	2011
41	2012
63	2013
75	2014
46	2015
52	2016
76	2017
62	2018
74	2019
90	2020
92	2021
47	2022
2	2023

between the two clusters because both clusters refer to methods and processes.

Cluster 1 focused on diagnostic methods and systems, while cluster 2 emphasized monitoring systems and emergency response. These two issues can be related in some cases, especially in medical and therapeutic fields, where the diagnosis and monitoring of the patient's condition can help each other. Both clusters refer to practical applications and components of different inventions, suggesting correlations in research and development fields.

The dominant terms in cluster 3 included devices-find-use, invention-provides-devices, model-discloses-device, and contraction-deposit-blood. This cluster focuses on widely used devices and methods for removing blood sediments, with terms such as device, blood, and sediment. Cluster 1 also included the terms "devices-find-use" and "invention-provides-devices". This similarity indicates a conceptual correlation between the two clusters because both refer to inventions and devices.

While cluster 1 focused on diagnostic methods and systems, cluster 3 addressed specific devices and methods for removing blood sediments. These issues can be related, especially in medical fields, where diagnosis and

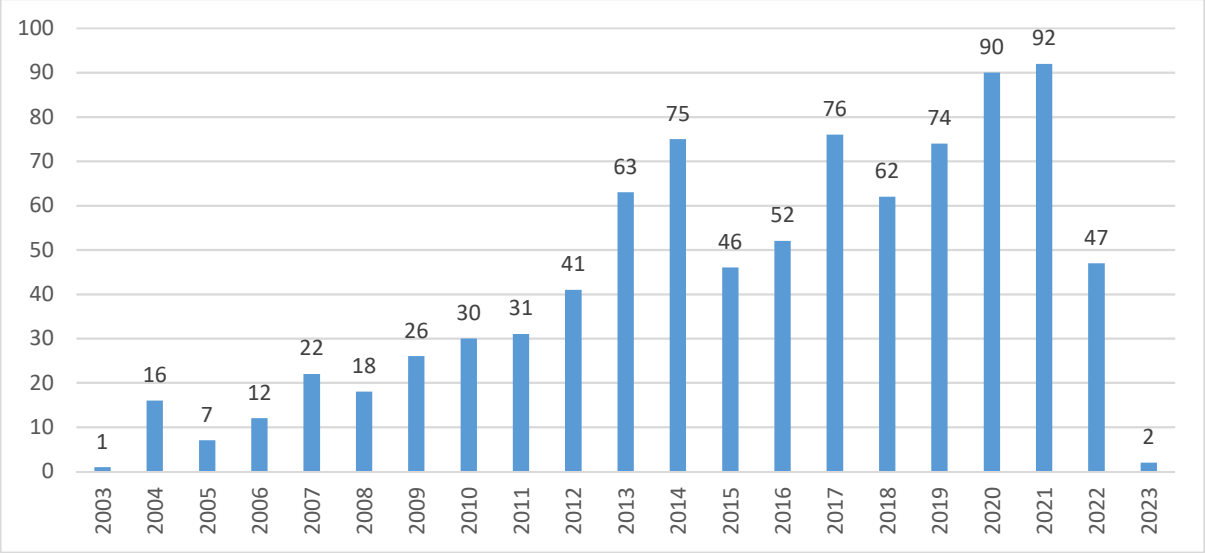

Figure 2. Frequency of patents per year

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treatment can assist one another. Both clusters refer to practical applications and components of different inventions, indicating correlations in research and development fields where devices and methods are interdependent.

The dominant terms in cluster 4 were tube-defines-lumen, catheter-comprises-sensor, devices-find-use, and invention-provides-method.

The topic of this cluster pertained to sensors and tubes used in cardiac systems.

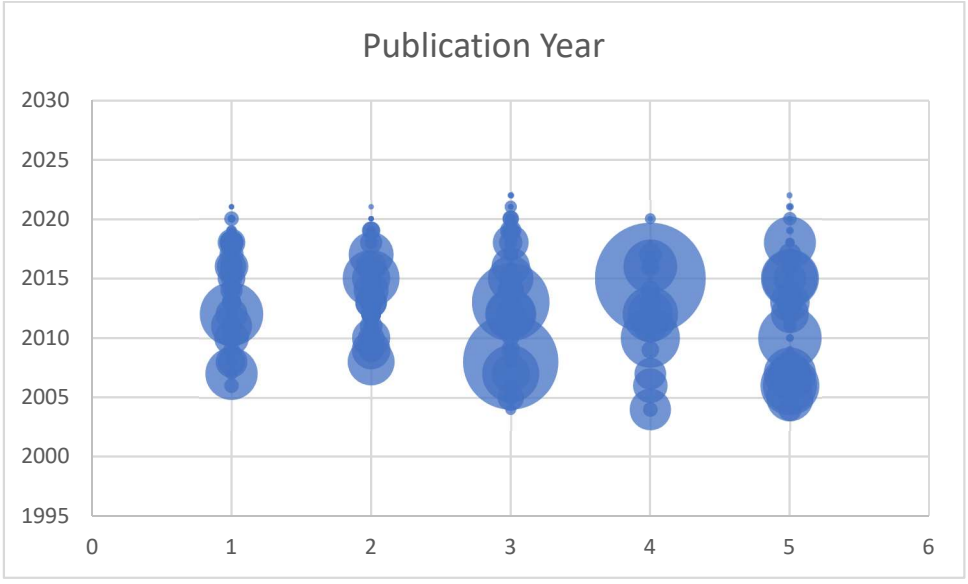

Figure 3. Frequency of clusters in different years

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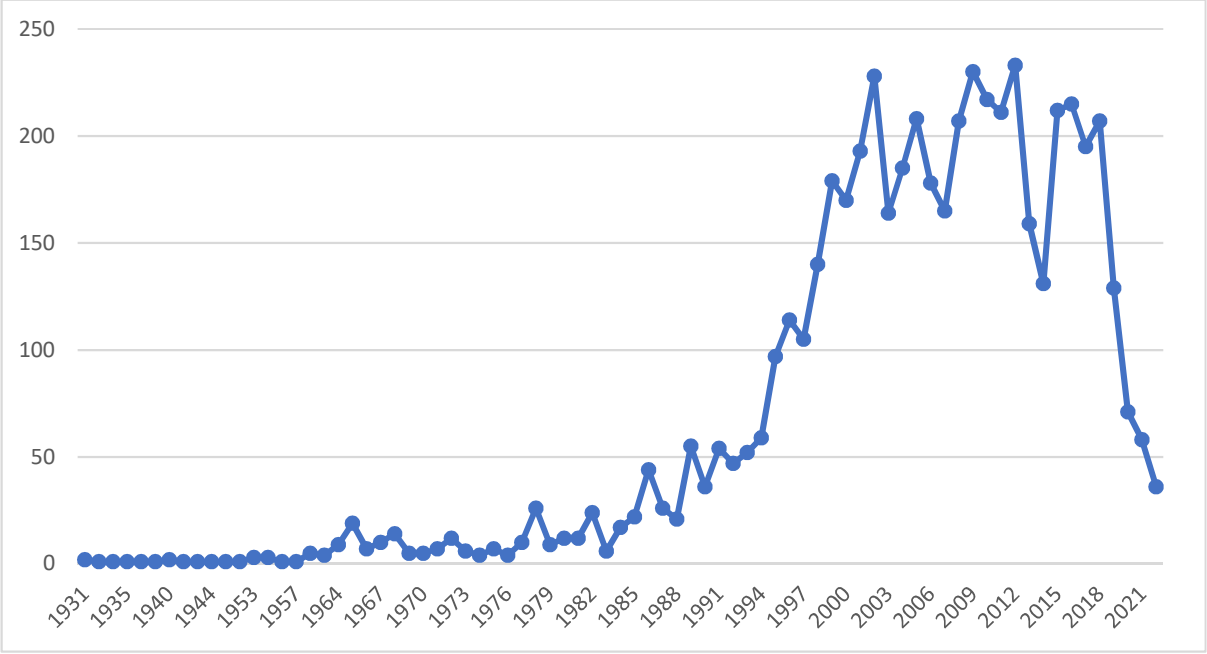

Figure 4. The process of citations for the registration of patents

Figure 2 shows the frequency of clusters in different years. Table 4 presents the average year of activity of each cluster.

The main years of activity of each cluster show that the first cluster had the highest frequency in 2012, the second and fourth clusters in 2015, the third cluster in 2008, and the fifth cluster reached its highest frequency in 2010 (Figure 3).

It can be seen that the average activity of the clusters was from 2014 to 2016, and the highest amount of work was produced in these years.

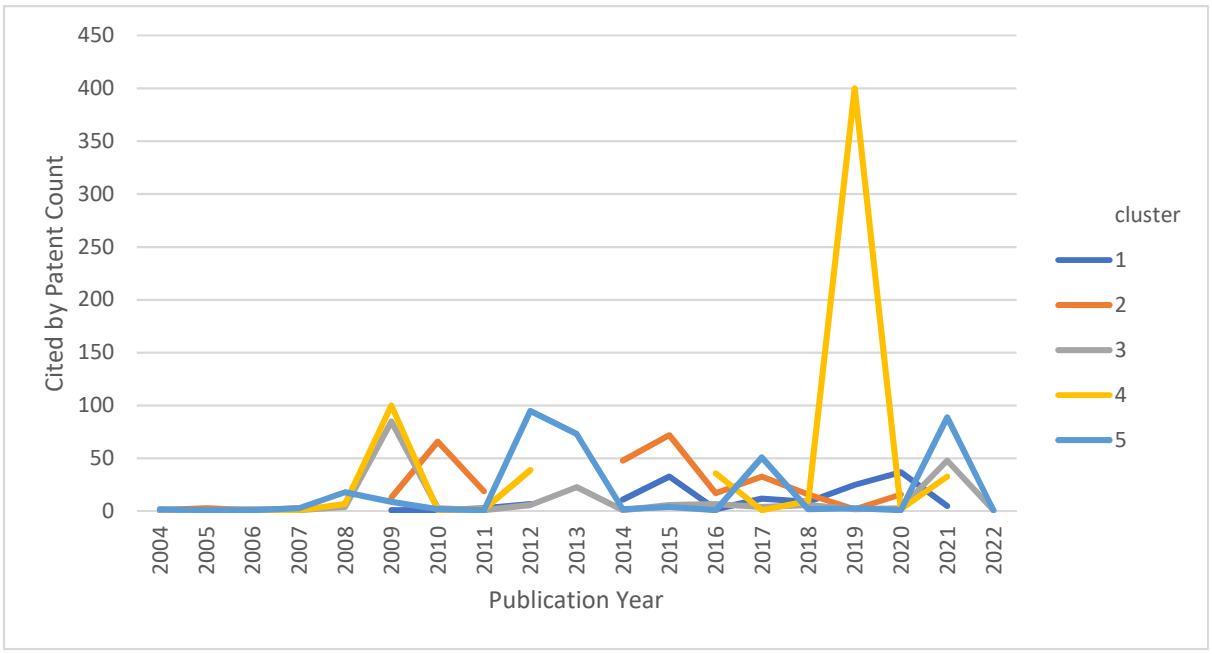

Figure 5. The process of citations of patents by clusters

Table 3. Extracted clusters and keywords of each cluster

Cluster	Keywords	No.
1	Devices-find-use	7
	Contraction-deposit-blood	4
	Invention-provides-devices	4
	Method-comprises-steps	4
	Disclosure-uses-data	3
	Method-uses-algorithm	3
	Bradykinin-exert-effects	2
	Cornu-has-effects	2
	Detection-provides-guidance	2
	Device-measure-impedance	2
2	Method-comprises-steps	8
	Device-obtains-data	7
	Determine-beat-data	7
	Device-has-processor	7
	Pulse-represents-wave	7
	Signal-comprises-sequence	7
	Devices-find-use	6
	Invention-provides-compound	5
	Invention-provides-compounds	5
	Invention-provides-devices	5
3	Devices-find-use	11
	Invention-provides-devices	11
	Model-discloses-device	6
	Contraction-deposit-blood	5
	Invention-provides-compounds	5
	Invention-provides-method	4
	Methods-stratify-states	4
	Bioluminescent-endoscopy-methods	3
	Method-comprises-steps	3
	That-block-molecules	3

Cluster	Keywords	No.
4	Tube-defines-lumen	3
	Catheter-comprises-sensor	3
	Devices-find-use	2
	Invention-provides-method	2
	Invention-provides-methods	2
	Method-comprises-steps	2
	Methods-produce-descriptions	2
	Ranges-overlap-parameters	2
	Calcification-includes-calcification	2
	Methods-employ-models	2
5	Tube-defines-lumen	3
	Catheter-comprises-sensor	3
	Devices-find-use	2
	Invention-provides-method	2
	Invention-provides-methods	2
	Method-comprises-steps	2
	Methods-produce-descriptions	2
	Ranges-overlap-parameters	2
	Calcification-includes-calcification	2
	Methods-employ-models	2

Table 4. Average year of activity of each cluster

Cluster	Mean Year
1	2016.01
2	2016.17
4	2014.72
3	2015.67
5	2015.58

Table 5. Clusters of applications of institutions active in registering patents

Cluster	Keywords	No.
Cluster 1	Lantheus Medical Imaging Inc	6
	Analytics for Life	9
	Bayer IP Gmbh	4
	Dean Steven G	4
	Evalve INC	4
	Medtronic INC	4
	Muench Frederick	4
	Backbeat Medical Inc	3
	Univ Jiangnan	3
Cluster 2	Gambro Lundia AB	12
	Lantheus Medical Imaging Inc	7
	Backbeat Medical Inc	4
	Bayer Schering Pharma AG	4
	Olde BO	4
	Solem Kristian	4
	Evalve Inc	3
	Koninklijke Philips NV	3
	Shandong College of Electronic Tech	3
	Abbott Cardiovascular Systems Inc	2
Cluster 3	Abbott Cardiovascular Systems Inc	7
	Lantheus Medical Imaging Inc	7
	Analytics for Life	4
	Backbeat Medical Inc	4
	Abbott Cardiovascular Systems	3
	Bridgepoint Medical Inc	3
	Dean Steven G	3
	Delta Tooling Co Ltd	3
	Medtronic Inc	3
	Anlauf Sonja	2

Cluster	Keywords	No.
Cluster 4	Medtronic Inc	3
	Opsens Inc	3
	Chan Keith	2
	Chiang Shou Shan	2
	Lantheus Medical Imaging Inc	2
	Spilker Ryan Leonard	2
	Town Winston	2
	Univ Leland Stanford Junior	2
	Abbott Cardiovascular Systems Inc	1
	Afanasev Aleksandr Mikhajlovich	1
Cluster 5	Lantheus Medical Imaging Inc	10
	Abbott Cardiovascular Systems Inc	4
	Analytics for Life Inc	4
	Backbeat Medical Inc	4
	Bayer Schering Pharma AG	4
	Topharman Shanghai Co LTD	4
	Bayer IP Gmbh	3
	Doss Mirko	3
	Gambro Lundia Ab	3
	Medtronic Inc	3

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The process of citations for patent registrations in the field of cardiovascular systems was also different, with the most patents registered in 2002, 2010 and 2014. A turning point in the citation process for this subject area can be noted from 1960 onwards (Figure 4).

Figure 5 illustrates the citation process of patents by other patents in the field of cardiovascular systems, differentiated by cluster and across various years. Each cluster has received more citations during certain years, with cluster 4 receiving the most citations in 2015. This difference is caused by the difference in the application of each cluster and the dominant research approach at different times. The difference in the number of citations in different clusters indicates the scope and concentration of patents. Cluster 3 with the highest number of citations likely owes this to its broader coverage of technologies and applications, as indicated by phrases such as “devices-finding-use” and “inventing-providing-devices”. In contrast, clusters 1 and 2, with similar numbers of citations, focused more on specific technologies or applications, and terms, such as “a method comprising steps” and “device-containing a processor”, indicating this specialization. Clusters 4 and 5 had the lowest number of citations due to their limited focus on specific components or processes, such as “Lule-Lumen” and “catheter-includes-sensor”. Possible reasons for these differences include the technological importance of the patents, patent quality, publication timing, and biases in citation practices.

The applications of patents were also divided into six clusters, with the frequency displayed in each cluster.

Table 6. Patent ownership by cluster

Owner	Cluster					Total
	1	2	4	3	5	
Backbeat Medical Inc	3	4		3	3	18
Lantheus Medical Imaging Inc		3	2	2	4	14
Abbott Cardiovascular Systems Inc	1	3	1	5	3	14
Analytics for Life	5	1		3	3	14
Medtronic Inc	4		2	2	2	13
Bayer Schering Pharma Aktiengesellschaft	3	3	1		1	10
Gambro Lundia AB		4	1		2	8
Board of Regents the University of Texas System	2	2		1	2	8
Boston Scientific Scimed Inc	2	2		2	2	8
Uim Pressure Implant Inc	2	1			2	7
Koninklijke Philips N.V		3		1	1	6
The Cleveland Clinic Foundation	1			4	1	6
E.S. Bio-Tech Limited	1			1	3	5
Evalve INC	1	1		1		5
Koninklijke Philips Electronics N V	1		1	1		4
Scifluor Life Sciences LLC		1		2	1	4
Ph Pharma Co. LTD		1		2	1	4
Endotronix Inc		2			2	4
Cardiac Pacemakers Inc		1			2	4
Intra-Cellular Therapies Inc	1				2	4
Globoasia Llc		1	2	1		4
Lumen Biomedical Inc	1			1	2	4
Drexel University		2			1	4
Project Moray Inc	1			2	1	4
UAB “Daumantai LT”, LT			1	2		4
Academisch Medisch Centrum			1	2		3

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In the analysis of patent usage, the frequency in each cluster showed that BackBeat Medical had the highest activity with 18 entries across clusters 1, 2, 3 and 4, while Abbott Cardiovascular Systems was involved in all clusters with a frequency of 14. Tables 5 and 6 shows the patent ownership by cluster. It can be seen that BackBeat Medical Inc had the largest number of patents, which were primarily in clusters 2, 1, 3 and 5.

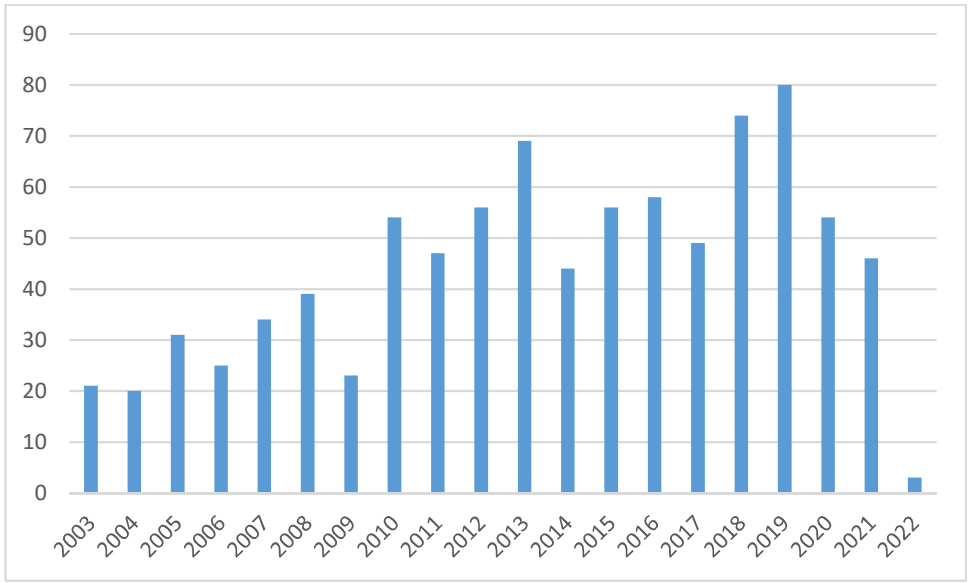

Figure 6. Time process of application of patents

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The time process of application

Figure 6 shows the time process of application from 2003 to 2019. There was a drop in applications in 2009, 2014 and 2017, but the overall trend was upward. Since 2019, there has been a gradual downward trend, which seems to increase over time.

Figure 7 shows the frequency network and the relationships between SAO cases. Figure 7 shows the relationship between inventions and methods, effects and systems, and fully used tools. It indicates that to sustain progress, it is necessary to use up-to-date methods and make significant decisions. The existence of general terms, such as: Has, That, includes, and use relates to the type of use of patents in practice. The keywords “has”, “that”, “layer”, “have”, “data”, “includes”, “find” and

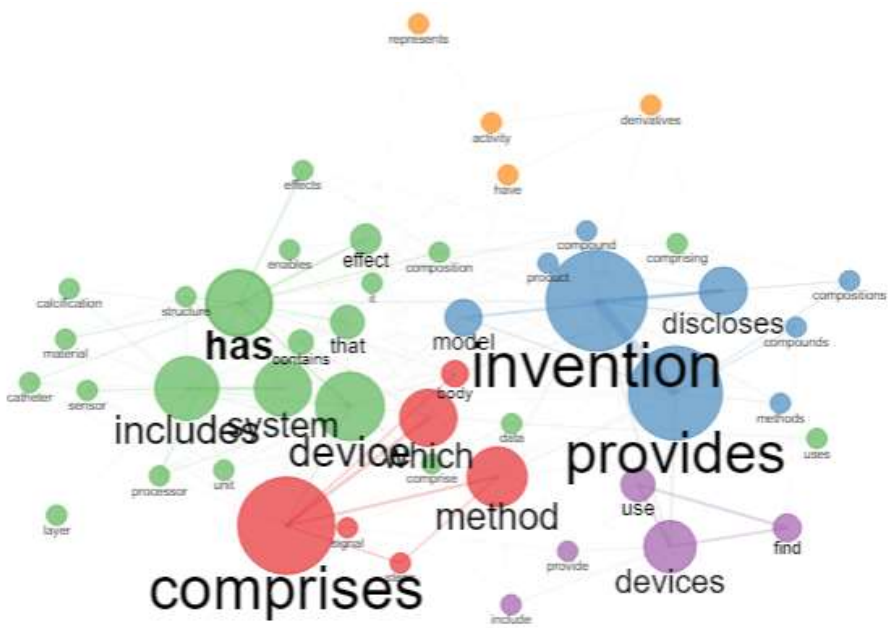

Figure 7. Frequency network and the relationship between SAO cases

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"use" represents different relationships and features in systems and inventions. "Has" and "have" refer to possession or characteristics, while "that" is used to describe characteristics in dependent clauses. "Layer" refers to structural components in multilayer systems, and "data" refers to information that is collected and analyzed. "Includes" refers to the inclusion of components in a system, while "find" and "use" refer to the act of discovering and using things. The key connections between these words show that inventions usually involve methods for analyzing data and that systems comprise various components, all while serving distinct functions and applications.

Discussion

By examining 218 patents with the participation of Iranian inventors, Arani and Naghshineh pointed out the importance of inventions in the development of technology and considered it a turning point in policy-making and decision-making in the development and research sector [9]. This finding is consistent with the present article. During the study period, out of 883 patents in the field of the cardiovascular system, 1611 cases were extracted and divided according to IPC subject categories, which can facilitate better decision-making in disease diagnosis and policy formulation for monitoring systems to reduce mortality based on patent ownership metrics.

Abdollahi and Naghshineh showed that patents can be used to measure the future development of technology based on the number of citations and to show the direction of technological advancement [10]. In this article, this insight can aid in the continuity of life by utilizing these technologies and demonstrating how to implement them in macro decision-making through up-to-date methods.

In another study, it was concluded that considering the global challenges, such as economic recession, continental changes, and public consequences (such as security, health, and food), human innovations (inventions) are necessary to find appropriate solutions in the future [11]. Valinejadi et al. showed that the indexed scientific productions of researchers at Hamedan University of Medical Sciences in the citation databases of Web of Science and Scopus amounted to 472 records between 1998 and 2008, with the highest number of scientific outputs occurring in 2008 (61 documents in Web of Science and 79 documents in Scopus) [12]. In comparison, the present study indicated that the highest number of citations came from patent registrations and research articles covering the period from 1960 to 2023, with the peak number of citations occurring in 2019.

Majidi and Dehghani in a comparative study of citation analysis and the technological impact of patents, revealed that the majority of patents involving Iranian inventors fell under subject category C (chemistry and metallurgy), while the majority involving Turkish inventors fell under subject category A (essential goods) [13]. This article highlights a conceptual correlation among some clusters, pointing to differences in methods and processes.

Abdekhoda et al. showed that during the years under review, patents had a considerable focus regarding their subject matter, with a greater potential for research outputs to lead to patenting and innovation in the areas of chemistry and metallurgy than in other fields [14]. In this article, cluster 3 with the highest number of citations was attributed to broader coverage of technologies and applications within its patents, such as the terms "devices-finding-use" and "invention-providing-devices".

In the field of patents, few studies have been conducted using natural language processing and scientometrics, which can refer to SAO analytical methods in the processing and analysis of various scientific sources or patent documents. One of the vital applications of this method is in the analysis and processing of technologies. Gerken and Moehrle [15] developed a new tool based on the SAO analysis method in patents, and the output of their findings led to the identification of emerging technologies. Choi et al. [7] identified technology development trends in 2012 by combining the SAO method with social network analysis. In addition, they discovered technological opportunities using the SAO method, and the results of these articles are consistent with our research, indicating conceptual correlations between different topics in this field, which can help identify and develop new technologies.

Franceschini and Maisano analyzed the publications and patents of European researchers in the field of producing technology and production systems. This article aimed to compare a sample of European researchers in the field of producing technology and production systems based on scientific publications and patents. The researchers were evaluated and compared with the indicators related to the outputs of individual researchers and group researchers from various countries [16]. The results of this study also provide preliminary indications of the inventions arising from researchers' activities in their fields of interest, identifying similarities and differences between different institutions and subjects.

Meyer [17] showed that few patent sources are related to articles in this field. Also, this research found that patents from universities have more citations to scientific articles compared to those from other institutions, which is consistent with the present study. This can indicate the key role of universities in advancing research and scientific innovations.

Conclusion

The current research identified and analyzed emerging technologies in cardiovascular systems, using text mining and scientometric techniques to examine trends and developments in this field over many years. The results indicate that emerging technologies, particularly in patient care systems and wearable technologies, can enhance the quality and efficiency of health services.

The analysis of patent data shows that in recent years, the number of patents in this field has increased significantly, with 2021 witnessing the highest number at 92 patents. Also, the clustering based on the SAO technique indicates the conceptual correlations between different topics in this field, which can help identify and develop new technologies.

The results of this research also indicated that universities have more citations to scientific articles than other institutions, which can indicate the key role of universities in advancing research and scientific innovations. The identification and analysis of emerging technologies in cardiovascular systems is a crucial tool for decision-makers and researchers to predict and plan in this field, potentially improving the processes of diagnosis, treatment, and patient care. This article showed that through diagnostic methods and systems, diseases are discovered, and monitoring systems and emergency responses can reduce mortality caused by these diseases. With accurate and timely diagnosis of diseases, coupled with the development of medical imaging tools and specialized medical devices, it is possible to reduce mortality rates and improve lifestyles.

Sponsor

This research did not receive any financial support from funding organizations in the public, commercial, or non-profit sectors.

Ethical Considerations

Compliance with ethical guidelines

This study was approved by the Ethics Committee of Qom University of Medical Sciences (Code: IR.MUQ.REC.1402.049).

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Authors' contributions

All authors contributed equally to the conception and design of the study, data collection and analysis, interpretation of the results, and drafting of the manuscript. Each author approved the final version of the manuscript for submission.

Conflict of interest

The authors declared no conflict of interest.

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