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Application of artificial intelligence in heart diseases: A bibliometrics review based on CiteSpace analysis

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Abstract: *This study analyzes the research status and trends concerning the global application of AI in heart diseases within the past 36 years, to aid researchers navigate more studies in the future. We acquired publications from to 1986–2021 from PubMed using terms from Medical Subject Headings (MeSH) thesaurus. Subsequently, we filtered the type and language of publications in Web of Science and analyzed the data for descriptive statistics, fitting curves, and CiteSpace for visualization analysis.A total of 2038 records related to the application of AI in heart diseases were imported into CiteSpace. There has been a growing number of publications over the past 36 years roughly. Two author clusters focused on application of AI in heart diseases for clinical practice and data-driven medicine.And USA produced the most academic achievements with high impact. Machine learning, neural network, classification, diagnosis, heart failure, atrial fibrillation, and myocardial infarction have become the principal research hotspots and trends in recent years. Generally, AI techniques are increasingly applied to heart diseases in areas ranging from studies on medical data to clinical practice-related robotics-assist. Compared with conventional approaches, AI has been outperforming for heart diseases in terms of surgery operation, identification, detection, prediction, classification, and risk stratification. It has the potential to make healthcare feasible, safe, and accessible.*

Keywords: *Artificial intelligence; Heart diseases; bibliometric analysis; CiteSpace; publications*

1. Introduction

Artificial intelligence (AI) is a general term that implies the use of a computer to model intelligent behavior with minimal human intervention[1]. AI, a branch of computer science, was formally proposed in 1956. In the past 50 years, AI has made great progress, becoming an extensive interdisciplinary and frontier science. It is involved in information theory, cybernetics, automation, bionics, biology, psychology, mathematics, logic, linguistics, medicine, and philosophy. AlphaGo's defeat of the Go world champion is a milestone in the development of AI. Currently, AI is applied to the fields of robotics, computer vision, natural language processing (NLP), cognitive inference, and machine learning (ML).

Pathological conditions of heart diseases involve the heart, including structural and functional abnormalities, which cause heart failure (HF), cardiomyopathy, myocardial ischemia, and atrial fibrillation (AF). It not only brings a huge economic burden to the public and the family, but also leads to high mortality and readmission rates. Traditionally, the structural and functional abnormalities of the heart depend on laboratory tests and echocardiography (ECG) for diagnosis and surgery. However, AI introduces a new approach in heart disease by allowing in-time diagnosis, advanced prediction, and therapy without delay. For example, ML, a core part of AI, has been applied to clinical tasks and has shown better performance in many studies regarding heart disease prediction of 1-year mortality[2],, adverse events[3],and diagnosis of left ventricular hypertrophy[4].This is beneficial for providing patients' psychological and physical intervention. Additionally, robotic-assisted surgery results in less trauma to the tissue.

Originally, bibliometrics were derived from the field of library and information science to reveal the law of literature information. To gain a better insight into research frontiers, emerging trends, and sudden changes during one period, an advanced method is proposed. CiteSpace, a web-based Java application, was developed for data analysis and visualization[5]. It is a unique and influential software in the field of bibliometrics and facilitates research to expose the relationship between authors, countries, and institutions in one area from databases such as Web of Science(WOS)[6], Scopus, and PubMed, such as Alzheimer's disease[7], COVID-19[8],There is insufficient attention on the bibliometric and visual analysis application of AI in heart diseases, although AI has gradually and closely integrated clinical activities and academic study. This study analyzes research and trends concerning the global application of AI in heart diseases within the past 36 years, using CiteSpace to conduct visualization analysis with acquired articles.

2. Method

2.1. Data Sources

Data collection was divided into two stages. In the first stage, we collected data from PubMed, a medical literature network database developed by the National Center for Biotechnology Information (NCBI) of the National Library of Medicine (NLM). We used terms from the Medical Subject Headings (MeSH) thesaurus to retrieve publications, covering all literature related to AI and heart disease. Using the index term "heart diseases [MeSH]" AND "artificial intelligence [MeSH]," we found 2,851 studies, including clinical trials and meta-analyses, published between 1986–2021. Subsequently, we downloaded the data from PubMed using an Excel document. As PubMed could not identify the type of publication, we kept all publications type as "article." The next stage was filtering the type of publication by the Web of Science database. Initially, we input PMID, which is a unique number of papers, into the Web of Science database for advanced retrieval with logic operation symbol "OR" among all publications' PMID. We selected the type of publication as "Article" and language as "English." Finally, we obtained 2,038 records from the Web of Science database for further analysis using CiteSpace. Studies were downloaded on March 4, 2021. Each downloaded study included the authors, title, abstract, descriptors, and references.

2.2. Statistical Analysis

The selected records were exported as plain text, SPSS v.25 was used for the quantitative statistics and fitting curve of literature publishing year.Citespace 5.7 R2 was used to visually analyze the annual volume of authors, institutions(universities,affiliated hosptals or research centers), countries, and keywords of AI in heart diseases and draw relevant charts. Also,it presents the structure, laws, and distribution of scientific knowledge and relationship among authors, institutions and countries.

3. Results

3.1. Publication years and growth trends

This study included 2038 publications that met the inclusion criteria (see Figure 1). The number of studies related to the application of AI in heart diseases increased slowly during 1986-2015, including 1,121 manuscripts in total, indicating that AI was not very popular in heart diseases. A 1986 study on linear prediction techniques was initially used for automatic ECG classification. In the same year, AI was introduced to MeSH terms. From 2016 to 2021, the number of articles were 917, almost covering half of the total publication number with a rapid increase. Moreover, the number of papers exceeded 100 per year and peaked in 2019, with 279 publications (13.6%). This implied that the integration of AI and heart diseases was gaining traction. This is because advanced technology began to be embedded into clinical fields and brought a huge evolution in medicine, such as disease diagnosis, prevention, and even surgery (Figure 1). To understand the growth of literature related to application of AI in heart diseases over time, we set time (year) as the independent variable and cumulative publications as the dependent variable to establish fitting curves using SPSS v.25 from 1986-2020. We excluded 8 articles published in 2021, because they added noise value in the model. The results indicate that quadratic curve-fitting model demonstrated outstanding performance. The R2 was 0.985, which approached to 1, and F test was significant ($P < 0.05$), indicating that the model fitted well (Figure 2).

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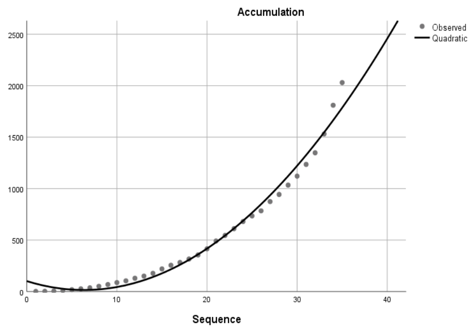

Figure 1: The annual volume of publication

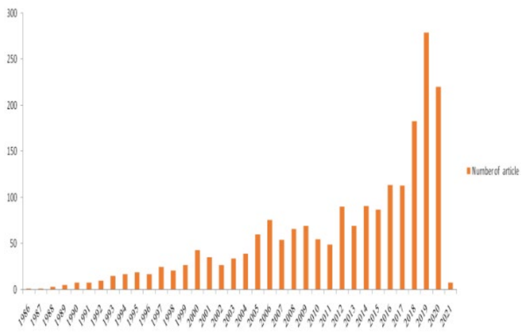

Figure 2: Time sequence distribution and fitting curve of the amount of literature

3.2. Authors

The author has the power to drive the development of the research. Thus, we can detect high-impact authors based on the connections between authors and the number of articles. The larger the size of the node, the more studies published by the authors. Among the authors, "Johannes Bonatti" had the largest number of nodes, implying that they authored the most papers. This was followed by "Nikolaos Bonaros" and "U Rajendra Acharya", as shown in Table 1. The thicker lines between the two nodes indicate greater cooperation between authors. As shown in Figure 1, the overall network density was 0.0035 with thinner lines, indicating that the authors were interested in the application of AI in heart diseases, but there was a lack of cooperation between these authors. However, in this study, there was a tendency to generate three stable groups of collaborators that contained two or more core authors. "Johannes Bonatti," "Thomas Schachner," "Nikolaos Bonaros," and "Dominick Wiedemann" formed a cluster, and most authored more than 15 articles. "Christian Tesche," "U Joseph Schoepf," and "James K Min" developed a collaborative group, which was the densest co-authors cluster. "Wr Chitwood," "Cr Smith," and others consisted of a third cluster. The top 10 authors, "Johannes Bonatti," "Nikolaos Bonaros," and "U Rajendra Acharya," had strong cooperation (Figure 3).

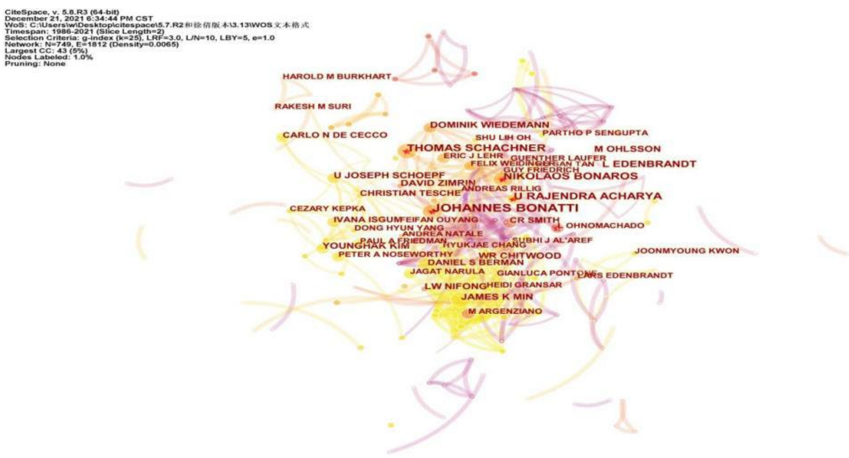

Figure 3: Author collaboration network

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Table 1: The top 10 authors

Rank	Author	Number of Publication	Rank	Author	Number of Publication
1	JOHANNES BONATTI	24	6	U JOSEPH SCHOEPF	12
2	NIKOLAOS BONAROS	17	7	L EDENBRANDT	12
3	U RAJENDRA ACHARYA	15	8	CHRISTIAN TESCHE	11
4	THOMAS SCHACHNER	15	9	WR CHITWOOD	10
5	JAMES K MIN	12	10	DOMINIK WIEDEMANN	10

3.3. Institutions

Cooperation network analysis was used to explore the relationship between research institutes. This may reveal direct cooperation among different institutions for academic assessment. As shown in Figure 5, the node size represents the number of articles published by the institutions, and the lines between nodes represent the cooperation between different institutions. This study included 737 nodes, 1372 links, and a network density of 0.0051. This indicates that the institutions were relatively scattered and did not generate a strong and extensive cooperative network relationship. Stanford University, Brigham & Women's Hospital had established the leader cooperation group. In addition, lines from Stanford University, Brigham & Women's Hospital, and Cedars Sinai Med Ctr were thicker, indicating strong cooperation. Simultaneously, tStanford University, Brigham & Women's Hospital, and Cedars Sinai Med Ctr ranked three of the top publications, publishing 34, 28, and 27 articles, respectively (Table 2). Although Zhejiang University and Shanghai Jiao Tong University ranked top 10 in the number of publications, they had weak cooperation with other institutions (Figure 4).

Figure 4: Institutes collaboration network

Table 2: The top 10 institutions publishing publications about AI studies in heart

Rank	Institution	Number of Publications	Rank	Institution	Number of Publications
1	Stanford Univ	34	6	Harvard Univ	25
2	Brigham & Womens Hosp	28	7	Mayo Clin	24
3	Cedars Sinai Med Ctr	27	8	Harvard Med Sch	23
4	Lund Univ	25	9	Zhejiang Univ	23
5	Columbia Univ	25	10	Shanghai Jiao Tong Univ	20

3.4. Countries/Region

The larger node size means more papers published in one country, and the thicker lines represent close cooperation in different countries. In this study, it generated 82 nodes and 531 links (Figure 5).Totally, the network density was 0.1599, indicating many countries tended toward focusing on application of AI in heart diseases, and they developed close cooperation gradually. The top 3 countries for published articles were the USA, which produced the most academic achievements, and the number of articles was more higher than any other countries, followed by China and Germany. For the majority of countries, there was a positive relationship between the number of publications and centrality. The USA occupied approximately 30% of the total number of publications with centrality reaching 0.52. It was followed by Germany(174), England (145) and Italy(100),with centrality≥0.1, which implying good quality of papers, showed as in Table 3. On the contrary, China ranked second in the number of publications with lowest centrality(0.01), indicating that it was necessary to seek for more cooperation

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and improve quality of articles.

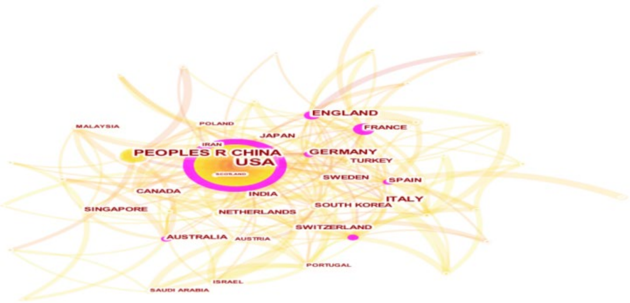

Figure 5: Co-country in AI application of heart diseases

Table 3: The top 10 countries with high centrality

Rank	Country/Region	Number of Publications	Centrality	Rank	Country/Region	Number of Publications	Centrality
1	USA	776	0.52	6	NETHERLANDS	95	0.03
2	PEOPLES R CHINA	317	0.01	7	CANADA	93	0.05
3	GERMANY	174	0.24	8	SOUTH KOREA	82	0.05
4	ENGLAND	145	0.12	9	SWEDEN	81	0.07
5	ITALY	100	0.10	10	JAPAN	71	0.07

3.5. Keywords

High-frequency keywords are typically used to identify the research focus in one field. As shown in Figure 6, node size represents the frequency of keywords, the lines between nodes represent the connection established at different times, and the thickness of the lines represents the intensity of the keyword. According to the results, 785 keywords were found, forming 5,020 links with a density of 0.0163. These keywords were divided into three broad categories (Table 4): about algorithms such as ML and neural networks; disease, including AF, coronary artery disease, and MI; and classification, diagnosis, and risk factors for diseases. Cclassification was the most obvious node, followed by ML and neural networks.

Figure 6: Analysis of keywords

Table 4: The top 10 high frequency keywords

Rank	Keywords	Frequency	Rank	Keywords	Frequency
1	classification	169	6	atrial fibrillation	129
2	machine learning	164	7	coronary artery disease	128
3	neural network	143	8	risk	121
4	diagnosis	141	9	myocardial infarction	111
5	disease	137	10	mode	110

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3.6. Evolution of research hotspots regarding AI application in heart disease

Figure 7 reveals the evolution of AI applications in heart diseases. Each node represented the time the keywords first appeared, the size of the node represented the research hotspot, and the lines between keywords represented a co-occurrence relationship between a certain keyword and other keywords. Results indicate that "MI" was the highest frequency keyword in the first five years, followed by "AI," implying that scholars began to explore the combination of AI and heart diseases for diagnosis with neural networks. Later, researchers attempted to establish a disease risk or mortality prediction model for AF or other heart disease classifications using artificial neural networks. In 2010, ML represented the largest node size, and many studies focused on it. Additionally, a support vector machine (SVM), as a supervised learning algorithm, also appeared at the same time. With the advancement of technology, deep learning has been introduced for feature selection, risk factor identification, disease management, and biomarker selection.

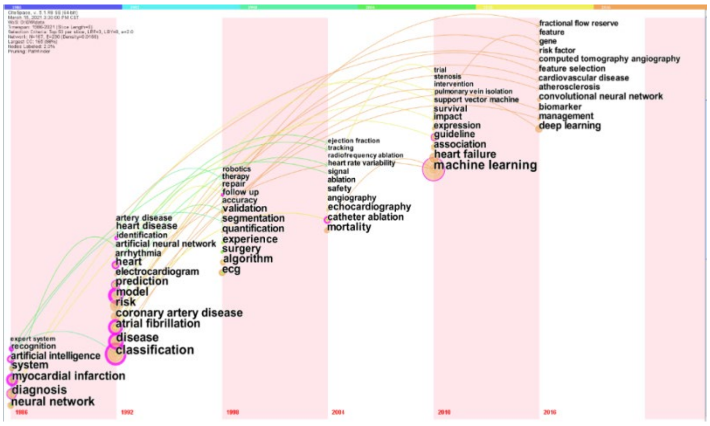

Figure 7: keywords analysis in AI application of heart diseases

3.7. Burst detection

Usually, burst detection aims to catch the highest frequency words during one period to identify the research hotspot at that time. In this study, we detected bursts between 1986 and 2021.The lines on the right of the figure indicate the time, and the red part indicates the keywords were the research hotpots. Figure 8 showed 25 keywords with the highest burst strength, and they could clarify the evolution trend of AI and heart diseases from 1986 to 2021, surgery had the highest burst strength, followed by experience, neural network, and catheter ablation, with a burst strength > 20. In addition, 13 keywords lasted more than 10 years, even though the neural network lasted almost 20 years.

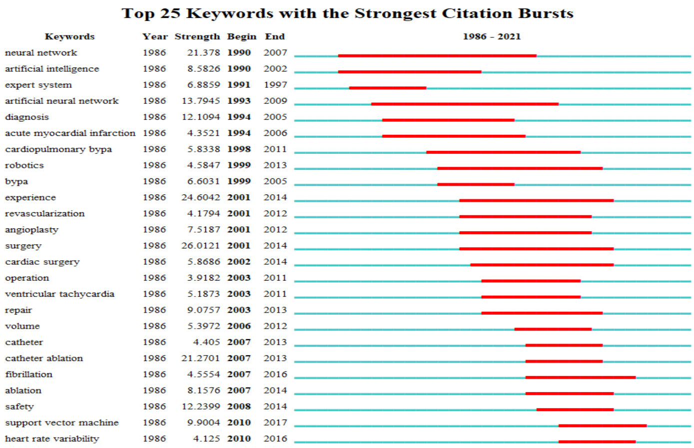

Figure 8: The citation burst of AI in heart disease

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4. Discussion

4.1. General Information

To some extent, literature reflects the development of a discipline. In this study, we utilized CiteSpace to analyze original articles on the application of AI in heart diseases published from 1986 through 2021. There has been a growing number of publications over the past 36 years roughly. In particular, the number of publications about the application of AI in heart diseases has increased sharply in the past five years. This is because advanced technology has begun to permeate clinical activities and scientific research, bringing a huge influence in medicine. In this study, the relationship between the accumulation and time of the publications about application of AI in heart diseases, seems compliant with Price's Law approximately. Findings exhibit a rising trend in 2019, implying the fast development of this field. More focus can be put on combinations of AI and heart diseases due to great potential.Results indicate that outstanding authors are inclined to two aspects in research: clinical practice and data-driven medicine. “Johannes Bonatti,” “Thomas Schachner,” and “Nikolaos Bonaros” developed a group for research and cooperated with each other, producing more than 50 manuscripts in total. This indicates their core academic status and high impact in the field of AI and heart disease. These authors are interested in clinical practice, such as coronary surgery using robotic technology and assessment of the robot-assisted surgery effect. “Christian Tesche,” “U Joseph Schoepf,” and “James K Min” generated one academic group and drove medicine development based on patients’ electronic health records (EHR). Centrality is normally related to the number of publications. Stanford University, Brigham & Women’s Hospital, and Cedars Sinai Med Ctr, which all belong to the USA with the highest centrality, have in-depth cooperation and produce about 30% of the total publications. Conversely, China ranked second in the number of publications with the lowest centrality. This suggests the need to seek more global cooperation to promote the quality of articles and the application of AI in heart diseases. In particular, Zhejiang University and Shanghai Jiao Tong University performed well in terms of the number of articles. This is because the Chinese central government has encouraged institutions to set up big data centers and provided policy and financial support. For example, Peking University, Xiamen University, Zhejiang University, and Chongqing Medical University have integrated multi-disciplinary superior resources, collaborating with affiliated hospitals, to speed up the convergence of AI and medicine.

4.2. Research hotspots and trends

The keywords draw attention to research hotspots relating to the use of AI in heart diseases; the time zone diagram reveals the tendency in this field. According to the clustering analysis of keywords, we divided them into three clusters: approach, diseases, and objective. These expose research on the application of AI in heart diseases mainly focused on the following aspects.

4.2.1. Robot-assisted surgery or treatment

Robotics, one of the most important AI branches, is utilized for patients with heart diseases. In the beginning, a robotic surgical system was introduced into minimally invasive cardiac surgery. It resulted in less injury and better recovery among patients[9]. To get better visualization, robot-assisted surgery has been applied to pre-surgical planning and intra-operative image guidance. In particular, they perform arterial revascularization for multivessel coronary artery disease and create endoscopic coronary anastomoses endoscopic coronary artery operations[10],, which have proved to be safe and have efficacy[11]. Moreover, a robotic navigation system (RNS) for the treatment of paroxysmal AF by circumferential pulmonary vein isolation (CPVI), was comparable to manual ablation[12]. Robot-assistance makes it possible to realize telehealth, such as remote ECG examination in rural areas[13] .

4.2.2. Research related to clinical decision support based on data

Initially, a study on linear prediction techniques was used for automatic ECG classification. In the same year, AI was introduced to MeSH terms, implying that AI has gradually received the attention of scholars and clinical workers. It is divided into two stages: in the first stage(In the 1980s), cognitive inference is the focus, in particular, the expert system, which represents the most advanced technique in the 1980s. The expert system is a knowledge base based on rules and provides clinical problem-solving skills. It is the most famous expert system in the field of medicine, and guides the choice and strategy for clinical practitioners in heart disease treatment and diagnosis, such as HF and acute myocardial infarction (AMI). Neural networks have been used to detect coronary artery disease(CAD)[14],stratify coronary artery bypass grafting candidates preoperatively[15], predict the probability of patients’ transient ischemic episodes during ambulatory monitoring[16],and distinguish between atrial septal defect and healthy

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subjects[17].

In the second stage(from 2010), ML emerges and makes it possible to deal with mass medical data. ML technique, one of the core AI technologies now, contains various algorithms. It has advantages in processing a greater number and complexity of variables and is widely used in establishing model for classification or prediction of heart disease from 2010. SVM, a classical ML algorithm, has outstanding performance in heartbeat time series classification[18], and even multi-level ECG signal quality classification[19]. Extreme gradient boosting(XGBoost) tends to outperform in the prediction of neurological recovery among out-of-hospital cardiac arrest (OHCA) patients[20]. "Random forest" is also a popular algorithm for predicting risk among acute coronary syndrome patients[21] and for 1-year survival of out-of-hospital cardiac arrest (OHCA)[22]. With the development of technology, researchers have attempted to use a variety of methods to explore heart diseases. NLP, a part of AI technology, is used to describe the contribution of free text in primary care to the recording of information about MI, including subtype, left ventricular function, laboratory results and symptoms, and recording of cause of death[23].Deep learning (DL), emerged around 2016, is a new branch in ML technique. It assesses the prevalence of disease using prediction models and has a powerful performance in classification of interpretation using image and sound signals[24-25]. It also evaluates readmission of HF patients[26] and recognizes heart disease in medical images with high accuracy and agreement with clinical results[27].

Generally, diversified data elements are integrated in research, ranging from structured to unstructured data due to continuous improvements in the algorithm. Studies were derived from ECG for identifying the hypertrophic cardiac regions in hypertrophic cardiomyopathy[28] and recognizing the ECG signals for ischemic heart disease (IHD) diagnosis[29]. Subsequently, authors integrated demographics, diagnoses, procedures, labs, physician notes and medications to set up a prediction model for 30-day readmission among HF patients[30], and the stratification of patients[31]. Images are also one of the main sources for research. For example, ultrasound images for automatic segmentation[32]and ECG images for classifying aortic valvular stenosis[33]. Photoplethysmographic signals are used to detect AF[34].

4.2.3. Strengths and Limitations

A few studies have used visualized analysis focused on cardiovascular diseases and valvular heart diseases. The current study focused on the combination of AI and heart disease, providing a new approach for data-driven medicine. However, there are still a few limitations. First, the data were only extracted from the WOS database and could not cover all publications. More data should be taken into consideration, such as those in Scopus. Second, the limited type and language of literature may have led to the exclusion of some important publications. Third, there was a time gap between the downloading of publications and the completion of the manuscript. The database is still constantly renewing, and publications published during this period were not included in this study.

5. Conclusion

Visualization techniques offer a transparent way to comprehend the application of AI in heart diseases. It is undeniable that AI techniques are increasingly applied in heart diseases in areas ranging from studies about medical data to clinical practice related robotics-assist. AI has been outperforming surgeries for heart diseases, as well as its identification, detection, prediction, classification, and risk stratification, compared with conventional approaches. With the increasing volumes of medical data and complex diseases, AI may play a vital role in the breakthrough of heart diseases. Moreover, AI should be strengthened and utilized in diverse clinical settings. In the future, it is important to reduce the cost of medical burden and pain of patients. Finally, scientists should push AI toward continuous improvement, making healthcare safe feasible and accessible.

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