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Review Article

Cardiovascular diseases

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Role of artificial intelligence and machine learning in cardiovascular disease diagnosis and management: a bibliometric analysis

Pawan Kumar[1], Asmitha Bhateja[2], Ankur Gupta[3*]

[1] Department of Community Medicine and School of Public Health, Postgraduate Institute of Medical Education and Research, Chandigarh, India.
[2] Chitkara University, Rajpura, Punjab, India.
[3] Advanced Cardiac Centre, Postgraduate Institute of Medical Education and Research, Chandigarh, India.

*Correspondence:ag_pgi@yahoo.com

Abstract

Background: Cardiovascular disease remains a significant cause of global morbidity and mortality. With the rising burden of CVD, there is a pressing need for innovative diagnostic and management solutions worldwide. The advent of AI-ML offers diverse options for addressing these challenges, with potential applications spanning from cardiac imaging to risk prediction. This bibliometric analysis seeks to examine the scientific literature on AI and ML in cardiovascular disease.

Methods: A comprehensive bibliometric analysis was conducted on publications retrieved from PubMed, focusing on the role of AI and ML in CVD research from 2013 to 2023. The study zanalyzed publication growth rates, distribution by countries and journals, citations, funding sources, and keyword co-occurrence.

Results: A total of 895 articles were identified, showing an average annual growth rate of 32.6% in publications. The USA, China, and the UK emerged as leading contributors. The most cited article was "Artificial Intelligence in Precision Cardiovascular Medicine", with 394 citations. The National Institute of Health (NIH) was the top funding institution. Key recurring terms included "Machine learning," "Stroke", "Artificial Intelligence", and "Deep learning'.

Conclusions: Integrating AI and ML in cardiovascular medicine signifies a transformative shift, offering solutions to longstanding challenges in CVD diagnosis and management. The surge in publications over the past decade indicates growing interest and potential in this interdisciplinary field. However, as the technology continues to evolve, addressing its ethical and practical challenges is crucial.

Keywords: *artificial intelligence, machine learning, cardiovascular disease, diagnosis, management, vosviewer, bibliometry, cardiac imaging, risk prediction, analysis*

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Evidence in Context

• 27% of Indians, especially the elderly and middle-aged, are affected by hypertension. • Significant underdiagnosis among rural reproductive-age women. • Socioeconomic factors heavily influence awareness and treatment-seeking behaviors. • 74% of women seek treatment, but 26% do not, highlighting healthcare access gaps. • Urgent need for targeted health campaigns and improved primary care accessibility.

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Introduction

Cardiovascular disease (CVD) poses a significant global health challenge, leading to substantial morbidity and mortality [1]. According to the World Health Organization (WHO), CVD is responsible for nearly 17 million deaths yearly, constituting about 31% of all global mortality. Ischemic heart diseases (IHDs) and Stroke were among the top five causes of healthy years lost globally due to CVD [2]. The burden continuously escalates year after year, particularly in low- and middle-income (LMIC) nations, where 80% of deaths occur in these nations [3]. The challenges in CVD diagnosis management are multifaceted.

Traditional diagnostic methods may miss subtle yet critical signs, leading to delayed or inaccurate diagnoses. As the global community grapples with these alarming statistics, there is an urgent need for innovative solutions to address the challenges in CVD diagnosis and management [4].

Artificial Intelligence and Machine Learning in Healthcare

Over the past few years, the healthcare industry has witnessed substantial technological advancement, especially in the domains of Artificial Intelligence (AI) and Machine Learning (ML). AI is expanding its footprint in medical sciences and offering algorithmic solutions to clinical professionals in their practice, assisting in diagnosis, prognosis, and therapeutic strategies [5]. The recent development of AI and ML has created transformative prospects in research, especially in the realm of CVD. AI technologies such as ML, Robotics, Imaging, and Natural Language Processing (NLP) have now been integrated in cardiovascular medicine [6].

Role of AI-ML in Cardiovascular Medicine

AI and ML in Cardiovascular Imaging

Cardiac imaging is critical for identifying a variety of CVDs. AI-powered computers can analyze images, detect abnormalities, and even forecast future cardiac events. For example, ML models can analyze echocardiograms with exceptional accuracy to estimate heart chamber sizes, wall thickness, and ejection fraction. These algorithms can also identify small changes in cardiac MRIs or CT images, allowing them to anticipate problems such as heart failure or coronary artery disease before they become clinically evident [7].

Predictive Analytics in Cardiology

The capabilities of AI and ML go beyond imaging. Today, thereis an abundance of data accessibility due to the growth of wearable health devices and the digitalization of health records. ML algorithms can filter through this data, detecting patterns and forecasting results. For example, ML models may estimate the chance of a patient having a heart attack in the following year by zanalyzing their electronic health record, allowing for early treatment [8].

AI-driven Decision Support Systems

With its multifaceted conditions and treatments, cardiology often presents doctors with difficult decision-making circumstances. AI-powered decision support systems can help physicians by making real-time suggestions based on patient data. For example, when a patient complains of chest discomfort, these systems may analyze the clinical data, imaging, and lab findings and provide probable diagnosis and therapy courses [9].

Precision Medicine and Drug Discovery

AI algorithms in drug discovery and development can rapidly analyze vast amounts of data to identify potential drug candidates for cardiovascular diseases, predicting the effects of various compounds on human biology and significantly expediting the drug discovery process, which normally requires years and substantial resources [10].

Risk Stratification

AI can analyze electronic health records, genetic data, and other relevant information to stratify patients based on their risk of developing cardiovascular diseases. High-risk individuals can then be targeted for preventive measures, screenings, or more frequent check-ups [11].

Virtual Health Assistants

Virtual assistants powered by AI can offer patients personalized support and guidance, providing valuable insights into their conditions, addressing their queries, and sending reminders to take medication or complete prescribed exercises, thereby enhancing patient engagement andoverallcare. These assistants can act as an extension of the healthcare team, ensuring that patients are well-informed and adhering to their treatment plans. This highly advanced technology is continuously evolving rapidly, and it is conceivable that there have been even more breakthroughs in this realm [12,13].

Other applications

In cardiovascular medicine, other notable uses encompass AI-driven personalized treatment strategies designed to cater to each patient's unique needs, guaranteeing optimal therapeutic results. Cardiac rehabilitation programs, enhanced by AI, deliver tailored exercise and therapy plans, ensuring the best recovery results. The realm of rehabilitation and aftercare is transformed by AI's precision in assisting patients throughout their recuperation. Moreover, incorporating AI into remote monitoring tools offers uninterrupted supervision, swiftly identifying irregularities and assuring prompt patient care. Together, these innovations signify a shift towards a more personalized and forward-thinking approach in cardiac care [14].

The present article uses bibliometric tools to assess the status, trends, and frontiers of research activities on the use of AI-ML in diagnosing and managing CVD, such as most referenced publications, countries, journals, authors, and funding agencies involved in AI-ML CVD research. Moreover, it is a valuable resource for clinicians, researchers, and stakeholders seeking guidance and a deeper understanding of the current AI-ML landscape in CVD research.

Methods

Search Protocol

The search algorithm gathered data from PubMed (MEDLINE), which has over 33 million citations ranging from biomedical literature and life sciences. PubMed stands as a premier repository for biomedical literature. PubMed contains citations and abstracts from peer-reviewed journals, scholarly journals, books, and conference proceedings.

Table 1: PubMed Search query terms

Query	PubMed Search Key terms (As of 15/6/2023)	Results
#1	(((((((((("Artificial Intelligence"[Title]) OR ("Machine Learning"[Title])) OR ("Deep Learning"[Title])) OR ("Neural Networks"[Title/Abstract])) OR ("Machine Learning Algorithms"[Title/Abstract])) OR ("Predictive Modelling"[Title])) OR ("Big Data Analytics"[Title])) OR ("medical image processing"[Title])) OR ("Data science"[Title])) OR ("Disease prediction"[Title])) OR ("Computer-Aided Diagnosis"[Title/Abstract]) OR ("Supervised Machine Learning"[Title/Abstract])) OR ("unsupervised Machine Learning"[Title/Abstract])	1,13,572
#2	(((((((((("Cardiovascular disease*"[Title])) OR ("coronary heart disease*"[Title])) OR ("stroke"[Title])) OR ("cardiovascular medicine"[Title])) OR ("congenital heart disease*"[Title])) OR ("ischemic heart disease*"[Title])) OR ("Myocardial Infarction"[Title]) OR ("peripheral arterial diseases"[Title/Abstract])) OR ("rheumatic heart disease*"[Title/Abstract])) OR ("cerebrovascular disease*"[Title/Abstract])) OR ("deep vein thrombosis"[Title/Abstract])) OR ("pulmonary embolism"[Title/Abstract])	3,89,220
#3	#1 AND #2	**895**

Filters applied:

Publication Period: 2013 to 2023 **|** **Language:** English | **Species:** Humans | **Text Availability**: Full text |

Others: Excluded Preprints

Inclusion Criteria

We researched peer-reviewed articles focusing on the role and use of AI in CVD research. Literature published from 1/1/2013 to 15/6/2023 was included in the search. The data was acquired on 1/7/2023 from the PubMed database. This study's timeframe was between 2013 and 2023 due to the significant advancements and rapid progression of AI-ML applications, particularly in the medical domain.

Exclusion Criteria

Grey literature, preprints, book chapters and novels were excluded from the review. Additionally, publications not written in English were also not considered.

Data Extraction

All data was sourced from PubMed in .txt (text) format, encompassing 11 fields and containing details like 1) author, 2) title, 3) journal name, 4) publication year, and 5) citation. This data was then inputted into a Microsoft Excel spreadsheet for error verification. Subsequently, the consolidated dataset was imported into VosViewer for bibliometric analysis.

Visualization and Bibliometric Indicators

The VOSviewer (version 1.6.19 developed by the Center for Science and Technology (CST), Leiden University, the Netherlands) was used to analyze and visualize author keywords. VOSviewer is an open source software for creating and visualizing bibliometric network maps. Networks can be built via patterns like keywords, co-occurrence, co-citation, bibliographic coupling, or co-authorship. This tool is popular for mapping scientific research and helping users understand how different studies or topics are connected within a specific field [15].

The retrieved records were thoroughly examined, and the following bibliometric indicators were obtained: publications growth rate, distribution (country, publications, documents citation, funding sources and co-occurrence of authors keywords).

Results

Overview of the retrieved publications

In this section, 895 articles were identified from PubMed from 2013-2023 (till 15/6/23). The analysis considered full-text publication to provide an understanding of the literature available in the field of AI-ML in CVD research. It must be noted that grey literature, preprints, novels, and book chapters were excluded from the analysis to maintain a rigorous focus on peer-reviewed, scientifically validated sources.

Total number of publications and Growth Rate

The data highlights increasing publication growth in the realm of topics from 2013 to 2023, with an average annual increase rate of 32.6%. Specifically, 2022 saw a peak in publications with a total of 262 articles, constituting 29.2% of the total articles. The preceding year, 2021, contributed 181 articles, contributing to 20.2% publications. Meanwhile, 2020 witnessed the publication of 164 articles, making up 16.3% of the total count. As of the midpoint of the current year, up to 15/6/23, there have been 121 recorded publications, representing 13.5% of the overall dataset **[figure 1]**.

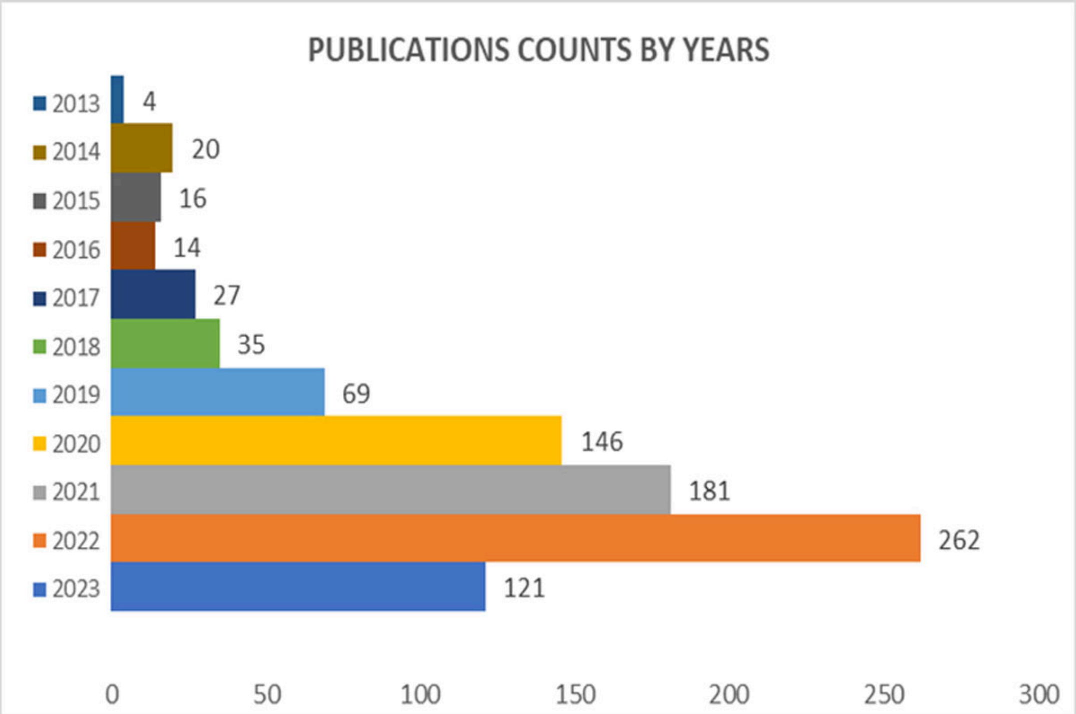

Figure 1. Distribution of Publications between 2013-2023 (till 15/6/2023)

Distribution by countries

Figure 2 provides insights into the global landscape of AI -ML research in CVD, identifying regions that contributed to the field and potentially uncovering areas where further research collaboration or exploration is needed. The data indicates that the United States of America (USA) has the highest number of publications, with a total of 213 articles. China came second with 183 articles, while the United Kingdom produced 112 publications. Germany had 66 publications, while South Korea had 54. Canada, Italy, Japan, and India also made considerable contributions, with 50, 45, 41, and 32 articles, respectively. Most of the nations on the list are highly developed economies. The varying shades on the QGIS map represent the number of publications from each country, allowing for a visual and spatial understanding of the distribution of scholarly articles across different regions.

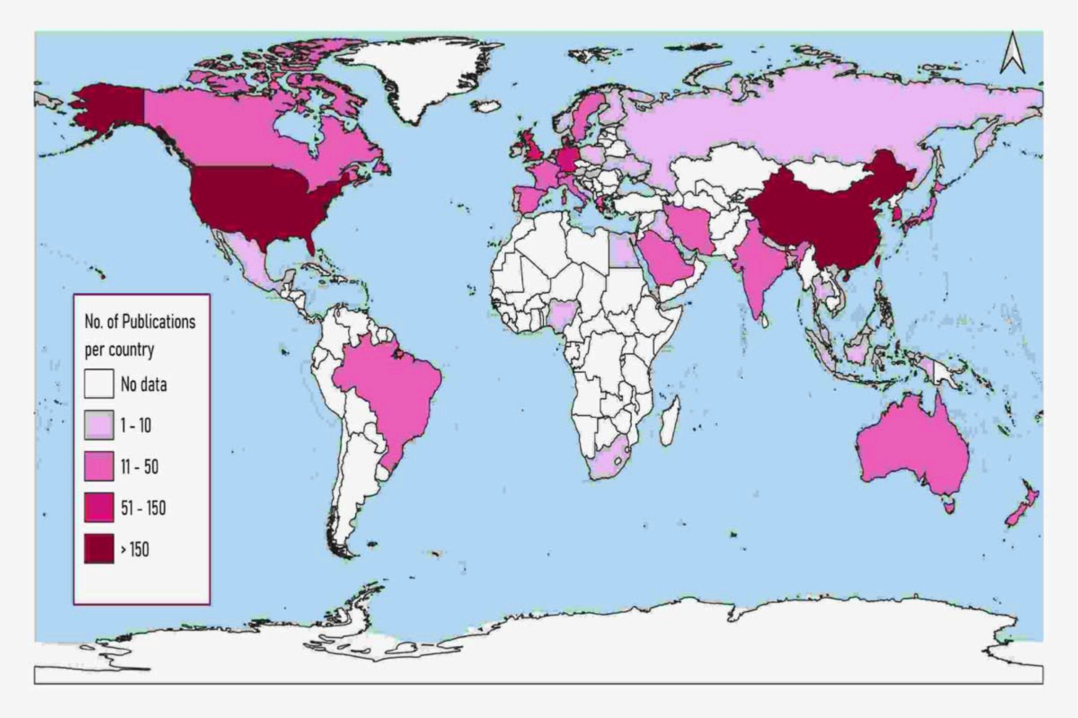

Figure 2. Choropleth map depicting the distribution of global publications by country between 2013 and 2023 as recorded by PubMed (https://pubmed.ncbi.nlm.nih.gov/) until June 30. The map was created using QGIS 3.30.1, with the base layer map sourced from ArcGIS Hub

Distribution by academic journals

Figure 3 presents the top journals that have published research on AI-ML in CVD studies. During this time, 332 different journals have published 895 articles on the topic. The Journal of Scientific Reports (Sci Rep) contributed the largest, with 37 out of 895 articles. Following closely were Sensors (Basel) with 33 articles, PLoS One with 32, Stroke with 25, and the Annual International Conference of the IEEE Engineering in Medicine and Biology Society (Annu Int Conf IEEE Eng Med Biol Soc) with 23 articles.

Figure 3. Publications distribution by journals

Distribution by citations

The top 5 articles were determined by their citation frequency, as tracked by Web of Science, with the most frequently cited articles ranking highestinthelist. The top-cited article was titled "Artificial Intelligence in Precision Cardiovascular Medicine" by Krittanawong et al. (2017), with a total citation count of 394. The article "Automatic Detection of Cerebral Microbleeds from MR Images via 3D Convolutional Neural Networks" by Dou et al. (2016), with 388 citations, was second on the list. This was followed by "Machine learning in cardiovascular medicine: are we there yet?" by Shameer et al. (2018), which gathered 211 citations, addressing the progress and challenges of machine learning in cardiovascular medicine. The articles "Classification of myocardial infarction with multi-lead ECG signals and deep CNN" by Baloglu et al. (2019) and "Clinical applications of ML in CVD and its relevance to cardiac imaging" by Al'Aref et al. (2019) have also received notable attention, with 207 and 204 citations respectively. These highly cited articles reflect the significance of AI-ML in diagnosing and managing CVD.

Table 2: Top 5 Highly Cited articles

Document Title	Authors	Year	APY (Average per year	Total
1. Artificial Intelligence in Precision Cardiovascular Medicine	Krittanawong, C et al.	2017	56.29	394
2. Automatic Detection of Cerebral Microbleeds from MR Images via 3D Convolutional Neural Networks	Dou, Qi et al.	2016	48.5	388
3. Machine learning in cardiovascular medicine: are we there yet?	Shameer, K et al.	2018	35.17	211
4. Classification of myocardial infarction with multi-lead ECG signals and deep CNN	Baloglu, UB et al.	2019	41.4	207
5. Clinical applications of machine learning in cardiovascular disease and its relevance to cardiac imaging	Al'Aref, SJ et al.	2019	40.8	204

Funding sponsors

The chart shows the most notable institutions that have sponsored the advancement of AI-ML in CVD research. The "National Institute of Health (NIH)" was the leading institution, with 91 sponsored publications. It was followed by "United States Government, Non-Public Health Service (PHS)" with 20 publications. Other than that, "Non-US Government" funded 374 publications worldwide **[figure 4]**.

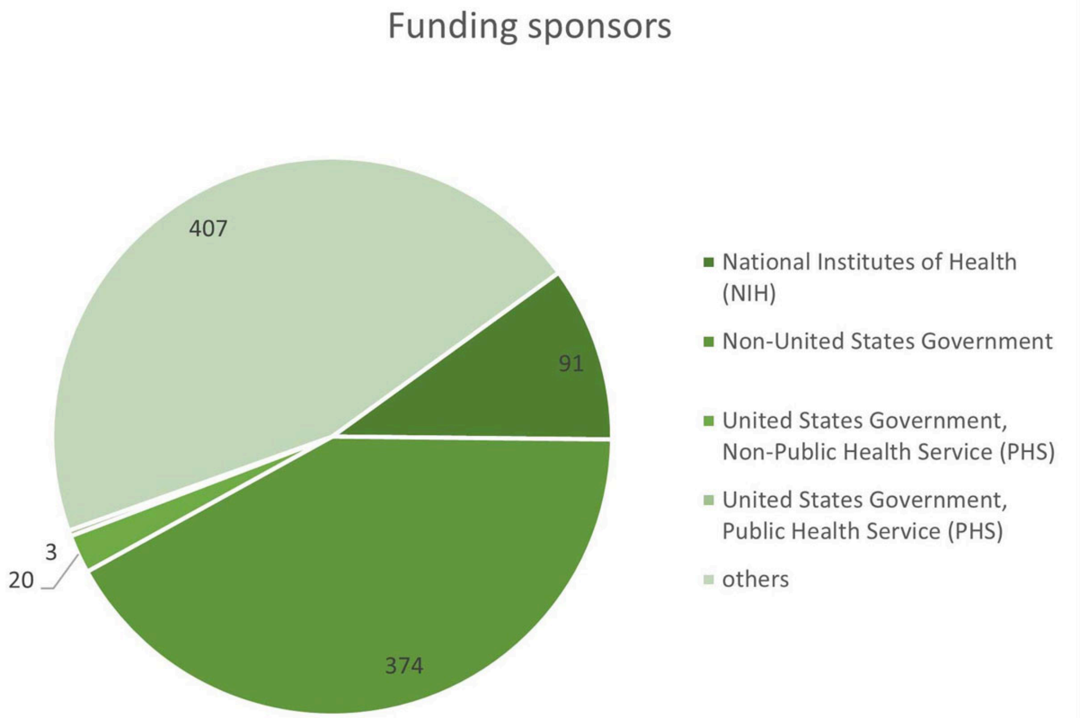

Figure 4: Top funding institutions and the corresponding number of publications

Analysis of keywords

Figure 5 shows a network visualization of authors' keywords that appear together frequently. From a total of 1520 keywords, 77 keywords that appeared at least 5 times were selected and grouped into clusters. The keywords with the strongest connections are highlighted in the diagram, showing the most important topics and theirrelationships.

In the figure, coloured and differently-sized circle fields are interconnected at varying distances. The colours signify groupings or clusters, enabling the identification of topics with closely related aspects. The visualization uses circle size to represent the frequency of keyword usage, with larger circles indicating more frequent usage. The proximity of keywords to each other reflects their connection strength, with closer distances signifying stronger relationships. The connecting lines between terms illustrate their co-occurrence and relationships across the studies, providing a clear map of the keywords' interconnectedness. The figure highlights that some of the most frequently utilized keywords include "Machine learning" (occurrence=244), "stroke" (occurrence=151), "Artificial Intelligence" (occurrence=105), and "Deep learning" (occurrence=99).

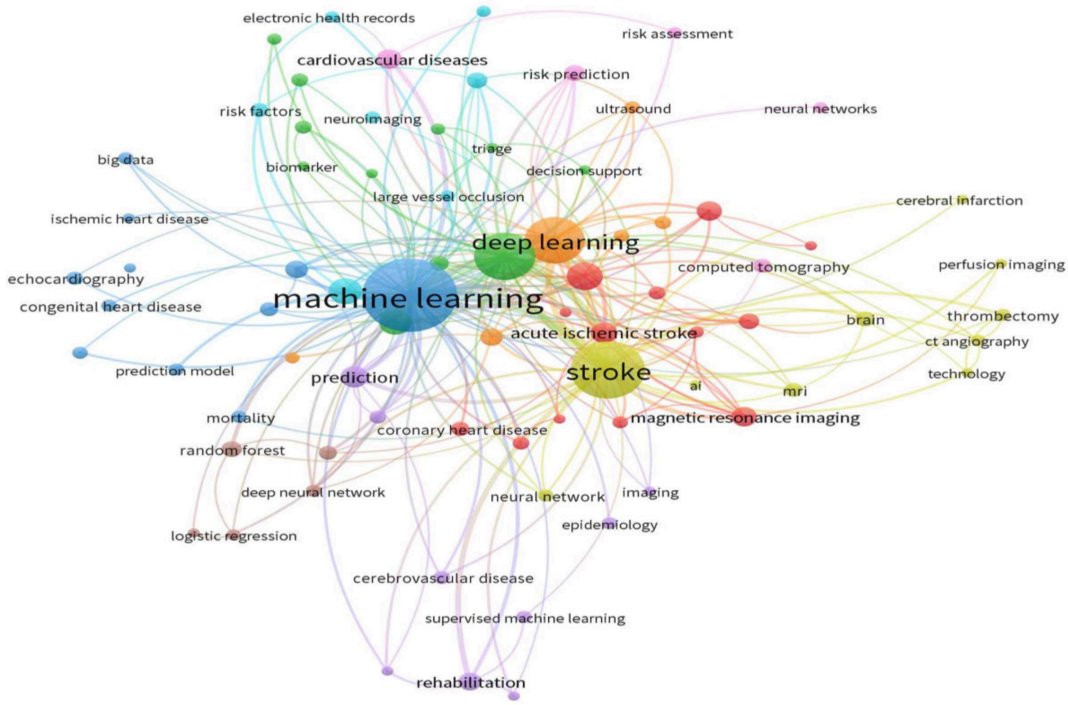

Figure 5. Co-occurrence analysis of authors' keywords

Discussion

AI has made tremendous progress in recent years, with ML emerging as the cutting-edge technology driving AI's rapid advancement [16]. Researchers have shown significant interest in the expanding use of ML in healthcare, with a particular emphasis on leveraging AI capabilities in - Health behavior analysis, Disease Diagnosis, Predictive outcomes and risk assessment [17].

The present study's findings reflect a surge in AI-ML applications in cardiovascular sciences. The use of this technology significantly gained more attention in the diagnosis and treatment of CVD in the past decade. While the number of academic publications on this domain is rapidly increasing, undoubtedly, the advancement in AI is primarily centred in developed countries, notably the USA and China, which account for 44.2% of publications in this study. Developing nations may need more time to develop the essential competencies to match the standards of developed nations. Regarding international collaboration, both China and the United States have been instrumental in fostering global partnerships, with the most substantial and productive collaborations occurring between the two nations, showcasing the significance of their bilateralcooperation [18]. 16 European countries like the United Kingdom (UK), Germany, France, Netherlands, Spain, Switzerland, Sweden, and Italy, contributed more than 35% in research articles. This can be attributed to their established and well-funded research infrastructures and a concentrated focus on innovation and technology [19]. Other Asian countries like India, Japan, Singapore, South Korea, Saudi Arabia, and Iran accounted for more than 15% of publications despite limited research funding and infrastructural constraints [20].

The 77 items were categorized into 9 clusters, each represented by a distinct color. The first 5 clusters, depicted in shades of blue to yellow, contained 13, 11, 11, 10, and 9 items, respectively. The size of each item's label in the network visualization was determined by its weight and cluster membership, providing a visual representation of the items' relative importance within their respectiveclusters **[Figure 5].** The visualization shows the connections and relationships between keywords through co-citation links, with line thickness representing the strength of the connection. Initially, AI applications focused on predictive modeling, risk assessment, and medical imaging for Stroke and Myocardial Infarction, utilizing supervised and unsupervised Machine Learning algorithms like Logistic Regression, Random Forest, Decision Tree, Support Vector Machines (SVM), and deep learning techniques including Convolutional Neural Networks (CNN). The figure illustrates the early stages of AI adoption in healthcare, highlighting the key areas of focus and the algorithms

Used to drive innovationinthefield. **[Figure 5]**. Moreover, the keywords "congenital heart disease", “coronary heart disease”, “cerebrovascular disease”, “heart failure”, and “pulmonary embolism” make up a significant part of the visualization as well, suggesting that many scholars applied AI-ML to these CVD as well.

The top five articles on AI and ML in cardiovascular medicine, ranked by Web of Science citations, include Krittanawong et al., 2017, with 394 citations. This is followed by Dou et al., 2016 with 388 citations. Furthermore, since 2018, there has been an increasing number of authors focusing on this research area.

Among the top five journals, three catered to the medical field, while two were from engineering. Out of the 15 journals in the field, nine were dedicated to medical sciences, three each to Bioinformatics/Medical Informatics and Engineering. The varied Impact Factors (IFs) of these journals suggest that the topic has garnered attention only in recent times. Furthermore, the diverse categories of these journals, spanning from medicine to engineering and bioinformatics, hint at interdisciplinary collaborations and the convergence of multiple fields.

The medical field has experienced a notable surge in AI advancements, with the US, Europe, and China emerging as the primary contributors [17]. Contrary to the early engagement of the US and Europe in the domain of AI, China entered the field at a later stage. Nevertheless, China has demonstrated a commendable proficiency in curating extensive clinical datasets vital for the meticulous training of AI models, an accomplishment that remains unparalleled by its counterparts. The rapid progression of China in the AI domain can be attributed to its strategic investments in research and development, coupled with a robust technological infrastructure and a vast population that provides a rich source of data for AI training [18]. Moreover, the Chinese government has proactively fostered AI research, recognizing its potential to revolutionize healthcare and other sectors. This proactive approach has led to the establishment of numerous AI research centres and collaborations with tech giants, ensuring a steady flow of resources and expertise [21].

Integrating AI and ML in cardiovascular medicine has undeniably transformed patient care. The ability of AI algorithms to analyze vast datasets and discern patterns has paved the way for personalized medicine, where treatment plans are tailored to individual patient profiles. This personalization ensures optimal therapeutic outcomes, minimizing potential side effects and maximizing efficacy [9]. Furthermore, the predictive capabilities of AI have enhanced the early detection of cardiovascular anomalies, allowing for timely interventions and reducing the overall burden of CVD.

However, ethical concerns have arisen with the proliferation of AI in healthcare. Even if anonymized, patient data use raises questions about privacy and consent. Ensuring the security of this data against potential breaches is paramount. Moreover, AI algorithms' decision-making process, often termed the "black box" phenomenon, can be opaque. This lack of transparency can pose challenges, especially when AI-driven decisions need to be explained to patients or their families [22].

Another challenge is the potential over-reliance on AI systems. While AI can assist clinicians, it should not replace the human touch and clinical judgment that are integral to patient care. Fusing AI insights with a clinician's expertise ensures a holistic approach to patient management [23]. Collaborations between countries, especially between developed and developing nations, can bridge the technological gap and ensure that the benefits of AI are universally accessible. Sharing knowledge, resources, and best practices can foster innovations catering to diverse populations and healthcare settings [24].

In conclusion, integrating AI and ML in cardiovascular medicine heralds a new era of precision medicine, where diagnosis and treatment are optimized for individual patients. While the potential of AI is vast, it is essential to navigate its challenges judiciously, ensuring that patient care remains at the forefront. As research in this domain continues to expand, collaborations and interdisciplinary approaches will be pivotal in harnessing the full potential of AI for the betterment of global healthcare.

Limitations

In this study, we exclusively used PubMed for our analysis, which might limit the

Diversity of included publications. Although PubMed offers a robust platform for bibliometric analysis, incorporating other databases like Web of Science (WOS), Scopus, or IEEE in future research could provide a more extensive collection of papers, enriching the study's depth. Articles included in our study were restricted to peer-reviewed and English-language publications. Future research should consider broadening the search criteria to include diverse sources and languages for a more holistic understanding of the subject.

Conclusion

Integrating AI-ML into cardiovascular medicine has marked the beginning of a revolutionary new era, offering innovative solutions to the persistent challenges of CVD diagnosis and management. As the global burden of CVD continues to rise, particularly in LMICs, the potential of AI and ML to enhance diagnostic accuracy, predicting patient-centric outcomes, and tailored treatments to individual patient profiles is more crucial than ever. This bibliometric analysis underscores the burgeoning interest in this interdisciplinary field, with a notable surge in publications over the past decade. The global landscape of AI-ML research in CVD is dominated by technologically advanced nations, emphasizing the need for broader collaborations to ensure equitable access to these advancements. The diverse range of applications, from cardiac imaging to risk stratification and drug discovery, highlights the versatility and potential of AI and ML in revolutionizing cardiovascular care. As the field continues to evolve, it is imperative to address the ethical and practical challenges associated with AI, ensuring that the technology is harnessed responsibly and to its fullest potential for the betterment of patient care worldwide.

Supporting information

None

Ethical Considerations

None

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Author contribution statement

Pawan Kumar: Conceptualization (lead); writing – original draft (lead); formal analysis (lead); writing – review and editing (equal). **Asmitha Bhateja**: conceptualization, Software (lead); writing – review and editing (equal). **Ankur Gupta**: Conceptualization (lead); writing – original draft (lead); formal analysis (lead); writing – review and editing (equal).

All authors attest they meet the ICMJE criteria for authorship and gave final approvalforsubmission.

Data availability statement

Data included in article/supp. material/referenced in the article.

Additional information

No additional information is available for this paper.

Declaration of competing interest

The authors declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

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