Using Artificial Intelligence for the Detection of Heart Diseases by Electrocardiogam: A Bibliometric Analysis

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Abstract. This bibliometric analysis examines 2,803 articles on artificial intelligence (AI) in electrocardiograms (ECG) for the detection of cardiovascular diseases (2014-2024). The United States and China lead the scientific production, with the Mayo Clinic and authors such as Friedman, Noseworthy and Attia standing out in the field.
AI models with high accuracy are identified, such as Random Forest (100%), Active-DNN (99.86%) and 2D-CNN (99%). In addition, the most cited article (868 citations) confirms the importance of convolutional neural networks (CNN) in the detection of atrial fibrillation.
Advances in AI have optimized cardiovascular diagnosis, although its clinical application in different populations needs to be validated.

Keywords: Artificial Intelligence, Bibliometric Analysis, Electrocardiogram.

1 Introduction

Cardiovascular diseases (CVD) are the leading cause of death worldwide, accounting for 30% of deaths in the United States and 45% in Europe during 2014. These diseases impose a significant financial burden on health systems, with an estimated cost of 210 billion euros annually for the European Union alone [1]. In Mexico, CVD also ranks first as a cause of death, with 51,586 deaths recorded in the period January-March 2024. According to data from INEGI [2], patients over 65 years of age are the most affected, followed by the age group between 35-64 years.

In this context, “the processing of biomedical signals such as the electrocardiogram has a relevant importance in disease prevention” [3]. According to Liberczuk et. al [3], the electrocardiogram is a noninvasive study, which provides valuable information about cardiac activity. Traditionally, the diagnosis of these diseases has depended on specialist physicians who identify specific features such as ST-segment elevation (complete depolarization of the ventricular myocardium) for acute myocardial infarction, T-wave changes to suggest potassium abnormalities, and other macroscopic deviations [4] to interpret the results based on their knowledge and experience to determine the diagnosis and treatment of patients. In contrast, rapid

advances in artificial intelligence (AI) and the availability of large volumes of medical data offer a unique opportunity to revolutionize this field. Implementation of AI can optimize CVD control by enabling faster detection and guiding clinical decision-making more effectively [5]. Furthermore, the cardiovascular disease treatment market is expected to have a compound annual growth rate of 3.67%, leading to a market volume of €5.94 billion in 2024 [6].

Considering the increasing importance of AI in cardiovascular diagnosis [7], this study aims to analyze global research trends on AI implementation in ECG for early detection of CVD through a bibliometric analysis. The research covers the period 2014-2024, using Web of Science [8], Scopus [9] and Dimensions [10] databases to obtain a comprehensive view of the field.

The bibliometric analysis incorporates Bibliometrix (R) and VOSviewer as tools for the construction of bibliometric networks. The analysis focuses on the identification of thematic trends, institutional collaborations, contributions from leading authors and most used artificial intelligence models. It also includes citation patterns and keyword co-occurrence. The combined use of multiple databases allows for a more robust characterization of the evolution of this field over the last decade, providing a solid basis for understanding current and future research directions in this area.

2 Bibliometric Studies of Artificial Intelligence to Detect Cardiovascular Diseases with Electrocardiograms

In recent years, the use of bibliometric analysis to study the emergence of artificial intelligence (AI) in cardiology has grown exponentially, providing a comprehensive and clear perspective on emerging trends, predominant algorithms, and international collaborations in this area. Several studies stand out for their focus on specific subtopics and advanced methodologies, which has allowed the identification of research patterns and future opportunities.

In a study based on data from the Web of Science Core Collection (WoSCC) and analyzed using tools such as VOSviewer and Bibliometrix to analyze 912 publications, the authors address the impact of artificial intelligence on the management of atrial fibrillation (AF) between 2013 and 2023 [12]. The authors highlight emerging trends such as the use of deep neural networks for real-time monitoring. They also identify the United States and China as leaders in scientific production, with prominent institutions such as Mayo Clinic. This article provides a robust overview of mature and emerging topics in the field of cardiology. In a complementary manner, another analysis uses the Web of Science Core Collection (WoSCC) and VOSviewer to analyze 2,229 publications until 2021, emphasizing the role of convolutional neural networks (CNN) in electrocardiogram (ECG) diagnosis [13]. It focuses on international collaborations, where China and the United States lead scientific production, showing a strong impact on practical applications. Its visual representation of author and country networks offers a unique perspective for understanding the global impact of artificial intelligence (AI) in cardiology.

On the other hand, an additional study performs a bibliometric analysis between 2004 and 2021, studying 636 publications related to artificial intelligence (AI) in arrhythmias, specifically atrial fibrillation (AF) and ventricular arrhythmia [7]. Also based on the Web of Science Core Collection, it highlights the increasing use of advanced algorithms such as CNN and support vector machines (SVM). Their findings underline a continued focus on improving the diagnosis and prognosis of these conditions through artificial intelligence (AI).

Another work uses CiteSpace and VOSviewer and WoSCC as a database to analyze research from 2000 to 2023, focusing on specific keyword patterns, such as "late gadolinium enhancement" and "carotid ultrasound" [14]. It is distinguished by its ability to identify research patterns related to classification and diagnosis in cardiology, with a focus on deep neural network techniques and artificial intelligence (AI) applications for the treatment of cardiovascular diseases.

Finally, one study covers data from 2013 to 2024, using Scopus and Web of Science along with tools such as Bibliometrix and VOSviewer to analyse 1,791 publications [15]. It offers a global perspective, identifying key collaboration networks between countries such as the United States, the United Kingdom and China, as well as highlighting leading institutions such as Stanford University and Harvard Medical School. Their analysis includes a particular focus on machine learning, deep learning and natural language processing (NLP) applied to arrhythmias.

In summary, the studies highlight the impact of artificial intelligence (AI) in the diagnosis and treatment of cardiovascular diseases, with an emphasis on advanced algorithms. However, they differ in the period of analysis, data sources and methodologies used.

In contrast to previous studies, which are generally based on the analysis of one or two databases and the use of one or two data visualization tools, the present work adopts a broader and more comprehensive approach. A bibliometric analysis is carried out by integrating information from three internationally recognized databases: Web of Science, Scopus and Dimensions. In addition, a set of two leading bibliometric tools in the field is used: Bibliometrix (R) and VOSviewer, which allow obtaining a more complete and robust view of scientific production, identifying trends and patterns.

3 Methodology

3.1 Comparison of Methodologies

The study methodology is based on a comparative analysis of the strategies used in three relevant bibliometric works. Strengths and limitations were identified in each of them, concluding that the most solid and recommendable methodology is the one presented in [12], due to its systematic structure and complete coverage of the key aspects.

The data search was performed in the WoSCC, Scopus and Dimensions databases, using specific search strings and well-defined inclusion and exclusion criteria. The

literature analysis was carried out using the R software and the Bibliometrix and VOSviewer tools, allowing a thorough quantitative and qualitative evaluation.

3.2 Data source and search strategy

Data were downloaded from the WoSCC, Scopus and Dimensions databases and to ensure complete and accurate inclusion of research in this field, search parameters were set as follows. In WoSCC and Dimensions the following search string was used: ((("Artificial Intelligence" OR "AI") AND ("ECG" OR "Electrocardiogram")) AND "Cardiology") in a time period from 2014 to 2024 and only in Dimensions the document types: article, chapter or edited book were included. In Scopus the following search string was used: (("Artificial Intelligence" OR "AI") AND ("ECG" OR "Electrocardiogram")), in a period from 2014 to 2024, limited in the subject area: medicine, computer science and engineering. As inclusion criteria in the keywords: artificial intelligence, electrocardiography, electrocardiogram and document type: article. The search was completed on December 11, 2024 to avoid inconsistent results due to database updates.

3.3 Data extraction and analysis

The downloaded literature was imported into R (4.4.2) and VOSviewer (1.6.20) software for visual analysis. The specific inclusion and exclusion criteria were as follows. Inclusion criteria: research articles specifically targeting the application of artificial intelligence in electrocardiograms. Exclusion criteria: conference/meeting abstracts, unpublished articles/reviews, repeated/retracted publications, letters, and notes. Using the R software package “bibliometrix”, Biblioshiny was applied to analyze and visualize national publications and collaborations, top publishing journals, author publication calendars, trending topics, and keyword thematic maps in the field and effectively visualizes the development time and trends, however, its performance in presenting co-occurrence networks is average. VOSviewer excels at visualizing co-occurrence networks in scientific knowledge, providing a clearer visualization of relationships and nodes, complementing Biblioshiny [16]. This paper used VOSviewer to visually analyze co-occurrence networks of institutions, authors, and clustering keywords. The size of nodes indicates their frequency of occurrence, while the connections of nodes are represented as link lines [17].

4 Results

4.1 Publication outputs and citation trend

Through the literature review, 377 publications from the WoSCC database, 2,302 from Scopus and 124 from Dimensions were included in the bibliometric analysis. Figure 1 illustrates the annual volume of publications in the three different databases, showing a clear overall increase in this field of research in WoSCC, Scopus and Dimensions. Scopus consistently indexes a significantly higher number of

publications, probably due to its broader coverage compared to WoSCC and Dimensions.

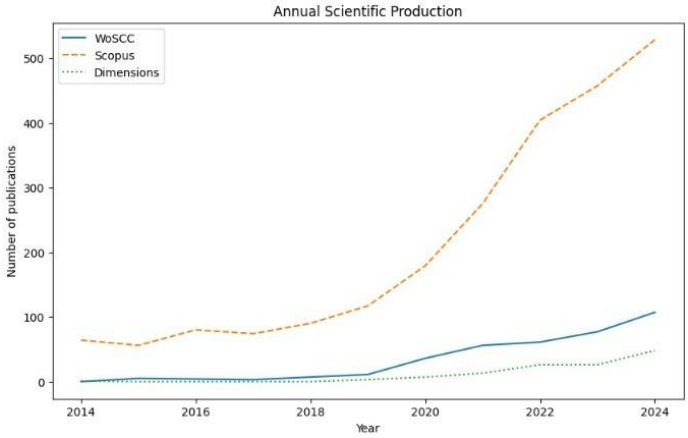

Fig. 1. Annual scientific production of WoSCC, Scopus and Dimensions between 2014 - 2024.

4.2 Analysis of countries/regions

Seventy-three countries have published articles on the application of artificial intelligence in electrocardiograms. Table 1 shows the top ten countries with the highest number of author appearances by country affiliation in the period 2014 - 2024. In first place is the United States with a total of 5,411 author appearances across the 3 databases, in second place is China with a Multi-Country Publication (MCP) index of 4,213 and in third place is India with an index of 1,685. Figure 2 illustrates a map of scientific output by country from the three databases showing which countries contribute the most to scientific output.

Table 1. Scientific production of countries.

Rank	Country	MCP
1	USA	5,411
2	CHINA	4,213
3	INDIA	1,685
4	UNITED KINGDOM	1,170
5	KOREA	1,105
6	SAUDI ARABI	947
7	CANADA	731
8	AUSTRALIA	437
9	ITALY	434
10	FRANCE	403

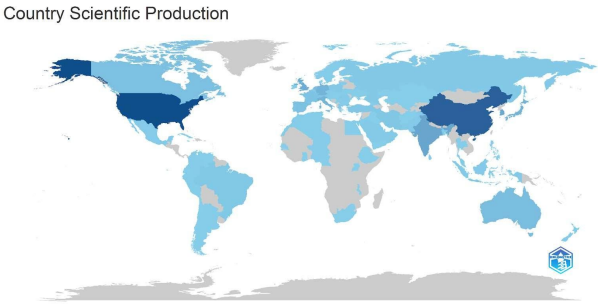

Fig. 2. Scientific production of countries between 2014-2024.

4.3 Analysis of institutions

A total of 2,571 institutions participated in this study. Figure 3 shows the top 10 institutions ranked by volume of publications in the period 2014-2024. The Mayo Clinic in the United States emerged as the most productive institution with 668 publications, dedicated to the practice of medicine, education and research. Followed by Imperial College London, which specializes in medicine, science, engineering and business, with 116 publications and in third place the National Defense Medical Center, responsible for training doctors, nurses and military medical personnel with 92 publications in this period. And finally, in fourth place The Cardiovascular Institute, dedicated to improving cardiovascular health through pioneering researchers, intellectual leadership, education and patient care with 67 publications in the last decade.

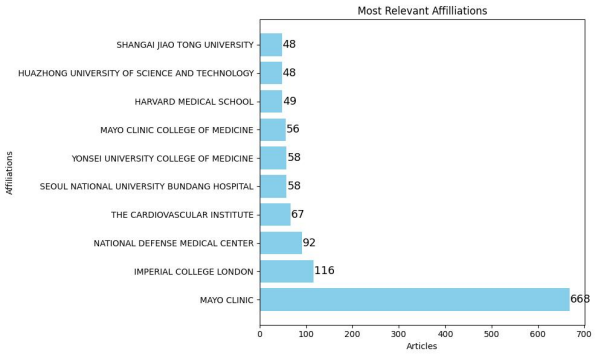

Fig. 3. Most relevant affiliations of publications on artificial intelligence applied to electrocardiograms between 2014-2024.

4.4 Analysis of authors

With a total of 8,787 authors, an evaluation was carried out to identify the most influential authors in the field in the last decade based on the production of publications and the H index. Friedman Pa, leads the volume of publications with 77

published articles, H index of 20 and a TC = 2.576 with a main focus on artificial intelligence applied in electrocardiograms for the detection of cardiovascular diseases. In second place, Noseworthy Pa, from the Mayo Clinic in the United States has a total of 69 publications, an H index of 19 and a TC = 2.424 and taking third place, Attia Zi with a total of 61 publications, an H index of 17 and a TC = 2.313 as can be corroborated in figure 4. In figure 5, through a network generated by VOSviewer, the authors who generate the greatest scientific production can be visualized.

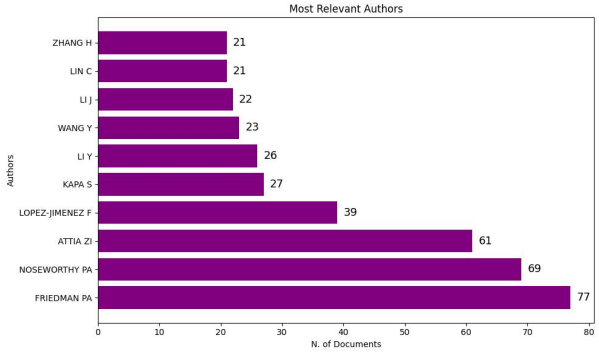

Fig. 4. Most relevant authors in the field between 2014-2024.

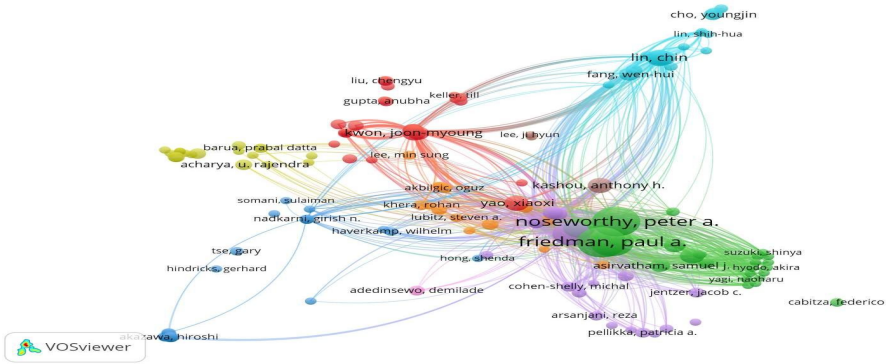

Fig. 5. Co-occurrence of authors cited in the field in the period 2014-2024.

4.5 Analysis of significant publications

A comprehensive analysis of the 10 most cited publications was conducted to improve our understanding of the significant advances in this area [Table 2]. Among the most cited articles, [18] stood out, with a total of 868 citations and a normalized Total Citation (TC) of 67.20 in the last decade, underlining its impact on the field. This study focuses on the implementation of AI algorithms to identify patients with atrial fibrillation in sinus rhythm, demonstrating how these tools can significantly improve diagnostic accuracy in clinical scenarios.

Table 2. Most relevant publications in the field between 2014-2024.

Rank	Article	Total Citations	Normalized TC	AI Model	Accuracy
1	An artificial intelligence-enabled ECG algorithm for the identication of patients with fibrillation during sinus rhythm: a restrospective analysis of outcome prediction [18]	868	67.20	CNN	79.4%
2	Review of Convolutional Neural Network [19]	822	63.64	Efficient CNN with Local Connections (Eff.-CNN-LS)	
3	Deep learning approach for active classification of electrocardiogram signals [20]	543	42.04	Deep Neural Network with Active Learning (Active-DNN)	99.86%
4	ECG Arrhythmia Classification Using STFT-Based Spectrogram and Convolutional Neural Network [21]	419	32.44	Two-Dimensional Convolutional Neural Networks (2D-CNN)	99%
5	Emotion recognition using wireless signals [22]	342	26.48	EQ-Radio & Support Vector Machine (SVM)	87%
6	Congestive heart failure detection using random forest classifier [23]	286	22.14	Random Forest Classifier	100%
7	Machine learning, medical diagnosis, and biomedical engineering research - commentary [24]	268	20,75	SVM with quadratic kernel	81.1%
8	Digital Twin for Intelligent Context-Aware IoT Healthcare Systems [25]	243	18.81	Long Short-Term Memory (LSTM)	97.09%
9	Age and Sex Estimation Using Artificial Intelligence From Standard 12-Lead ECGs [26]	243	18.81	CNN trained with 12-lead ECGs	90.04%
10	Ventricular fibrillation and tachycardia classification using a machine learning approach [27]	228	17.65	SVM with Gaussian radial basis kernel	96.3%

4.6 Keywords analysis

Keyword analysis is a crucial method to identify core topics in a research domain and monitor the progression of scientific advances [7]. As shown in Figure 6, the keyword co-occurrence map reveals several significant findings.

First, there is a central cluster that groups terms such as “artificial intelligence”, “electrocardiogram” and “deep learning”, reflecting the main focus of research on the use of artificial intelligence techniques for the analysis of electrocardiograms and the diagnosis of cardiovascular diseases. In addition, other clusters are identified that address specific topics such as “blood pressure”, “congenital heart disease” or “left ventricular systolic dysfunction”, indicating a concentration of efforts on AI applications for the management of specific cardiac conditions.

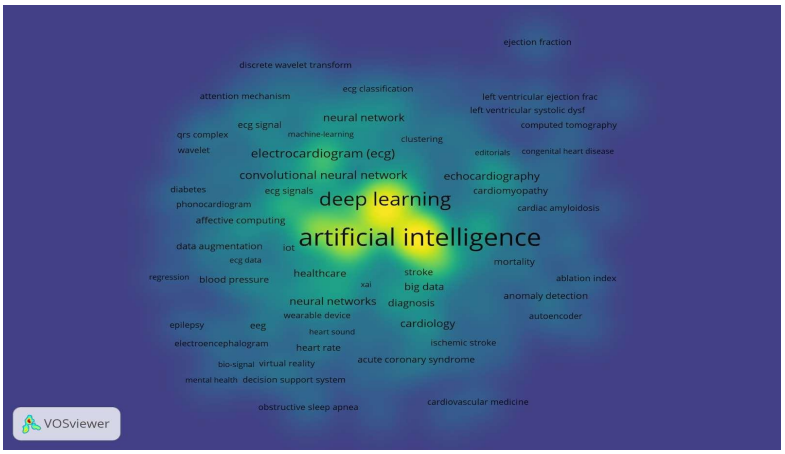

Fig. 6. Co-occurrence of keywords in the field in the period 2014-2024.

5 Discussion

Bibliometric analysis on the application of artificial intelligence (AI) in electrocardiograms (ECG) for the detection of cardiovascular diseases reveals a significant increase in scientific production in the last decade. The United States and China lead the production, with institutions such as the Mayo Clinic playing prominent roles in the development of advanced algorithms. Among the most influential authors are Friedman, Noseworthy and Attia, whose contributions have had a high impact on the scientific community.

The study of the most widely used AI models in the literature shows that the best performing algorithms include Random Forest Classifier, with 100% accuracy in detecting CHF [23], followed by Active-DNN, with 99.86% accuracy [20], and 2D-CNN, with 99% accuracy [21]. These models stand out for their ability to detect complex patterns in ECG signals, improving diagnostic accuracy in clinical settings.

Furthermore, the most cited article in the literature [18], with 868 citations, reinforces the importance of using convolutional neural networks (CNN) in the

detection of atrial fibrillation. Although the accuracy of this model is 79.4%, its impact lies in the clinical validation of AI in cardiovascular diagnosis, suggesting that CNN remains a fundamental technique in medical research and application.

These findings highlight the evolution of AI in cardiology, demonstrating that advances in deep learning and classification algorithms have significantly improved the ability to detect cardiac abnormalities. However, challenges remain related to the generalizability of the models across different populations and clinical settings, highlighting the need for further studies to validate their applicability in real-world medical practice.

6 Conclusions

This paper provides a comprehensive analysis of the evolution of artificial intelligence applied to the detection of cardiovascular diseases using electrocardiograms in the period 2014-2024. There is an exponential growth in the adoption of advanced techniques, with the United States and China as the countries with the highest scientific production. Institutions such as the Mayo Clinic and authors such as Friedman, Noseworthy and Attia have led the impact in this field.

Key findings include the identification of the most effective AI models for ECG analysis, including Random Forest Classifier (100% accuracy), Active-DNN (99.86%) and 2D-CNN (99%), due to their ability to detect patterns in cardiac signals with high accuracy. Furthermore, the most cited article (868 citations) reaffirms the relevance of convolutional neural networks (CNN) in the detection of atrial fibrillation, consolidating their use as a standard tool in cardiovascular research.

The integration of deep learning models, Random Forest, and logistic regression has optimized the ability of algorithms to process ECG signals, allowing for faster and more personalized diagnoses. These advances represent an interdisciplinary convergence between cardiovascular medicine and artificial intelligence systems, offering great potential to improve the diagnosis and treatment of heart diseases globally.

Despite progress in this area, further exploration of the clinical validation and applicability of these models in different populations and hospital settings is necessary. Future research should focus on ensuring the interpretability and reliability of AI algorithms for their adoption in everyday medical practice.

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