ISSN: 0034-8082

DOI Link: https://doi.org/10.59671/CTqfE
Vol.409, Issue.7, Part.1, July 2025, PP. 33-54

ARTIFICIAL INTELLIGENCE IN CARDIOLOGY: A BIBLIOMETRIC ANALYSIS OF BRAZILIAN RESEARCH

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Received April 2025 Accepted June 2025 Published July 2025

ABSTRACT

This study presents a bibliometric analysis of Brazilian scientific production on the application of artificial intelligence (AI) in cardiology between 2013 and 2023. A total of 31 publications indexed in the Scopus database were analyzed, involving 334 authors, with a notable increase in studies after 2018. The most productive and influential researcher was Antonio Luiz Pinho Ribeiro, from UFMG. A high level of collaboration among authors was observed, forming clusters based on co-authorship. The main types of documents were journal articles, conference papers, and reviews, primarily in the fields of medicine and computer science. The most frequent publication source was Arquivos Brasileiros de Cardiologia, with the most cited work focusing on photoplethysmography signal analysis. Funding came mainly from national institutions such as CNPq and FAPEMIG. The most recurrent keywords were "artificial intelligence," "machine learning," and "cardiology." International collaboration was strongest with the USA, China, and Portugal. The upward trend suggests growing interest and investment in the field.

Keywords: Artificial Intelligence. Cardiology. Bibliometric Analysis. Machine Learning

1. INTRODUCTION

Given the exponential growth of scientific information in the healthcare field - driven by the development of information technologies and the volume of data a physician must handle - artificial intelligence (AI) has proven useful in managing and analyzing large amounts of information and data in order to propose solutions to medical problems (Lobo, 2017; Souza Filho *et al*., 2019).

AI contributes to technological advancement across multiple fields, serving as an essential tool for the future and directly impacting human life. Initially motivated by the goal of imparting human-like intelligence to machines, AI now enables the expansion and augmentation of human intelligence, as it can handle large datasets, complex information, and tasks that surpass human capacity (Jiang *et al*., 2022; Souza Filho *et al*., 2019). In order to replicate human cognitive functions through logic, AI is composed of a set of technologies designed to act, solve, and analyze problems. One of its subfields is machine learning, which focuses on the development of algorithms and models that allow computers to learn from data and improve their performance in specific tasks by analyzing large volumes of data (big data) to extract knowledge and make decisions. The more data the model receives, the more it improves its learning and delivers accurate results through pattern recognition (Google, 2024).

In medicine, medical data and information are generated in significant daily volumes, and are characterized by "complexity, high dimensionality, nonlinearity, and sometimes strong dynamics" (Jiang *et al*., 2022, p. 11). Due to the overwhelming volume of raw data a physician must manage, AI helps reduce the workload of healthcare professionals - such as in the analysis of indicators, image processing, disease diagnostics, patient assistance, prevention of disease-related outcomes, and medication recommendations (Beam *et al*., 2023; Jiang *et al*., 2022; Karatzia, Aung, & Aksentijevic, 2022; Souza Filho *et al*., 2019).

Artificial intelligence has been increasingly applied in medicine, particularly in cardiology - a field marked by complex methods and large volumes of data (Zhang *et al*., 2024) - bringing significant advancements in clinical decision-making, diagnosis, treatment, and prognosis (Kilic, 2020; Lobo, 2017).

In cardiology, AI is used for diagnostics through the automated interpretation of images in echocardiograms, magnetic resonance imaging (MRI), and computed tomography (CT), as well as other complex medical data. It is also applied in predictive analyses to assess the risk of patients developing heart diseases or experiencing adverse cardiac events such as heart attacks or heart failure. Additionally, AI is used for monitoring cardiac parameters via devices like smartphones and smartwatches, which record electrocardiogram (ECG) data to help detect atrial fibrillation or other arrhythmias, among others (Itchhaporia, 2022; Kilic, 2020). According to Karatzia, Aung, and Aksentijevic (2022), patient data such as comorbidities and demographics have helped enhance machine learning performance. The authors present some AI devices used in cardiology, which can be seen in Figure 1, along with examples.

Figure 1 – AI Devices in Cardiology

Device name	Parent company name	Description
Atrial fibrillation history feature	Apple Inc.	Detection of atrial fibrillation
LINQ II Insertable Cardiac Monitor, Zelda AI ECG Classification System	Medtronic, Inc.	Arrhythmia detector and alarm (including ST-segment measurement and alarm)
Gili Pro Biosensor (Also Known as Gili Biosensor System)	Continuse Biometrics Ltd.	Hardware and software for optical camera-based measurement of pulse rate, heart rate, breathing rate, and/or respiratory rat
Analytic for Hemodynamic Instability (AHI)	Fifth Eye Inc.	Adjunctive hemodynamic indicator with decision point
ECG 2.0 App	Apple Inc.	Ambulatory ECG rhythm assessment
Bodyguard Remote Monitoring System	Preventice Technologies, Inc.	Arrhythmia detector and alarm (Including ST-segment measurement and alarm)
AI-ECG Tracker	Shenzhen Carewell Electronics Co., Ltd	Assessment of arrhythmias using ECG data acquired from adults without pacemakers
Eko Analysis Software	Eko Devices Inc.	Support in the evaluation of patients' heart sounds and ECG's
FFRangio	CathWorks Ltd.	Analysis of previously acquired angiography DICOM data for patients

Source: Karatzia, Aung e Aksentijevic (2022, p. 10)

In order to analyze the Brazilian scientific output on AI and its relationship with cardiology - aiming to provide an overview of trends in Brazilian research in related fields and to visualize them graphically - a bibliometric approach was used as the study method. Bibliometrics provides important quantitative indicators for the scientific evaluation of institutions, countries, authors, sources of information, and research areas, categorized into productivity indicators, citation indicators, and linkage indicators (Glänzel, 2003; Okubo, 1997; Spinak, 1998).

Thus, the present study aims to analyze the scientific output of authors affiliated with Brazilian institutions who have investigated artificial intelligence and cardiology during the period from 2013 to 2023, based on data extracted from Scopus and using the Scopus Analyze Search tool and Bibliometrix for data analysis.

2 METHODOLOGY

Searches were conducted in the Scopus database in the month of July, using the search terms "cardiology" and "artificial intelligence". An 11-year period - from 2013 to 2023 - was applied, and all types of materials were considered for analysis. The search results can be seen in Table 1:

ISSN: 0034-8082

Table 1 – Search Strategy in the Scopus Database.

Database	Search Strategy	Date of Retrieval	Total Records
Scopus	TITLE-ABS-KEY ("cardiology") AND TITLE-ABS-KEY ("artificial intelligence") AND AFFILCOUNTRY (brazil) AND PUBYEAR > 2012 AND PUBYEAR < 2024	July 2024	31
Overall Total			31

Source: Prepared by the authors.

After obtaining the search results, the "Analyze results" option in the Scopus database was used to analyze publication trends. To generate other bibliometric indicators, records were exported from Scopus in BibTeX format and processed using the Bibliometrix tool. Data analysis was carried out through the Biblioshiny interface, which enabled the creation of graphs and collaboration networks.

The Bibliometrix tool was developed by Aria and Cuccurullo (2017) and is an open-source package written in the R statistical and graphical programming language. Biblioshiny is a web-based application that allows users to access the main features of Bibliometrix through an interactive interface. (University of Naples Federico II, 2024)

3 RESULTS PRESENTATION AND DISCUSSION

The research identified 31 publications by authors affiliated with Brazilian institutions, totaling 334 authors. All publications were co-authored, with an average of 11.7 co-authors per document and 19.81 citations per document. These works are listed in Table 2:

Table 2 – Publications by Authors Affiliated with Brazil (2013–2023).

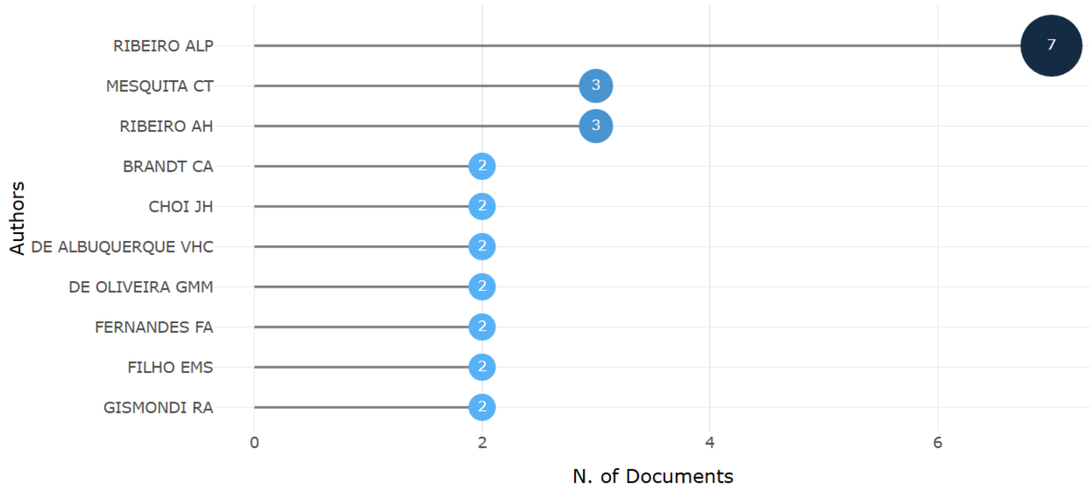
Authors	Title
Cabral e Oliveira (2014)	One-class classification for heart disease diagnosis
Lima *et al*. (2015)	Petri net application in simulation of ambulatory processes
Fonseca *et al*. (2016)	Machine learning approaches to estimate simulated cardiac ejection fraction from electrical impedance tomography
Moraes *et al*. (2018)	Advances in photopletysmography signal analysis for biomedical applications
Moreira (2018)	Electrocardiogram Fiducial Points Detection for Health Care Systems
Souza Filho et al. (2019)	Inteligência artificial em cardiologia: conceitos, ferramentas e desafios – “quem corre é o cavalo, você precisa ser o jóquei”
Lopes *et al*. (2019)	Guideline of the Brazilian society of cardiology on telemedicine in cardiology – 2019
Ribeiro e Oliveira (2019)	Toward a patient-centered, data-driven cardiology
Ribeiro *et al*. (2019)	Tele-electrocardiography and bigdata: The CODE (Clinical Outcomes in Digital Electrocardiography) study
Souza *et al*. (2020)	Ética, Inteligência Artificial e Cardiologia
Nielsen *et al*. (2020)	European Heart Rhythm Association (EHRA)/Heart Rhythm Society (HRS)/Asia Pacific Heart Rhythm Society (APHRS)/Latin American Heart Rhythm Society (LAHRS) expert consensus on risk assessment in cardiac arrhythmias: use the right tool for the right outcome,
Siqueira *et al*. (2020)	Machine learning applied to support medical decision in transthoracic echocardiogram exams: a systematic review
Siqueira *et al*. (2021)	Artificial intelligence applied to support medical decisions for the automatic analysis of echocardiogram images: a systematic review
Freedman *et al*. (2021)	World Heart Federation Roadmap on Atrial Fibrillation – A 2020 Update
Souza-Filho, Fernandes (2021)	Deep learning and artificial intelligence in nuclear cardiology
Mesquita e Rezende *et al*. (2021)	Nuclear cardiology: basic and advanced concepts in clinical practice
Baronti e Araujo (2021)	Diagnosing support expert system for symptomatic fever onset of Kawasaki disease
Oliveira *et al*. (2022)	The CirCor DigiScope dataset: from murmur detection to murmur classification
Spadon *et al*. (2022)	Pay Attention to Evolution: Time Series Forecasting with Deep Graph-Evolution Learning
Marques *et al*. (2022)	Artificial neural network-based approaches for computer-aided disease diagnosis and treatment
Bass *et al*. (2022)	Human vs. machine vs. core lab for the assessment of coronary atherosclerosis with lumen and vessel contour segmentation with intravascular ultrasound
Bass *et al*. (2022)	Machine Learning in Medicine: Review and Applicability
Sangha *et al*. (2022)	Automated multilabel diagnosis on electrocardiographic images and signals
Oliveira *et al*. (2022)	A physics-guided Deep Learning approach for functional assessment of cardiovascular disease in IoT-based smart health
Oliveira *et al*. (2023)	CML-Cardio: a cascade machine learning model to predict cardiovascular disease risk as a primary prevention strategy
Costa, Postolache e Araujo (2023)	From cloud AI to embedded AI in cardiac healthcare
Oliveira *et al*. (2023)	The Best Articles of 2022 in the Arquivos Brasileiros de Cardiologia and Revista Portuguesa de Cardiologia
Sangha *et al*. (2023)	Detection of left ventricular systolic dysfunction from electrocardiographic images
Gomes *et al*. (2023)	Use of deep neural networks in the detection and automated classification of lesions using clinical Images in ophthalmology, dermatology, and oral medicine: a systematic review
Kim *et al.* (2023)	Atherosclerosis Imaging Quantitative Computed Tomography (AI-QCT) to guide referral to invasive coronary angiography in the randomized controlled CONSERVE trial
Firmino *et al*. (2023)	Heart failure recognition using human voice analysis and artificial intelligence

Source: Prepared by the authors.

ISSN: 0034-8082

The 10 authors with the highest number of publications are shown in Figure 2. Due to inconsistencies in the name of one of the authors, which appeared in two variations, standardization was performed in the BibTeX file.

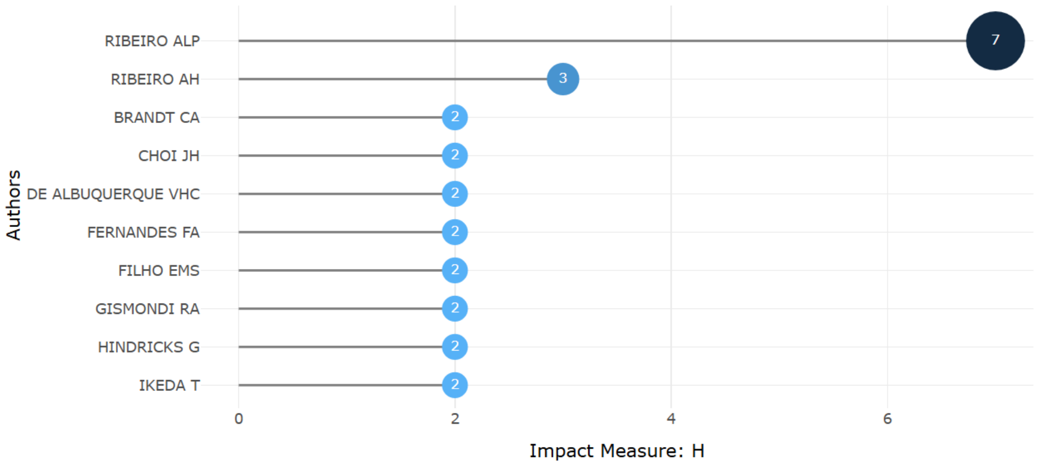
Figure 2 – Documents per Author



Source: Prepared by the authors.

The author with the highest number of published works was Ribeiro, ALP (Antonio Luiz Pinho Ribeiro), who is affiliated with the Federal University of Minas Gerais. He is a Full Professor specializing in cardiology, with publications that employ artificial intelligence-enabled electrocardiography. Besides being the author with the most publications on the topic, he also has the greatest impact, with the highest H-index among the analyzed authors, as shown in Figure 3:

Figure 3 – Main Authors with the Highest H-index

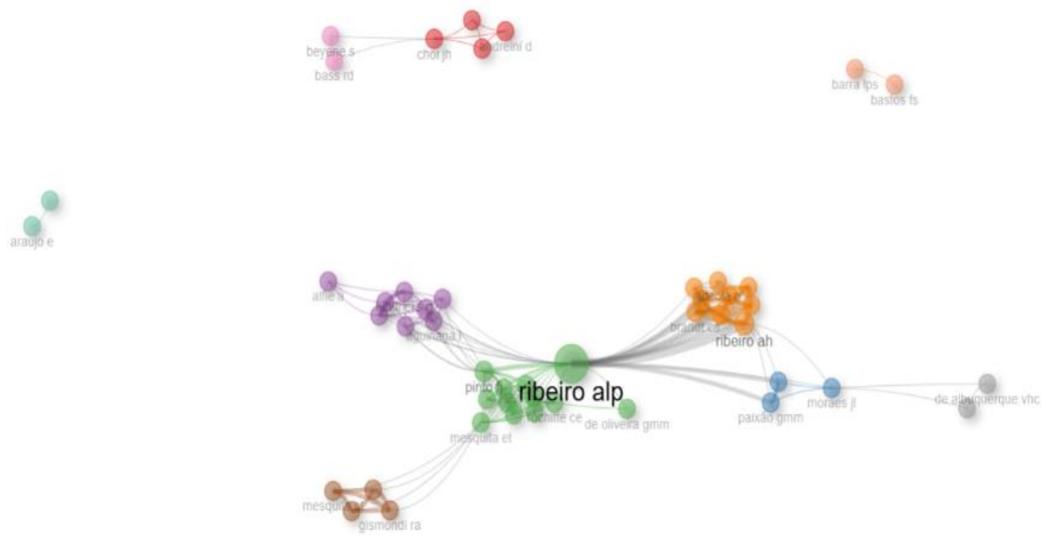


Source: Prepared by the authors.

The collaboration network shown in Figure 4 illustrates the cooperation among authors within 10 clusters represented by different colors, each corresponding to groups of authors who are strongly connected to one another. Authors represented by the largest circles are those with the highest occurrence in publications. The proximity or relatedness of authorship was determined based on the number of co-occurrences; thus, the more frequently authors appear together in publications, the stronger their relationship and the shorter the average distance between them in the visualization. The thickness of the links represents the frequency of collaboration.

Notably, the green cluster highlights the author Ribeiro, A. L. P., who has strong collaboration with authors in the orange and blue clusters. Additionally, isolated clusters without collaboration with other authors can be observed, indicating limited connections among authors working on these topics.

Figure 4 – Collaboration Among Authors

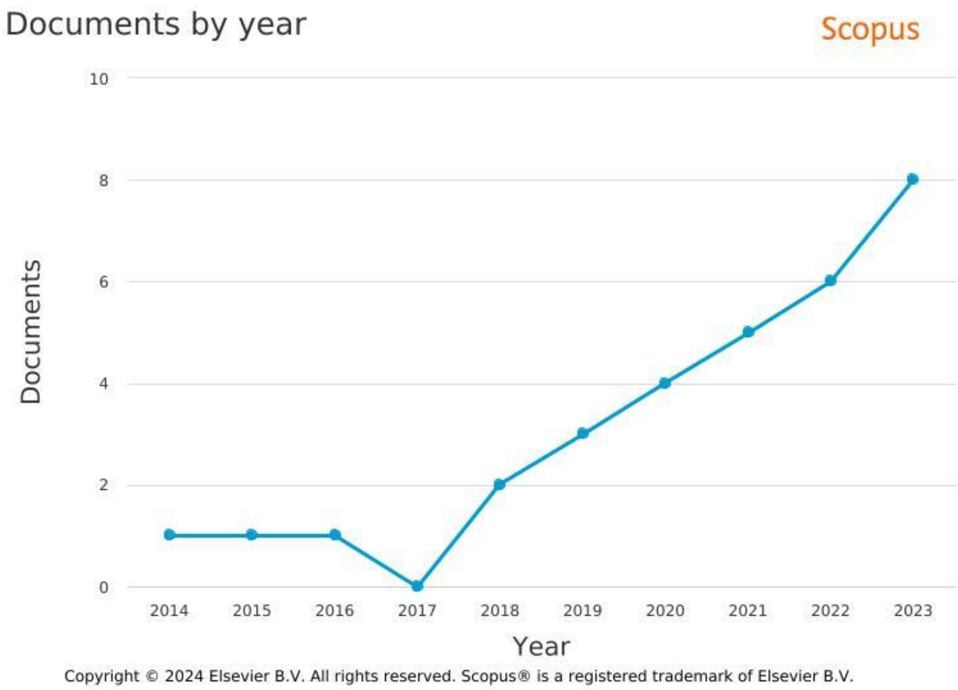


Source: Prepared by the authors.

4 DOCUMENTS OF AUTHORS' SCIENTIFIC PRODUCTION

The analysis of 11 years of document production is illustrated in Figure 5. It can be observed that there were no publications in 2013; however, an annual growth trend began in 2018, reaching the highest number of publications in 2023. This trend is also supported by Zhang *et al*. (2024), who reported a rapid increase in articles between 2016 and 2023 on the application of AI in the field of cardiovascular diseases, and by Jimma (2023), who studied the use of AI in the health sector. According to Jimma (2023), the growth in scientific production is linked to investments in AI technologies in healthcare and the pursuit of improvements in patient health quality, resulting in transformations in health services. For Zhang *et al*. (2024), the use of AI in cardiology, especially in cardiovascular imaging techniques, is expected to increase in the coming years.

Figure 5 – Documents per Year



Source: Scopus (2024)

Figure 6 represents the types of documents published on AI and cardiology, with a highlight on articles (35.5%), which are one of the main means of scientific dissemination, followed by conference papers (22.6%), representing faster communications compared to publishing articles in scientific journals, and reviews (22.6%), which are important for synthesizing and discussing recent research findings on a given topic. Since AI is a subject that has gained prominence only recently, with rapid implementation across various fields generating discussions and continuous improvements, this justifies the faster communication through these different forms of publication: journal articles, conference papers, and reviews.

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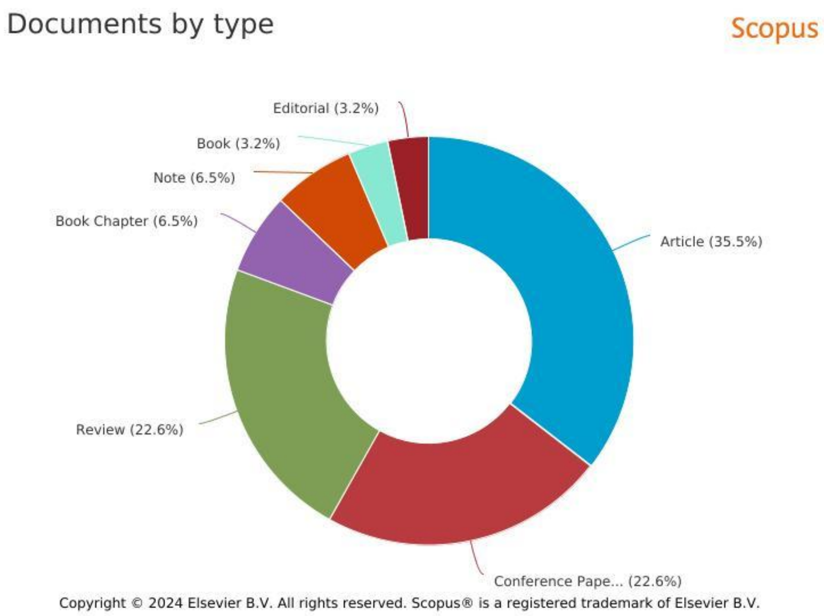
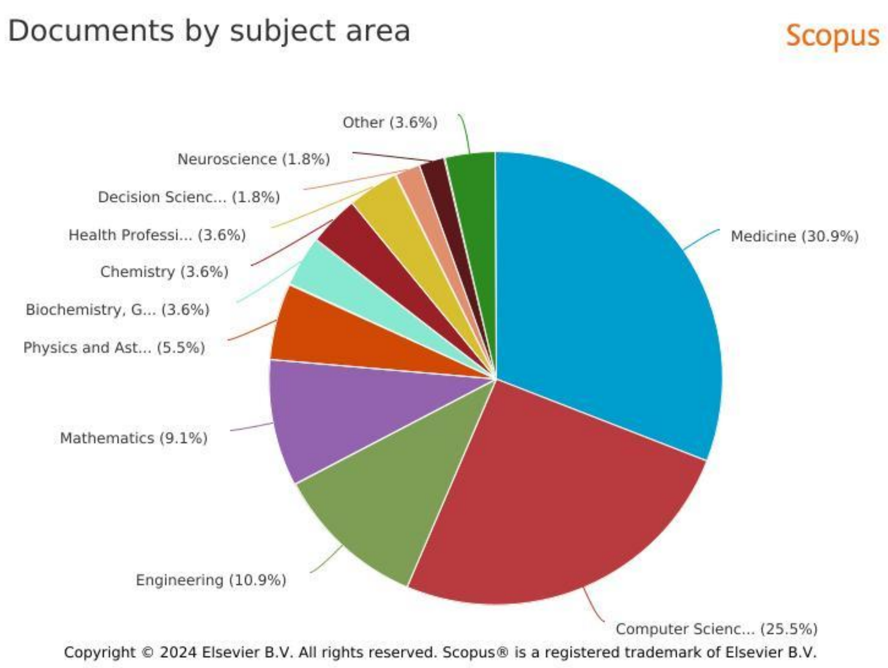
Figure 6 – Documents by Publication Type



Source: Scopus (2024)

Figure 7 depicts the fields in which AI and cardiology have been researched, with the main publications in medicine and computer science.

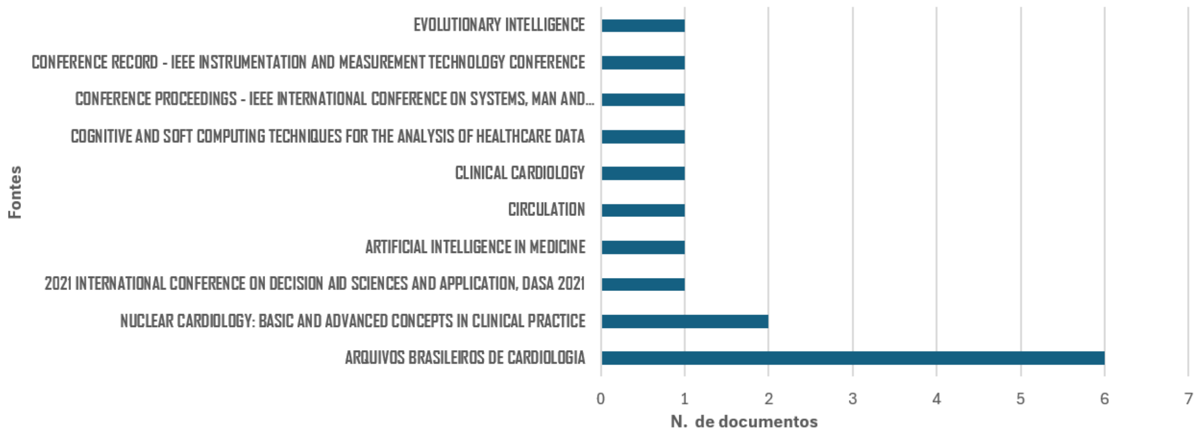
Figure 7 – Documents by Field



Source: Scopus (2024)

Among the sources that have published the most Brazilian research on AI and cardiology (Figure 8) is the Arquivos Brasileiros de Cardiologia, a journal belonging to the Brazilian Society of Cardiology (SBC), indexed in the Journal Citation Reports (JCR) with an impact factor of 2.0, published in both English and Portuguese. Another notable source is the book titled Nuclear Cardiology: Basic and Advanced Concepts in Clinical Practice, published by Springer.

Figure 8 – Sources with the Highest Number of Publications by Authors Affiliated with Brazilian Institutions

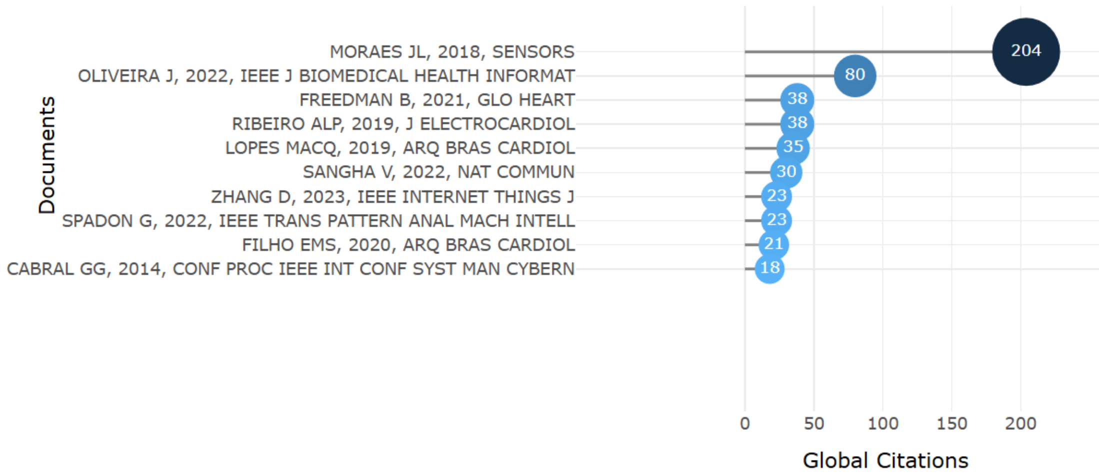


Source: Prepared by the authors.

Among the Brazilian publications that have received the most citations (Figure 9) is the journal article by Moraes *et al*. (2018), titled “Advances in photoplethysmography signal analysis for biomedical applications,” which has received 204 citations. The article associates technologies applied to photoplethysmography, an optical technique used in monitoring heart rate to aid in diagnostics. The second most cited article is by Oliveira *et al*. (2022), called “The CirCor DigiScope dataset: from murmur detection to murmur classification,” with 80 citations, which addresses the creation of a pediatric heart sound dataset aimed at improving machine learning for the detection and analysis of heart murmurs for diagnostic purposes.

ISSN: 0034-8082

Figure 9 – Most Cited Sources



Source: Prepared by the authors.

5 INSTITUTIONS AND FUNDING OF RESEARCH

Figure 10 presents the institutions that have published the most on the topic of Brazilian research, highlighting the Federal University of Minas Gerais, to which the most cited Brazilian author with the highest number of publications is affiliated.

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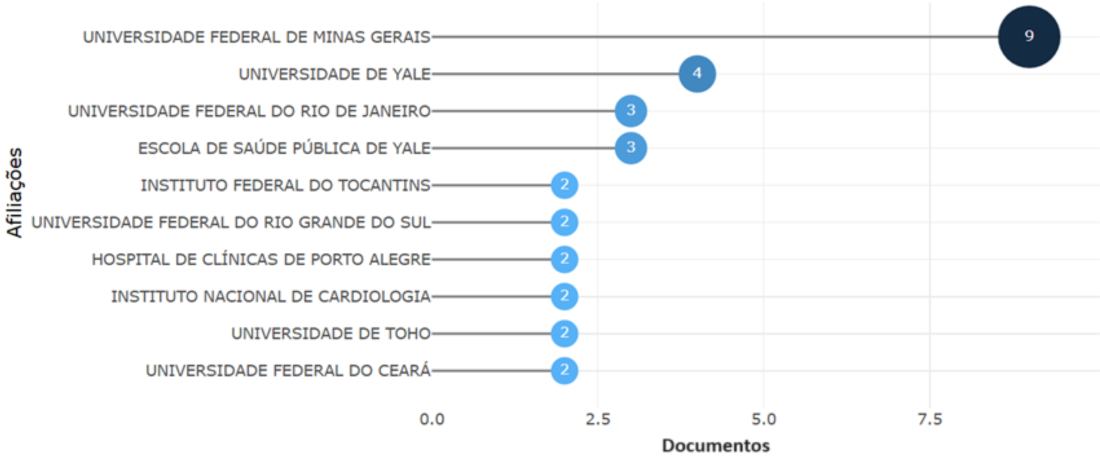
Figure 10 – Institutions with the Highest Number of Publications

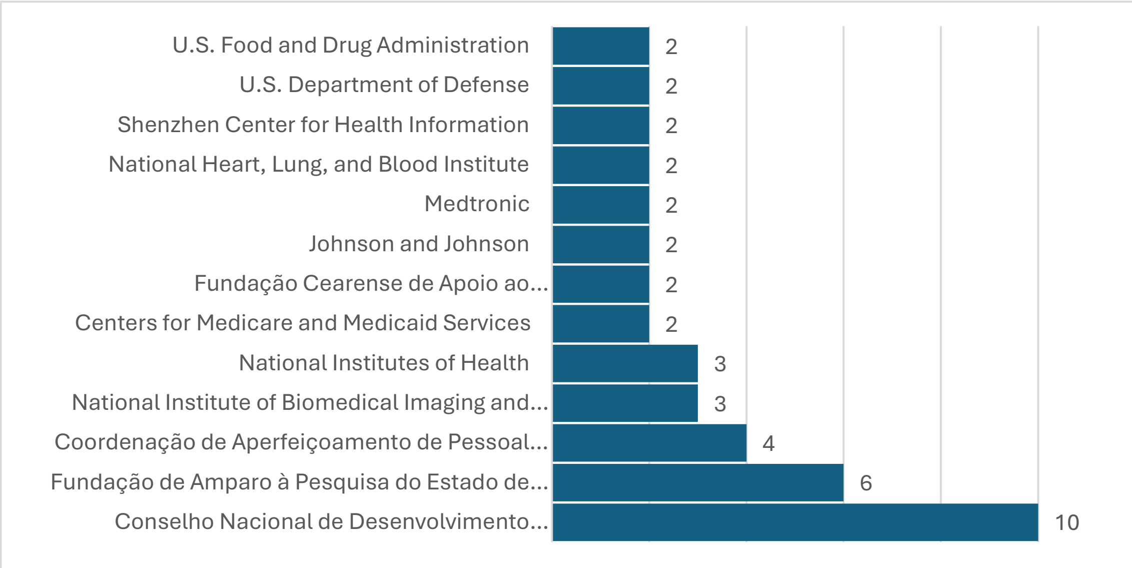


Source: Prepared by the authors.

The institutions that funded the most research on these topics (Figure 11) were the National Council for Scientific and Technological Development (CNPq), followed by the Research Support Foundation of the State of Minas Gerais (FAPEMIG).

ISSN: 0034-8082

Figure 11 – Institutions with the Highest Research Funding



Source: Prepared by the authors

6 THEMATIC RESEARCH TREND

Author keywords were mapped to identify research trends. According to Sigolo (2024, p. 2), "keyword analysis has been a technique to build scientific maps of important terms, to verify the cognitive structure of a research field and to visualize the intellectual content of a publication corpus." Figure 12 shows a co-occurrence matrix of keyword frequencies in pairs grouped into links similar to those of other documents, generating a co-occurrence network. The more co-occurrences identified, the closer the words appear to the center of the network map.

Terms with larger circles represent the most frequent keywords, and the greater the joint occurrence in the same document, the more they cluster by color. The closer they are on the map, the stronger the relationship between them. Three clusters were generated, where the most frequent keywords in the blue cluster are artificial intelligence, humans, machine learning; in the red cluster, emphasis on cardiology and heart; and in the green cluster, major clinical study, female, and male. The thickness of the links shows the strength of the relationship between the words. For example, in the red cluster, research related to cardiology and heart, diagnosis, and diseases is linked with terms in the blue cluster related to machine learning and artificial intelligence research. The green cluster's words are more associated with the blue cluster's research, such as clinical studies linked to female and male subjects using technologies.

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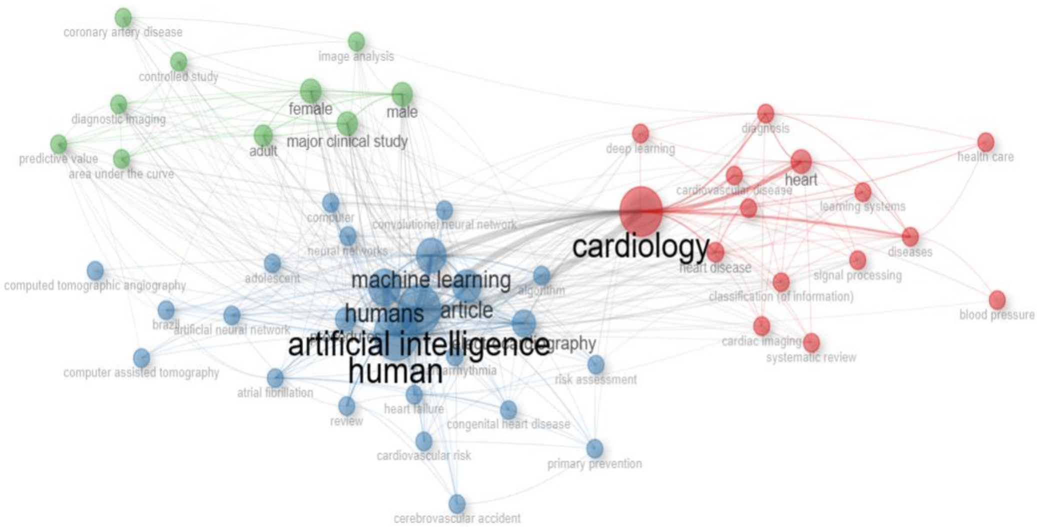
Figure 12 – Keyword co-occurrence network



Source: Prepared by the authors

7 COLLABORATION OF BRAZILIAN RESEARCH WITH OTHER COUNTRIES

According to Shiferaw (2024), the USA, followed by China, were the countries that published the most research using AI in cardiology. Thus, as shown in Table 3 and Figure 13, the main collaborations of Brazilian research are with the USA, China, and notably Portugal

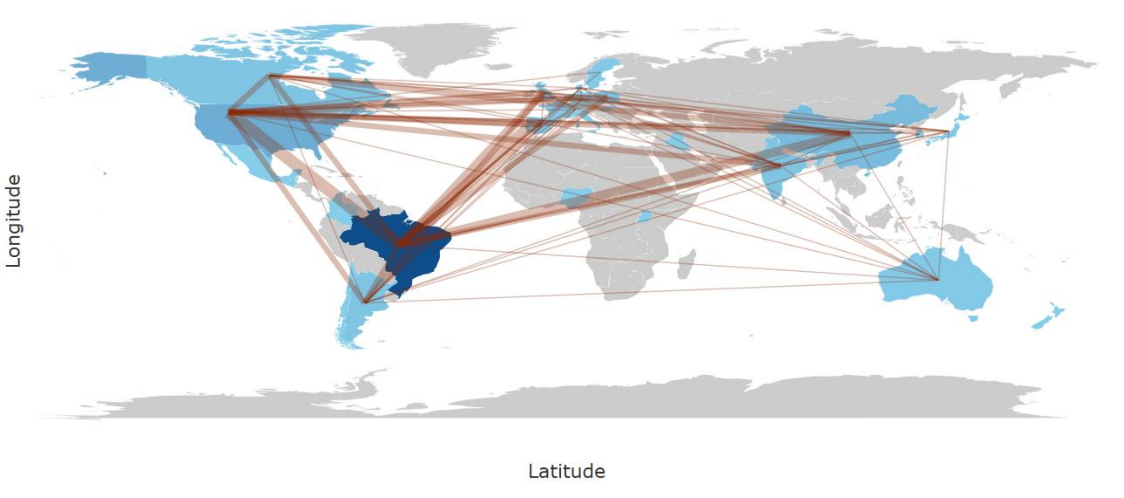
Table 3 – Countries with the Most Collaborations with Brazil

Country	Frequency of Collaborations
USA	8
China	5
Portugal	5
United Kingdom	4
Argentina	3
Canada	3
Índia	3

Source: Prepared by the authors

ISSN: 0034-8082

Figure 13 – Brazilian Scientific Collaboration with Other Countries



Source: Prepared by the authors

8 CONCLUSION

Although the number of Brazilian publications on AI in cardiology is still relatively small, it has grown in recent years, as evidenced by the bibliometric analysis covering the period from 2013 to 2023. This analysis provided an overview of Brazilian research, including the most prolific author, the institutions that most invested in and published on the topic, as well as the trending topics, the countries with which Brazil collaborated most frequently, and other relevant indicators. AI is a technology that is increasingly present in medical procedures, assisting both physicians and patients. Its ongoing advancement will enable more accurate diagnoses, the analysis of diverse and complex data, and predictive assessments of cardiovascular diseases.

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