

Global Mapping of Research on Artificial Intelligence Applied to Myocarditis

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Abstract

Background: Myocarditis remains a diagnostic challenge, and interest in using artificial intelligence to support noninvasive diagnostic evaluation has grown rapidly. Although the literature at the intersection of artificial intelligence and myocarditis has expanded substantially, it remains fragmented and lacks comprehensive synthesis.

Objectives: To map the global scientific output on the application of artificial intelligence to myocarditis by identifying leading contributors, collaboration patterns, and emerging thematic trends.

Methods: We conducted a bibliometric analysis of articles on artificial intelligence applied to myocarditis indexed in the Web of Science Core Collection. The R package bibliometrix and VOSviewer were used to perform bibliometric network and thematic analyses.

Results: A total of 47 articles were included. Scientific output increased markedly after 2021, coinciding with the COVID-19 pandemic, and peaked in 2025. China led in publication volume, whereas the United Kingdom and Germany achieved the greatest citation impact. No publications originated from Latin America, the Caribbean, or Africa. International collaboration networks remain fragmented. Keyword and thematic analyses identified the integration of deep learning with cardiovascular magnetic resonance imaging as the principal motor theme, reflecting a shift away from traditional endomyocardial biopsy. The most highly cited authors were primarily computer and data scientists.

Conclusions: Research at the intersection of artificial intelligence and myocarditis is an emerging field undergoing methodological consolidation, with growth accelerated by the COVID-19 pandemic. Cardiovascular magnetic resonance imaging has become the primary data source for artificial intelligence-based applications. The principal challenge appears to be translational, underscoring the need for stronger collaboration between algorithm developers and clinicians. The successful integration of these models into routine clinical practice will likely depend on multidisciplinary collaboration and validation across diverse, multicenter populations.

Keywords: Myocarditis; Artificial Intelligence; Machine Learning; Deep Learning.

Introduction

Myocarditis is characterized by diffuse or focal inflammation of the myocardium, most commonly resulting from infectious agents, immune-mediated reactions, or chronic inflammatory processes.¹ Clinically, it remains a diagnostic challenge because of its heterogeneous and often nonspecific presentation, ranging from an asymptomatic course to heart failure, arrhythmias, and sudden death.¹ Traditionally, endomyocardial biopsy has been considered the diagnostic gold standard;

however, advances in cardiovascular magnetic resonance imaging and the refinement of the Lake Louise criteria have transformed the noninvasive diagnostic approach.¹ Emerging clinical scenarios, particularly the expansion of cardio-oncology driven by the increasing incidence of myocarditis associated with immune checkpoint inhibitors, have further intensified the need for more accurate and timely diagnostic tools capable of supporting clinical decision-making while reducing reliance on invasive procedures.²

Artificial intelligence, including the subfields of machine learning and deep learning, has emerged as a promising tool for diagnostic support.³ The ability of these algorithms to process large data sets, identify complex phenotypic patterns, and predict clinical outcomes suggests that artificial intelligence may advance precision medicine and contribute to the evolution of modern cardiology.³ Despite growing technological interest, research at the intersection of artificial intelligence and myocarditis has expanded in a fragmented manner, with limited efforts to systematically characterize

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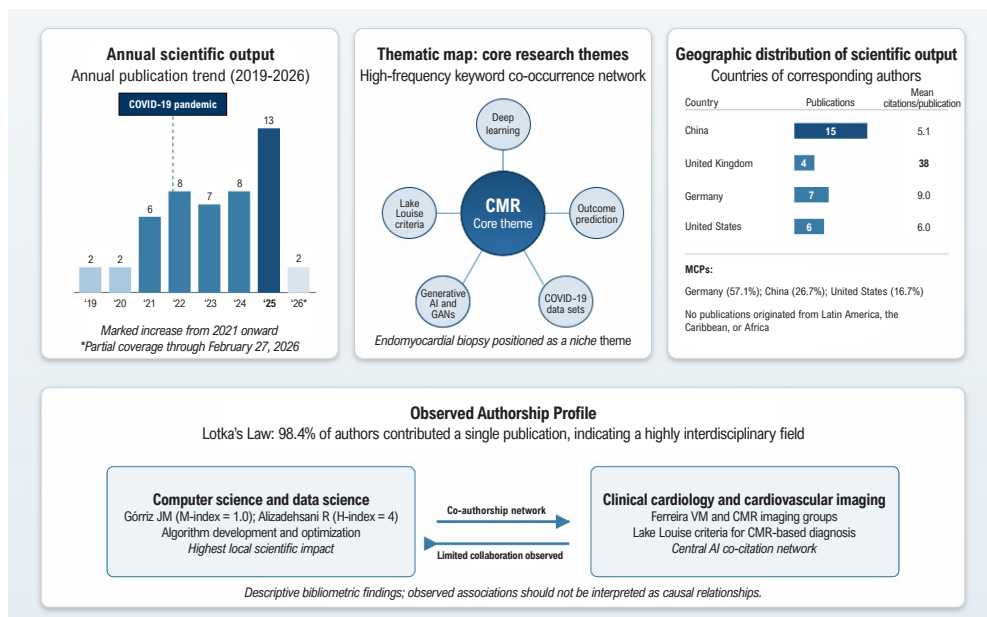
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Central Illustration: Global Mapping of Research on Artificial Intelligence Applied to Myocarditis



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Descriptive bibliometric synthesis of 47 publications (2019-2026) indexed in the Web of Science Core Collection, illustrating annual scientific output, the thematic structure of the field (centered on CMR), geographic distribution, and the interdisciplinary authorship profile. AI: artificial intelligence; CMR: cardiovascular magnetic resonance; GAN: generative adversarial network; MCP: multiple-country publication.

the field, identify leading research areas, map collaboration networks, or highlight emerging methodological trends.

Bibliometric analysis provides a robust methodological framework for mapping the scientific landscape of a research field.⁴ Unlike conventional systematic reviews, bibliometric approaches enable visualization of a field's intellectual structure, identification of co-authorship networks, assessment of the geographic distribution of scientific production, and analysis of the temporal evolution of research topics.^{4,5}

This study aimed to conduct a bibliometric analysis of the global scientific literature on the application of artificial intelligence to myocarditis. Specifically, we sought to identify the leading contributors (i.e., authors, countries, institutions, and journals) as well as the major thematic clusters within the field, thereby providing a comprehensive reference to guide future research and support the integration of artificial intelligence technologies into personalized cardiovascular medicine (Central Illustration).

Methods

Data source

The Web of Science Core Collection was selected as the data source for this bibliometric analysis because of its extensive coverage of indexed scientific journals.⁶ The

following advanced search string was applied: ("myocarditis" OR "inflammatory cardiomyopathy") AND ("artificial intelligence" OR "machine learning" OR "deep learning"). The search was performed on February 27, 2026. Only original research articles were included, with no restrictions on the year of publication.

All eligible records were retrieved in a single search session, yielding 82 articles. Two independent review authors manually screened titles and abstracts to exclude duplicate records and studies not primarily focused on myocarditis, following standardized recommendations for bibliometric research in the medical literature.⁷ This screening process resulted in a final data set of 47 articles for analysis. The bibliographic records were exported in plain text format and saved as download.txt files for subsequent processing.

Bibliometric analysis

Data processing, bibliometric analyses, and visualization were performed using R (version 4.5.2) and VOSviewer (version 1.6.20). The R environment, through the *bibliometrix* package, enabled comprehensive bibliometric analyses, including data extraction, network construction, and assessment of the scientific productivity and impact of countries, institutions, journals, authors, and co-cited references.⁵ The results were presented using bibliometric network maps and graphical visualizations.

Temporal analyses were also performed to examine the evolution of high-frequency keywords, providing insights into the development of research topics and emerging trends within the field. In addition, VOSviewer was used to construct and visualize co-citation and keyword co-occurrence networks.⁸

Results

Publication analysis

A total of 47 publications published between 2019 and 2026 were included in this study. The temporal distribution of publications shows modest scientific output through 2020, followed by sustained growth beginning in 2021. Annual publication volume increased from two articles in 2019 to 13 in 2025, representing the highest level of scientific production during the study period. The apparent decline observed in 2026 reflects the partial coverage of the year of publication, as the literature search was conducted on February 27, 2026.

Citation patterns differed from publication trends. Scientific impact, measured by the mean number of citations per article per year, peaked in 2021 at 5.7 citations/year. Thereafter, the average annual citation rate progressively declined, reaching values close to zero for articles published in 2025 and 2026, reflecting the limited time available for newly published studies to accumulate citations (Figure 1A).

Country analysis

Analysis of the corresponding authors' affiliations showed that China was the leading contributor ($n = 15$ [31.9%]). Germany ranked second ($n = 7$ [14.9%]), followed by the United States ($n = 6$ [12.8%]) and the United Kingdom ($n = 4$ [8.5%]).

Patterns of international collaboration varied considerably among the most productive countries. Germany exhibited the highest proportion of multiple-country publications (MCP), with 57.1% of its studies (four of seven) involving international collaboration. In contrast, China's scientific output was predominantly domestic, comprising 11 single-country publications and an MCP rate of 26.7%. Among the leading publishing countries, the United States demonstrated the lowest level of international collaboration, with five of its six publications involving only domestic authors (MCP rate: 16.7%) (Figure 1B).

In terms of scientific impact, the United Kingdom ranked first, with 152 total citations and a mean of 38 citations per article. China ranked second in total citations (76), although its mean citation rate was substantially lower (5.1 citations/article). Germany accumulated 63 citations overall, corresponding to an average of nine citations per publication (Table 1).

Despite producing fewer publications, Switzerland and Australia achieved high citation impact, with averages of 36 and 32 citations per article, respectively. The United States accumulated 36 total citations, corresponding to a mean of six citations per publication. Overall, scientific production was concentrated in China, Europe, and the United States.

Affiliation analysis

The institutions with the highest publication output are presented in Table 1. The University of Bonn ranked first with 11 publications, accounting for approximately 25% of the total sample, followed by Taipei Medical University ($n = 10$), University of London ($n = 8$), and Mayo Clinic ($n = 7$).

Inter-institutional collaboration was characterized by compartmentalized research networks composed of clusters with limited interaction. The orange cluster represents a Euro-Australian collaboration network involving Deakin University and University of Granada, highlighting the contribution of research groups specializing in computer science and signal processing (Figure 2A).

The German network, represented by the red cluster, is characterized by dense regional collaboration among medical centers, led by Johannes Gutenberg University Mainz, University of Bonn, and Hannover Medical School. The green cluster represents the British research consortium, comprising strong collaborative links among the University of London, Imperial College London, and King's College London.

Author analysis

Author productivity was led by Alizadehsani R ($n = 4$), followed by Górriz JM ($n = 3$). In terms of local impact, defined as the number of times a document within the analyzed data set was cited by other documents in the same data set, eight authors tied for the highest score, each with four local citations: Alizadehsani R, Alkadhi H, Di Noto T, Gantert E, Manka R, Mannil M, Soda P, and von Spiczak J.

Application of Lotka's Law demonstrated a marked deviation from the classical theoretical distribution.⁹ Overall, 98.4% of authors contributed only a single publication, whereas only a small proportion authored two or more articles.

The co-authorship network in artificial intelligence research on myocarditis was fragmented into eight distinct clusters, two of which were centered on authors with the highest local impact. The largest cluster (red) was organized around Alizadehsani R and Górriz JM, whereas the blue cluster comprised Kaya K, Luetkens JA, Pennig L, and Zimmer S. The network visualization highlights the presence of isolated collaborative groups with no external connections, with link thickness representing the frequency of direct co-authorship (Figure 2B).

Additional indicators of local scientific impact, including the H-index and M-index, further characterized author influence within the field. Alizadehsani R achieved the highest H-index ($H = 4$), with four publications receiving at least four citations each. Górriz JM ranked second ($H = 3$). After adjustment for academic age, Górriz JM attained the highest M-index ($M = 1.0$), followed by Alizadehsani R ($M = 0.8$). Three additional authors demonstrated comparable performance, each with an H-index of 2 and an M-index of 0.67: Kaya K, Luetkens JA, and Pennig L (Figure 3).

Journal analysis

The distribution of scientific output by journal identified the Journal of Clinical Medicine as the most productive journal,

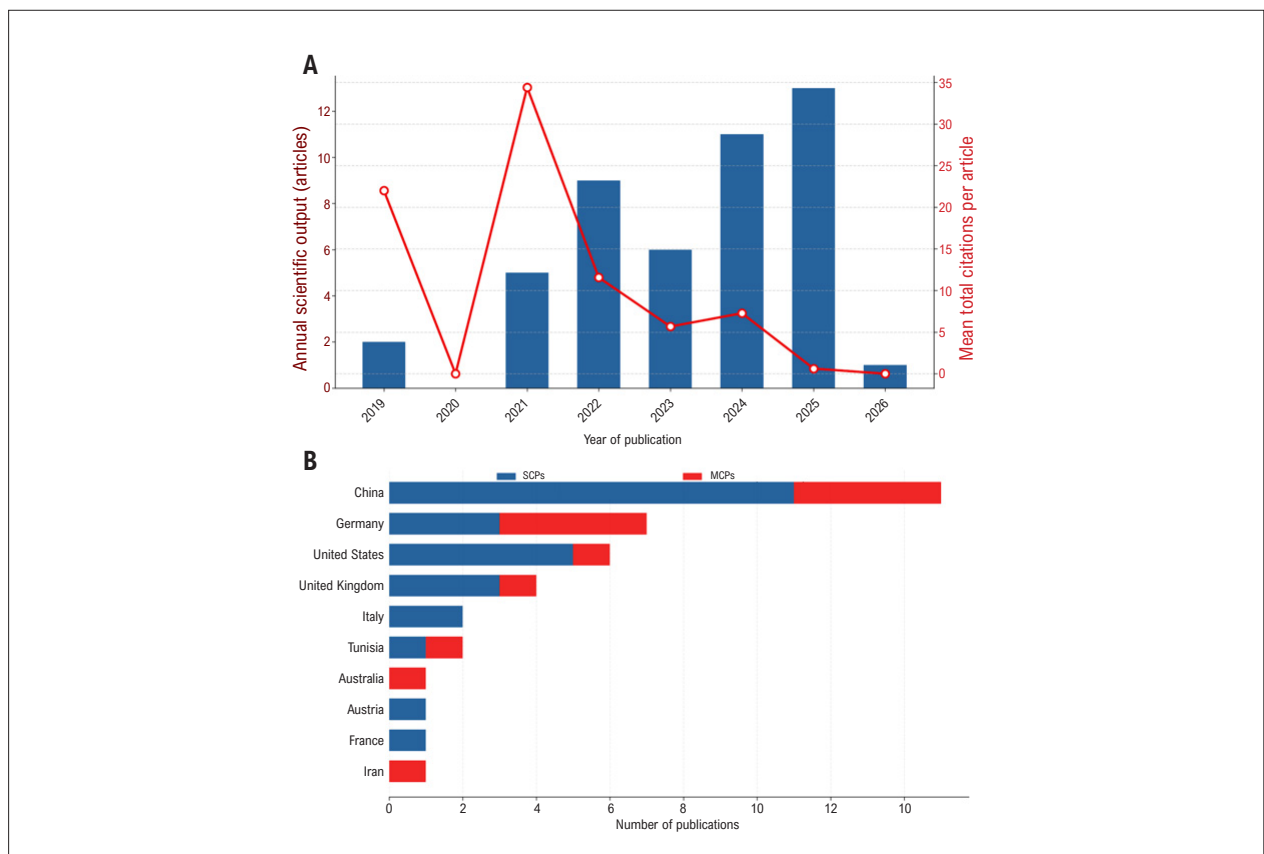


Figure 1 – Scientific production and geographic distribution. A) Annual scientific output and mean total citations per article. B) Scientific output by country, classified as SCPs and MCPs. MCP: multiple-country publication; SCP: single-country publication.

with four published articles. However, analysis of local citation impact showed that *Circulation* ranked first in total citations ($n = 58$), followed by the *Journal of the American College of Cardiology* ($n = 53$), the *Journal of Cardiovascular Magnetic Resonance* ($n = 42$), and *Radiology* ($n = 42$) (Table 1).

Application of Bradford's Law characterized the dispersion of publications and identified the core journals in this research field.¹⁰ The analysis revealed a small core (Zone 1) comprising four journals that concentrated the largest number of publications on the topic, each contributing two articles: i) *CAAI Transactions on Intelligence Technology*; ii) *Diagnostics*; iii) *Journal of Cardiovascular Magnetic Resonance*; and iv) *Quantitative Imaging in Medicine and Surgery*.

Global citation analysis

Global citation counts provide an indicator of an article's scientific influence within the broader academic community. The most highly cited publication in the data set ($n = 116$) was the study first-authored by Joy G,¹¹ titled "Prospective Case-Control Study of Cardiovascular Abnormalities 6 Months Following Mild COVID-19 in Healthcare Workers," published in the *Journal of the American College of Cardiology*. The study investigated cardiovascular abnormalities following SARS-CoV-2 infection using artificial intelligence-based analytical approaches.

The second most highly cited article ($n = 41$), titled "CNN-KCL: Automatic myocarditis diagnosis using convolutional neural network combined with k-means clustering," was first-authored by Sharifrazi D,¹² with Alizadehsani R as a co-author. The study proposed a deep learning framework for the automated diagnosis of myocarditis.

Co-cited reference analysis

The intellectual structure of research on artificial intelligence applied to myocarditis was mapped through co-citation network analysis at three levels: i) journals, ii) authors, and iii) individual references.

The journal co-citation network exhibited a tripartite structure. The red cluster represents clinical cardiology and comprises high-impact journals, including *Circulation*, the *Journal of the American College of Cardiology*, and the *European Heart Journal*. The blue cluster corresponds to the cardiovascular imaging domain, encompassing specialized journals such as *Radiology*, the *Journal of Cardiovascular Magnetic Resonance*, and *JACC: Cardiovascular Imaging*. The green cluster reflects the technological and multidisciplinary dimension of the field, integrating journals from computer science and general scientific research, with *Lecture Notes in Computer Science* occupying a prominent position (Figure 4A).

Table 1 – Global leaders in scientific productivity in research on artificial intelligence applied to myocarditis

Rank	Leading countries (total citations)	Leading institutions (total articles)	Most cited journals (total citations)
1	United Kingdom (152)	University of Bonn (11)	Circulation (58)
2	China (76)	Taipei Medical University (10)	Journal of the American College of Cardiology (53)
3	Germany (63)	University of London (8)	Journal of Cardiovascular Magnetic Resonance (42)
4	Switzerland (36)	Mayo Clinic (7)	Radiology (42)
5	United States (36)	Technical University of Munich (6)	European Heart Journal (34)
6	Australia (32)	Imperial College London (5)	JACC: Cardiovascular Imaging (33)
7	Italy (16)	Deakin University (4)	Lecture Notes in Computer Science (33)
8	Austria (8)	Johannes Gutenberg University Mainz (4)	European Radiology (25)
9	Iran (8)	Medical University of Innsbruck (4)	Scientific Reports (22)
10	Korea (4)	Okayama University (4)	arXiv (21)

Note: Data represent the top 10 entities in each category based on publications indexed in the Web of Science Core Collection (2019-2026). Values in parentheses indicate total citations for countries and journals and the total number of original articles for institutions.

The author co-citation network revealed two major intellectual fronts at the intersection of artificial intelligence and myocarditis. The blue cluster represents the clinical and diagnostic domain, centered on Ferreira VM, whose work on cardiovascular magnetic resonance has become a cornerstone in the diagnosis of myocardial inflammation (Figure 4B).¹³

The red cluster represents the algorithmic and methodological domain, centered on authors whose work focuses on the development of computational models, including Moravvej SV,¹⁴ Vakilian S,¹⁵ and Hong L.¹⁶ This cluster also includes prominent computer scientists, such as Cortes C, co-developer of support vector machines (SVMs).¹⁷ The network demonstrates a strong structural connection between these two domains, reflecting the frequent co-citation of authors from both the medical and computational sciences.

At the reference level, the co-citation network places the article by Ferreira VM (2018) at its center, linking multiple thematic clusters. This landmark publication introduced the updated Lake Louise criteria for the diagnosis of myocarditis using cardiovascular magnetic resonance imaging.¹³ The network also highlights seminal methodological contributions, including the work of Cortes C,¹⁷ which established the theoretical foundations of SVMs. Building upon these foundational studies, a dense and highly interconnected body of recent applied research has emerged, with notable contributions from Moravvej SV (2021, 2022), Danaei S (2022), Sudre CH (2017), and Hong L (2023) (Figure 5).

Co-occurrence analysis

The conceptual structure of the field was mapped through keyword co-occurrence analysis, identifying terms that

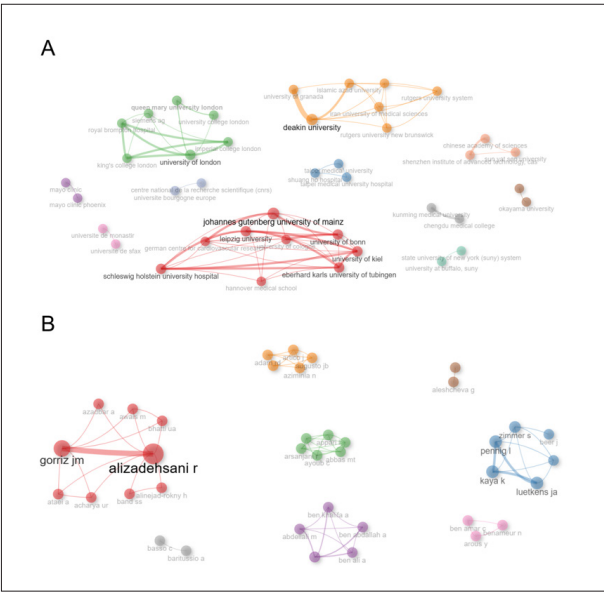


Figure 2 – Author impact metrics.

frequently co-occurred across the articles included in the data set. Three high-frequency keywords (*myocarditis*, *diagnosis*, and *artificial intelligence*) served as the central nodes of the predominant thematic clusters (Figure 6).

The red cluster is centered on *myocarditis* and links challenging clinical scenarios, including fulminant myocarditis and immune checkpoint inhibitor-associated myocarditis, with advanced computational approaches such as generative

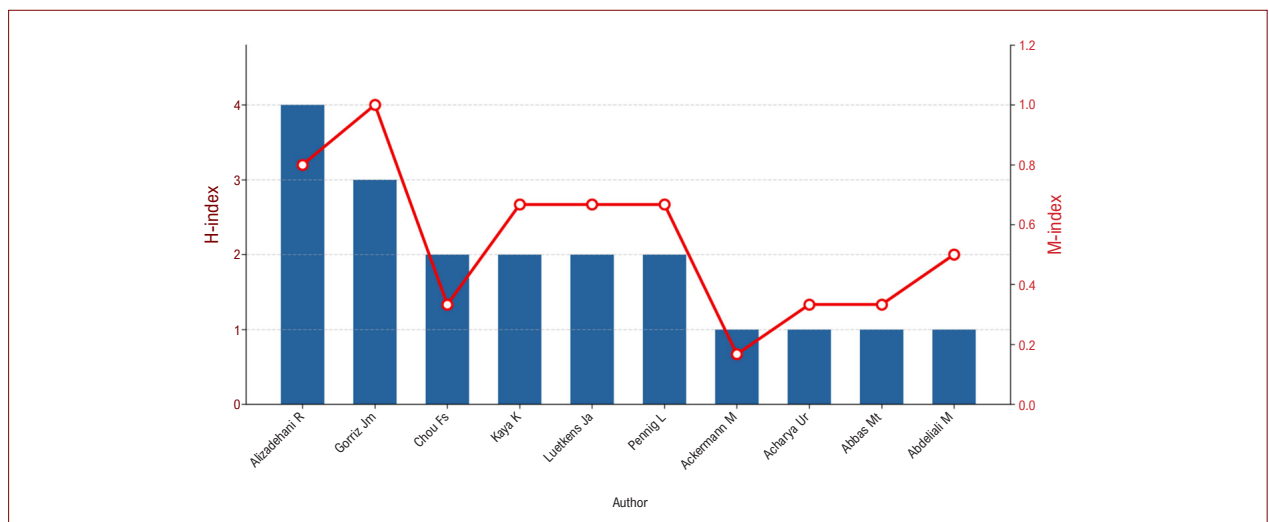


Figure 3 – Author impact metrics.

adversarial networks, reinforcement learning, and data augmentation techniques.

The blue cluster is organized around *diagnosis* and comprises terms related to algorithmic development, including *deep learning*, *classification*, and *prediction*, which are strongly associated with cardiovascular magnetic resonance imaging. The green and purple clusters connect *artificial intelligence* and *machine learning* with differential diagnoses and imaging biomarkers, including cardiac sarcoidosis, viral myocarditis, and late gadolinium enhancement.

The orange and brown clusters suggest the substantial influence of the COVID-19 pandemic on the evolution of the literature. The orange cluster is centered on COVID-19 and SARS-CoV-2, whereas the brown and purple clusters reflect the influence of professional society recommendations, represented by terms such as *position statement* and *working group*, highlighting ongoing efforts to standardize the diagnosis of myocarditis. When the network was filtered to retain only the strongest associations, the most prominent and densely connected relationship was observed among the nodes *diagnosis*, *cardiovascular magnetic resonance imaging*, and *myocarditis*.

Research hotspots and emerging trends

The intellectual structure of the field and emerging research fronts were characterized using a thematic map, which classifies research domains into four quadrants according to density (degree of development) and centrality (relevance within the research network).

The upper-right quadrant comprises the motor themes, characterized by both high centrality and high density, representing the most influential and well-developed topics in the field. The predominant themes include *cardiovascular magnetic resonance*, *artificial intelligence*, *magnetic resonance imaging*, *outcomes*, and *position statement* (Figure 7).

The lower-right quadrant contains the basic themes, which are highly relevant to the field but exhibit a lower degree of internal development. This quadrant includes *deep learning*,

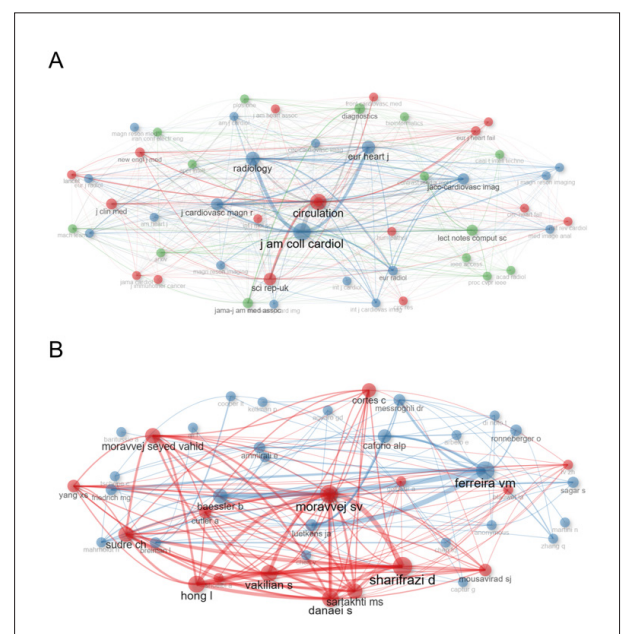


Figure 4 – Journal and author co-citation networks. A) Journal co-citation network. B) Author co-citation network.

magnetic resonance imaging, and *strain*. At the interface with the motor themes are clusters related to *myocarditis*, *COVID-19*, *SARS-CoV-2*, *disease*, and *fulminant myocarditis*.

The upper-left quadrant contains the niche themes, which are highly developed but remain peripheral to the overall research network. These include *endomyocardial biopsy* and *inflammatory cardiomyopathy*. The lower-left quadrant comprises emerging or declining themes, whose interpretation depends on their temporal evolution. This region is dominated by broad prediction-oriented terms, including *classification*, *prediction*, *diagnosis*, and *machine learning*.

Temporal analyses based on keyword frequency and trend-topic plots identified a clear inflection point in 2021, corresponding to the marked increase in scientific output and driven by the rapid growth of the terms *myocarditis*, *diagnosis*, and *artificial intelligence*. From 2023 onward, *deep learning* and *cardiovascular magnetic resonance* became increasingly prominent. Among all keywords, *machine learning* exhibited the longest period of sustained use throughout the study interval.

Discussion

This bibliometric analysis indicates that the intersection of artificial intelligence and myocarditis represents an emerging and still relatively immature research field. Publication output increased markedly after 2021, coinciding with the COVID-19 pandemic, which likely served as a global catalyst for research in this area. The heightened clinical interest in virus-induced myocardial injury, together with the availability of large hospital data sets generated during the pandemic, may have accelerated the adoption of machine learning and deep learning algorithms for risk stratification and diagnostic support in patients with suspected myocarditis.^{11,18}

The recent decline in the mean number of citations per article should not be interpreted as evidence of diminishing scientific relevance. A more plausible explanation is citation latency, an inherent limitation of bibliometric analyses.¹⁹ Articles published within the past 24 months have had limited time to accumulate citations. Accordingly, the citation peak observed in 2021 likely reflects the methodological foundation upon which subsequent research in the field has been built.

Nevertheless, the current growth rate remains modest compared with the broader field of cardiology.²⁰ This finding suggests that artificial intelligence applications in myocarditis are still undergoing methodological consolidation. Continued expansion of artificial intelligence in cardiology is anticipated over the coming decades, particularly in cardiovascular imaging, where artificial intelligence-based approaches are expected to play an increasingly prominent role.^{3,21}

The analysis of country-level contributions revealed distinct research strategies among the leading publishing nations. China accounted for the largest number of publications, suggesting a strong national emphasis on the development

and implementation of artificial intelligence-based diagnostic technologies. In contrast, the European research network, led by the United Kingdom and Germany, produced fewer publications but achieved substantially greater citation impact, with most of the highly cited studies originating from these countries. The United States exhibited a predominantly domestic research profile, possibly reflecting greater reliance on institutional and private data sets than on international collaborative consortia. A notable finding was the complete absence of publications from Latin America, the Caribbean, and Africa. This geographic imbalance raises important concerns regarding the external validity and generalizability of artificial intelligence models for myocarditis, as training and validation data sets may inadequately represent these populations, thereby increasing the risk of algorithmic bias in clinical decision-support systems.²²

The authorship structure of the field also remains highly fragmented. According to Lotka's Law, 98.4% of authors contributed only a single publication on the topic, indicating a research landscape characterized by isolated contributions rather than sustained activity from dedicated research groups.⁹ Examination of the academic backgrounds of the authors with the greatest local impact highlights another defining characteristic of the field: its pronounced interdisciplinarity and the leading role currently played by researchers from engineering, computer science, and other quantitative disciplines in advancing medical artificial intelligence.²³ Juan Manuel Górriz, who achieved the highest M-index (1.0), has a background in Physics and Electronic Engineering and specializes in statistical signal processing for biomedical applications.²⁴ Roohallah Alizadehsani, who led the field in both publication count and H-index, holds a doctorate in Computer Engineering and focuses on the development of machine learning algorithms for cardiovascular diseases.²⁵

This profile suggests that the methodological and technological development of artificial intelligence models is currently outpacing their clinical validation. The prominent role of engineers and data scientists indicates that research has primarily focused on the design, training, and optimization of computational models capable of processing complex data sets, particularly cardiovascular imaging and other high-dimensional clinical data.²⁶

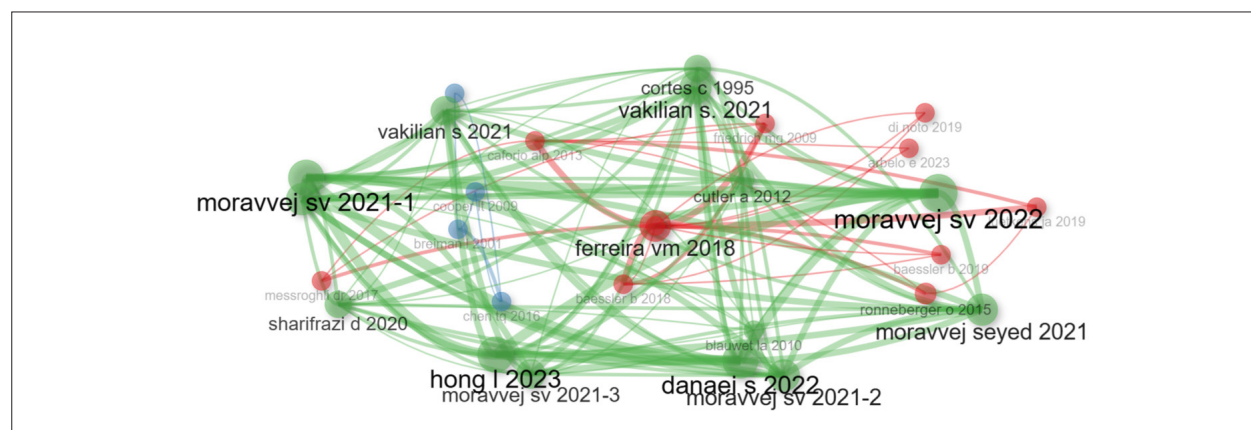


Figure 5 – Reference co-citation network.

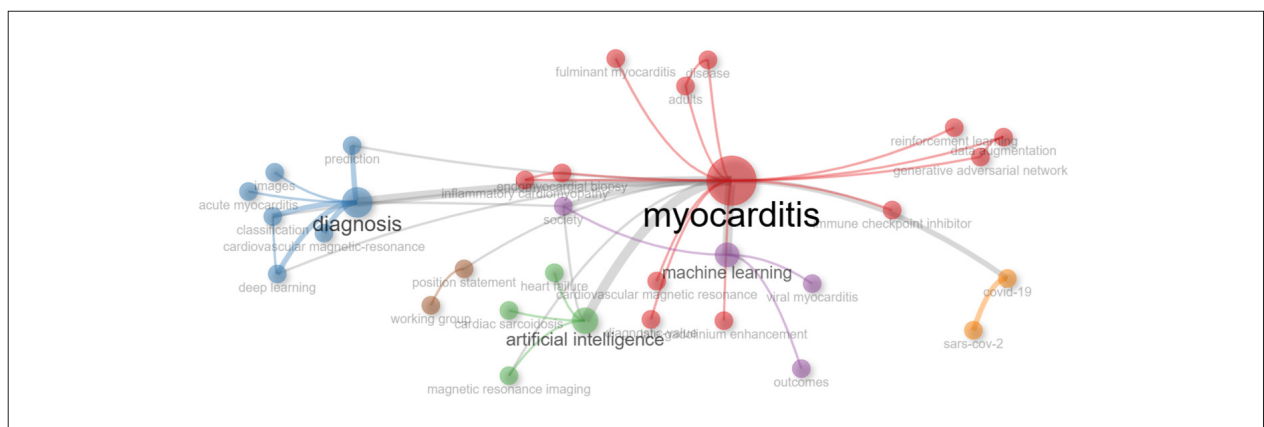


Figure 6 – Reference co-citation network.

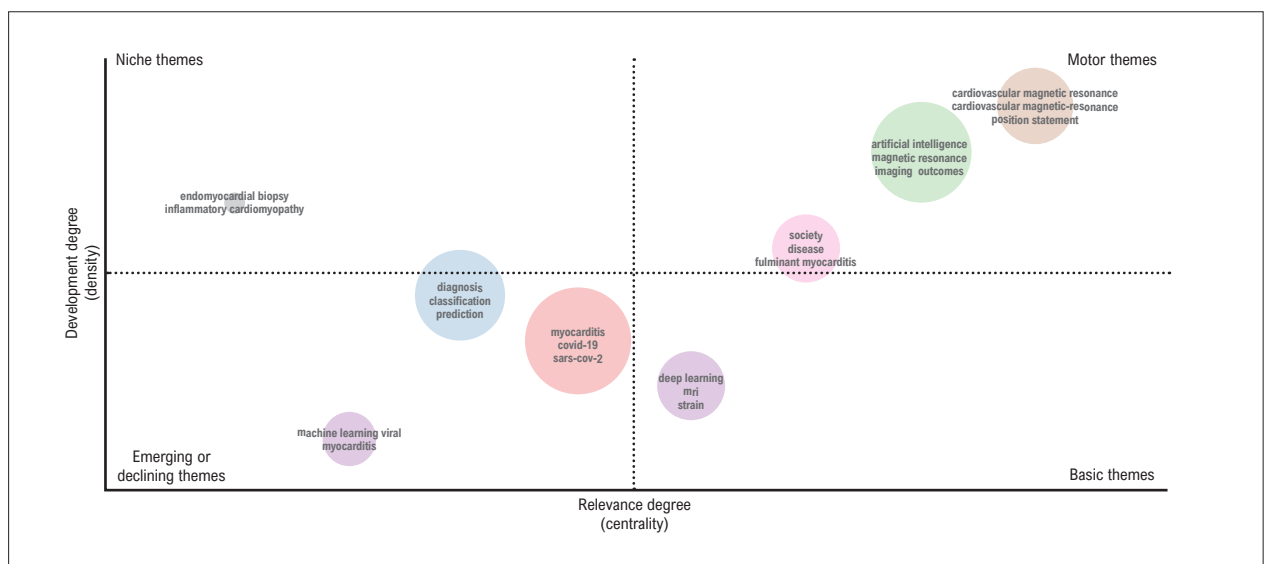


Figure 7 – Thematic map of research trends and emerging hotspots.

A similar pattern is evident in the leading journals within the field. Scientific dissemination is concentrated in journals focused on innovation in cardiovascular imaging and diagnostic technologies, reflecting the reliance of current artificial intelligence models on imaging-derived biomarkers for myocarditis detection. The translation of these technologies into routine clinical practice, however, will likely require a greater emphasis on translational research.³ Bridging the gap between computational development and bedside implementation will depend on multidisciplinary teams in which expertise in algorithm development is integrated with the pathophysiological interpretation and rigorous data curation provided by cardiologists and clinical investigators.

This evolution in the diagnostic paradigm is further reflected in the thematic map and keyword co-occurrence networks. Although endomyocardial biopsy remains the traditional diagnostic gold standard, it is positioned within a niche thematic cluster, whereas cardiovascular imaging techniques dominate

the motor themes. Current research is increasingly focused on refining deep learning and machine learning algorithms to identify subtle imaging patterns and improve the performance of noninvasive diagnostic approaches.^{3,13,21}

Beyond improving diagnostic accuracy, recent studies have explored the use of generative artificial intelligence and data augmentation techniques to address the limited availability of data for rare or underdiagnosed clinical presentations, including fulminant myocarditis and immune checkpoint inhibitor-associated myocarditis.^{27,28} In parallel, the prominence of the keyword *outcomes* among the motor themes reflects growing interest in prognostic modeling and clinical event prediction. Finally, the co-occurrence of artificial intelligence-related terms with guideline-oriented keywords, such as *position statement* and *working group*, suggests an increasing emphasis on establishing standardized frameworks for the evaluation, validation, and reporting of artificial intelligence applications in cardiovascular imaging.²⁹

Limitations

Several limitations of this study should be acknowledged. First, data extraction was restricted to the Web of Science Core Collection; therefore, relevant articles indexed exclusively in databases such as Scopus, Embase, or PubMed may not have been captured. Nevertheless, the Web of Science was selected because it provides the standardized metadata required for robust bibliometric and citation network analyses.⁶

Second, the search strategy relied on predefined keywords. Consequently, studies describing specific computational techniques (e.g., random forests or SVMs) without explicitly including the broader terms *artificial intelligence* or *machine learning* in the title, abstract, or keywords may have been excluded.

Third, bibliometric analyses are inherently subject to citation latency bias,¹⁹ whereby recently published articles have had insufficient time to accumulate citations regardless of their scientific quality or potential impact. This limitation was partially addressed by incorporating the M-index, which accounts for the time-dependent nature of citation accumulation.

Finally, the relatively small number of included publications (n = 47) may limit the generalizability of the findings. However, this characteristic also reflects the early developmental stage of artificial intelligence research applied to myocarditis, highlighting the emergence of a specialized and still-expanding research field.

Conclusion

This bibliometric analysis provides a comprehensive overview of the global scientific landscape at the intersection of artificial intelligence and myocarditis. The field remains in an early stage of development, is characterized by marked geographic disparities, and is currently driven predominantly by researchers from engineering and computer science rather than by clinical cardiologists. Its recent expansion coincided with the COVID-19 pandemic, while cardiovascular magnetic resonance imaging has emerged as the primary data source underpinning artificial intelligence-based diagnostic models.

The successful translation of these technologies into routine clinical practice will likely depend on multidisciplinary collaboration and rigorous validation across diverse populations,

particularly in regions that remain underrepresented in the current literature, such as Latin America, the Caribbean, and Africa. Although this study was limited to a single bibliographic database and included a relatively small number of publications, these findings provide a valuable baseline for future investigations and contribute to a better understanding of the evolution, current status, and future directions of this rapidly developing field.

Author Contributions

Conception and design of the research and Statistical analysis: Costa GCFO, Rodriguez JGV, Costa GFO; Acquisition of data: Costa GCFO, Costa GFO; Analysis and interpretation of the data, Writing of the manuscript and Critical revision of the manuscript for intellectual content: Costa GCFO, Rodriguez JGV, Costa GFO, Pimentel AML, Mesquita ET.

Potential Conflict of Interest

No potential conflict of interest relevant to this article was reported.

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Study Association

This study is not associated with any thesis or dissertation work.

Ethics Approval and Consent to Participate

This article does not contain any studies with human participants or animals performed by any of the authors.

Use of Artificial Intelligence

The authors did not use any artificial intelligence tools in the development of this work.

Availability of Research Data

All datasets supporting the results of this study are available upon request from the corresponding author.

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