A bibliometric analysis of the advance of artificial intelligence in medicine

Laberiano Andrade-Arenas[1], Cesar Yactayo-Arias[2]
[1]Facultad de Ciencias e Ingeniería, Universidad de Ciencias y Humanidades, Lima, Perú
[2]Departamento de Estudios Generales, Universidad Continental, Lima, Perú

Article Info

Article history:

Received Dec 1, 2023
Revised Feb 23, 2024
Accepted Feb 25, 2024

Keywords:

Artificial intelligence
Bibliometry
Machine learning
Medicine
VOSviewer

ABSTRACT

This bibliometric study analyzes the evolution of research in artificial intelligence (AI) applied to medicine from 2015 to September 2023. Using the Scopus database and keywords related to AI, machine learning, and deep learning in medicine, tools such as VOSviewer and Bibliometrix were used to explore publication trends, subject areas, co-authorship networks, and the most productive countries, among others. 2,064 articles were analyzed, and a significant increase in global academic production has been evident in the last five years. International collaboration was notable, with China and the United States leading in knowledge contribution. The keyword analysis highlights the breadth of topics and applications of AI in medicine, with particular emphasis on cancer detection, dengue diagnosis, and medical image analysis, among others. In conclusion, this study highlights the growing academic interest in the application of AI in medicine and the need for collaborative research. The findings underscore the relevance of these technologies in key areas of health care, contributing significantly to advances in medical diagnosis and prognosis.

Corresponding Author:

Cesar Yactayo-Arias
Departamento de Estudios Generales, Universidad Continental
Avenida Alfredo Mendiola 5210, Lima, Perú
Email: cyactayo@continental.edu.pe

1. INTRODUCTION

In recent decades, medicine has witnessed a technological revolution driven by the rapid progress of artificial intelligence (AI) and its various branches, including machine learning and deep learning. In this sense, the convergence of AI and machine learning is redefining medical practice, with precision medicine being one of the most beneficial areas [1], [2]. This phenomenon is particularly evident in emergency medicine, where machine-learning-based solutions aim to improve the quality of care [3]. Furthermore, machine learning is emerging as a promising tool in medicine, allowing efficient analysis of large data sets and facilitating personalized and precise approaches [4]–[6]. Similarly, these algorithms are used for risk stratification, guidance of medical treatment, and prediction of patient prognosis.

The implementation of machine learning algorithms has become widespread in various fields of medicine, for example in the field of stroke, where remarkable accuracy has been demonstrated in tasks ranging from image interpretation to stroke subtype classification [4]. This progress is being extended to cardiovascular medicine as a whole, which is increasingly adopting technologies based on artificial intelligence. Similarly, life sciences and healthcare have undergone a transformation driven by advanced computational approaches such as machine learning, especially in the analysis of complex biological data such as the microbiome [7]. In this context, machine learning has the ability to identify complex patterns in large data sets, overcoming the limitations of rule-based systems and human experts [8]. Laboratory medicine benefits greatly from the application of machine learning, leveraging large real-world data sets to solve complex problems [9].

Furthermore, deep learning-based applications offer significant potential for improving the quality of medical services [10]. In particular, AI is gaining ground in pathological evaluation for personalized medicine [11]. Unlike conventional approaches, deep learning, as an advanced branch of machine learning, has the ability to automatically learn complex features directly from raw data. This feature makes it particularly valuable in areas such as medical imaging, electronic medical records, genomics, and drug development [12]. In addition, deep learning has been the subject of intense research over the past decade, with applications ranging from natural language processing to the early detection of diseases such as dementia [13]. In the field of pathology, recent progress in deep learning is easing the computational examination of histological samples, enhancing the diagnosis and understanding of diverse diseases [14]. Within the realm of cancer, deep learning is demonstrating its utility in the classification of tumors and the prediction of gene expression [14]. In addition, deep learning is experiencing rapid growth in medical imaging applications, improving everything from scanner performance to automated disease detection and diagnosis [15]. This review critically analyzes the impact of artificial intelligence and machine learning on contemporary medicine, from its applications in emergency medicine and stroke medicine to laboratory medicine. Ethical and social concerns associated with the use of these technologies in healthcare will also be addressed. Using an interdisciplinary approach, the contributions of deep learning in different areas of medicine will be explored, highlighting its potential to improve the quality of services and the early detection of disease.

The application of AI in medicine has radically changed the way diseases are diagnosed, personalized treatments are developed, and healthcare systems are managed. This revolution has opened new perspectives for improving medical care [16], [17], clinical efficiency, and patient quality of life. Moreover, as AI has established itself as an essential tool in medicine [18], [19], it is essential to understand its impact and development in the scientific field. However, the large amount of research and development in this field poses a challenge: the need to systematically evaluate and quantify the growth of scientific literature related to AI in medicine. This bibliometric analysis is crucial for identifying trends, determining the relevance of previous research, and providing a solid framework for future advances in the field. In this context, this paper presents an exhaustive bibliometric analysis of the scientific literature related to the progress of artificial intelligence in medicine. This approach allows not only to quantify the scientific production in this field but also to identify outstanding authors, institutions, and journals, as well as to evaluate the temporal evolution of publications. In addition, keywords and research areas will be analyzed to shed light on the most relevant and emerging topics in this exciting interdisciplinary field.

The main objective of this study is to provide an up-to-date panoramic view of the progress of artificial intelligence in medicine based on a quantitative analysis of scientific literature. The aim is to identify the most relevant trends and highlight the most significant contributions of the scientific community in this constantly evolving field. This bibliometric analysis is critical as medicine faces increasingly complex challenges. The ability to quantify and understand the growth of AI research in medicine will help researchers, healthcare professionals, and policymakers make informed decisions. It will also help identify areas that require greater attention and development. Finally, this study will provide a solid foundation for future research and collaboration in the convergence of artificial intelligence and medicine.

2. METHOD

2.1. Database selection

The choice of the Scopus database for the bibliometric analysis is supported by its recognition as one of the largest open-access databases in the world [20]. Scopus offers impressive breadth and diversity by covering a wide range of scholarly sources, including journals, which is essential for a complete and representative bibliometric analysis. Its focus on open access democratizes research and facilitates global collaboration, providing global geographic coverage that enriches the research perspective. In addition, the advanced analytical tools it offers, such as citation tracking and trend identification, make Scopus a valuable choice for researchers who want to explore the scientific literature in depth, backed by its strong reputation and credibility in the academic community.

2.2. Inclusion and exclusion criteria

The inclusion criteria were carefully defined to ensure the quality and relevance of research on the topic of artificial intelligence in medicine. Articles published between January 2015 and September 2023 were considered, in their final and complete form, with open access, and exclusively from scientific journals. Papers presented at conferences, preprints, books, and other types of publications were excluded. The exclusive inclusion of scientific articles is based on the purpose of maintaining the quality and reliability of the research analyzed in this study. Journal articles are considered to be a more consolidated and reliable source of information, which is particularly important when researching critical topics such as the application of artificial intelligence in medicine, where the accuracy and quality of information are essential.

2.3. Data collection and extraction
2.3.1. Collection

The collection was performed through an exhaustive search of the Scopus database, using a search strategy that included a number of keywords relevant to the research topic [21], such as "artificial intelligence," "machine learning," "deep learning," and "medicine." These keywords were combined using Boolean operators (("artificial intelligence") OR ("machine learning") OR ("deep learning") AND ("medicine")) to refine the search and ensure the inclusion of relevant studies. In addition, date filters were applied to ensure that only the most recent publications were included, ranging from January 2015 to September 2023, and other defined inclusion and exclusion criteria were a total of 2,064 articles collected for analysis.

2.3.2. Extraction

The VOSviewer software and the Bibliometrix package were used for data extraction. The extracted data include information on the authorship of the articles, the institutions to which the authors belong, the year of publication, the keywords used, and other details relevant to the bibliometric analysis. This data extraction methodology guarantees the acquisition of current and relevant information in the field of artificial intelligence applied to medicine, allowing a complete and representative analysis.

3. RESULTS
3.1. Publication trend

Bibliometric research shows a remarkable increase in the publication of research related to artificial intelligence, machine learning, and deep learning in medicine over the years. As shown in Figure 1, an exponential increase in the number of publications is observed from 2015 to 2023, from 14 in 2015 to 516 by September 2023. This increase reflects the growing interest in the application of these technologies in the medical field, suggesting rapid progress and greater adoption of artificial intelligence in clinical practice. The year 2022 stands out as a period with a significant number of publications (564 articles), indicating a high point of research in this area.

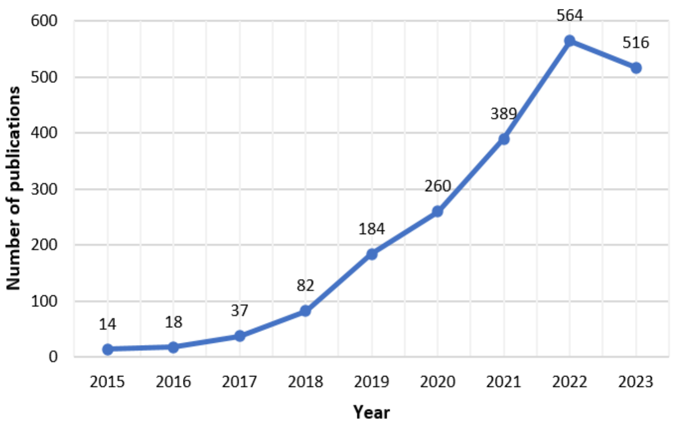

Figure 1. Number of articles per year of publication

3.2. Geographical distribution

The most productive countries in research on artificial intelligence and its various applications in medicine stand out by the number of documents published. As shown in Figure 2, China leads the list with 421 documents, closely followed by the United States with 418. India ranks third with 205 documents, and the United Kingdom and Germany rank fourth and fifth with 153 and 112 documents, respectively. This shows a diverse geographical distribution of knowledge production in this field, with a strong presence of China and the United States as major contributors.

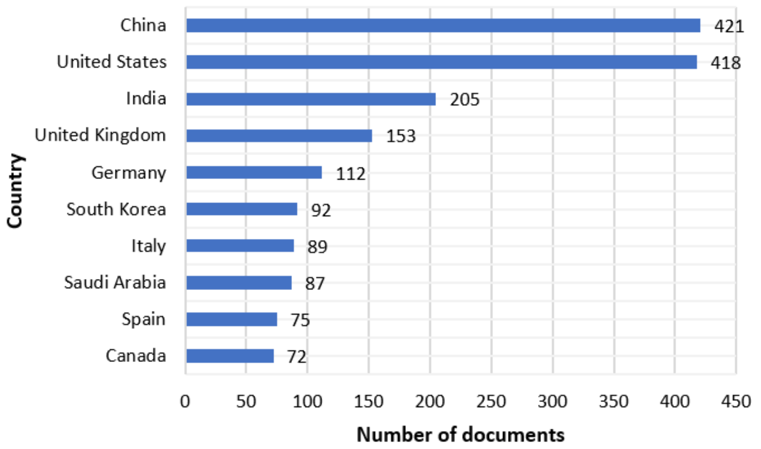

Figure 2. Top 10 most productive countries

On the other hand, Figure 3 illustrates the co-authorship network by country, where the size of the nodes increases as more articles are disseminated in a given country. Similarly, the connections between the nodes reflect the close collaboration between two countries, with wider lines indicating more intense collaboration [22]. The analysis of the co-authorship network in AI in medicine shows an organized structure with 7 clusters and strong global collaboration, represented by 747 links and a total link strength of 1,725. Countries such as the United States, China, the United Kingdom, India, Germany, and Italy lead the collaboration, while Hungary and Croatia show minimal participation in the network, with only one link and one link strength each. The geographical diversity in the network indicates extensive international collaboration in the field, which promotes a diversity of perspectives and knowledge in research. These results provide valuable insights into the dynamics of AI research in medicine and suggest opportunities for greater collaboration in some countries.

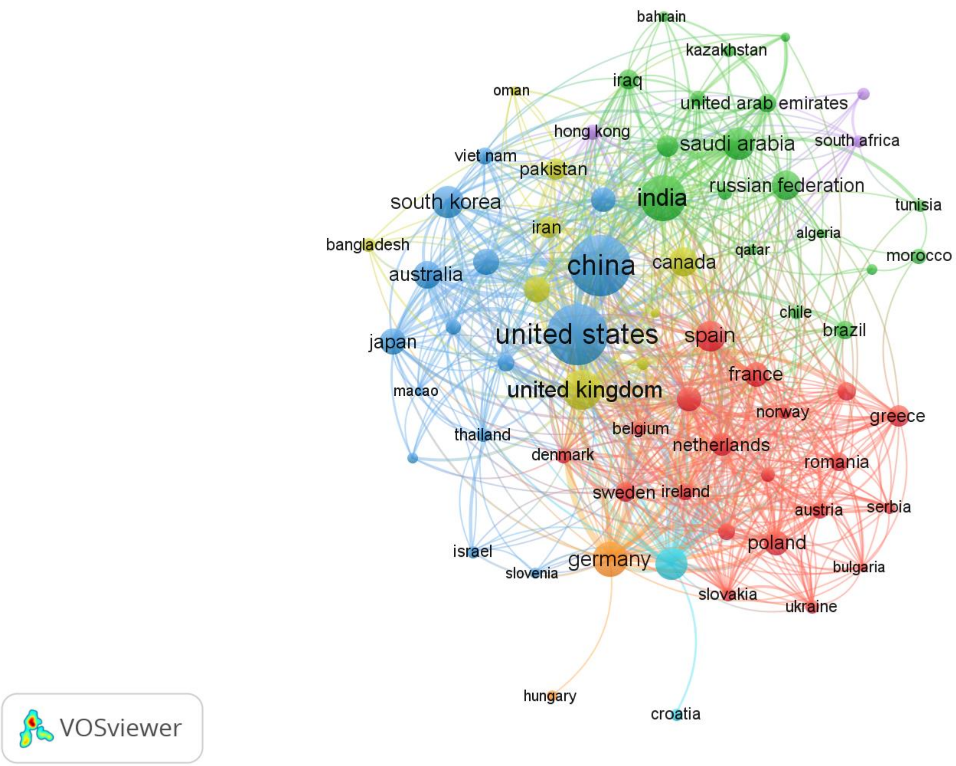

Figure 3. Co-authorship network by countries

Furthermore, Table 1 provides a revealing insight into the languages that play a prominent role in contributing to research in artificial intelligence and its applications in medicine. In this context, English emerges as the predominant language, covering a significant proportion of 96.08% of the 2064 articles analyzed. This underlines the importance of English as the main vehicle for communication and dissemination of knowledge in this discipline at a global level, facilitating international collaboration and access to information. However, linguistic diversity is also present, with languages such as Russian (1.74%), Spanish (0.48%), Chinese (0.39%), and Turkish (0.24%) contributing, albeit to a lesser extent, to the richness of perspectives and approaches to research in the field. This diversity of languages reflects the inclusion of diverse scientific communities in the global conversation about artificial intelligence and medicine.

Table 1. Knowledge distribution languages

Language	Number of publications	Percentage
English	1983	96.08%
Russian	36	1.74%
Spanish	10	0.48%
Chinese	8	0.39%
Turkish	5	0.24%
German	4	0.19%
Korean	3	0.15%
French	3	0.15%
Croatian	3	0.15%
Portuguese	2	0.10%
Japanese	2	0.10%
Ukrainian	1	0.05%
Slovenian	1	0.05%
Polish	1	0.05%
Persian	1	0.05%
Italian	1	0.05%
Total	2064	100%

3.3. Scientific journals

Table 2 highlights the ten most productive scientific journals in the field of artificial intelligence and its applications in medicine, the total number of publications (TP), their location in quartiles (Q), the h-index (H), and the diversity of countries involved in the production of knowledge in the field of artificial intelligence and medicine. The magazine "IEEE Access" leads the list with 148 publications classified in quartile 1 (Q1) and based in the United States. This reflects its influence and leadership in research. It is followed by "Angewandte Wissenschaften (Schweiz)" with 101 publications, classified in quartile 2 (Q2) and based in Switzerland. It is also interesting to note that Switzerland has a prominent presence in the journals "Applied Sciences," "Electronics," "Healthcare," and "Bioengineering," which suggests a significant contribution from this country in research in the field of artificial intelligence and medicine.

Table 2. Most relevant sources

No	Journal	TP	Q	H	Country
1	IEEE Access	148	Q1	204	United States
2	Applied Sciences (Switzerland)	101	Q2	101	Switzerland
3	Jmir Medical Informatics	56	Q2	41	Canada
4	Electronics (Switzerland)	37	Q2	62	Switzerland
5	International Journal of Advanced Computer Science and Applications	33	Q3	35	United Kingdom
6	Healthcare (Switzerland)	25	Q2	48	Switzerland
7	Frontiers in Artificial Intelligence	24	Q2	21	Switzerland
8	iScience	24	Q1	61	United States
9	Bioengineering	23	Q2	46	Switzerland
10	Computers, Materials and Continua	20	Q2	51	United States

3.4. Affiliations

Table 3 highlights the most prominent academic affiliations in the field of artificial intelligence and its applications in medicine. Stanford University tops the list with an impressive total of 66 published articles, reflecting its preeminent role in generating knowledge in the field. Zhejiang University follows closely with 57 articles, highlighting the significant contribution of academic institutions in China to research in this field. Third and fourth are the Technical University of Munich and the University of California, with 42 articles each, highlighting the collaboration between renowned academic institutions in different parts of the world. These results indicate a diverse geographic distribution of leading institutions in AI research in medicine, underscoring the globalization and multidisciplinary approach that characterizes this field of study.

Table 3. Most relevant affiliations

No	Affiliation	Articles
1	Stanford University	66
2	Zhejiang University	57
3	Technical University of Munich	42
4	University Of California	42
5	Tianjin University of Traditional Chinese Medicine	39
6	Fudan University	36
7	University of Michigan	36
8	University of Toronto	36
9	Dalian University of Technology	35
10	Chengdu University of Traditional Chinese Medicine	33

3.5. Most cited documents

The bibliometric study highlights five highly cited papers on artificial intelligence in medicine as shown in Table 4. First, "DARPA's explainable artificial intelligence program," published in AI Magazine in 2019, accumulated an outstanding number of 600 citations, indicating strong influence and recognition in the scientific community. This is followed by "Resistance to medical artificial intelligence," published in the Journal of Consumer Research in 2019, with 451 citations, indicating significant attention to resistance to the implementation of AI in medicine. Additionally, work on "Interpretable classifiers using rules and Bayesian analysis," published in Annals of Applied Statistics in 2015, accumulates 413 citations, highlighting the continued importance of interpretability in medical prediction models. Taken together, these documents reflect important areas of interest and focus at the intersection of AI and medicine, including the importance of interpretability, the importance of machine learning in data integration in the medical field, the growing concern for the security and privacy of medical images, and the consideration of resistance in the adoption of these technologies in the medical field.

Table 4. Most cited documents

Author	Title	Journal	Year	Citations
Gunning and Aha [23]	DARPA's explainable artificial intelligence program	AI Magazine	2019	600
Longoni *et al*. [24]	Resistance to medical artificial intelligence	Journal of Consumer Research	2019	451
Letham *et al.* [25]	Interpretable classifiers using rules and Bayesian analysis: building a better stroke prediction model	Annals of Applied Statistics	2015	413
Kaissis *et al.* [26]	Secure, privacy-preserving and federated machine learning in medical imaging	Nature Machine Intelligence	2020	365
Zitnik *et al.* [27]	Machine learning for integrating data in biology and medicine: principles, practice, and opportunities	Information Fusion	2019	224
Johnson *et al.* [28]	Machine learning and decision support in critical care	Proceedings of the IEEE	2016	225
Vellido [29]	The importance of interpretability and visualization in machine learning for applications in medicine and health care	Neural Computing and Applications	2020	198
Zeng *et al.* [30]	RIC-Unet: an improved neural network based on Unet for Nuclei segmentation in histology images	IEEE Access	2019	179
Bai *et al.* [31]	MolAICal: a soft tool for 3D drug design of protein targets by artificial intelligence and classical algorithm	Briefings in Bioinformatics	2021	117
Alzubaidi *et al.* [32]	Towards a better understanding of transfer learning for medical imaging: a case study	Applied Sciences (Switzerland)	2020	109

3.6. Applications of artificial intelligence in medicine

Table 5 shows the importance of specific applications of artificial intelligence in medicine, highlighting its implementation in different areas of healthcare. Prominent areas of focus include cancer detection, automation of fetal organ classification from ultrasound images, malnutrition risk prediction, pathology detection from chest X-rays, glaucoma diagnosis, and diabetes detection. These applications demonstrate the broad contributions of artificial intelligence, particularly through the use of machine learning and deep learning techniques. The intersection of artificial intelligence and medicine is manifested in its ability to address diagnostic and prognostic problems in various areas of health, highlighting its potential to improve accuracy and efficiency in clinical practice. This analysis highlights the significant impact of artificial intelligence on current medical research and its specific contributions to the detection and diagnosis of various medical conditions.

Table 5. Areas of application of AI in medicine

Area	Author	Title	Applied model	Year
Breast cancer diagnosis	Gao and Rezaeipanah [33]	An ensemble classification method based on deep neural networks for breast cancer diagnosis	Deep learning	2023
Automate fetal organ classification from ultrasound images	Ghabri *et al*. [34]	Transfer learning for accurate fetal organ classification from ultrasound images: a potential tool for maternal healthcare providers	Deep learning	2023
Prediction of gestational diabetes mellitus	Watanabe *et al.* [35]	Prediction of gestational diabetes mellitus using machine learning from birth cohort data of the Japan environment and children's study	Machine learning	2023
Prediction of non-small cell lung cancer (NSCLC)	Kinoshita *et al.* [36]	Development of artificial intelligence prognostic model for surgically resected non-small cell lung cancer	Machine learning	2023
Malnutrition risk prediction	Di Martino *et al.* [37]	Explainable AI for malnutrition risk prediction from m-Health and clinical data	Machine learning	2023
Skin cancer classification	Gururaj *et al*. [38]	DeepSkin: a deep learning approach for skin cancer classification	Deep learning	2023
	Waheed *et al.* [39]	Melanoma skin cancer classification based on CNN deep learning algorithms	Deep learning	2023
Histopathological diagnosis	Litjens *et al.* [40]	Deep learning as a tool for increased accuracy and efficiency of histopathological diagnosis	Deep learning	2022
Prediction of the risk of liver metastasis in rectal cancer	Qiu *et al*. [41]	Application of machine learning techniques in real-world research to predict the risk of liver metastasis in rectal cancer	Machine learning	2022
Detection of pathologies in chest x-rays	Rajpurkar *et al.* [42]	Deep learning for chest radiograph diagnosis: a retrospective comparison of the CheXNeXt algorithm to practicing radiologists	Deep learning	2018
Prediction of non-small cell lung cancer	Yu *et al.* [43]	Predicting non-small cell lung cancer prognosis by fully automated microscopic pathology image features	Machine learning	2016
Diabetes screening	Zee *et al.* [44]	Digital solution for detection of undiagnosed diabetes using machine learning-based retinal image analysis	Machine learning	2022
Dengue classification	Hamdani *et al.* [45]	Dengue classification method using support vector machines and cross-validation techniques	Machine learning	2022
Glaucoma diagnosis	Omar *et al.* [46]	GLAUDIA: a predicative system for glaucoma diagnosis in mass scanning	Machine learning	2021
	Kitaguchi *et al.* [47]	Deep-learning approach to detect childhood glaucoma based on periocular photograph	Deep learning	2023
Diagnosis of cardiovascular diseases	Baghdadi *et al.* [48]	Advanced machine learning techniques for cardiovascular disease early detection and diagnosis	Machine learning	2023

3.7. Keywords

The analysis of the network of author keywords in the field of artificial intelligence in medicine reveals a structure organized in 13 clusters, indicating a thematic diversity of research as shown in Figure 4. The network is composed of 1,449 links with a total link strength of 3,380, suggesting a strong interconnection between the keywords. Among the clusters identified, fundamental concepts stand out, such as machine learning with 152 links and 874 total strengths, artificial intelligence with 128 links and 680 total strengths, and deep learning with 131 links and 569 total strengths. In addition, specific terms related to the application of artificial intelligence in medicine, such as convolutional neural networks (67 links, 239 total strength), healthcare (37 links, 91 total strength), digital health (21 links, 69 total strength), and "precision medicine" (57 links, 166 total strength), highlight the importance of research in areas such as machine learning, digital healthcare, and precision medicine. These results reflect the relevance and interconnectedness of key concepts in scientific research on artificial intelligence in medicine, providing a comprehensive view of trends and approaches in this emerging field.

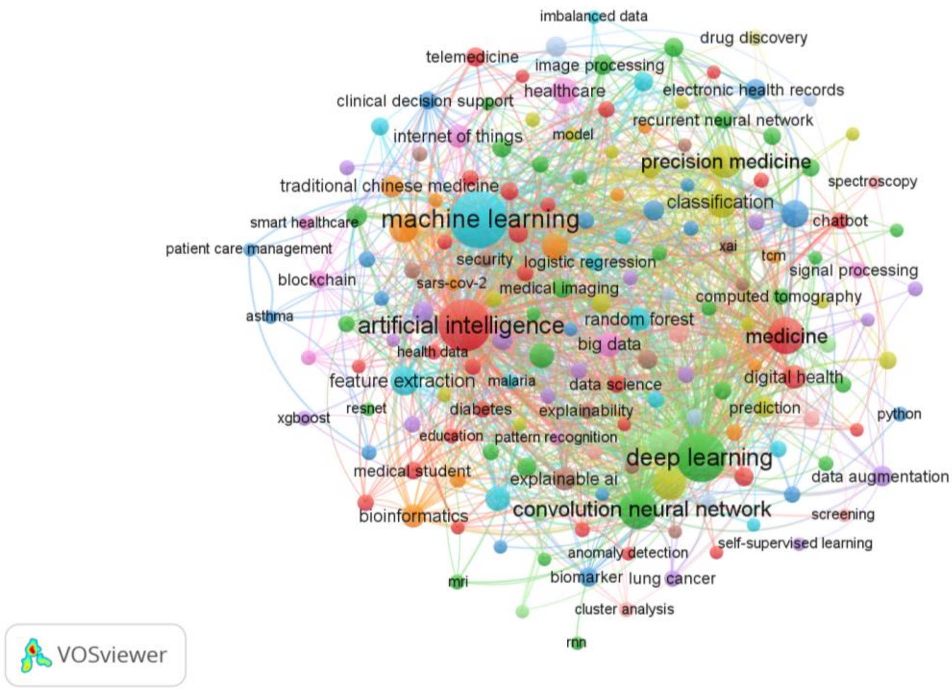

Figure 4. Author keyword network

4. DISCUSSION

4.1. Increasing publication trend

From 2015 to September 2023, an exponential growth was observed in publications related to artificial intelligence (AI) in medicine, from 14 to 516. This trend reflects the growing importance of AI, including its aspects such as machine learning and deep learning, in the medical field. AI technology has become a widespread trend in medical informatization due to the complexity of the structure and the huge amount of medical information generated in the current medical informatization process [49]. AI promises to transform healthcare by providing safety, autonomy, and timely access to care in hard-to-reach areas while reducing administrative burden and physician burnout. It is also expected to help reduce medical errors and improve diagnostic accuracy through the integration, analysis, and interpretation of data using algorithms and specialized software [50]. This increase in publications underscores the growing importance of AI in medicine, with the potential to significantly reshape healthcare delivery.

4.2. Geographic and linguistic distribution in research

The geographic distribution of contributions to AI research in medicine shows a distinct pattern, with China leading the list, followed by the United States, India, the United Kingdom, and Germany. This phenomenon highlights the significant commitment of these countries to advancing the knowledge and application of artificial intelligence in medicine. In addition, international collaboration, as measured by co-authorship, shows that countries such as the United States, China, the United Kingdom, India, Germany, and Italy are at the forefront, demonstrating the importance of global collaboration in this field. On the other hand, a minimal participation of Hungary and Croatia is observed, possibly indicating a need for greater integration and participation of these countries in AI research in medicine.

Regarding the language used for knowledge contributions, the predominance of English highlights the universality of this language in scientific communication. However, it is noteworthy that other languages, such as Russian, Spanish, and Chinese, among others, have a minimal presence in research contributions in this field. This could indicate a gap in the representation of different linguistic communities in the scientific literature of artificial intelligence in medicine. It would be important to encourage linguistic diversity in research to ensure a broader representation of perspectives and contributions in this ever-evolving field.

4.3. Applications of AI in medicine

The integration of advanced technologies such as AI in cancer detection and prediction has led to significant advances and diversified applications. In the case of breast cancer, the implementation of internet of things (IoT)-based systems driven by deep learning facilitates automated detection, reducing the burden on the healthcare system and contributing to the early detection of pathologies. The application of convolutional neural network models, such as InceptionResNetV2 and InceptionV3, demonstrates their effectiveness in predicting accuracy for CT and X-ray images [33]. In the field of non-small cell lung cancer (NSCLC), AI supported by the XGBoost algorithm demonstrates excellent ability to predict postoperative prognosis, improving accuracy compared to traditional methods [36]. In dermatology, the combination of convolutional neural networks and transfer learning techniques is shown to be effective in skin lesion classification, providing a valuable tool for the early detection of skin cancer [38]. Furthermore, the application of machine learning algorithms, such as XGBoost, to the prediction of liver metastases in rectal cancer demonstrates a significant impact on clinical decision-making, supported by substantial accuracy in the evaluation of multiple metrics [41]. In the context of lung cancer, the use of machine learning methods to analyze histopathological images demonstrates the ability of AI to accurately predict patient prognosis, thereby contributing to precision oncology [43].

Furthermore, the incorporation of this technology in the detection and diagnosis of diseases such as glaucoma, pediatric glaucoma, cardiovascular disease (CVD), and dengue has shown significant progress. In the case of glaucoma, a mass detection model is proposed using various machine learning techniques, which manages to reduce the false negative rate and shows effectiveness in large-scale detection [46]. Childhood glaucoma, a leading cause of blindness in children, is addressed with a deep learning model based on periocular photographs that outperforms the accuracy of ophthalmologists and glaucoma specialists, highlighting its potential for early diagnosis [47]. In the field of CVD, the usefulness of machine learning algorithms for feature selection and early detection is highlighted by the outstanding performance of the CatBoost model [48]. For dengue, the classification of disease types is successfully addressed using machine learning methods, with a support vector machine (SVM) being the most effective in terms of precision, recall, and accuracy [45].

Similarly, in obstetrics, a deep learning model is proposed to automatically classify fetal organs from ultrasound images, achieving a remarkable accuracy of 99.84% [34]. In the field of gestational diabetes mellitus (GDM) prediction, AI algorithms such as random forest (RF) and gradient boosting decision tree (GBDT) show high accuracy and reveal unexpected associations with variables such as quality of life and maternal birth weight [35]. Similarly, to address malnutrition in the elderly population, an AI framework based on heterogeneous mHealth data is presented using explainable (XAI) methods such as random forest (RF) and gradient boosting, with an emphasis on feature interpretation. relevant for early detection and explainability of malnutrition risk [37]. In the histopathological diagnosis of cancer, "deep learning" is presented as an effective tool to automatically identify prostate cancer and detect breast cancer metastases, offering an improvement in the efficiency and objectivity of sample analysis [40]. On the other hand, in the interpretation of chest radiographs, CheXNeXt, a neural network, demonstrates performance comparable to that of practicing radiologists, suggesting the potential to expand access to chest radiography diagnosis through the prospective use of this algorithm in clinical settings [42].

These cases illustrate the exceptional versatility of AI in diagnosing various diseases and underscore its positive impact on both diagnostic efficiency and prognosis. These advances not only strengthen the reliability of medical diagnoses but also promise to radically transform healthcare by providing faster, more accurate, and more accessible solutions. The successful integration of deep learning algorithms in specific fields such as obstetrics, prediction of gestational diabetes, early detection of malnutrition, histopathological diagnosis of cancer, evaluation of chest X-rays, and others highlights the ability of AI to address a wide range of medical challenges. These advances not only underscore the importance of artificial intelligence research in medicine but also herald a future in which collaboration between healthcare professionals and intelligent tools powered by AI will become the norm, bringing significant benefits to medical care and the overall well-being of patients.

4.4. Limitation of the study and future work

The limitations of this bibliometric study lie in the specific selection of articles from open access journals, which could exclude relevant research found in restricted access journals. In addition, the decision to use only the Scopus database may have excluded important studies available on other platforms. Such a selection of sources could have introduced biases in the results, limiting the representativeness of the full panorama of research in AI applied to medicine. In future work, it is suggested to extend the search to other databases and to consider a more inclusive approach in terms of access to articles, thus guaranteeing a more comprehensive and diverse vision of research in this field. In addition, it would be beneficial to conduct comparative analyses between different databases to evaluate possible differences in trends and academic contributions. This more holistic approach would provide a more complete and equitable perspective on AI research in medicine, allowing for a more accurate understanding of its evolution and contributions to the scientific community.

5. CONCLUSION

This bibliometric study examines the evolution of research in AI applied to medicine from 2015 to September 2023, revealing a significant increase in academic production worldwide over the last five years. In this context, the author's keyword network analysis sheds light on the thematic richness and variability of AI applications in medicine. Keywords such as artificial intelligence, machine learning, deep learning, medicine, digital health, and telemedicine emerge as highlights, underscoring the diversity of areas explored at the intersection of technology and health. This panorama reflects not only the quantitative growth of research but also the breadth and depth of topics addressed, highlighting the versatility of AI in contemporary medicine. It also highlights critical health areas where these technologies have been successfully applied to address specific challenges, such as the detection of various types of cancer, the accurate diagnosis of dengue fever, and the advanced analysis of medical images. These concrete approaches highlight the significant impact of AI technologies in concretely improving diagnostic efficiency and accuracy in prognostic evaluation, underscoring their relevance and contribution to the evolution of modern medicine. International collaboration emerges as a distinctive feature, with China and the United States leading the research contributions. This scenario highlights the key position of these countries in advancing knowledge at the intersection of AI and medicine. Furthermore, the preeminence of the English language in the global dissemination of this knowledge is highlighted, underscoring the need for effective communication to advance the understanding and application of AI in medical practice. This bibliometric analysis not only provides a comprehensive view of current trends but also underscores the continued importance of exploring and developing new frontiers in the convergence of artificial intelligence and modern medicine.

ACKNOWLEDGEMENTS

Thank you for the constant support to all those involved, who through their suggestions made the research materialize.

REFERENCES

[1] B. Mueller, T. Kinoshita, A. Peebles, M. A. Graber, and S. Lee, "Artificial intelligence and machine learning in emergency medicine: a narrative review," *Acute Medicine & Surgery*, vol. 9, no. 1, Jan. 2022, doi: 10.1002/ams2.740.

[2] S. M. Pappada, "Machine learning in medicine: it has arrived, let's embrace it," *Journal of Cardiac Surgery*, vol. 36, no. 11, pp. 4121–4124, Nov. 2021, doi: 10.1111/jocs.15918.

[3] Z. Krajcer, "Artificial intelligence in cardiovascular medicine: historical overview, current status, and future directions," *Texas Heart Institute Journal*, vol. 49, no. 2, Mar. 2022, doi: 10.14503/THIJ-20-7527.

[4] M. Daidone, S. Ferrantelli, and A. Tuttolomondo, "Machine learning applications in stroke medicine: advancements, challenges, and future prospectives," *Neural Regeneration Research*, vol. 19, no. 4, pp. 769–773, Apr. 2024, doi: 10.4103/1673-5374.382228.

[5] K. Stankevičiūtė, J.-B. Woillard, R. W. Peck, P. Marquet, and M. van der Schaar, "Bridging the worlds of pharmacometrics and machine learning," *Clinical Pharmacokinetics*, vol. 62, no. 11, pp. 1551–1565, Nov. 2023, doi: 10.1007/s40262-023-01310-x.

[6] F. S. Ahmad, Y. Luo, R. M. Wehbe, J. D. Thomas, and S. J. Shah, "Advances in machine learning approaches to heart failure with preserved ejection fraction," *Heart Failure Clinics*, vol. 18, no. 2, pp. 287–300, Apr. 2022, doi: 10.1016/j.hfc.2021.12.002.

[7] X. Cheng and B. Joe, "Artificial intelligence in medicine: microbiome-based machine learning for phenotypic classification," 2023, pp. 281–288.

[8] N. Rabbani, G. Y. E. Kim, C. J. Suarez, and J. H. Chen, "Applications of machine learning in routine laboratory medicine: current state and future directions," *Clinical Biochemistry*, vol. 103, pp. 1–7, May 2022, doi: 10.1016/j.clinbiochem.2022.02.011.

[9] V. Azimi and M. A. Zaydman, "Optimizing equity: working towards fair machine learning algorithms in laboratory medicine," *The Journal of Applied Laboratory Medicine*, vol. 8, no. 1, pp. 113–128, Jan. 2023, doi: 10.1093/jalm/jfac085.

[10] S. Kim *et al.*, "An open medical platform to share source code and various pre-trained weights for models to use in deep learning research," *Korean Journal of Radiology*, vol. 22, no. 12, 2021, doi: 10.3348/kjr.2021.0170.

[11] P. Ruusuvuori, M. Valkonen, and L. Latonen, "Deep learning transforms colorectal cancer biomarker prediction from histopathology images," *Cancer Cell*, vol. 41, no. 9, pp. 1543–1545, Sep. 2023, doi: 10.1016/j.ccell.2023.08.006.

[12] S. Yang, F. Zhu, X. Ling, Q. Liu, and P. Zhao, "Intelligent health care: applications of deep learning in computational medicine," *Frontiers in Genetics*, vol. 12, Apr. 2021, doi: 10.3389/fgene.2021.607471.

[13] K. Karako, P. Song, and Y. Chen, "Recent deep learning models for dementia as point-of-care testing: potential for early detection," *Intractable & Rare Diseases Research*, vol. 12, no. 1, Feb. 2023, doi: 10.5582/irdr.2023.01015.

[14] S. Ramesh, J. M. Dolezal, and A. T. Pearson, "Applications of deep learning in endocrine neoplasms," *Surgical Pathology Clinics*, vol. 16, no. 1, pp. 167–176, Mar. 2023, doi: 10.1016/j.path.2022.09.014.

[15] M. Decuyper, J. Maebe, R. van Holen, and S. Vandenberghe, "Artificial intelligence with deep learning in nuclear medicine and radiology," *EJNMMI Physics*, vol. 8, no. 1, Dec. 2021, doi: 10.1186/s40658-021-00426-y.

[16] S. Albahra *et al.*, "Artificial intelligence and machine learning overview in pathology & laboratory medicine: a general review of data preprocessing and basic supervised concepts," *Seminars in Diagnostic Pathology*, vol. 40, no. 2, pp. 71–87, Mar. 2023, doi: 10.1053/j.semdp.2023.02.002.

[17] V. B. Kolachalama, "Machine learning and pre-medical education," *Artificial Intelligence in Medicine*, vol. 129, Jul. 2022, doi: 10.1016/j.artmed.2022.102313.

[18] R. J. Woodman and A. A. Mangoni, "A comprehensive review of machine learning algorithms and their application in geriatric medicine: present and future," *Aging Clinical and Experimental Research*, vol. 35, no. 11, pp. 2363–2397, Sep. 2023, doi: 10.1007/s40520-023-02552-2.

[19] J. Sim, Q. Fong, W. Huang, and C. Tan, "Machine learning in medicine: what clinicians should know," *Singapore Medical*

Journal, May 2021, doi: 10.11622/smedj.2021054.
[20] R. Jáuregui-Velarde, D. Hernández Celis, C. Yactayo Arias, and L. Andrade-Arenas, "A critical review of the state of computer security in the health sector," *Bulletin of Electrical Engineering and Informatics (BEEI)*, vol. 12, no. 6, pp. 3805–3816, Dec. 2023, doi: 10.11591/eei.v12i6.5394.
[21] R. Jáuregui-Velarde, L. Andrade-Arenas, P. Molina-Velarde, and C. Yactayo-Arias, "Financial revolution: a systemic analysis of artificial intelligence and machine learning in the banking sector," *International Journal of Electrical and Computer Engineering (IJECE)*, vol. 14, no. 1, pp. 1079–1090, Feb. 2024, doi: 10.11591/ijece.v14i1.pp1079-1090.
[22] B. Yuan and N. K. Basha, "A bibliometric analysis of smart home acceptance by the Elderly (2004-2023)," *International Journal of Advanced Computer Science and Applications*, vol. 14, no. 9, 2023, doi: 10.14569/IJACSA.2023.0140911.
[23] D. Gunning and D. W. Aha, "DARPA's explainable artificial intelligence program," *AI Magazine*, vol. 40, no. 2, pp. 44–58, Jun. 2019, doi: 10.1609/aimag.v40i2.2850.
[24] C. Longoni, A. Bonezzi, and C. K. Morewedge, "Resistance to medical artificial intelligence," *Journal of Consumer Research*, vol. 46, no. 4, pp. 629–650, Dec. 2019, doi: 10.1093/jcr/ucz013.
[25] B. Letham, C. Rudin, T. H. McCormick, and D. Madigan, "Interpretable classifiers using rules and Bayesian analysis: building a better stroke prediction model," *The Annals of Applied Statistics*, vol. 9, no. 3, Sep. 2015, doi: 10.1214/15-AOAS848.
[26] G. A. Kaissis, M. R. Makowski, D. Rückert, and R. F. Braren, "Secure, privacy-preserving and federated machine learning in medical imaging," *Nature Machine Intelligence*, vol. 2, no. 6, pp. 305–311, Jun. 2020, doi: 10.1038/s42256-020-0186-1.
[27] M. Zitnik, F. Nguyen, B. Wang, J. Leskovec, A. Goldenberg, and M. M. Hoffman, "Machine learning for integrating data in biology and medicine: principles, practice, and opportunities," *Information Fusion*, vol. 50, pp. 71–91, Oct. 2019, doi: 10.1016/j.inffus.2018.09.012.
[28] A. E. W. Johnson, M. M. Ghassemi, S. Nemati, K. E. Niehaus, D. Clifton, and G. D. Clifford, "Machine learning and decision support in critical care," *Proceedings of the IEEE*, vol. 104, no. 2, pp. 444–466, Feb. 2016, doi: 10.1109/JPROC.2015.2501978.
[29] A. Vellido, "The importance of interpretability and visualization in machine learning for applications in medicine and health care," *Neural Computing and Applications*, vol. 32, no. 24, pp. 18069–18083, Dec. 2020, doi: 10.1007/s00521-019-04051-w.
[30] Z. Zeng, W. Xie, Y. Zhang, and Y. Lu, "RIC-Unet: an improved neural network based on Unet for Nuclei segmentation in histology images," *IEEE Access*, vol. 7, pp. 21420–21428, 2019, doi: 10.1109/ACCESS.2019.2896920.
[31] Q. Bai, S. Tan, T. Xu, H. Liu, J. Huang, and X. Yao, "MolAICal: a soft tool for 3D drug design of protein targets by artificial intelligence and classical algorithm," *Briefings in Bioinformatics*, vol. 22, no. 3, May 2021, doi: 10.1093/bib/bbaa161.
[32] L. Alzubaidi *et al.*, "Towards a better understanding of transfer learning for medical imaging: a case study," *Applied Sciences*, vol. 10, no. 13, Jun. 2020, doi: 10.3390/app10134523.
[33] Y. Gao and A. Rezaeipanah, "An ensemble classification method based on deep neural networks for breast cancer diagnosis," *Inteligencia Artificial*, vol. 26, no. 72, pp. 160–177, Sep. 2023, doi: 10.4114/intartif.vol26iss72pp160-177.
[34] H. Ghabri *et al.*, "Transfer learning for accurate fetal organ classification from ultrasound images: a potential tool for maternal healthcare providers," *Scientific Reports*, vol. 13, no. 1, Oct. 2023, doi: 10.1038/s41598-023-44689-0.
[35] M. Watanabe *et al.*, "Prediction of gestational diabetes mellitus using machine learning from birth cohort data of the Japan environment and children's study," *Scientific Reports*, vol. 13, no. 1, Oct. 2023, doi: 10.1038/s41598-023-44313-1.
[36] F. Kinoshita *et al.*, "Development of artificial intelligence prognostic model for surgically resected non-small cell lung cancer," *Scientific Reports*, vol. 13, no. 1, Sep. 2023, doi: 10.1038/s41598-023-42964-8.
[37] F. Di Martino, F. Delmastro, and C. Dolciotti, "Explainable AI for malnutrition risk prediction from m-Health and clinical data," *Smart Health*, vol. 30, Dec. 2023, doi: 10.1016/j.smhl.2023.100429.
[38] H. L. Gururaj, N. Manju, A. Nagarjun, V. N. M. Aradhya, and F. Flammini, "DeepSkin: a deep learning approach for skin cancer classification," *IEEE Access*, vol. 11, pp. 50205–50214, 2023, doi: 10.1109/ACCESS.2023.3274848.
[39] S. R. Waheed *et al.*, "Melanoma skin cancer classification based on CNN deep learning algorithms," *Malaysian Journal of Fundamental and Applied Sciences*, vol. 19, no. 3, pp. 299–305, May 2023, doi: 10.11113/mjfas.v19n3.2900.
[40] G. Litjens *et al.*, "Deep learning as a tool for increased accuracy and efficiency of histopathological diagnosis," *Scientific Reports*, vol. 6, no. 1, May 2016, doi: 10.1038/srep26286.
[41] B. Qiu, X. hu Su, X. Qin, and Q. Wang, "Application of machine learning techniques in real-world research to predict the risk of liver metastasis in rectal cancer," *Frontiers in Oncology*, vol. 12, Dec. 2022, doi: 10.3389/fonc.2022.1065468.
[42] P. Rajpurkar *et al.*, "Deep learning for chest radiograph diagnosis: a retrospective comparison of the CheXNeXt algorithm to practicing radiologists," *PLOS Medicine*, vol. 15, no. 11, Nov. 2018, doi: 10.1371/journal.pmed.1002686.
[43] K.-H. Yu *et al.*, "Predicting non-small cell lung cancer prognosis by fully automated microscopic pathology image features," *Nature Communications*, vol. 7, no. 1, Aug. 2016, doi: 10.1038/ncomms12474.
[44] B. Zee *et al.*, "Digital solution for detection of undiagnosed diabetes using machine learning-based retinal image analysis," *BMJ Open Diabetes Research & Care*, vol. 10, no. 6, Dec. 2022, doi: 10.1136/bmjdrc-2022-002914.
[45] H. Hamdani, H. R. Hatta, N. Puspitasari, A. Septiarini, and H. Henderi, "Dengue classification method using support vector machines and cross-validation techniques," *IAES International Journal of Artificial Intelligence (IJ-AI)*, vol. 11, no. 3, pp. 1119–1129, Sep. 2022, doi: 10.11591/ijai.v11.i3.pp1119-1129.
[46] Y. Omar, M. A.-E. ElSheikh, and R. Hodhod, "GLAUDIA: a predicative system for glaucoma diagnosis in mass scanning," *Health Informatics Journal*, vol. 27, no. 2, Apr. 2021, doi: 10.1177/14604582211009276.
[47] Y. Kitaguchi *et al.*, "Deep-learning approach to detect childhood glaucoma based on periocular photograph," *Scientific Reports*, vol. 13, no. 1, Jun. 2023, doi: 10.1038/s41598-023-37389-2.
[48] N. A. Baghdadi, S. M. Farghaly Abdelaliem, A. Malki, I. Gad, A. Ewis, and E. Atlam, "Advanced machine learning techniques for cardiovascular disease early detection and diagnosis," *Journal of Big Data*, vol. 10, no. 1, Sep. 2023, doi: 10.1186/s40537-023-00817-1.
[49] X. Kong *et al.*, "Disease-specific data processing: An intelligent digital platform for diabetes based on model prediction and data analysis utilizing big data technology," *Frontiers in Public Health*, vol. 10, Dec. 2022, doi: 10.3389/fpubh.2022.1053269.
[50] D. Lanzagorta-Ortega, D. L. Carrillo-Pérez, and R. Carrillo-Esper, "Artificial intelligence in medicine: present and future," (in Spanish), *Gaceta Médica de México*, vol. 158, no. 91, Jun. 2023, doi: 10.24875/GMM.M22000688.

BIOGRAPHIES OF AUTHORS

Laberiano Andrade-Arenas Doctor in systems and computer engineering. Master’s in systems engineering. Graduated with a master's degree in University Teaching. Graduated with a master's degree in accreditation and evaluation of educational quality systems engineer. scrum fundamentals certified, a research professor with publications in Scopus-indexed journals. He can be contacted at email: landrade@uch.edu.pe.

César Yactayo-Arias bachelor's degree in administration from Universidad Inca Garcilazo de la Vega and a master's degree in education from Universidad Nacional de Educación Enrique Guzmán y Valle, he is a doctoral candidate in administration at Universidad Nacional Federico Villarreal. Since 2016 he has been teaching administration and mathematics subjects at the Universidad de Ciencias y Humanidades and since 2021 at the Universidad Continental. Currently, he also works as an administrator of educational services at the higher level, he is the author and co-author of several refereed articles in journals, and his research focuses on TIC applications to education, as well as management using computer science and the internet. He can be contacted email: yactayocesar@gmail.com.