Rev. Fac. Med. Hum. 2024; 24(3):113-121.
DOI: 10.25176/RFMH.v24i3.6407
REVIEW ARTICLES

ISSN Versión Online: 2308-0531
Facultad de Medicina Humana URP
RFMH

GLOBAL RESEARCH ON THE USE OF ARTIFICIAL INTELLIGENCE IN IMAGING FOR BREAST CANCER DETECTION: A BIBLIOMETRIC ANALYSIS

INVESTIGACIÓN GLOBAL SOBRE USO DE INTELIGENCIA ARTIFICIAL EN IMAGENOLOGÍA PARA LA DETECCIÓN DE CÁNCER DE MAMA: ANÁLISIS BIBLIOMÉTRICO

Juan Guillermo Murillo León [1,a], Valentina Espinosa Rivero [2,a], Isabella Saportas Peláez [3,a], Luis Enrique Calderón Mina [3,a], Angie Paola Cortes Sanjuanelo [4,a], Sebastián Alejandro Arias Tamayo [5,a], Nury Liseida Guevara Rosero [6,a], Manuel Cantillo Reines [7,a], Ciro Daniel Galeano Ortiz [8,a], Yelson Picón Jaimes [9,a,b,c]

REVIEW ARTICLES

ABSTRACT

Introduction: Breast cancer remains one of the most prevalent cancers globally, specifically the most common in females. The use of artificial intelligence promises to contribute to early diagnosis through imaging. Previously, the landscape and evolution of this scientific production have not been described. **Methods:** Cross-sectional bibliometric study using Scopus as the data source. The bibliometrix package in R was employed for calculating bibliometric indicators and visualizing the results. **Results:** 1292 documents published between 1989 and 2024 were selected. 75.3% (n=973) were articles with primary data, followed by 16.2% (n=209) corresponding to reviews. An international collaboration rate of 26.5% was identified, with an annual production growth of 10.78%. It was observed that risk classification through screening, digital breast tomosynthesis, transfer learning, segmentation, and feature selection were the most commonly used keywords. In the last five years, deep learning and mammography have been the most popular topics. International collaboration has been led by the United States, China, and the United Kingdom. **Conclusions:** A notable growth in global research on the use of artificial intelligence in breast cancer imaging for detection was identified, particularly since the 2010s, primarily through the publication of articles with primary data. The relationship between artificial intelligence and imaging for breast cancer diagnosis has focused on risk and prediction.

Keywords: Artificial Intelligence; Mammography; Mammary Ultrasonography; Breast Neoplasms; Bibliometrics. (Source: MESH-NLM)

RESUMEN

Introducción: El cáncer de mama sigue siendo uno de los cánceres más frecuentes a nivel global, específicamente, el más frecuente en el sexo femenino. El uso de inteligencia artificial promete contribuir al diagnóstico precoz, a través de la imagenología. Previamente, no se ha descrito el panorama y avance de esta producción científica. **Métodos:** Estudio bibliométrico de corte transversal, que usó Scopus como fuente de datos. Se utilizó el paquete bibliometrix de R para el cálculo de indicadores bibliométricos y visualización de los resultados. **Resultados:** Se seleccionaron 1292 documentos, publicados entre 1989 y 2024. El 75,3% (n=973) fueron artículos con datos primarios, seguido de un 16,2% (n=209) correspondiente a revisiones. Se identificó una colaboración internacional del 26,5%, y un crecimiento anual de la producción del 10,78%. Se observó que, la clasificación de riesgo por screening, tomosíntesis digital de la mama, aprendizaje por transferencia, segmentación y selección por características, son las palabras clave más comúnmente usadas. En los últimos cinco años, el aprendizaje profundo y la mamografía, han sido los temas con mayor popularidad. La colaboración internacional, ha sido liderada por Estados Unidos, China y Reino Unido. **Conclusiones:** Se identificó un crecimiento notable en la investigación global sobre el uso de inteligencia artificial en imagenología para la detección de cáncer de mama, marcado a partir de la década del 2010, esencialmente por medio de publicación de artículos con datos primarios. La relación entre inteligencia artificial e imagenología para diagnóstico de cáncer de mama, se ha centrado en riesgo y predicción.

Palabras clave: Inteligencia Artificial; Mamografía; Ecografía Mamaria; Cáncer de Mama; Bibliometría. (Fuente: DeCS-BIREME)

[1] Department of Medicine, Fundación Universitaria San Martin, Sabaneta, Colombia.
[2] Department of Medicine, Universidad de la Sabana, Chía, Colombia.
[3] Department of Medicine, Fundación Universitaria San Martin, Cali, Colombia.
[4] Department of Medicine, Universidad Simón Bolívar, Barranquilla, Colombia.
[5] Department of Medicine, Unidad Central del Valle del Cauca, Tuluá, Colombia.
[6] Department of Medicine, Universidad del Valle, Cali, Colombia.
[7] Department of Medicine, Universidad del Magdalena, Santa Marta, Colombia.
[8] Department of Medicine, Universidad Militar Nueva Granada, Bogotá, Colombia.
[9] Fac Ciències Salut Blanquerna, University Ramon Llul, Barcelona, Spain.
[a] Physician.
[b] Master's in Epidemiology and Public Health.
[c] Doctoral Candidate in Health, Well-being, and Bioethics.

Cite as: Murillo León JG, Espinosa Rivero V, Saportas Peláez I, Calderón Mina LE, Cortes Sanjuanelo AP, Arias Tamayo SA, Guevara Rosero NL, Cantillo Reines M, Galeano Ortiz CD, Picón Jaimes Y. Global research on the use of artificial intelligence in imaging for breast cancer detection: a bibliometric analysis. Rev Fac Med Hum. 2024;24(3):113-121. doi 10.25176/RFMH.v24i3.6407

Journal home page: http://revistas.urp.edu.pe/index.php/RFMH

INTRODUCTION

Breast cancer remains one of the most common cancers globally, particularly prevalent in women, with high morbidity, mortality, healthcare costs, and impact on quality of life [1,2]. In Latin America, it is estimated that one-fourth of global cases are diagnosed, with nearly 500,000 instances [2]. While the prognosis for breast cancers has significantly improved in high-income countries, it remains weak in low- and middle-income countries due to significant barriers in implementing early diagnosis and management strategies[3-6].

Screening, primarily through mammography, has proven useful in the early detection of this cancer [7]. However, its reproducibility and impact vary across different scenarios due to factors related to human resource training, infrastructure, or public policies. Therefore, tools have been designed to complement the performance of this diagnostic aid, such as artificial intelligence, to promote patient flow[8]. The execution of studies with algorithms designed based on imaging patterns and clinical characteristics has significantly improved the diagnostic performance of breast cancer [9]. Nonetheless, there are no research groups, work lines, or large cohorts facilitating the grouping of population-based data[10-12].

To understand the global research landscape on a tool that can modify early breast cancer detection and be replicable in numerous scenarios, including low- and middle-income countries [13], this study aimed to analyze the global scientific production related to the use of artificial intelligence in imaging for breast cancer detection.

METHODS

A cross-sectional bibliometric study was conducted using Scopus, the largest database of peer-reviewed scientific literature. This database has been previously used for this type of analysis [14,15]. Unlike other search engines, citation indices, and databases like PubMed or Web of Science, Scopus has a greater number of indexed Latin American biomedical journals, facilitating the identification of evidence from this region. A structured search was designed and executed to identify articles related to the use of artificial intelligence in imaging for breast cancer detection. This took into account the affiliation reported in the metadata and corroborated by the official full-text publication.

The search strategy was built using MeSH terms and synonyms, both in English and Spanish. Following a pilot test, the following search was defined: TITLE-ABS-KEY("Breast Carcinoma In Situ") OR TITLE-ABS-KEY("Breast Ductal Carcinoma") OR TITLE-ABS-KEY("Lobular Carcinoma") OR TITLE-ABS-KEY("Triple Negative Breast Neoplasms") OR TITLE-ABS-KEY("Unilateral Breast Neoplasms") OR TITLE-ABS-KEY("Inflammatory Breast Neoplasms") OR TITLE-ABS-KEY("Breast Cancer") OR TITLE-ABS-KEY("Mammary Cancer") OR TITLE-ABS-KEY("Malignant Neoplasm of Breast") OR TITLE-ABS-KEY("Breast Malignant Neoplasm") OR TITLE-ABS-KEY("Breast Malignant Tumor") OR TITLE-ABS-KEY("Cancer of Breast") OR TITLE-ABS-KEY("Cancer of the Breast") OR TITLE-ABS-KEY("Breast Carcinoma") AND TITLE-ABS-KEY("Artificial Intelligence") OR TITLE-ABS-KEY("Computational Intelligence") OR TITLE-ABS-KEY("Machine Intelligence") OR TITLE-ABS-KEY("Computer Reasoning") OR TITLE-ABS-KEY("Computer Vision System") OR TITLE-ABS-KEY("Machine Learning") OR TITLE-ABS-KEY("Deep Learning") OR TITLE-ABS-KEY("Sentiment Analysis") OR TITLE-ABS-KEY("Neural Networks") AND TITLE-ABS-KEY("Early Detection of Cancer") OR TITLE-ABS-KEY("Cancer Screening") OR TITLE-ABS-KEY("Cancer Early Diagnosis") OR TITLE-ABS-KEY("Early Diagnosis").

This search was conducted until February 10, 2024, and filtered with the labels "Humans" and "Journals." This excluded literature not following the regular peer-review process for publication in scientific journals, such as books, book series, abstracts, and conference proceedings. No time limit window was set for the

inclusion of articles. Subsequently, a manual review was conducted to remove duplicates and articles unrelated to the topic of interest based on the title, abstract, and keywords. This was all done in Microsoft Office Excel 2016.

Next, the data of the variables of interest were standardized to reduce discrepancies in the way metadata is originally recorded. Thus, categories were regrouped. For example, in the case of article typology, all original studies providing primary data, regardless of observational or experimental design, were categorized as "Primary Data Articles"; similarly, all reviews, regardless of design (whether narrative, systematic, or meta-analysis), were categorized as "Reviews." Editorials, letters to the editor, comments, etc., were categorized as "Correspondence."

For statistical analysis, network metrics were employed to visualize trends, characteristics, and calculate scientific impact. The bibliometrix package in R was used for this analysis, which allows the calculation of quantitative bibliometric indicators and the visualization of results (version 4.3.1) [16]. Synonyms, errors, plurals, and variants were strictly regrouped to homogenize the analysis. Keywords, authors, and institutions were standardized in this way. Additionally, a descriptive analysis of the scientific production found was executed. The most prolific authors and the distribution of publications were characterized using Lotka's Law. Collaboration networks were constructed to determine the degree and strength of collaboration between countries.

To measure the impact of institutions and countries, the h-index and the absolute value of accumulated citations were used. The definitions and specifications of these metrics' use in bibliometric studies have been previously described[17,18]. The calculation of frequencies and percentages was performed using Microsoft Office Excel 2016.

Ethical Aspects

This study did not require approval from an ethics committee, considering it did not involve research on humans, biological models, or medical history.

RESULTS

Initially, 1833 documents were identified. After applying inclusion and exclusion criteria, 1292 documents were finally selected. Of the total documents initially identified, 540 were conference papers. The time window for the analyzed evidence ranged from 1989 to 2024 (35 years). Among the selected documents, 75.3% (n=973) were primary data articles, followed by 16.2% (n=209) reviews. An international collaboration rate of 26.5% was identified, with an annual production growth of 10.78% (Table 1). A slow growth was observed until 2013, after which there was a notable increase in publication volume, peaking in 2023 with over 300 articles published (Figure 1-A). In contrast, the number of citations obtained over time fluctuated, peaking in 2019 (Figure 1-B). Applying Lotka's law, it was found that 84% of authors had published only one document, followed by 9.8% with two documents.

The United States was the most prolific country with 311 documents, and also had the highest impact (h-index of 52 and 11,757 citations). It was followed by China (h-index of 33 and 4231 citations) and India (h-index of 30 and 2862 citations), with 213 and 186 documents, respectively. Regarding affiliations/institutions, Radboud University Medical Center (Netherlands) was the most prolific and impactful, with 29 documents and an h-index of 19 (1425 citations), followed by Harvard Medical School (h-index of 12 with 1814 citations), Karolinska Institutet (h-index of 14 with 1145 citations), and Massachusetts General Hospital (h-index of 14 with 1858 citations), all with 24 documents each.

Table 1. General characteristics of global scientific production on the use of artificial intelligence in imaging for breast cancer detection (N=1292).

	n	%
Article type		
Primary data articles	973	75.3
Reviews	209	16.2
Correspondences*	110	8.5
Authors		
Authorships	5517	-
Authors of single-authored documents (N=5517)	85	1.54
Collaboration		
Single-authored articles	94	-
Co-authorships per article (average)	5.7	-
International co-authorship	26.5	-
Keywords	2206	-
Journals	535	-
Average article age (years)	3.84	-
Average citations per document	23.9	-
Annual growth	-	10.78

*Includes letters to the editor, editorials, comments, etc.

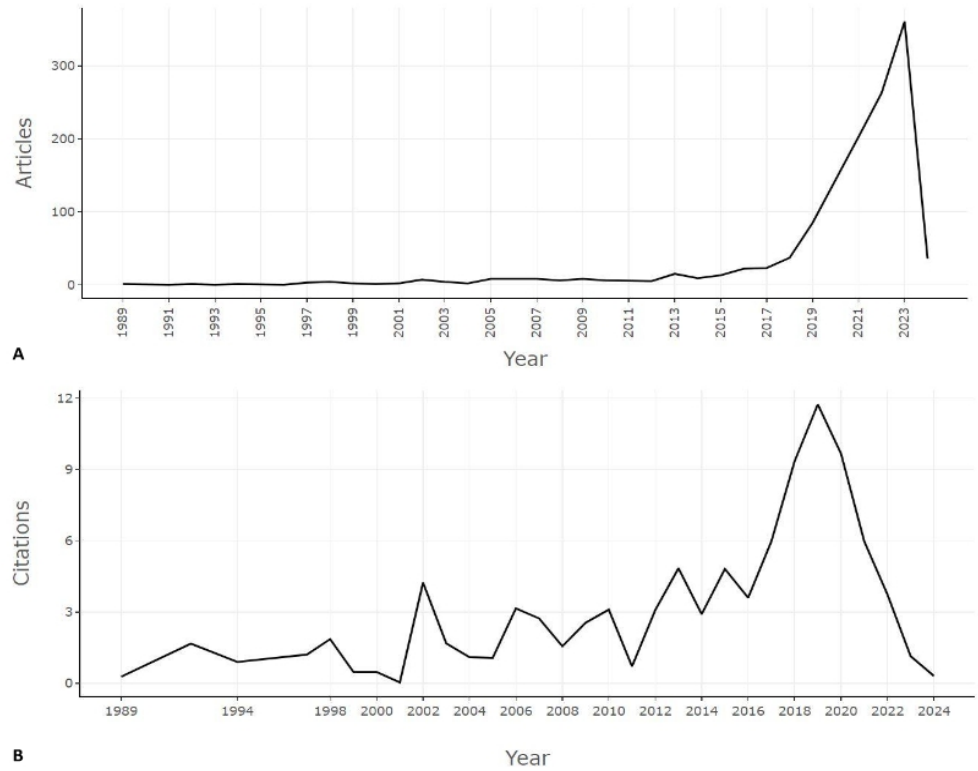

Figure 1. Annual Scientific Growth of Global Research on the Use of Artificial Intelligence in Imaging for Breast Cancer Detection. **A.** Annual Publication Frequency. **B.** Average Citations Received per Article per Year.

REVIEW ARTICLE

REVIEW ARTICLE

In terms of journals, Radiology had the highest number of documents (n=44) (Figure 2-A). However, Nature received the highest number of citations (2102 citations) (Figure 2-B). Still, Radiology had the highest impact, measured by h-index and g-index (19 and 38, respectively) (Figure 2C-D), while Diagnostics had the highest m-index (2.75) (Figure 2-E). Radiology and Cancers were the journals that grew most notably in the last seven years (Figure 2-F).

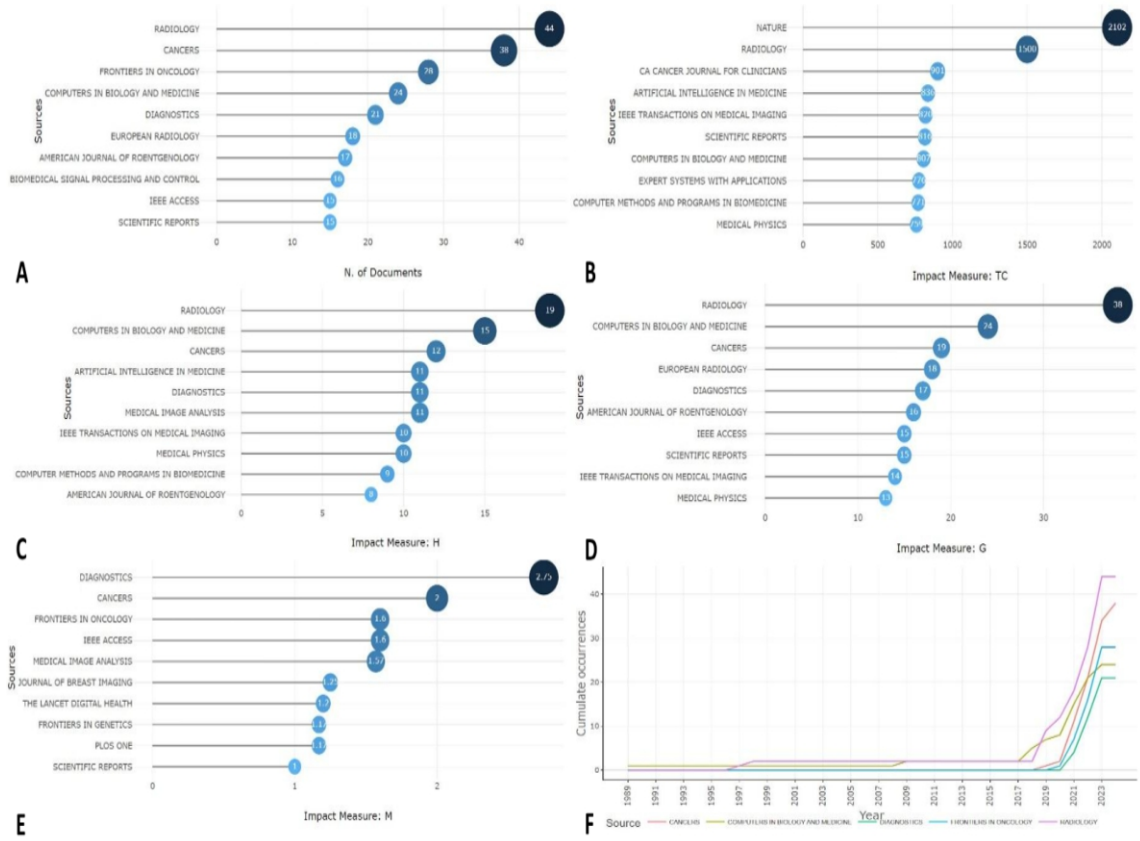

Figure 2. Impact and publication frequency in journals with the highest number of documents on the use of artificial intelligence in imaging for breast cancer detection. **A.** Frequency of Published Articles. **B.** Total Citations Received. **C.** h-Index Obtained. **D.** g-Index Obtained. **E.** m-Index Obtained. **F.** Cumulative Frequency Over Time of Articles in the Most Popular Journals

Regarding research trends and patterns, a word cloud construction revealed that risk classification by screening, digital breast tomosynthesis, transfer learning, segmentation, and feature selection were the most commonly used keywords (Figure 3-A). In the last five years, deep learning and mammography have been the most popular topics (Figure 3-B), while in the last 10 years, other topics such as machine learning, neural networks, breast density, data mining, and risk stratification have also gained great interest in this field (Figure 3C-D). Biomarkers linked to breast ultrasound and their diagnostic potential emerge as thematic niches, while digital breast tomosynthesis and liquid biopsy are emerging topics (Figure 3-E).

The multiple correspondence factor analysis shows a notable association between the topics of: 1) Radiomics, nuclear magnetic resonance, and risk stratification; 2) Mammography, neural networks, and image classification; 3) Breast density, tomosynthesis, and thermography (Figure 3-F).

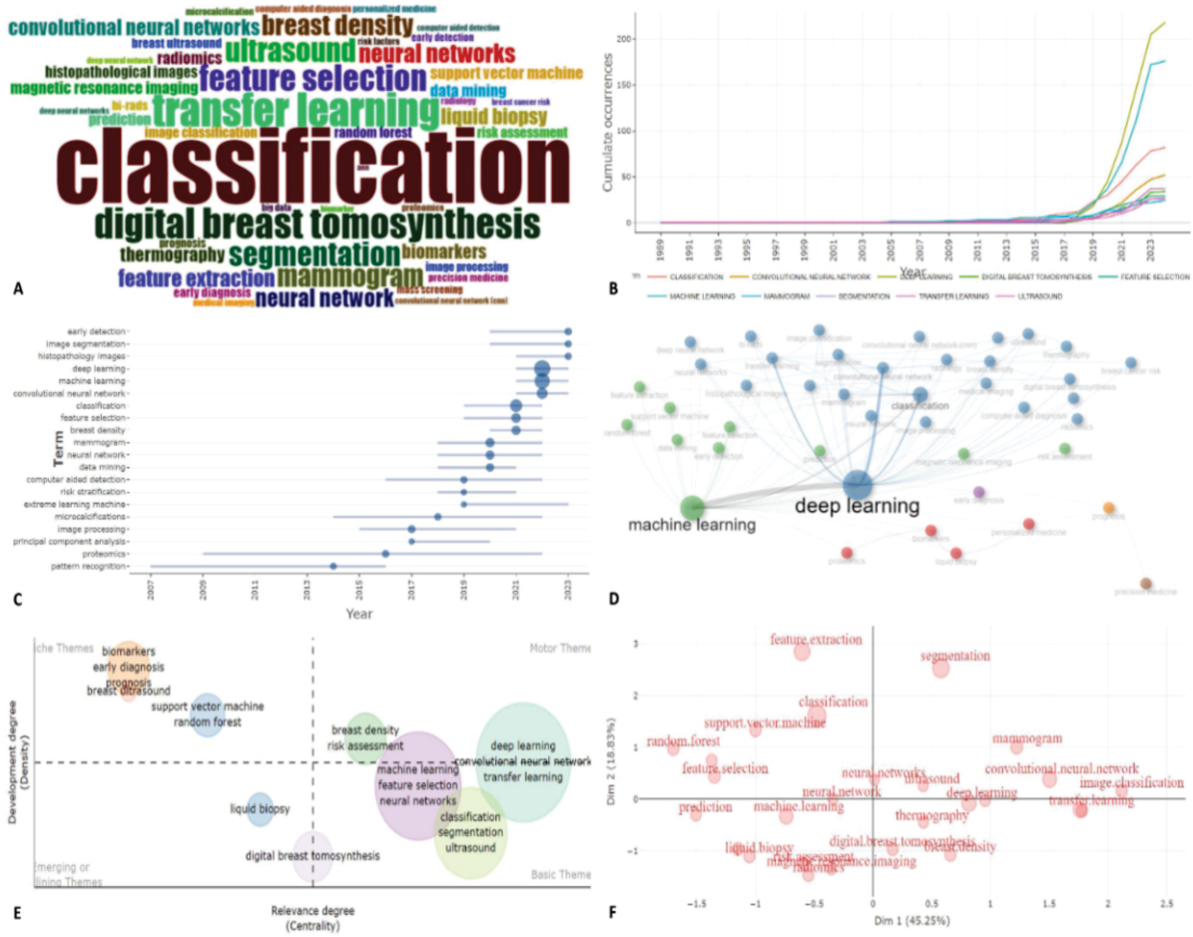

Figure 3. Evolution and trends in global research on the use of artificial intelligence in imaging for breast cancer detection. **A.** Word Cloud of the Most Frequent Keywords **B.** Evolution of the Most Frequent Topics Over Time **C.** Topic Frequency Since 2010 **D.** Co-occurrence Network of Keywords **E.** Thematic Map with Degree of Development and Relevance of Topics **F.** Multiple Correspondence Analysis with Degree of Contribution of Each Topic

In terms of collaboration networks, it was observed that Harvard Medical School, University of Pennsylvania, Karolinska Institutet, and Radboud University Medical Center lead international collaboration, with all institutions collaborating primarily with European and North American institutions (Figure 4-A). Regarding countries, strong collaboration was identified between the United States, China, and the United Kingdom. Specifically, China collaborates heavily with other Asian countries, while the United States and the United Kingdom collaborate with European countries (Figure 4-B). Apart from Brazil, no other Latin American country stood out in international collaboration on the topic of interest.

REVIEW ARTICLE

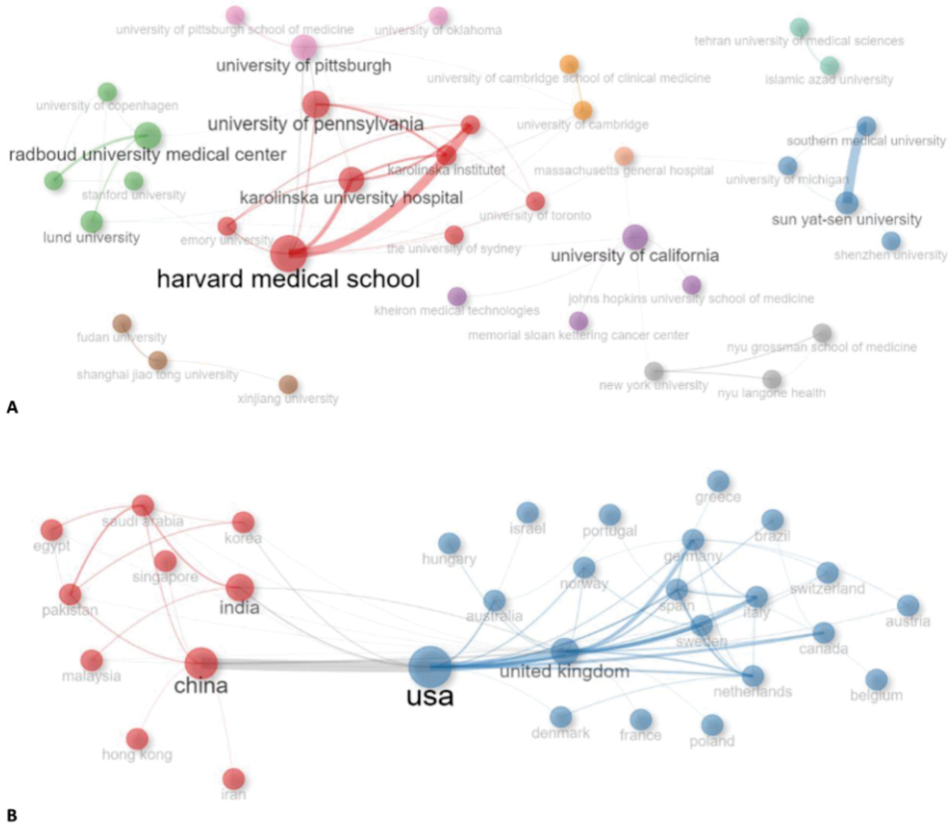

Figure 4. Institutional and country collaboration networks in global research on the use of artificial intelligence in imaging for breast cancer detection. **A.** Collaboration Between Affiliations **B.** Collaboration Between Countries

Summarizing the articles with the highest impact to date, measured by the number of citations received, the top three were: 1) International evaluation of an AI system for breast cancer screening (1282 citations; published in Nature in 2020; DOI: 10.1038/s41586-019-1799-6); 2) Artificial intelligence in cancer imaging: Clinical challenges and applications (901 citations; published in CA: A Cancer Journal for Clinicians in 2019; DOI: 10.3322/caac.21552); 3) Deep Learning to Improve Breast Cancer Detection on Screening Mammography (541 citations; published in Scientific Reports in 2019; DOI: 10.1038/s41598-019-48995-4).

DISCUSSION

This analysis reveals for the first time the evolution of global research patterns and trends related to the use of artificial intelligence in imaging for breast cancer diagnosis. It was identified that, although the first publications were recognized in the late 1980s and early 1990s, it was only from the 2010s onwards that there was a gradual yet notable increase in global scientific production on the use of artificial intelligence applied to imaging for breast cancer detection. This can be explained by the dissemination and advancement of omics tools, linked to artificial intelligence, which have rapidly expanded [19,20]. However, countries in Latin America and Africa still have modest levels of research and international collaboration, despite being regions with significant needs in breast cancer care and early detection [21].

Possibly, the absence of evidence and data on the current state of applied research in artificial intelligence in imaging and breast cancer has hindered the construction of an evidence-based roadmap that promotes research in this field. It can be inferred that due to the massive existence of networks, consensus, and international collaborations on breast cancer [22,23], primarily located in the United States and Europe, these continents have significantly progressed in innovating the application of new artificial intelligence techniques linked to early detection, risk stratification, and

prediction of breast cancer. Even so, an international collaboration percentage of less than 30% was determined. The application of translational research, searching for biomarkers through the use of omics, and supported by data mining analyzed by artificial intelligence, allows the construction of clusters based on common clinical, imaging, and histopathological characteristics, to achieve applicable results with acceptable performance in clinical practice[24,25].

Due to the emergence of this research niche, a notable number of citations and accumulated impact can be observed, despite the few years of dramatic growth in scientific production. The use of deep learning, neural networks, machine learning, and transfer learning allows feeding algorithms with a high degree of precision to identify patterns suggestive of malignancy, facilitating the precise detection of breast cancer [26]. Considering that there are non-modifiable variables in the pathophysiology and evolution of cancer [27], it is necessary to rigorously and solidly reproduce these types of studies to drive the achievement of health goals. Favorably, given the expected construction of new knowledge, the existing evidence is predominantly based on primary data. However, based on the gap in data origin, there are still many places in the world where data production is very low or non-existent, which could bias the predictive potential of an algorithm based on clinical, social, or genetic characteristics of different populations. Nevertheless, this does not detract from the significant advancement identified in the present analysis. As limitations, the use of a single database and citation index, Scopus, is noted, but it has been reported as the database with the largest number of indexed literature in health sciences. Additionally, the inherent bias of the margin of error of recorded metadata is acknowledged. However, to control this, the authors conducted a manual review and standardization process.

CONCLUSIONS

A notable growth in global research on the use of artificial intelligence in imaging for breast cancer detection was identified, marked from the 2010s, primarily through the publication of primary data articles. The production has been led by the United States, China, and India. However, international collaboration networks are led by the United States, China, and the United Kingdom. Among the most popular research niches and patterns are transfer learning, deep learning, neural networks, machine learning, segmentation, and feature selection, linked to mammography and digital breast tomosynthesis for risk stratification.

Authorship contribution: All authors participated in the research by designing the project, collecting and analyzing the data, as well as preparing the manuscript for this study.

Conflict of interest: The authors declare no conflict of interest.

Funding: Self-funded.

Received: February 20, 2024.
Approved: June 16, 2024.

Correspondence: *Yelson Picón Jaimes.*
Address: *Fac Ciències Salut Blanquerna, University Ramon Llul, Barcelona, España.*
Telephone: *+34 645 68 54 60*
Email: *colmedsurg.center@gmail.com*

REFERENCES

1. World Health Organization. Breast cancer [Internet]. [Consultado 10 Febrero 2024]. Disponible en: https://www.who.int/news-room/fact-sheets/detail/breast-cancer

2. Pan American Health Organization. Cáncer de mama [Internet]. [Consultado 10 Febrero 2024]. Disponible en: https://www.paho.org/es/temas/cancer-mama

3. Martei YM, Pace LE, Brock JE, Shulman LN. Breast Cancer in Low- and Middle-Income Countries: Why We Need Pathology Capability to Solve This Challenge. Clin Lab Med. 2018; 38(1):161-173. doi: 10.1016/j.cll.2017.10.013

4. Francies FZ, Hull R, Khanyile R, Dlamini Z. Breast cancer in low-middle income countries: abnormality in splicing and lack of targeted treatment options. Am J Cancer Res. 2020; 10(5):1568-1591.

5. Reyes A, Torregrosa L, Lozada-Martinez ID, Cabrera-Vargas LF, Nunez-Ordonez N, Martínez Ibata TF. Breast cancer mortality research in Latin America: A gap needed to be filled. Am J Surg. 2023; 225(5):937-938. doi: 10.1016/j.amjsurg.2023.01.010

6. Reyes-Monasterio A, Lozada-Martinez ID, Cabrera-Vargas LF, Narvaez-Rojas AR. Breast cancer care in Latin America: The ghost burden of a pandemic outbreak. Int J Surg. 2022; 104:106784. doi: 10.1016/j.ijsu.2022.106784

7. Gerami R, Sadeghi Joni S, Akhondi N, Etemadi A, Fosouli M, Eghbal AF, et al. A literature review on the imaging methods for breast cancer. Int J Physiol Pathophysiol Pharmacol. 2022; 14(3):171-176.

8. Aristokli N, Polycarpou I, Themistocleous SC, Sophocleous D, Mamais I. Comparison of the diagnostic performance of Magnetic Resonance Imaging (MRI), ultrasound and mammography for detection of breast cancer based on tumor type, breast density and patient's history: A review. Radiography (Lond). 2022; 28(3):848-856. doi: 10.1016/j.radi.2022.01.006

9. Ahn JS, Shin S, Yang SA, Park EK, Kim KH, Cho SI, et al. Artificial Intelligence in Breast Cancer Diagnosis and Personalized Medicine. J Breast Cancer. 2023; 26(5):405-435. doi: 10.4048/jbc.2023.26.e45

10. Meng G, Xu H, Yang S, Chen F, Wang W, Hu F, et al. Bibliometric analysis of worldwide research trends on breast cancer about inflammation. Front Oncol. 2023; 13:1166690. doi: 10.3389/fonc.2023.1166690

11. Teles RHG, Hiroki CT, Freitas VM. Bibliometric analysis of an important diagnostic technique for the treatment of breast cancer. Transl Cancer Res. 2022; 11(10):3440-3442. doi: 10.21037/tcr-22-2120

12. Xu J, Yu C, Zeng X, Tang W, Xu S, Tang L, et al. Visualization of breast cancer-related protein synthesis from the perspective of bibliometric analysis. Eur J Med Res. 2023; 28(1):461. doi: 10.1186/s40001-023-01364-4

13. Lozada-Martinez ID, Lozada-Martinez LM, Fiorillo-Moreno O. Leiden manifesto and evidence-based research: Are the appropriate standards being used for the correct evaluation of pluralism, gaps and relevance in medical research? J R Coll Physicians Edinb. 2024. Online ahead of print. doi: 10.1177/1478271524122799

14. Lozada-Martinez ID, Visconti-Lopez FJ, Marrugo-Ortiz AC, Ealo-Cardona CI, Camacho-Pérez D, Picón-Jaimes YA. Research and Publication Trends in Pediatric Surgery in Latin America: A Bibliometric and Visual Analysis from 2012 to 2021. J Pediatr Surg. 2023; 58(10):2012-2019. doi: 10.1016/j.jpedsurg.2023.04.003

15. Lozada-Martinez ID, Lozada-Martinez LM, Cabarcas-Martinez A, Ruiz-Gutierrez FK, Aristizabal Vanegas JG, Amorocho Lozada KJ, et al. Historical evolution of cancer genomics research in Latin America: a comprehensive visual and bibliometric analysis until 2023. Front Genet. 2024; 15:1327243. doi: 10.3389/fgene.2024.1327243

16. Aria M, Cuccurullo C. Bibliometrix: An R-Tool for Comprehensive Science Mapping Analysis. J Informetr. 2017; 11:959–975.

17. Rousseau R, Egghe L, Guns R. Becoming Metric-Wise: A Bibliometric Guide for Researchers. 1st edition. Belgium: Chandos Publishing; 2018.

18. Todeschini R, Baccini A. Handbook of Bibliometric Indicators: Quantitative Tools for Studying and Evaluating Research. 1st edition. Italy: Wiley-VCH Verlag GmbH & Co. KGaA; 2016.

19. Miao Z, Humphreys BD, McMahon AP, Kim J. Multi-omics integration in the age of million single-cell data. Nat Rev Nephrol. 2021; 17(11):710-724. doi: 10.1038/s41581-021-00463-x

20. Gao F, Huang K, Xing Y. Artificial Intelligence in Omics. Genomics Proteomics Bioinformatics. 2022; 20(5):811-813. doi: 10.1016/j.gpb.2023.01.002

21. Newman LA. Breast cancer screening in low and middle-income countries. Best Pract Res Clin Obstet Gynaecol. 2022; 83:15-23. doi: 10.1016/j.bpobgyn.2022.03.018

22. Anderson BO, Ilbawi AM, Fidarova E, Weiderpass E, Stevens L, Abdel-Wahab M, et al. The Global Breast Cancer Initiative: a strategic collaboration to strengthen health care for non-communicable diseases. Lancet Oncol. 2021; 22(5):578-581. doi: 10.1016/S1470-2045(21)00071-1

23. Horr C, Buechler SA. Breast Cancer Consensus Subtypes: A system for subtyping breast cancer tumors based on gene expression. NPJ Breast Cancer. 2021; 7(1):136. doi: 10.1038/s41523-021-00345-2

24. Bernstam EV, Shireman PK, Meric-Bernstam F, N Zozus M, Jiang X, Brimhall BB, et al. Artificial intelligence in clinical and translational science: Successes, challenges and opportunities. Clin Transl Sci. 2022; 15(2):309-321. doi: 10.1111/cts.13175.

25. Zhang B, Shi H, Wang H. Machine Learning and AI in Cancer Prognosis, Prediction, and Treatment Selection: A Critical Approach. J Multidiscip Healthc. 2023; 16:1779-1791. doi: 10.2147/JMDH.S410301

26. Koh DM, Papanikolaou N, Bick U, Illing R, Kahn Jr. CE, Kalpathi-Cramer J, et al. Artificial intelligence and machine learning in cancer imaging. Commun Med. 2022; 2:133. doi: 10.1038/s43856-022-00199-0

27. You JS, Jones PA. Cancer genetics and epigenetics: two sides of the same coin? Cancer Cell. 2012 Jul 10;22(1):9-20. doi: 10.1016/j.ccr.2012.06.008