A bibliometric analysis of the advance of artificial intelligence in medicine

mian lin, Lingzhi Lin, Lingling Lin, Zhengqiu Lin, Xiaoxiao Yan

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Abstract

Background: The integration of artificial intelligence (AI) into medicine has ushered an era of unprecedented innovation, with substantial impacts on healthcare delivery and patient outcomes.

Objective: it is essential to comprehend the current state of development, primary research focal points, and to identify key contributors and their relationships in the application of AI in medicine through bibliometric analysis.

Methods: We employed the Web of Science Core Collection as our primary database and conducted a literature search spanning from January 2019 to December 2023.VOSviewer and R-bibliometrix were performed to conduct bibliometric analysis and network visualization, including the number of publications, countries, journals, citations, authors and keywords.

Results: A total of 1811 publications on research for artificial intelligence in medicine were released across 565 journals by 12376 authors affiliated with 3583 institutions from 97 countries. The United States emerged as the leading producer of scholarly works, exerting significant influence in this domain. Harvard Medical School exhibited the highest publication count among all institutions. The JOURNAL OF MEDICAL INTERNET RESEARCH attained the highest H-index (H-index=19), the most significant publication count (NP=76), and total citations (NC=1495). Among the keywords, four clusters were identified, encompassing the application of AI in digital health, COVID-19 and ChatGPT, precision medicine, epidemiology, and public health. "Outcomes" and "Risk" demonstrated a notable upward trend, indicating the utilization of AI in engaging with clinicians and patients to discuss patients' health condition risks, foreshadowing future research focal points.

Conclusions: Our bibliometric analysis delved into the advancements, focal points, and cutting-edge areas within the field of artificial intelligence in medicine, revealing potential future research opportunities. Research on artificial intelligence in medicine is rapidly progressing, as evidenced by a consistent increase in publications on the topic since 2019. Simultaneously, we identified leading countries, institutions, and scholars in the field and conducted an analysis of journals and representative literature. This study equips researchers with the necessary information to comprehend the current state, collaborative networks, and primary research focal points within the field. Furthermore, our findings propose a set of recommendations for future research.

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A bibliometric analysis of the advance of artificial intelligence in medicine

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Objective The integration of artificial intelligence (AI) into medicine has ushered an era of unprecedented innovation, with substantial impacts on healthcare delivery and patient outcomes. Therefore, it is essential to comprehend the current state of development, primary research focal points, and to identify key contributors and their relationships in the application of AI in medicine through bibliometric analysis.

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***Keywords**:* Artificial Intelligence; Medicine; Bibliometrics; VOSviewer

Introduction

Artificial Intelligence (AI) involves interpreting information and analyzing the application of algorithms. Advanced computer algorithms are utilized in AI to perform tasks such as decision-making and data interpretation, similar to humans. AI offers diverse options for identifying and solving various problems. Like humans, AI machines have the capacity for critical thinking. AI operates through multiple pathways, enabling systems to detect new patterns and derive different formulations from given data. It is an integral component of AI and is frequently employed in the field of medicine. The introduction of AI in medicine signifies a transformative era that yields remarkable innovations and significantly influences healthcare outcomes. This study undertakes a bibliometric analysis to track the evolution and proliferation of AI-focused research in medical science. The research commences by dissecting the fundamental concepts of intelligence, delineating disparities between the organic essence of natural intelligence and the contrived sophistication of its artificial counterpart. Through meticulous evaluation of biological, physiological, and psychological foundations, the study provides a comprehensive understanding of how natural intelligence informs and shapes the potential of AI in medical applications.

Bibliometric analysis is the study of the structure, quantity, and impact of academic literature. This analysis can be conducted on individual researchers, specific fields of research, institutions, or countries. It involves the use of mathematical and statistical techniques to extract and analyze information from published academic literature. The aim of bibliometric analysis is to identify trends, patterns, and changes in academic research. This analysis has important implications for the evaluation of research output, academic performance, and resource allocation[1,2].Therefore, we utilized VOSviewer and R-bibliometric to conduct a bibliometric analysis of the advancement of AI in medicine from January 2019 to December 2023, aiming to address the following questions: 1) Uncover the general trends in AI research within the field of medicine over the past five years. 2) Identify persistent challenges and research focal points. 3)Construct a knowledge graph in this field and offer valuable insights for future related research.

Methods

Data source and search strategy

A systematic search strategy was employed to retrieve publications on the topic of AI in medicine from the Web of Science Core Collection database spanning from January 2019 to December 2023. The Web of Science Core Collection provides access to over 21,000 journals across the fields of science, social sciences, and humanities[3].We opted for this database due to its multidisciplinary nature and citation indexing, which facilitates the identification of the most impactful publications pertaining to AI in medicine. Accessing this database allowed us to locate publications related to the study of occurrences, causes, genetic factors, symptoms, identification, and treatment. The Web of Science Core Collection is a widely recognized online database and is considered to be the most suitable for bibliometric analysis[3]. The search strategy was as follows: TI = (“artificial intelligence” OR “machine learning” OR “deep learning” AND “medicine”). The retrieval time was from January 2019 to December 2023. We only included articles in the retrieval period of January 2019 to December 2023.Our search was limited to English language only. The diagram outlining the process of choosing publications are show in Figure1.

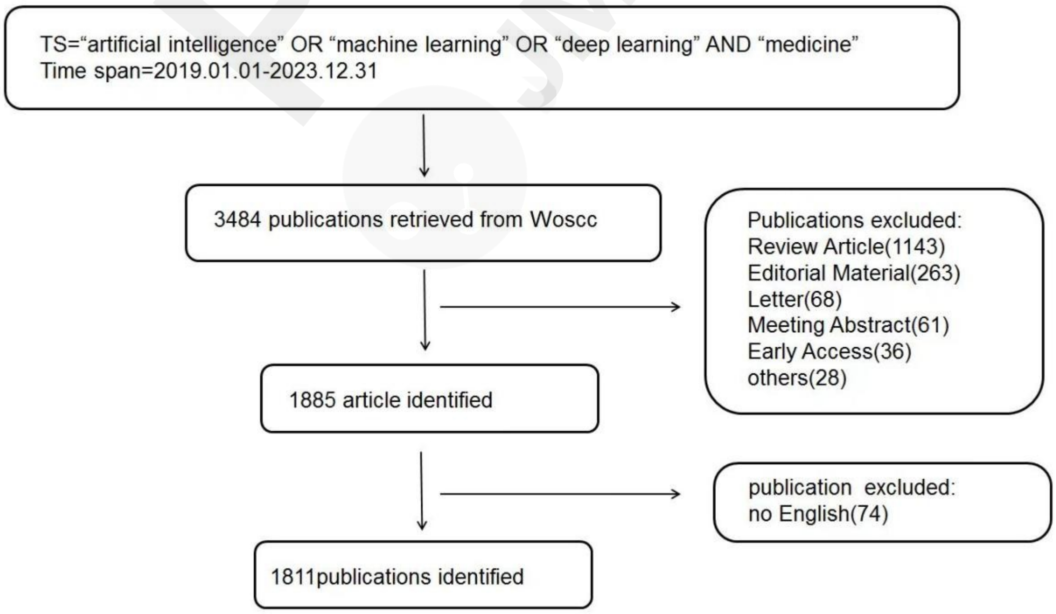

Figure 1. Flowchart for including and excluding literature studies.

Data extraction and analysis

The comprehensive data and referenced sources from all files in the WoSCC were acquired in either txt or BibTeX format and subsequently imported into VOSviewer 1.6.18 (Leiden University, The Netherlands) and R (Version 4.0.2), as required by the specific software for analysis and visualization of the information. The extracted data encompass information regarding article authorship, institutions, publications, keywords, and other pertinent details crucial for the bibliometric analysis. This methodology for data extraction ensures the acquisition of current and pertinent information within the realm of AI applied to medicine, thereby enabling a thorough and representative analysis.

Results

The annual growth trend of publications

A total of 1811 articles focusing on AI in medicine were retrieved from the WOSCC. These articles were collectively authored by 12376 individuals representing 3583 organizations across 97 countries. They were published in 565 journals and collectively cited 73095 references from 15180 journals. The dynamic changes in publication numbers over the past five years reflect the overall developmental trend within the field, demonstrating an average annual growth rate of 28.4%. This growth is visually depicted in Figure 2, illustrating a consistent year-on-year increase in publication output.

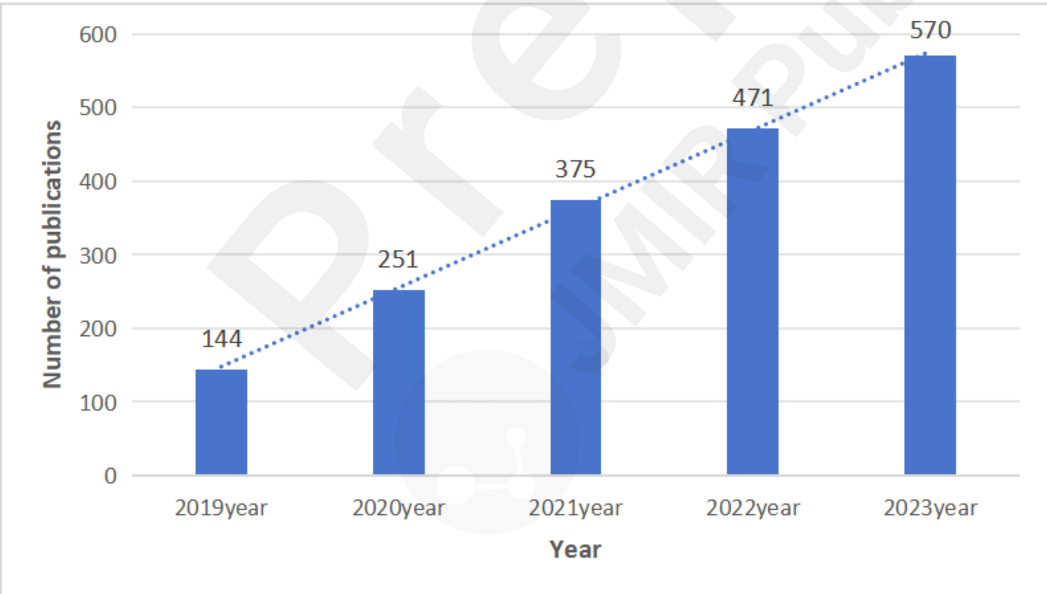

Figure 2. Trend of publications about the research of AI in medicine.

Geographical distribution

The table in this study presents the top 10 most productive countries in AI in medicine research, detailing their publication count (NP), total citations (NC), and average number of citations (AC). Among the countries listed, the United States (USA) led in publications with 709 papers (39.09%) and citations with 14764, followed by China with 371 papers (31.41%) and England with 189 papers

(16.00%). It is noteworthy that despite China ranking second in publication count, its average number of citations (AC) was relatively lower compared to other top 10 productive countries.

Table 1. Displays the breakdown of the leading 10 countries.

Rank	Country	Number of publications	Number of citations	Average citation
1	USA	708	14764	20.85
2	China	371	3547	9.56
3	England	189	5889	31.16
4	Germany	176	3567	20.27
5	Italy	143	2142	14.98
6	Canada	124	2882	23.24
7	South korea	102	959	9.40
8	Netherlands	98	3150	32.14
9	France	92	1573	17.10
10	Spain	77	1302	16.91

The study of scientific cooperation involves scholars working collectively to generate new scientific knowledge. Figure 3 illustrates the co-authorship analysis, where node size corresponds to the volume of disseminated articles within a given country. Additionally, the connections between nodes signify close collaboration between countries, with wider lines indicating more intense collaboration. The co-authorship network analysis of AI in medicine reveals an organized structure with 5 clusters and robust global collaboration, encompassing 624 links and a total link strength of 2653. Leading this collaboration are countries such as the United States, China, England, Germany, and Italy. Moreover, Table 2 presents the top 5 authors and co-cited authors who have significantly contributed to AI research in medicine. Notably, LI J emerges as the most productive author, with 15 articles, while HO MT stands out as the most co-cited author, accumulating 24 citations.

The wide range of geographical locations represented in the network highlights the strong global cooperation in the industry, which promotes a variety of viewpoints and expertise in research. The results provide valuable perspectives on the trends of AI research in the medical field and emphasize the potential for increased cooperation among specific nations.

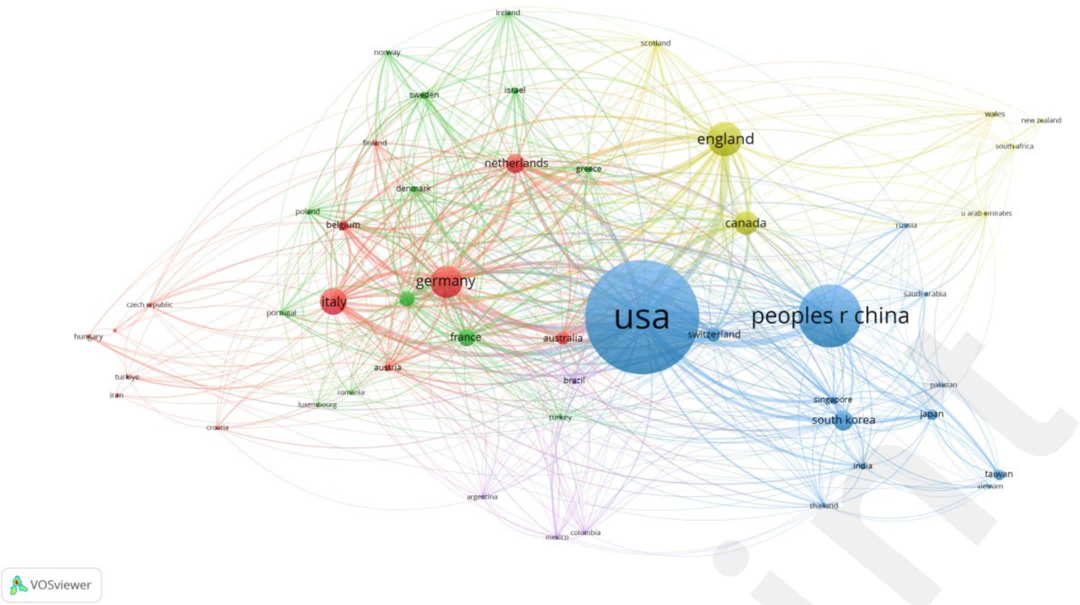

Figure 3. Co-authorship network by countries.

Table 2. Top 5 authors and co-cited authors.

Rank	Authors	Publications	Rank	Co-cited authors	Citations
1	LI J	15	1	HO MT	24
2	WANG J	13	2	CORRADO G	23
3	ZHANG J	12	3	KARTHIKESALINGAM A	23
4	ZHANG H	12	4	KELLY CJ	23
5	LIU Y	12	5	KING D	23

Journal analysis

We compiled the total citations and publication output from the top 10 sources with the highest H-index in the field of artificial intelligence in medicine, as shown in Table 3. Notably, the JOURNAL OF MEDICAL INTERNET RESEARCH exhibited the highest H-index (H-index=19) and publication count (NP=76). Applying Bradford's law to the 1495 sources, we identified 13 journals, including JOURNAL OF MEDICAL, CANCERS, BMJ OPEN, JMIR MEDICAL INFORMATICS, and JOURNAL OF PERSONALIZED MEDICINE, as core journals due to their relatively high publication output (Figure 4).

Table 3. Top 10 Journals and co-cited Journals.

Rank	Journal	H-index	NP	NC	PYS
1	JOURNAL OF MEDICAL INTERNET RESEARCH	19	76	1495	2019
2	NPJ DIGITAL MEDICINE	17	35	1807	2019
3	CANCERS	15	65	670	2019
4	FERTILITY AND STERILITY	14	26	470	2019

5	BMC MEDICAL INFORMATICS AND DECISION MAKING	12	45	933	2019
6	JMIR MEDICAL INFORMATICS	12	60	569	2019
7	JOURNAL OF PERSONALIZED MEDICINE	12	60	488	2020
8	DIAGNOSTICS	11	47	385	2020
9	LANCET DIGITAL HEALTH	11	12	898	2020
10	FRONTIERS IN ONCOLOGY	10	43	312	2019

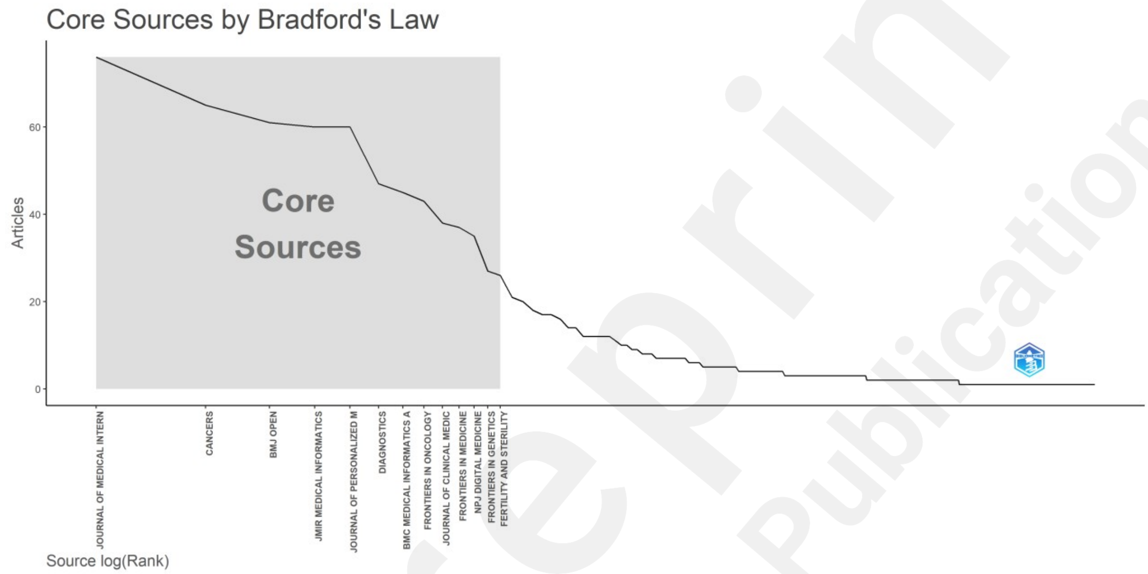

Figure 4. Core sources identified by Bradford's law.

Institution analysis

To assess the importance and collaboration among institutions, we generated a network plot (Figure 5). The size of each node represents the significance and activity level of the respective institution, while the thickness of the connecting lines indicates the level of collaboration between institutions. The institutions of research on AI in medicine were categorized into 12 major clusters. The most important and active institutions were Harvard medical school, followed by Stanford university, university Toronto, mayo clinic, and johns Hopkins University. Among the top five institutions, apart from university Toronto in Canada, the other four are all located in USA. In terms of collaboration, Harvard medical school demonstrated the highest degree of co-occurrence. The institution with the highest centrality in China was shanghai jiao tong university, followed by Sichuan university, and South China university. Furthermore, these institutions served as the core organizations facilitating collaboration among the same groups. Additionally, Harvard medical school and Stanford university exhibited notable differences in their distribution and structure within the co-occurrence network. They had the highest clustering coefficient among all institutions (Cluster=12), suggesting that they possess unique research characteristics, advantages, or distinct research directions and issues.

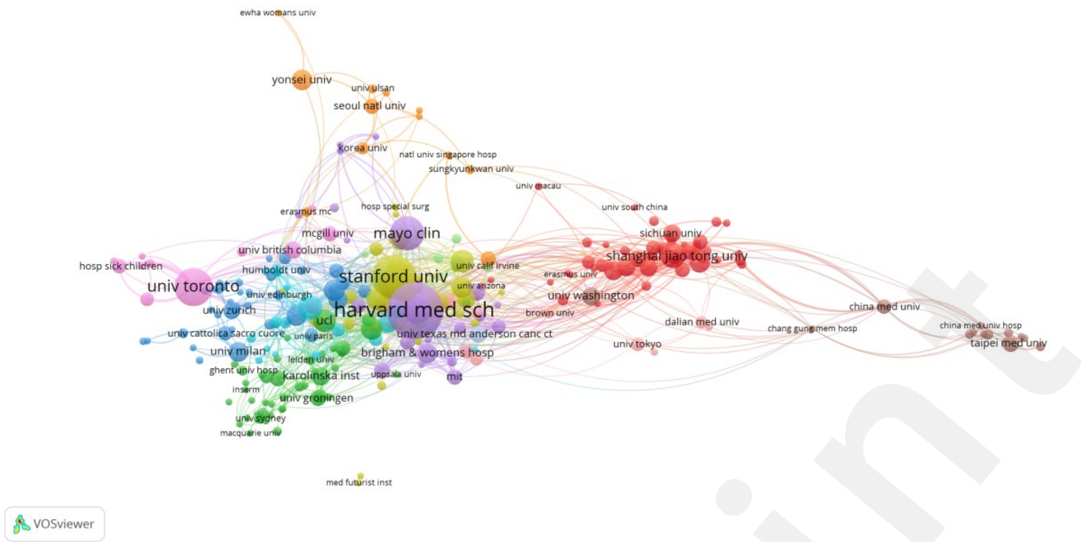

Figure 5. Scientific collaboration between institutions.

Top cited papers

The top 10 most cited papers in the field of AI in medicine are listed in Table 4, representing significant contributions and perhaps the most renowned works in this domain. Normalized Local Citations (NLC) serve to mitigate differences in citation counts arising from various fields and publication years. The article "Key challenges for delivering clinical impact with artificial intelligence," authored by Christopher J. Kelly from Google Health, London, UK, and published in BMC Medicine in 2019, holds the highest NLC (16.98). This article emphasizes the exciting opportunity presented by AI to enhance healthcare. It stresses the essential need for robust, prospective clinical evaluation to ensure the safety and effectiveness of AI systems. Such evaluation should employ clinically applicable performance metrics that extend beyond technical accuracy to encompass the impact of AI on care quality, healthcare professionals' variability, clinical practice efficiency and productivity, and patient outcomes[4].Following closely in NLC ranking is an article titled "The state of artificial intelligence-based FDA-approved medical devices and algorithms: an online database," authored by Stan Benjamens from the Netherlands in 2020. This article provides insights into the currently available AI-based medical devices and algorithms that have received approval from the US Food & Drug Administration (FDA)[5].

Document co-citation is a technique used to reveal co-cited literature by multiple authors. Specifically, this method visualizes the co-occurrence of citations in two publications to evaluate their connection[6]. Figure 6 displays a map of co-citation references for AI in medicine. The paper titled ‘High-performance medicine: the convergence of human and artificial intelligence' by Eric J Topol[7]，which is the most frequently referenced (2019), with 110 citations. This article illustrated AI had an impact at three levels in medicine: for clinicians, predominantly via rapid, accurate image interpretation; for health systems, by improving workflow and the potential for reducing medical errors; and for patients, by enabling them to process their own data to promote health. The second-ranked paper demonstrates the classification of skin lesions using Deep Convolutional Neural Networks (CNNs)[8]. The authors trained a CNN using a dataset of 129,450 clinical images—two orders of magnitude larger than previous datasets—comprising 2,032 different diseases. The CNN achieves performance on par with all tested experts across both tasks, demonstrating an AI capable of classifying skin cancer with a level of competence comparable to dermatologists.

Table 4. Top 10 most locally cited papers on related research.

Document	DOI	Year	Normalized Local Citations
KELLY CJ, 2019, BMC MED	10.1186/s12916-019-1426-2	2019	16.98
SIDEY-GIBBONS JAM, 2019, BMC MED RES METHODOL	10.1186/s12874-019-0681-4	2019	9.60
BENJAMENS S, 2020, NPJ DIGIT MED	10.1038/s41746-020-00324-0	2020	16.40
TRAN BX, 2019, J CLIN MED	10.3390/jcm8030360	2019	8.86
BI WL, 2019, CA-CANCER J CLIN	10.3322/caac.21552	2019	7.38
OH S, 2019, J MED INTERNET RES	10.2196/12422	2019	7.38
ZANINOVIC N, 2020, FERTIL STERIL	10.1016/j.fertnstert.2020.09.157	2020	12.61
GUO YQ, 2020, J MED INTERNET RES	10.2196/18228	2020	10.09
GHORBANI A, 2020, NPJ DIGIT MED	10.1038/s41746-019-0216-8	2020	10.09
CIKES M, 2019, EUR J HEART FAIL	10.1002/ejhf.1333	2019	5.17

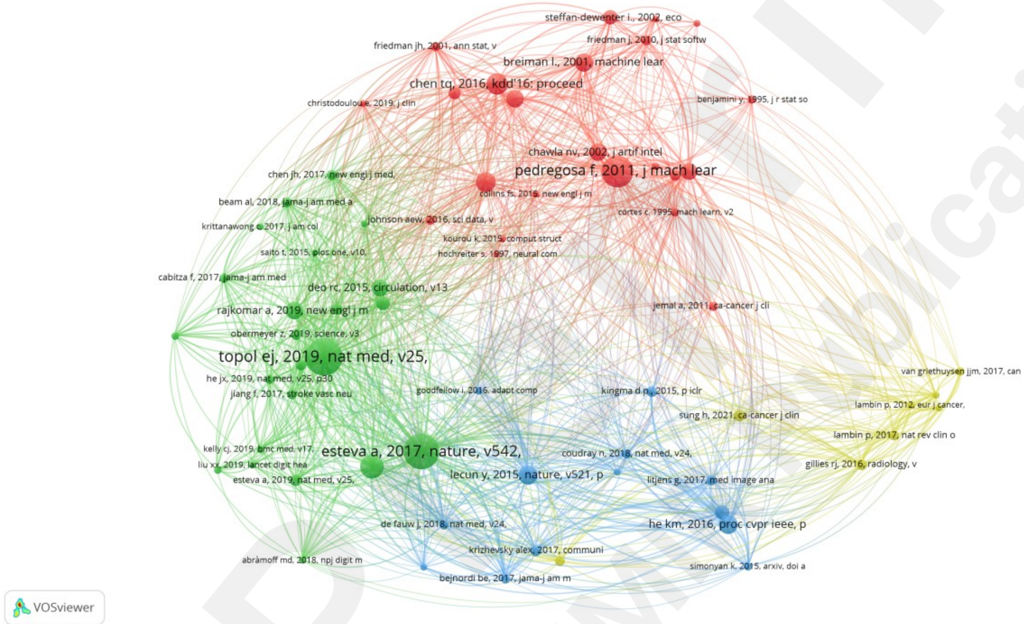

Figure 6. The analysis of co-cited documents.

Trend topics and keywords analysis

We depicted the most commonly used keywords in Figure 7, and then summarized the usage patterns and trends of author keywords at different times in Figure 8. The keyword "Classification" emerged as the most frequently used term after 2019, but has experienced a slight decline since 2021. Its usage witnessed a substantial surge, indicating a growing research focus on this specific area. Furthermore, keywords such as "Cancer", "Diagnosis", and "Prediction" gained high popularity from 2019 to 2022. Starting from 2022, the usage of keywords such as "Artificial intelligence", "Outcomes", and "Risk" has shown a significant upward trend, suggesting their potential as emerging research hotspots.

The co-occurrence relationships between keywords, authors, and publication sources were presented in a Three-Field Plot (Figure 9). The size of each node represented its frequency or importance, while the connections between nodes represented co-occurrence relationships between two indicators, with the thickness of the lines indicating the frequency or strength of the co-occurrence. Moving from left to right, the three fields represent authors, keywords, and relevant journals. The most robust co-occurrence relationship existed between the keyword "machine learning" and the Journal of Medical Internet Research. Additionally, among the most important keywords, "Artificial intelligence" is predominantly associated with the Journal of Medical Internet Research, while "deep learning" is primarily linked to the JMIR Medical Informatics.

Prominent authors demonstrate a robust co-occurrence with the keyword "machine learning". Importantly, specific authors exhibited strong co-occurrence with particular keywords; for instance, Wang J and Li J were closely associated with "machine learning", Liu Y with "artificial intelligence", and Lee S with "deep learning". These observations illuminate influential authors and teams in this research domain and offer insights into potential future research directions.Significant authors show strong co-occurrence with the keyword “machine learning”. Notably, certain authors exhibited strong co-occurrence with specific keywords; for example, Wang j and Li j was closely linked with “machine learning”, Liu y with “artificial intelligence” and Lee s with “deep learning”. These observations shed light on influential authors and teams in this research domain and provide insights into potential future research directions.

In order to identify popular topics and assist scholars in better understanding current scientific concerns, we conducted an analysis of keyword co-occurrence. The construction of the co-occurrence network based on authors' keywords facilitates the identification of semantic similarity between terms and reveals knowledge structures within the area of interest[9]. The parameters outlined at the end of the Methods section were utilized to elucidate the network depicted in Figure 10. Figure 10 illustrates the authors' keywords (nodes) grouped into 4 communities (clusters or subdomains). The coexistence of terms within the same cluster indicates their contextual similarity and relationship. The edges of the network signify the co-occurrence of terms within the same document. The red cluster comprises 9 terms, with primary keywords including "digital health," "COVID-19," and "AI." This cluster delves into the application of AI in digital health, COVID-19, and ChatGPT. The blue cluster, encompassing the remaining 37 nodes, prominently features keywords such as machine learning, artificial intelligence, precision medicine, and deep learning, exploring the application of AI in precision medicine. The green cluster investigates the application of AI in epidemiology, while the fourth cluster is associated with the application of AI in public health.

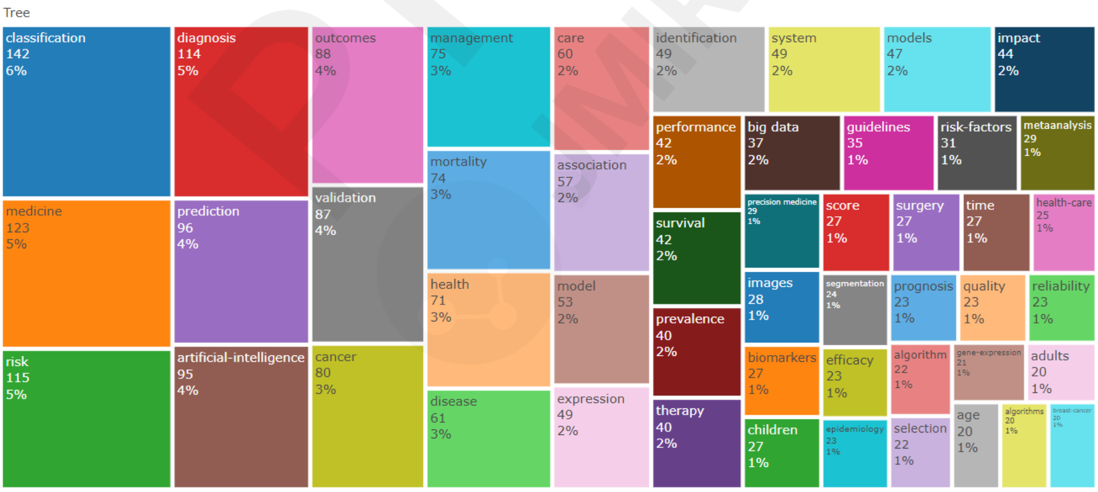

Figure 7. Tree Map of the keyword.

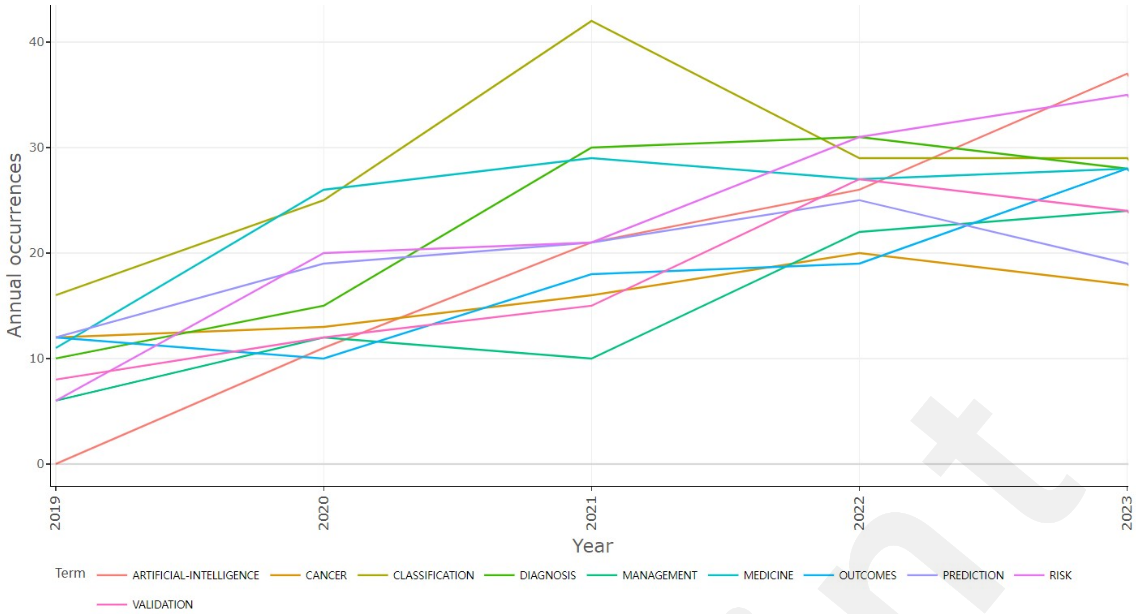

Figure 8. Line chart of author keywords in different time periods.

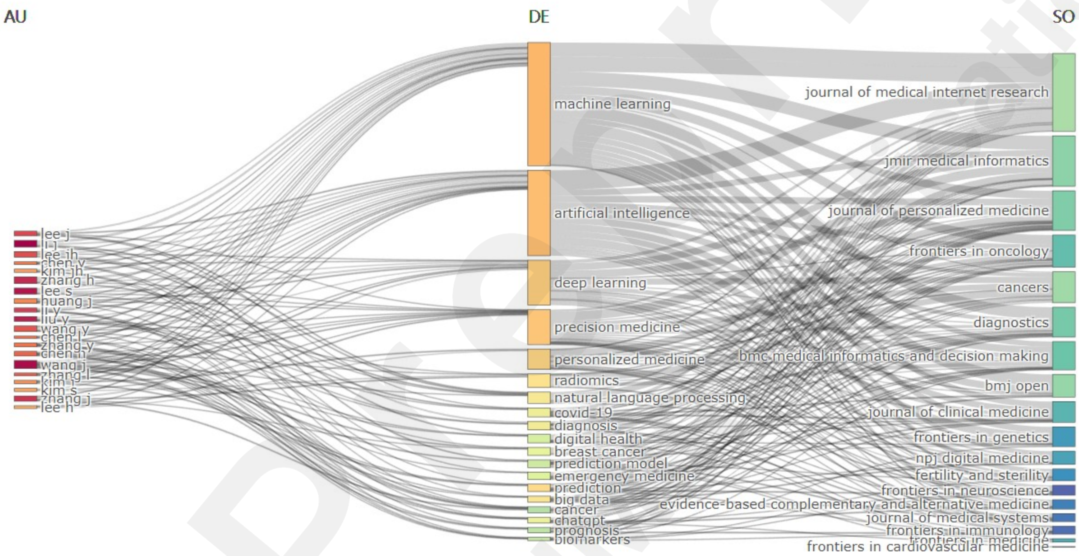

Figure 9. Three-field plots between authors, keywords, and sources. Abbreviations: AU, Author; DE, Keywords; SO, Sources.

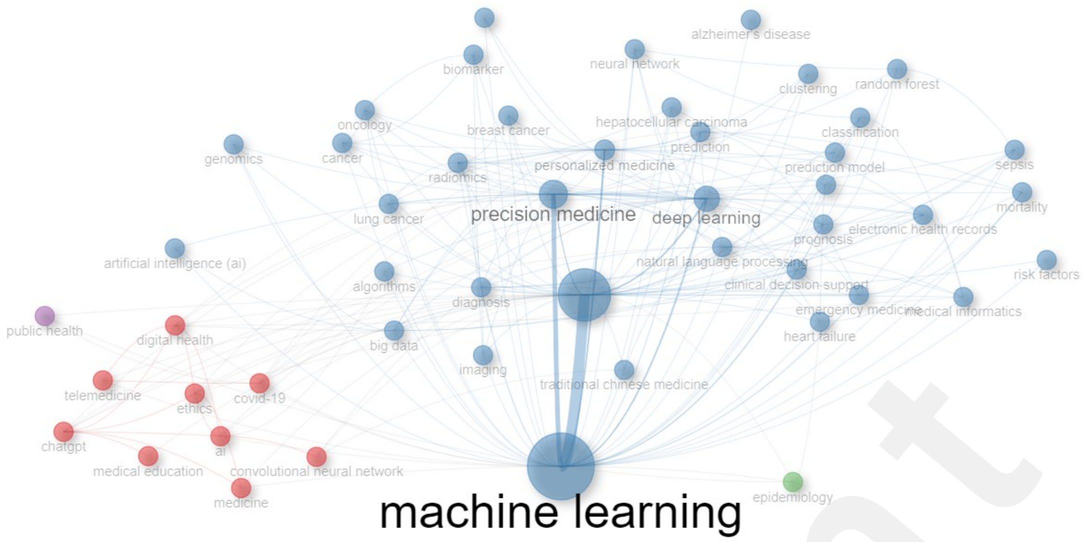

Figure 10. Research topics clustered by mapping co-occurrences of keywords.

Discussion

This study examines the characteristics of articles on AI in medicine over the past 5 years to delineate current research and provide guidance for future endeavors. The number of publications per year was monitored to discern trends over the specified period. Notably, highly cited articles, defined as those within the top percentile of citations, were documented, as they often denote pioneering research. The productivity of countries was assessed based on the volume of AI in medicine publications across the time frame. Utilizing keyword analysis, prevalent research themes and current topics of interest were identified. Mapping these bibliometric parameters over time facilitated the visualization of the evolution of global AI in medicine research. As depicted in Figure 2, only 144 articles were published in 2019, suggesting a nascent stage of understanding among researchers. Subsequently, there has been a consistent increase in the volume of research papers, with an average annual growth rate of 28.4%. This trend indicates a mounting scholarly interest in the study of AI in medicine, solidifying its status as a popular and enduring research topic.

The analysis of countries revealed that the USA made the highest contribution in terms of NP and NC, signifying its position as a leading and influential country in the field of AI in medicine. Notably, on February 11, 2019, the United States issued the executive order "Maintaining American Leadership in Artificial Intelligence," mandating all federal government agencies to execute strategic objectives aimed at expediting AI research and development[10]. While China ranked second in NP, its AC was relatively low. These findings indicate a disparity in China's output quantity and quality. Addressing this challenge necessitates enhancing collaboration with various nations, particularly the United States, England, and Germany, while also closely monitoring scientific advancements and conducting comprehensive research to elevate the standard of publications.

Another implication pertains to the factors contributing to research output in medical AI. Empirical data suggest that influential authors, as measured by the total number of citations and the number of citations per paper, are often individuals who either lead a field and maintain productivity throughout their careers, or develop a methodology applicable across various research domains. This trend has been noted in other studies, indicating that senior and productive authors play a pivotal role in driving the productivity of their collaborators.

At the institutional level, Harvard Medical School has emerged as the leading institution in terms of the highest number of published articles in this field, signifying its paramount importance and activity in this domain. In China, Shanghai Jiao Tong University, Sichuan University, and South China University have attained a relatively prominent position, albeit with limited connections to the United States. Consequently, it is imperative for research institutions across regions to foster extensive collaboration, thereby advancing global research in this field. This collaboration will aid in comprehending the similarities and differences, as well as the correlation with medicine among different racial groups.

Based on the journal analysis, research on AI in medicine tends to be prominent in large-scale journals related to comprehensive medical topics and internet-related issues. The NC metric serves as an indicator of a journal's influence, while the H-index provides a quantitative measure of both publication volume and citation count[11]. The Journal of Medical secured the top position in the H-index. This journal serves as a platform for the presentation and discussion of the increasingly extensive applications of new systems techniques and methods in hospital clinic and physician's office administration, pathology, radiology, pharmaceutical delivery systems, medical records storage and retrieval, and ancillary patient-support systems. It publishes informative articles, essays, and studies covering the entire spectrum of medical systems, from large hospital programs to innovative small-scale medical services. NPJ Digital Medicine, a peer-reviewed, open-access medical journal published by npj (Nature Partner Journals), a division of Nature Publishing Group, focuses on research in the field of digital medicine. It encompasses topics such as medical information technology, telemedicine, medical sensor technology, health data analysis, and the application of artificial intelligence in healthcare. The journal aims to foster innovation in digital medicine and provide a platform for researchers to share their original research and review articles to advance medical science. According to Bradford's Law, the Journal of Medical, Cancers, BMJ Open, JMIR Medical Informatics, and Journal of Personalized Medicine exhibit significant potential for future research in this field, offering valuable references for upcoming researchers. However, it is important to note that this law only considers the volume of publications in relevant categories, without factoring in research quality and impact[12]. Therefore, it is essential to integrate research findings from various journals to gain a comprehensive understanding of AI in medicine.

Keywords serve as a concise summary of the core ideas within an article and are widely regarded as important indicators that reflect research directions and hotspots within a specific field. To a large extent, changes in keywords over time reflect the evolution of these hotspots and can provide guidance for future research directions. Figure 8 illustrates a gradual shift in keywords from AI-based classification and the application of AI in cancer diagnosis and disease prediction towards outcomes and risk. "Classification" emerged as the most frequently used keyword. In 2019, Jenni A. M. et al[13]. developed three predictive models using machine learning techniques for the classification of breast cancer. These algorithms encompassed regularized General Linear Model regression (GLMs), Support Vector Machines (SVMs) with a radial basis function kernel, and single-layer Artificial Neural Networks. The authors trained these algorithms on data from the evaluation sample before using them to predict diagnostic outcomes in the validation dataset. They then compared the predictions made on the validation datasets with real-world diagnostic decisions to calculate the accuracy, sensitivity, and specificity of the three models. The integration of advanced technologies such as AI in cancer detection and prediction has led to significant advances and diversified applications. In dermatology, the combination of convolutional neural networks and transfer learning techniques has proven effective in skin lesion classification, offering a valuable tool for the early detection of skin cancer[14]. The applications of AI in abdominal cancers have expanded to encompass diverse approaches for cancer detection, diagnosis, and classification, genomics and detection of genetic alterations, analysis of the tumor micro-environment, identification of predictive biomarkers, and follow-up[15]. Within the context of lung cancer, the use of machine learning methods to analyze histopathology images demonstrates AI's ability to accurately predict patient prognosis, thereby contributing to precision oncology[16]. Furthermore, the application of AI has achieved significant success in medical image-based cancer diagnosis, demonstrating favorable results in image classification, reconstruction, detection, segmentation, registration, and synthesis[17]. From 2022, there has been a notable increase in the usage of keywords such as "Outcomes" and "Risk," indicating the use of AI to engage with clinicians and patients in discussing the risk of patients' health conditions and their potential outcomes, representing a facet of precision medicine.

Identifying keywords and their evolution in various articles through co-occurrence analysis aids in exploring the focal points within the research field[18]. The red cluster delves into the application of AI in digital health and COVID-19. Digital health is defined as "the use of digital technologies to improve human health[19]." For instance, there is evidence supporting the use of AI to select patients for intervention by utilizing the electrocardiograph signal to predict atrial fibrillation[20]. Consequently, this approach allows for targeted therapies addressing actual necessary conditions and diseases. Explainable artificial intelligence applications can assist in predicting an Alzheimer's disease diagnosis in a cohort of patients with mild impairments, illustrating how interpretable machine-learning algorithms can elucidate complex patterns that inform individual patient predictions[21]. The focus of digital health has shifted beyond the mere diagnosis and treatment of diseases to encompass early prevention, precision intervention, and health management with the citizen at the center. Moreover, innovative AI technology can facilitate the development of intelligent telemedicine, thereby promoting the establishment of an extensive digital health platform, which may represent a key direction for future research.

The COVID-19 pandemic has profoundly impacted the world in unprecedented ways. Effectively managing the pandemic necessitates accurate and timely information regarding the spread of the SARS-CoV-2 virus, the efficacy of mitigation interventions, and its impact on diverse populations. Numerous previous studies have explored the use of AI in combating COVID-19. Hussain et al. [22]focused on leveraging big data, Internet of Things, AI, and cloud computing techniques to combat the COVID-19 pandemic. Additionally, Pham et al.[23], Chen et al. and Nguyen et al.[24] discussed the use of AI in vaccine and drug development. During the COVID-19 pandemic, AI has been widely employed to facilitate various tasks. Robots have been utilized for the efficient distribution of essential food items and for disinfecting areas using ultraviolet rays, thereby reducing human exposure to the virus[25].In hospitals, robots have taken over tasks traditionally performed by healthcare workers, thereby alleviating the burden on medical staff. Furthermore, hospitals have been equipped with 5G-powered temperature-detecting devices, and wearable accessories such as wristbands have been utilized for monitoring heart rates and detecting oxygen levels[26]. Additionally, robots have assisted patients during quarantine, enhancing the overall experience. They have also been employed to monitor patient health, conduct scans, and share this information with researchers using cloud services[26].Due to their lack of susceptibility to disease and ease of disinfection, robots have proven effective in laboratory testing and clinical trials. Moreover, robots have served as intermediaries between patients and doctors, thereby minimizing the risk of virus exposure to healthcare professionals[27].

ChatGPT is a large language model developed by Open AI, and it has the ability to analyze and generate text in a manner that is similar to human intelligence[28]. Merely a few months following its release, ChatGPT has already made a significant impact in the field of medical science, encompassing medical education, scientific research, medical writing, and diagnostic decision-making[29,30]. Specifically, ChatGPT can produce scientific articles with appropriate vocabulary and a spectrum of tones ranging from colloquial to highly technical[31]. Moreover, ChatGPT has the potential to provide valuable assistance to physicians in their clinical decision-making processes by generating accurate lists of differential diagnoses and offering insights for cancer screening decisions[32-34].

Over the past decade, AI research has been experiencing widespread adoption in the prediction, detection, diagnosis, classification, treatment, and survival prediction of diseases[35,36], thereby contributing to medical innovation for a more sustainable approach to precision medicine. This is frequently achieved through the utilization of biomarker tests or other tools that serve as "indicators of normal biological processes, pathogenic processes, or biological responses to exposure or intervention, including therapeutic interventions." [37]Susceptibility, prognostic, and predictive biomarkers are measured at a single point in time to forecast future events, whereas monitoring, response, and safety biomarkers are assessed serially to provide information on the improvement or worsening of a clinical outcome relative to a previous time point[37].

The use of AI in various fields has undergone exponential growth, with the first recorded automated application of pattern recognition dating back to a report published in The Lancet in 1960[38]. Precision medicine approaches are already being implemented in the context of cancer, encompassing both diagnosis and treatment. In the realm of cancer diagnosis, current literature [39-41]showcases numerous studies delving into AI's potential, comparing its results to manual detection by pathologists. AI demonstrates a remarkable level of accuracy, surpassing human pathologists in diagnosing specific types of cancer[42-44]. The prevailing precision medicine approach considers a range of factors, including tumor-associated and inherited genetic variations, environmental exposures, lifestyle, general health, and medical history of patients, in determining the most suitable treatment plans for cancer patients. Moreover, precision medicine applications hold promise for drug discovery, development, and clinical trial endeavors. As emphasized in recent literature[45], the use of AI algorithms to analyze data from large populations enables AI researchers and pharmaceutical scientists to uncover crucial trends and patterns. AI-based drug discovery and screening, coupled with laboratory automation, could enhance human involvement in drug design, chemical synthesis, drug screening, biological testing, and decision-making within the drug discovery and development process, potentially addressing the low success rates, lengthy drug development processes, and high costs often associated with traditional drug discovery and development[46,47]. Many clinical trial studies rely on digital pathology, radiology, and genomic data to optimize the design of combination regimens and determine appropriate dosing of chemotherapy and immunotherapy.

Machine learning (ML) is a subset of AI that enables computer algorithms to learn from data without being explicitly programmed to perform a task[48]. As depicted in Figure 10, deep learning has the most significant impact on precision medicine. Deep learning represents the most advanced form of ML presently available and has emerged since 2010 as an AI technique facilitating the analysis of medical images and genomic studies [49,50]. Recently, deep learning successfully identified two distinct subtypes of glioma from genomic data, providing insights into their individual molecular mechanisms[51]. Furthermore, deep learning has the potential to reduce drug discovery costs by efficiently screening for potential candidates, thereby reducing time compared to traditional methods[52]. The system was not explicitly directed to perform this task; it identified patterns from the data and "taught itself" what to look for and report.

As quoted in the synopsis of the Public Health and Epidemiology Informatics section of the 2017 IMIA Yearbook[53], precision public/global health and digital epidemiology are terms that are still in use in 2018[54,55]. The former term pertains to delivering the appropriate intervention to the right population at the right time[54]. The latter term involves utilizing digital data, particularly data not intentionally collected, to address epidemiological inquiries[55]. In epidemiology, the huge potential of Big Data was illustrated by a pioneering study reported by Deiner [56],who illustrated that the early detection of epidemics can be achieved by tracking online queries on disease symptoms using social media platforms such as Google Search and Twitter. Pattern recognition and data analytics served as tools for detecting, recognizing, and classifying patterns of disease incidence related to conjunctivitis. Conversely, wearable technologies will enable the monitoring and collection of individual medical information and the refinement of the care process. The fusion of AI with virtual reality and augmented reality[57], will enable the creation of both virtual medical services that citizens can access easily and directly, as well as increasingly effective and safe applications for robotic surgery.

It is noteworthy that the keyword "ethics" is depicted in Figure 10, indicating a growing focus on

AI ethics in medicine. Legal regulations and guidelines for medical AI are often formulated without engaging in dialogue among ethicists, developers, clinicians, and community members. This lack of collaboration may result in regulations that do not align with the experiences of community members as users of medical AI. Ethical concerns identified by policymakers and scholars may differ from those recognized by actual patients, providers, and developers, leading to a disconnect where ethical decision-making tools may not be perceived as relevant to AI users. Regulatory practices often stem from higher-level ethical theories and principles rather than from an examination of actual knowledge and practices of medical AI ethics using real-world examples[58]. Identifying empirical research on the knowledge, attitudes, and practices of medical AI ethics can lead to the development of mechanisms that may assist educators, researchers, and ethicists in clarifying and addressing perceived ethical challenges[59]. As AI interactions involve patients, families, and healthcare providers, it is crucial to comprehend individuals' awareness of the ethical issues that may impact their use of AI in healthcare delivery and to determine how these findings can inform the development and research of medical AI. By identifying what stakeholders (e.g., patients, clinicians, and developers) perceive as the ethical risks of medical AI, we can initiate dialogue and develop practice guidelines, organizational standards, and legal regulations to establish ethically informed AI interventions that are relevant and applicable in practice. While the application of AI has brought numerous benefits to the healthcare system and has improved medicine, unethical use of AI technology can pose risks to patients and physicians. Therefore, it is essential to establish ethical standards applicable to all stakeholders not only in healthcare services but also in health-related fields. Developing global and national protocols and regulations to regularly review and validate the appropriateness of AI products in clinical and practical settings is crucial.

There are still some limitations to this study. Firstly, this study only searched the WoSCC database, which is considered one of the most widely used large multidisciplinary abstract databases globally, but it may still have incomplete coverage. Secondly, only articles published in English were included, yet this limitation may not significantly impact the stability of the study's results, given that the WoSCC database primarily features English-language articles. Finally, there is a lag in the citation numbers for articles, which means that more recently published high-quality articles may have been underexplored. Future studies are recommended to be updated accordingly.

Conclusion

The study selected papers from WOSCC from 2019to 2023 on the combination of AI and medicine. Through bibliometric analysis, we have drawn the following conclusions: The USA leads the world regarding the number of publications and the centrality of literature. The research institutions in this field are mainly universities. Recent keyword clustering shows that“ digital health”, “covid-19”、“ precision medicine” and “epidemiology and public health” are the latest research frontier. In a word, this bibliometric study can help researchers discover the current status and emerging trends in artificial intelligence of medicine.

Conflicts of Interest

None declared.

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