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Application of Artificial Intelligence in Retinopathy of Prematurity From 2010 to 2023: A Bibliometric Analysis

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ABSTRACT

Background and Aims: Retinopathy of prematurity (ROP) remains a leading cause of childhood blindness worldwide. In recent years, artificial intelligence (AI) has emerged as a powerful tool for the screening and management of ROP. This study aimed to investigate the evolving and longitudinal publication patterns related to AI in ROP using bibliometric methodologies.

Methods: We conducted a descriptive analysis of AI in ROP documents retrieved from the Web of Science database up to September 10, 2023. Data analysis and visualization were performed using Bibliometrix and VOSviewer, covering publications, journals, authors, institutions, countries, collaboration networks, keywords, and trending topics.

Results: Our analysis of 188 publications on AI in ROP revealed an average of 7.62 authors per document and a notable increase in annual publications since 2017. The United States (98/188), Oregon Health & Science University (66/188), Investigative Ophthalmology & Visual Science (29/188) and author Michael F. Chiang (60/188) led contributions. A prominent 21-country network emerged as the largest in country-level coauthorship. Key technical terms included “artificial intelligence,” “deep learning,” “machine learning,“ and “telemedicine,” with a recent shift from “feature selection” to “deep learning,” “machine learning” and “fundus images“ in trending topics.

Conclusion: Our bibliometric analysis highlights advancements in AI research on ROP, focusing on key publication characteristics, major contributors, and emerging trends. The findings indicate that AI in ROP is a rapidly growing field. Future studies should focus on addressing the clinical implementation and ethical concerns of AI in ROP.

1 | Introduction

Retinopathy of prematurity (ROP) affects retinal blood vessel development in low-birth-weight preterm infants, a leading cause of childhood blindness [1]. In full-term infants, retinal development is typically complete, making ROP rare. Premature birth disrupts this process, particularly in peripheral areas, progressing outward from the optic nerve head with gestational age, increasing the risk of abnormal development [2]. Severe ROP may result in retinal detachment and even blindness, with associated conditions like glaucoma, strabismus, myopia, and amblyopia [3].

Global ROP epidemiology varies due to regional neonatal care disparities [1]. Data from 2010 estimates that approximately 184,700 preterm infants worldwide are affected by ROP, with

Jing Gao, and Na Fang contributed equally to this study approximately 20,000 suffering blindness [4]. Improved neonatal care has increased survival rates but also ROP incidence, especially in low- and middle-income countries, where it remains a preventable cause of blindness [5]. Effective screening demands frequent exams, posing challenges even in high-income countries, requiring skilled ophthalmologists and causing discomfort to infants [6]. A major breakthrough in the field would be the development of methods to enhance diagnostic accuracy and support clinical trials, which are crucial areas for advancement.

Artificial Intelligence (AI) technology has emerged as a promising tool to address these challenges by improving screening processes, standardizing practices, and mitigating human biases and fatigue [7]. AI blends technology and scientific study to develop computers capable of mimicking human cognitive abilities, allowing them to handle complex tasks and make decisions in real-world scenarios. The field of AI encompasses various technologies, including machine learning, deep learning, robotics, expert systems, fuzzy logic, and natural language processing, making it a vital component in advancing diagnostic accuracy and supporting clinical trials [8].

Efforts have been made to apply rapidly advancing AI technology across various medical fields [9, 10]. In ophthalmology, AI is increasingly being proposed to enhance diagnostic accuracy, predictive diagnostics, and overall clinical care in conditions such as diabetic retinopathy, glaucoma, and age-related macular degeneration [11–14]. In the context of ROP, AI's potential extends to diverse applications, including screening, diagnosis, and prognosis prediction. This encompasses advanced automated imaging processing techniques, precise disease classification, and the development of predictive analytics, all of which contribute significantly to the management of ROP [15–18].

Integrating AI with telemedicine has proven effective, expanding examination capabilities and potentially allowing earlier diagnosis for a broader patient population [19]. This is especially critical in rural or underserved areas with limited access to specialized care, where AI, via telemedicine, has the potential to overcome transportation and resource challenges, improving the timeliness and availability of ROP care [19–21].

Despite the existence of reviews on AI in ROP, a comprehensive bibliometric study of this field is lacking. To address this gap, we conducted a bibliometric analysis to map the landscape of AI research in ROP. This approach quantitatively evaluates publication metrics, identifying trends, key contributors, influential institutions, leading journals, common research themes and trending topics [22, 23]. Our study provides a detailed overview and strategic insights for future research directions in this rapidly evolving domain.

2 | Methods

2.1 | Search Strategy

We conducted an extensive search within the Web of Science (WoS) Core Collection on September 10, 2023. This database includes more than 21,000 peer-reviewed, high-quality scholarly journals from around the world, over 205,000 conference proceedings, and over 104,000 editorially selected books [24]. It is particularly renowned for its comprehensive bibliometric data. Our search aimed to capture the intersection of ROP and AI. The search strategy employed combined keywords pertinent to both fields. The search query was structured as follows: TS = ((“retinopathy of prematurity” OR “ROP” OR “Prematurity Retinopathy*” OR “Retrolental Fibroplasia*” OR “Fibroplasia Retrolental” OR “Fibroplasias Retrolental”) AND (“AI” OR “artificial intelligence” OR “computational intelligence” OR “machine intelligence” OR “computer reasoning” OR “computer vision system*“ OR “support vector machine” OR “random forest” OR “transfer learning” OR “neural network*“ OR “machine learning” OR “deep learning”)).

2.2 | Screening the Publications

In our study, we included all articles that discussed AI within the context of ROP for initial screening. For a more focused bibliometric analysis, we applied specific inclusion criteria (1): the article had to be written in English (2); ROP must be one of the outcomes (3); the study must employ AI technologies. We considered research papers published in peer-reviewed journals, as well as those presented in conference proceedings and published as conference abstracts or reviews. Conversely, we excluded publications formatted as letters, editorials, or book chapters. We did not impose any restrictions on the publication date. Two authors (J.G., N.F.), trained in bibliometric methodologies, independently screened the articles using a pre-established set of inclusion criteria. Discrepancies were resolved through discussion with a third author (Y.X.). Relevant articles were exported and saved in plain text format (including full records and cited references) for subsequent analyses.

2.3 | Data Analysis and Visualization

We used Microsoft Excel to count annual publications and identify the annual growth in this field. Additionally, we pinpointed the 10 most productive countries, institutions, journals, and authors using Microsoft Excel. For network analysis, we employed VOSviewer software (version 1.6.19) to identify and visualize coauthorship networks among institutions and countries, as well as the most commonly used keywords and their co-occurrences in this domain [25–27]. Furthermore, we utilized the Bibliometrix R package (version 4.2.1) to analyze the basic characteristics of publications and to identify trending topics [28].

3 | Results

We initially identified 399 documents. Exclusions were made for 17 documents that were letters, editorial materials, or book chapters. Additionally, three documents were excluded because they were published in non-English languages: Chinese, Russian, and Turkish. Upon reviewing titles and abstracts for relevance to the inclusion criteria, 191 documents were further excluded. Consequently, 188 documents met the criteria and were included in our study.

3.1 | Overview of AI-Related Research Publications in ROP

Table 1 summarizes general information of AI in research publications on ROP from the WoS database. Between 2010 and 2023, we identified 188 documents spanning 96 sources. The publication types comprised 89 original articles (47.34%), 42 meeting abstracts (22.34%), 25 proceedings papers (13.29%), and 32 review articles (17.02%). These works were authored by 787 contributors, with only 4 documents (2.12%) authored individually. The mean number of co-authors per document was 7.62, with a median number of co-authors of 7 (IQR: 4–11). The number of co-authors per document ranged from a minimum of 1 to a maximum of 46.

TABLE 1 | The basic characteristics of publications.

General information on AI in ROP research publications	
Timespan	2010:2023
Sources	96
Documents	188
Annual growth rate %	32.29
Document average age	2.34
Average citations per doc	15.43
References	4796
Document contents	
Keywords Plus (ID)	301
Author's Keywords (DE)	335
Authors	
Authors	787
Authors of single-authored docs	3
Authors collaboration	
Single-authored docs	4
Co-authors per Doc	7.62
International co-authorships %	37.77
Document types	
Article	89
Meeting abstract	32
Proceedings paper	25
Review	42

3.2 | Annual Publications and Trends

Figure 1 illustrates the number of annual publications and highlights the trend in AI-related research on ROP from 2010 to 2023. Since the first publication on AI in ROP in 2010, there were fewer than 5 related studies annually until 2017. However, in 2018, the number of studies sharply increased to 11, and it has continued to rise steadily, reaching 35 by 2020. In recent years, the annual output has consistently remained high, nearing nearly 40 publications per year.

3.3 | Top 10 Authors, Countries/Regions, Institutions, and Sources That Contributed the Most to ROP AI Publications

Table 2 details the leading figures in ROP AI research, including authors, countries, institutions, and journals. The analysis reveals that the most prolific author is Michael F. Chiang, with 60 publications. The United States stands as the country with the highest number of publications, totaling 98. Oregon Health & Science University leads the institutional contributions with 66 publications. The journal with the most published articles in this field is Investigative Ophthalmology & Visual Science, with 29 articles.

3.4 | Coauthorship Networks Among Institution and Country

In Vosviewer, coauthorship networks depict collaborations among authors, institutions, and countries. Nodes represent

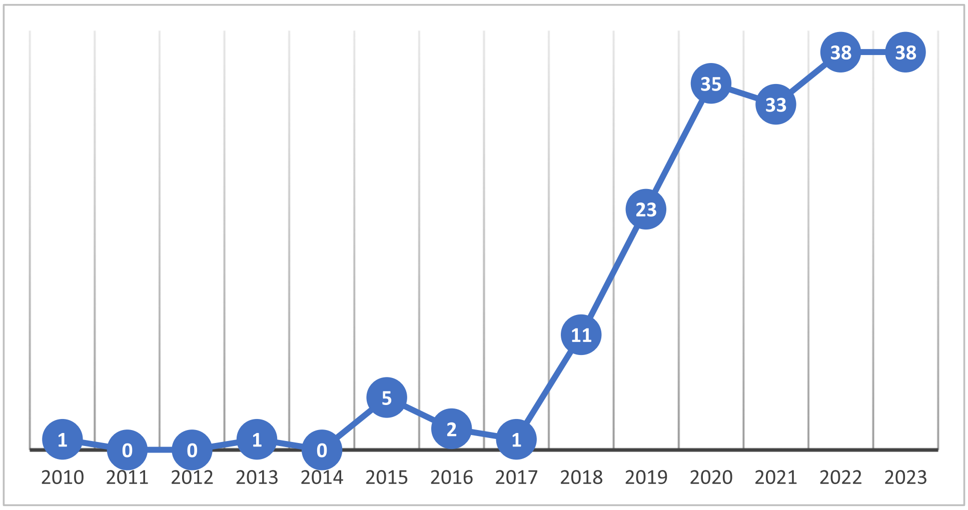

FIGURE 1 | Distribution of publications by year.

TABLE 2 | Top 10 authors, countries, institutions, and sources.

Rank	Author	Article count	Country/Region	Article count	Institution	Article count	Source	Article count
1	Chiang, Michael F.	60	USA	98	Oregon Health & Science University	66	Investigative Ophthalmology & Visual Science	29
2	Campbell, J. Peter.	55	People of China	39	University of Illinois	49	Jama Ophthalmology	8
3	Kalpathy-Cramer, Jayashree.	52	India	34	Massachusetts General Hospital	39	Translational Vision Science & Technology	8
4	Chan, R. V. Paul.	46	England	18	Northeastern University	25	Ieee Iccess	6
5	Ostmo, Susan.	41	South Korea	15	National Eye Institute	24	Ophthalmology Retina	6
6	Erdogmus, Deniz.	23	Singapore	11	Brigham and Women's Hospital	20	British Journal of Ophthalmology	4
7	Brown, James M.	22	Australia	7	Harvard Medical School	18	Current Opinion in Ophthalmology	4
8	Singh, Praveer.	22	Taiwan	7	Jinan University	10	Ophthalmology	4
9	Coyner, Aaron S.	16	Canada	6	Sungkyunkwan University	9	Ophthalmology Science	4
10	Ioannidis, Stratis	14	Nepal	6	University of Lincoln	9	Progress in Retinal and Eye Research	4

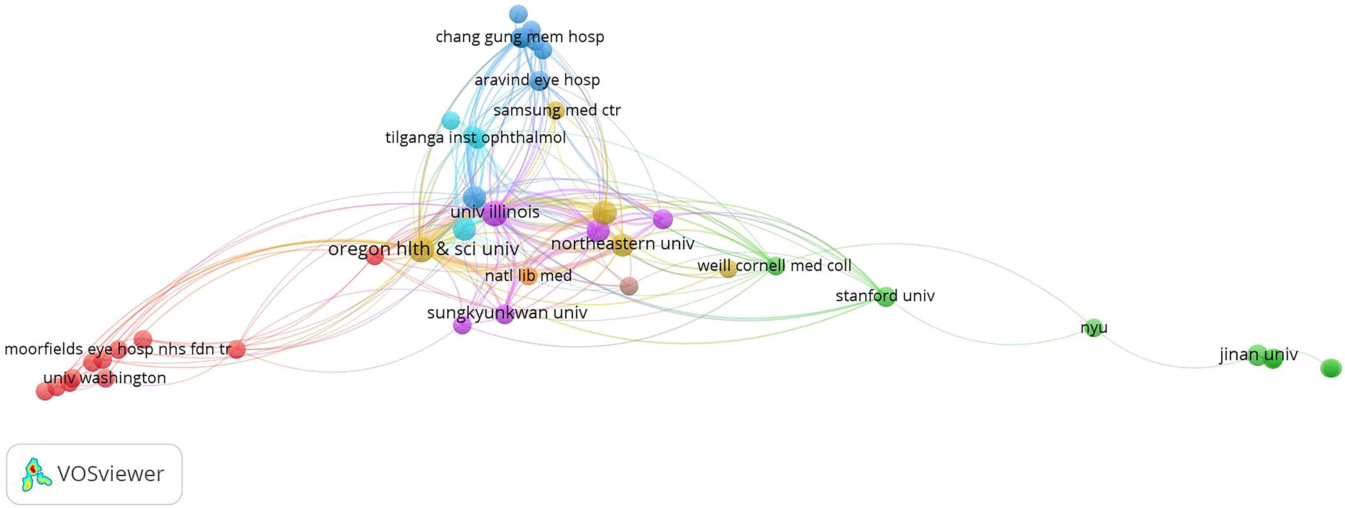

FIGURE 2 | The coauthorship network of institutions that contributed to AI research in ROP.

these entities and are scaled by publication output, with larges nodes indicating higher productivity. Curved lines denote collaborations, with wider lines indicating stronger ties. VOSviewer automatically clusters closely collaborating entities, distinguishing them with different colors.

Figure 2 illustrates coauthorship collaborations among institutions. In the institution coauthorship network, 55 out of 354 have published three or more papers. The most extensive network includes 43 institutions divided into eight clusters. Oregon Health & Science University leads in collaboration, with 66 articles, involvement in four clusters, 33 links, and a total link strength of 255 (Figure 3).

For country-level coauthorship, 21 out of 47 countries or regions have each published at least 3 papers. The most comprehensive collaborative network involves 21 countries or regions, organized into 5 clusters. The USA is at the forefront of this network with 98 articles, participation in 3 clusters, 19 links, and a total link strength of 85 (Figure 3).

3.5 | Co-Occurrence of Author Keywords

Table 3 lists the top 10 most frequently occurring author keywords in these documents, highlighting a blend of clinical and technical focus areas. Clinically oriented keywords such as "retinopathy of prematurity," "retina," "diabetic retinopathy," and "plus disease" were most common. On the technical side, "artificial intelligence," "deep learning," "machine learning," "telemedicine," and "fundus image" were predominant. The primary research trends in AI for ROP were determined through a co-occurrence analysis of these author keywords.

We analyzed the author keywords that appeared more than twice across 188 publications, merging synonyms (e.g., retinopathy of prematurity and ROP). Out of 335 author keywords, 33 valid keywords were selected for analysis. These keywords were grouped into 7 clusters based on their co-occurrence frequency, forming a network of keywords with 166 links. Figure 4 visualizes this network of 33 author keywords.

3.6 | Trend Topics in AI-Related Research on ROP

Figure 5 presents the evolution of trend topics in AI-related research on ROP from 2010 to 2023. We used a minimum frequency threshold of 3 and presented the top two keywords for each year. The size of each dot represents the frequency of the keywords, while its location indicates the year with the highest frequency. The horizontal line shows the duration over which the keywords maintain the minimum frequency threshold. This analysis enables researchers to discern the most dominant themes and observe the shifting relevance of various topics, thus shedding light on the field's evolution and identifying areas ripe for future exploration. It has been noted that the most frequent topics are "retinopathy of prematurity," "artificial intelligence," "deep learning," "machine learning," and "prematurity." While "feature selection" was the most popular topic in the early years, "fundus images" and "deep learning" have become popular in recent years.

4 | Discussion

In the realm of ophthalmic conditions, AI research in ROP is less extensive compared to other ocular diseases. One primary reason is the prevalence; ROP affects a smaller, more specific group - premature infants - unlike the broader adult populations impacted by diabetic retinopathy and glaucoma [29]. Consequently, AI research in ROP receives less investment and attention due to these limited resources and the condition's relative rarity [30]. Another significant factor is the requirement of large datasets for AI algorithm training and validation. Gathering such extensive data for ROP is challenging, both because of the smaller patient population and the stringent ethical and legal considerations involved in research with infants, particularly those in intensive care [31–33]. These constraints on data collection and the pace of research are not exclusive to ROP but are also evident in AI studies related to other pediatric conditions like strabismus [34]. Compared with other fields [35, 36], our study found a

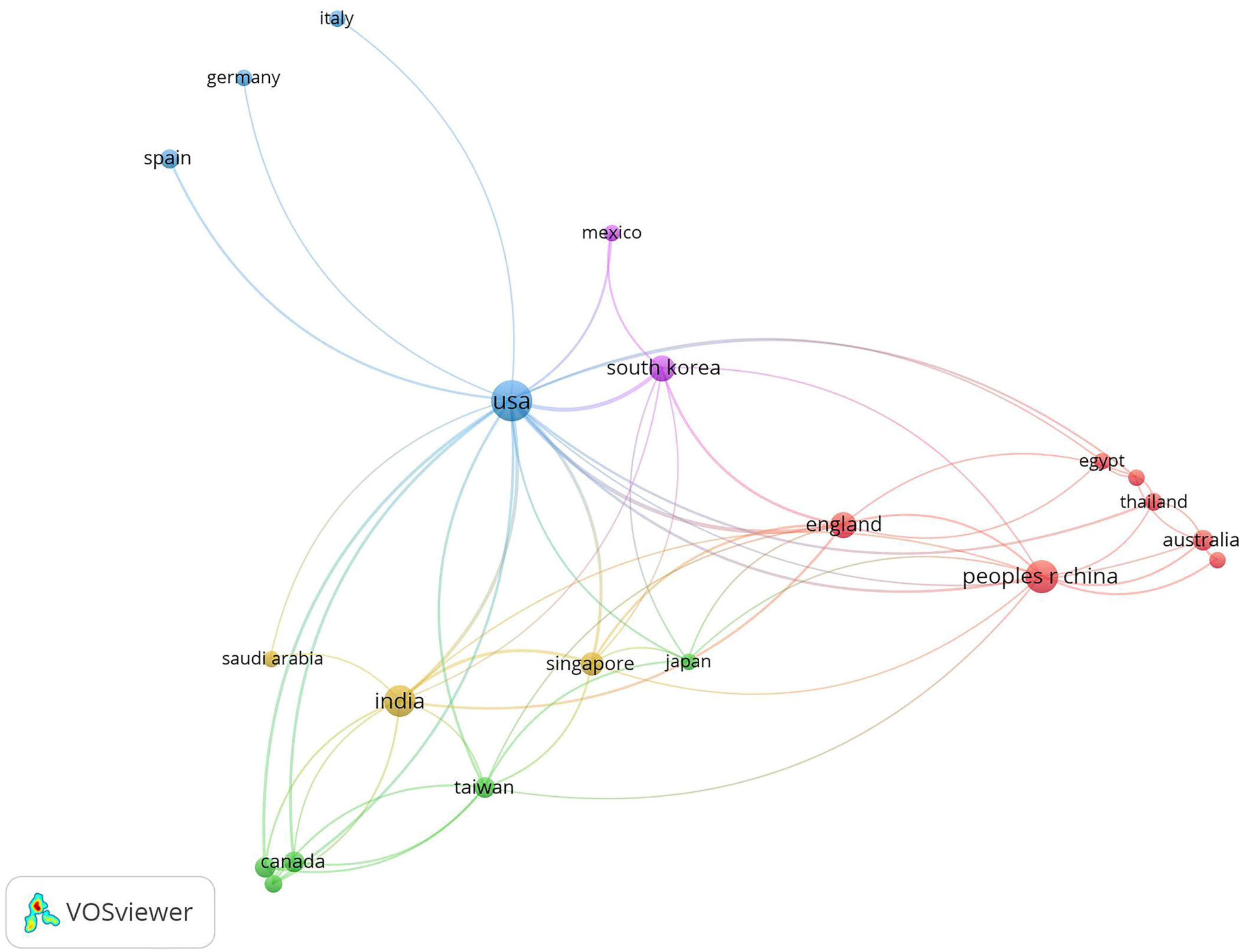

FIGURE 3 | The coauthorship network of countries that contributed to AI research in ROP.

TABLE 3 | Top 10 author keywords for AI in ROP.

Rank	Author keyword	Occurrences
1	Retinopathy of prematurity	84
2	Artificial intelligence	48
3	Deep learning	41
4	Machine learning	28
5	Retina	12
6	Telemedicine	12
7	Diabetic retinopathy	10
8	Fundus image	10
9	Plus disease	9
10	Ophthalmology	7

higher prevalence of multi-authored publications. This is likely due to the interdisciplinary nature of AI-related ROP research, which requires expertize from both medical and technological fields, leading to contributions from authors across various disciplines.

The annual growth trend in AI-related research on ROP from 2010 to 2023 demonstrates a significant increase, marking a transition from initial exploration to a more mature phase of continuous and robust academic output. This trend may be attributed to the increasing recognition of AI technology's potential applications in ophthalmology over the past decade, which has garnered growing attention from scholars. Concurrently, the increasing availability of comprehensive patient data, including widefield fundus images and clinical information, has provided a rich foundation for expanding AI research in ROP [37].

Of the 188 papers included in this study, 98 were from the United States. Additionally, 8 of the top 10 contributing institutions and 9 of the top 10 authors were based in the United States, highlighting the country's dominance in ROP AI-related research. The success of cross-institutional collaboration within i-ROP consortium, led by Oregon Health & Science University, is likely a key factor in the United States' leadership in this area. However, despite the i-ROP group's numerous cross-border collaborations and multi-ethnic studies in developing countries, the principal investigators are predominantly from developed countries like the United States. Considering that researchers

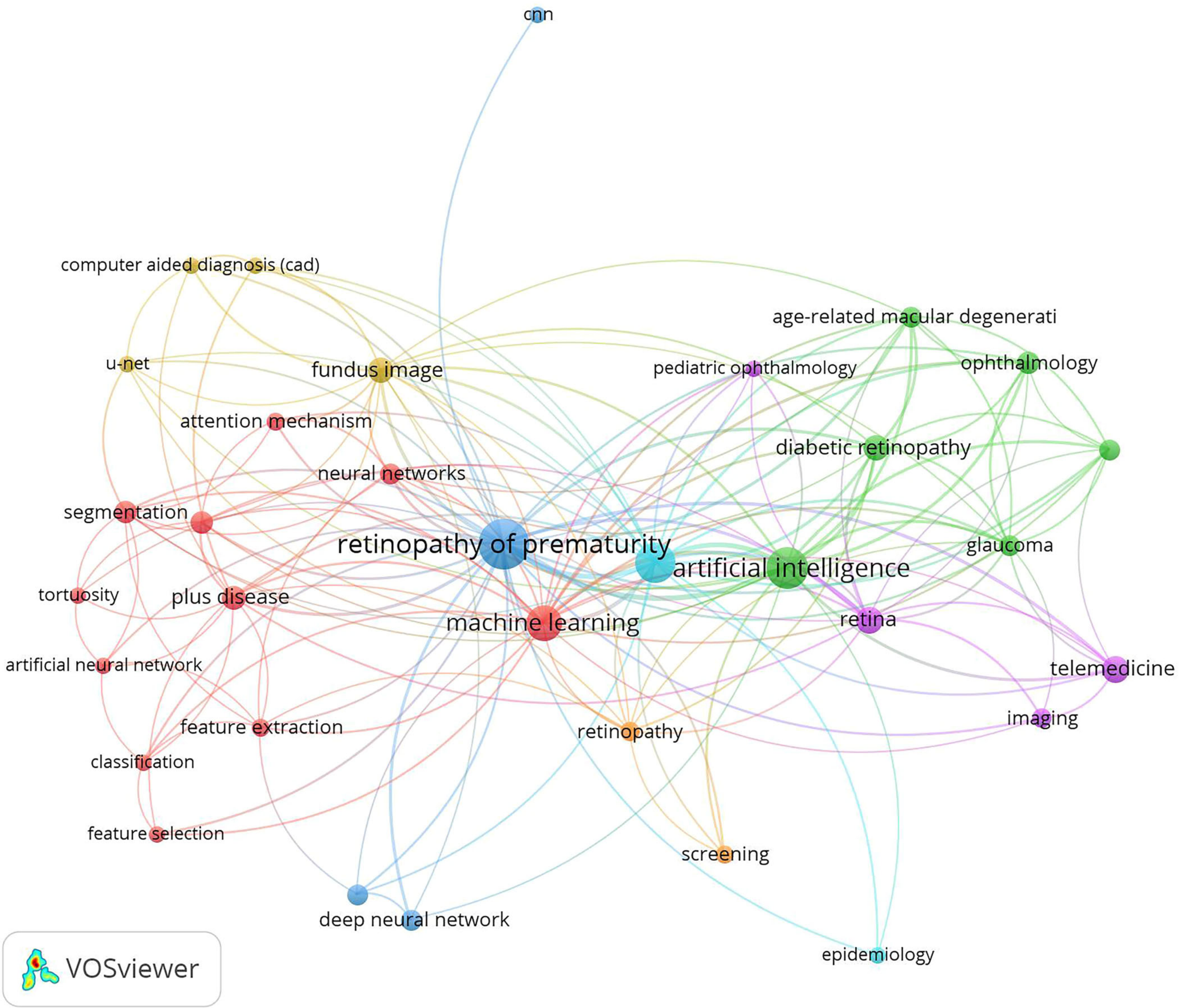

FIGURE 4 | Author keywords analysis network map.

from developing countries often possess better insights into local challenges, needs, and cultural contexts, their potential as principal investigators or leaders could significantly impact the relevance and outcomes of ROP-related research in those regions.

Clinicians are increasingly recognizing AI as a valuable potential tool to reduce the screening workload for ophthalmologists and neonatologists, and to enhance the management of ROP [37]. In addition to the high-frequency author keywords such as artificial intelligence and ROP, other frequently mentioned terms in our analysis included deep learning, machine learning, telemedicine, and fundus images. As a subset of AI, machine learning encompasses a range of technologies and algorithms designed to enable systems to recognize patterns, make informed decisions, and enhance their own performance over time by leveraging experience and data [38]. Deep learning, a more complex branch of machine learning, employs multi-layered neural networks to efficiently analyze intricate data, proving especially effective in image-based applications by learning from vast amounts of unstructured data [39]. In recent years, a significant shift has occurred in the application of AI, moving from machine learning methods that rely on user-defined feature extraction to deep learning algorithms, notably those exemplified by convolutional neural networks [8]. AI technology, particularly when based on deep learning models, shows high potential for screening, diagnosing, and monitoring ROP with notable accuracy [8, 18, 40–42]. Fundus images play a pivotal role in AI research related to ROP. They are essential for training AI models and are a key factor in the burgeoning growth of telemedicine in this field. These images not only provide a rich data set for model development but also facilitate enhanced remote diagnostic capabilities [11, 43–46]. Additionally, in ROP research, the development of collaborative edge cloud telemedicine systems based on deep learning offers a viable solution to address the shortage and uneven distribution of medical resources, particularly in rural areas [47]. Furthermore, remote digital fundus imaging through telemedicine plays a significant role in reducing the increasing burden of ROP screening on healthcare systems [48].

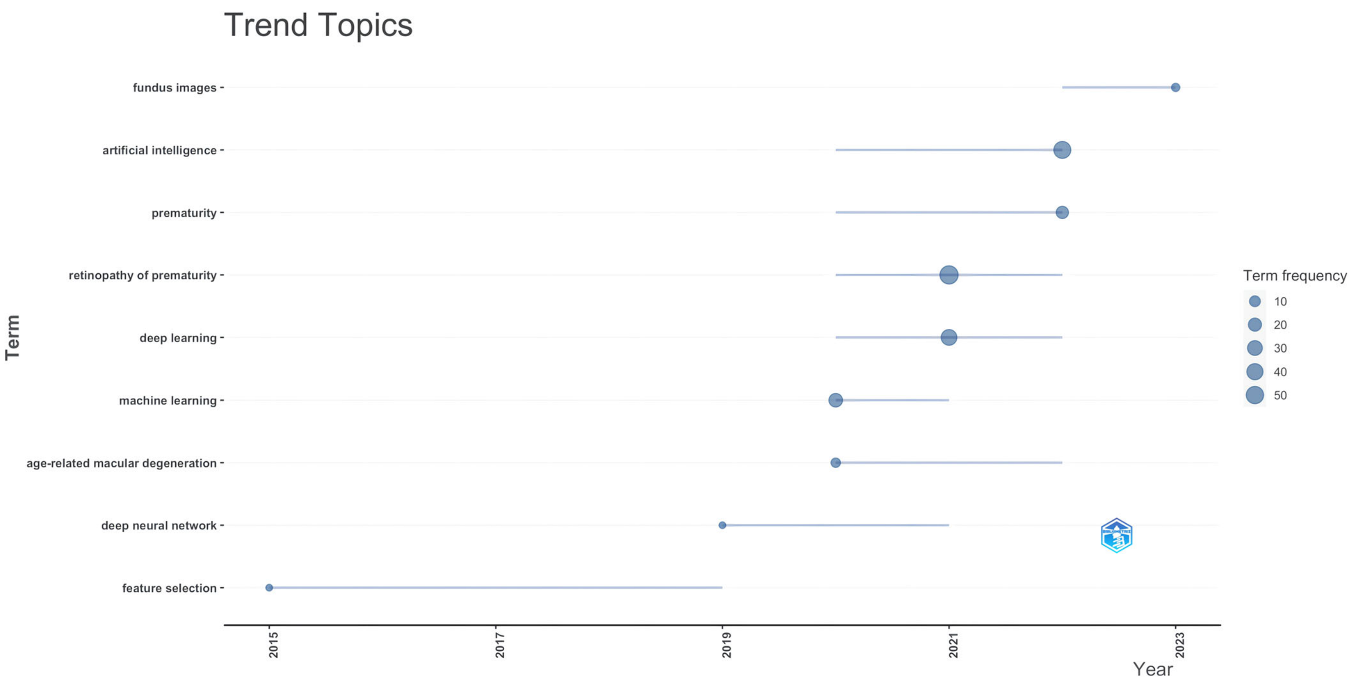

FIGURE 5 | Trending topics in AI-related research on ROP.

The analysis of trend topics indicates that the field is advancing toward increasingly sophisticated technologies and methodologies. In the early stages, the topics, such as "feature selection," focused on aiming to improve model performance by reducing dimensionality, enhancing interpretability, and potentially speeding up computation [49, 50]. With advancements in AI technology, current trends have shifted towards "deep learning, machine learning, and fundus images." Notably, "deep learning" emerged as a specialized branch of "machine learning," demonstrating exceptional capabilities in image recognition tasks, which are essential for diagnosing ROP from fundus images [11, 41]. However, it is important to recognize that current AI primarily serves as a potential adjunct tool and is not yet capable of fully replacing professionals in managing ROP [37]. The integration of AI in this field, through the use of machine learning and deep learning techniques, faces challenges. These include ensuring the generalizability and explainability of AI models, as well as overcoming technical and clinical obstacles [51].

5 | Limitations

To our knowledge, this study represents the first bibliometric analysis focusing on AI in the context of ROP. However, it is important to acknowledge certain limitations. First, our analysis was confined to articles from a single database, WoS. Although WoS is a comprehensive database offering a wide array of publication indicators ideal for bibliometric analysis, future studies could benefit from incorporating additional databases such as Scopus and PubMed to capture a broader spectrum of articles. Second, this study was limited to literature published in English. Future research could aim to include publications in other languages to broaden the scope and diversity of the articles reviewed.

6 | Conclusion

AI has profoundly influenced ophthalmology, including ROP research, garnering significant interest from researchers and practitioners. Our findings show that the United States is the leading contributor to ROP AI research, with significant collaborations among institutions. AI-related research on ROP has evolved from early efforts focused on improving model performance through dimensionality reduction, enhanced interpretability, and potentially faster computation, to the adoption of increasingly sophisticated technologies and methodologies in recent years. In the future, more researchers from low-or-middle-income countries are encouraged to take part in ROP AI research as major contributors. Future research should evaluate the impact of AI on ROP, addressing challenges such as the clinical implementation of AI models in these regions and ethical concerns related to preterm infants.

Author Contributions

Jing Gao: formal analysis, writing – review and editing, data curation, visualization, methodology, conceptualization, investigation, writing – original draft. **Na Fang:** conceptualization, writing – review and editing, data curation, methodology, investigation, formal analysis, visualization. **Yao Xu:** conceptualization, formal analysis, writing – original draft, writing – review and editing, visualization, methodology.

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Conflicts of Interest

The authors declare no conflicts of interest.

Data Availability Statement

The data that support the findings of this study are available from the corresponding author upon reasonable request. Also, all authors have read and approved the final version of the manuscript. Dr. Yao Xu had full access to all of the data in this study and takes complete responsibility for the integrity of the data and the accuracy of the data analysis.

Transparency Statement

The lead author Yao Xu affirms that this manuscript is an honest, accurate, and transparent account of the study being reported; that no important aspects of the study have been omitted; and that any discrepancies from the study as planned (and, if relevant, registered) have been explained.

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