· Bibliometric Research ·

Systematic bibliometric and visualized analysis of research hotspots and trends on the application of artificial intelligence in glaucoma from 2013 to 2022

Chun Liu[1], Lu-Yao Wang[1], Ke-Yu Zhu[1], Chun-Meng Liu[1], Jun-Guo Duan[2,3]

[1]Eye School of Chengdu University of TCM, Chengdu 610072, Sichuan Province, China
[2]Ineye Hospital of Chengdu University of TCM, Chengdu 610084, Sichuan Province, China
[3]Key Laboratory of Sichuan Province Ophthalmopathy Prevention & Cure and Visual Function Protection with TCM Laboratory, Chengdu 610072, Sichuan Province, China
Correspondence to: Jun-Guo Duan. Ineye Hospital of Chengdu University of TCM; Key Laboratory of Sichuan Province Ophthalmopathy Prevention & Cure and Visual Function Protection with TCM Laboratory, Chengdu 610072, Sichuan Province, China. duanjg@cdutcm.edu.cn
Received: 2023-11-10 Accepted: 2024-05-24

Abstract
● **AIM:** To conduct a bibliometric analysis of research on artificial intelligence (AI) in the field of glaucoma to gain a comprehensive understanding of the current state of research and identify potential new directions for future studies.

● **METHODS:** Relevant articles on the application of AI in the field of glaucoma from the Web of Science Core Collection were retrieved, covering the period from January 1, 2013, to December 31, 2022. In order to assess the contributions and co-occurrence relationships among different countries/regions, institutions, authors, and journals, CiteSpace and VOSviewer software were employed and the research hotspots and future trends within the field were identified.

● **RESULTS:** A total of 750 English articles published between 2013 and 2022 were collected, and the number of publications exhibited an overall increasing trend. The majority of the articles were from China, followed by the United States and India. National University of Singapore, Chinese Academy of Sciences, and Sun Yat-sen University made significant contributions to the published works. Weinreb RN and Fu HZ ranked first among authors and cited authors. *American Journal of Ophthalmology* is the most impactful academic journal in the field of AI application in glaucoma. The disciplinary scope of this field includes ophthalmology, computer science, mathematics, molecular biology, genetics, and other related disciplines. The clustering and identification of keyword nodes in the co-occurrence network reveal the evolving landscape of AI application in the field of glaucoma. Initially, the hot topics in this field were primarily "segmentation", "classification" and "diagnosis". However, in recent years, the focus has shifted to "deep learning", "convolutional neural network" and "artificial intelligence".

● **CONCLUSION:** With the rapid development of AI technology, scholars have shown increasing interest in its application in the field of glaucoma. Moreover, the application of AI in assisting treatment and predicting prognosis in glaucoma may become a future research hotspot. However, the reliability and interpretability of AI data remain pressing issues that require resolution.

● **KEYWORDS:** glaucoma; artificial intelligence; bibliometrics
DOI:10.18240/ijo.2024.09.22

Citation: Liu C, Wang LY, Zhu KY, Liu CM, Duan JG. Systematic bibliometric and visualized analysis of research hotspots and trends on the application of artificial intelligence in glaucoma from 2013 to 2022. *Int J Ophthalmol* 2024;17(9):1731-1742

INTRODUCTION

Glaucoma, as the leading cause of irreversible blindness worldwide, involves the irreversible damage to retinal ganglion cells, resulting in retinal ganglion cells death, visual field defects, and decreased visual function[1]. The estimated global number of glaucoma patients is projected to reach 111 million by 2040[2]. However, the actual severity of the problem could be greater than these numbers suggest, as epidemiological research indicates that approximately 50% of glaucoma cases go undiagnosed[3-4]. This is because glaucoma is a latent disease, and most patients only seek medical attention when they experience visual impairment or even vision loss in the intermediate to late stages of the disease. Additionally, aging is a well-established risk factor for the development of glaucoma, and with the aging population, the severity of the issue is expected to further escalate[5]. Studies have reported that early diagnosis of glaucoma can lower the risk of visual function impairment[6-7]. Timely treatment can help slow down disease progression, maintain visual function, and preserve or enhance long-term quality of life for patients[8]. Currently, the primary methods for diagnosing and monitoring the progression of glaucoma rely on optic disc analysis[9], visual field examinations[10], and optical coherence tomography scans[11]. However, even glaucoma experts achieve only moderate reliability when analyzing optic disc results[12]. Visual field testing can only detect corresponding defects when approximately 40% to 50% of retinal ganglion cells have been damaged[13], and the error rate in recognizing the retinal nerve fiber layer using optical coherence tomography can be as high as 46.3%[14]. In a clinical setting, doctors often have to rely on multiple test results to make an accurate diagnosis, which not only adds burden to patients but also results in redundant examinations and wastage of healthcare resources. Furthermore, there is an unequal distribution of healthcare resources, and there is a limited number of ophthalmologists available[15]. Therefore, achieving the goal of accurately diagnosing early-stage glaucomatous damage and precisely predicting disease progression becomes particularly challenging due to these factors.

Artificial intelligence (AI) may offer assistance in addressing this dilemma. In recent years, AI has experienced rapid advancement in the field of medicine[16-17], and its application in ophthalmology has also been expanding[18-21]. Utilizing AI technology for early screening and diagnosis in glaucoma patients can help reduce the risk of visual function impairment, and it can also predict the progression of glaucoma and design personalized treatment plans to improve patient outcomes[22-23]. The application of AI in glaucoma represents a promising strategy for alleviating the shortage of healthcare resources and reducing screening costs[24]. There has been a growing number of studies published on the application of AI in glaucoma. However, there is currently no literature that systematically evaluates the published relevant articles.

Bibliometric analysis quantitatively analyzes relevant literature in a research field, enabling an understanding of the historical development and current research status in that field, as well as the prediction of future research hotspots and trends[25-26]. Researchers also use bibliometric analysis to evaluate their respective research fields[27-30]. Furthermore, bibliometric analysis supports clinical decision-making and the development of guidelines[31]. Currently, the scientific bibliometric analysis of literature is primarily conducted using CiteSpace and VOSviewer[32-33]. However, to date, there has been no bibliometric research on the application of AI in glaucoma. To address this gap, this study evaluates the literature on the application of AI in glaucoma published from 2013 to 2022. The study aims to describe the current state of this field, summarize the main research clusters and popular research directions, and propose future prospects for this field. This study could provide valuable guidance and reference for scholars in this domain.

MATERIALS and METHODS

Database and Searching Strategy We conducted a search in the SCI-EXPANDED database of the Web of Science Core Collection for literature related to the application of AI in glaucoma from 2013 to 2022. The search was limited to articles written in English and included only articles as the publication type. Two authors (Wang LY and Zhu KY) conducted individual searches for relevant literature in database. To ensure the accuracy of the analysis, they excluded articles that did not meet the aforementioned criteria after reviewing the titles and abstracts of each article. The detailed search strategy can be found in Figure 1. Afterwards, the relevant information of the articles, including titles, abstracts, authors, affiliations, countries or regions, journals, keywords, and references, was downloaded in .txt format. All data used in this study were obtained from publicly available databases.

Data Analysis We utilized Microsoft Office Excel 2019 to process the analysis results and citation reports from database, presenting the number of publications per year, the main countries/regions, institutions, authors, and journals in the form of charts. We condensed the most crucial data from frequently cited articles and presented the research findings in the form of tables. VOSviewer (1.6.19) was employed to explore the collaborative networks of countries/regions and high-frequency keywords. In VOSviewer, the size of each node represents its frequency of appearance, while the thickness of the connections between nodes reflects the strength and closeness of their collaborative relationships. The size of the nodes is determined by their co-occurrence frequency in titles and abstracts. With CiteSpace(6.1.R6), we extracted keywords and references from highly cited publications for visualization analysis and generated dual-map overlays of journals. Consequently, CiteSpace can be employed to investigate research hotspots and trends in a particular field[34]. The parameter settings for CiteSpace were as follows: a time span from 2013 to 2022, a time slice set to 1y, a threshold set to n=50. For data processing steps, we utilized Pathfinder, pruning, and merging to simplify minor connections, while keeping the remaining parameters as default settings.

RESULTS

Growth Trends of Publications The number of research papers published in different periods reflects the popularity and development trends of research in a particular field. According to the retrieval strategy and screening process, we

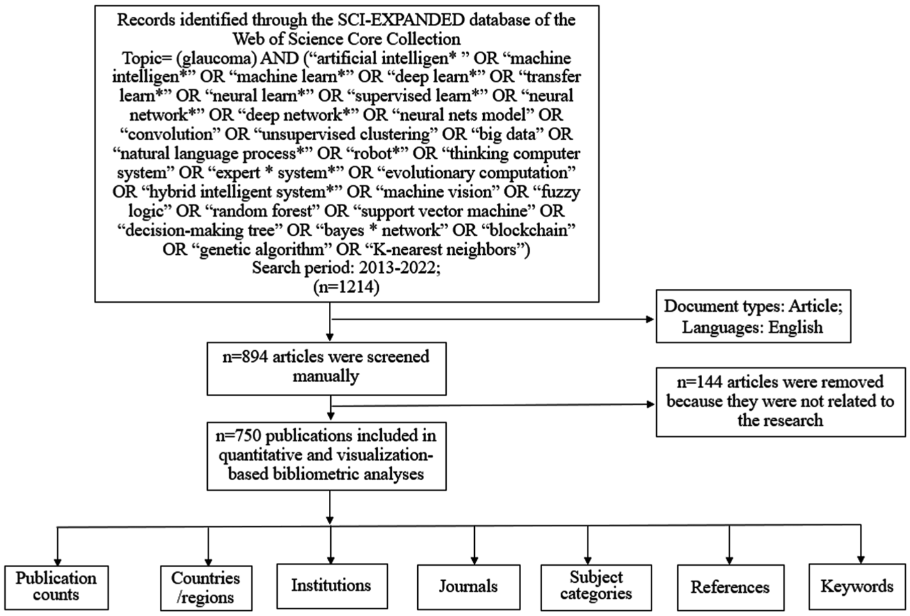


Figure 1 Detailed selection criteria and framework of bibliometric analysis steps for studying the application of AI in glaucoma research in the SCI-EXPANDED database of the Web of Science Core Collection AI: Artificial intelligence.

collected a total of 750 relevant articles on the application of AI in glaucoma research from database from 2013 to 2022. As shown in Figure 2, the number of research papers on the application of AI in glaucoma research has been steadily increasing since 2018. It reached its peak in 2021, with a total of 195 articles published throughout the year, and by fitting the data, we found a statistically significant relationship between the year and the number of articles (R^2=0.94459).

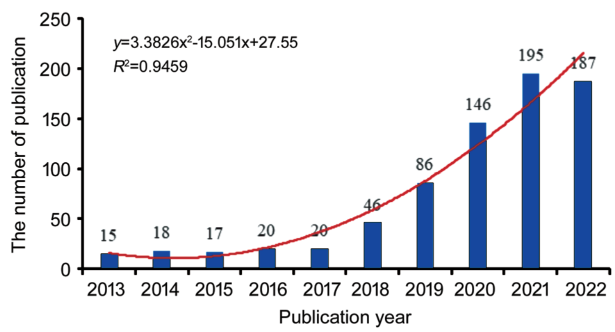


Figure 2 Annual number of publications on the application of AI in glaucoma from 2013 to 2022 AI: Artificial intelligence.

Contribution of Countries/Regions These citations cover a total of 68 countries or regions. The collaboration relationships between countries and regions were analyzed using the default settings of CiteSpace software. The size of each label and node area in Figure 3 represents the number of publications from each country/region. The top three countries or regions are China (196 articles), the United States (194 articles), and India (152 articles). The connections between nodes represent the collaboration relationships between different countries or regions, with more lines indicating more extensive collaborations between countries or regions. The centrality of nodes is a measure of their centrality. Generally, nodes with a centrality value greater than 0.1 indicate a connection with a large number of other nodes and hold important positions within the network. These hub nodes are depicted as purple circles and represent countries or regions with significant influence. The United Kingdom has the highest centrality (0.28), indicating that articles on the application of AI in glaucoma research published by the United Kingdom have the greatest overall impact. It is followed by India (0.27) and the United States (0.23). In general, China has the highest number of articles, while the United Kingdom has the greatest impact.

Figure 3 Cooperation of countries or regions that contributed to publications on the use of AI for glaucoma from 2013 to 2022 AI: Artificial intelligence.

Contribution of Institutions A total of 310 institutions have actively contributed to the application of AI in glaucoma research. The top 10 institutions in terms of the number of published articles were presented in Table 1, including 3

Table 1 Top 10 institutions with publications on the use of AI in glaucoma from 2013 to 2022

Rank	Institution	Count	Centrality	Countries/regions
1	National University of Singapore	36	0.13	Singapore
2	Chinese Academy of Sciences	29	0.03	China
3	Sun Yat-sen Univeity	26	0.09	China
4	University of California San Diego	25	0.09	United States
5	Singapore National Eye Center	24	0.15	Singapore
6	University of Tokyo	22	0.07	Japan
7	Harvard Medical School	21	0.07	United States
8	Columbia University	20	0.08	United States
9	Ngee Ann Polytechnic	20	0.06	Singapore
10	Capital Medical University	20	0.04	China

AI: Artificial intelligence.

Table 2 The top 10 authors and cited authors involved in research on the use of AI in glaucoma from 2013 to 2022

Rank	Author	Count	Cited author	Count
1	Weinreb, RN	20	Fu HZ	230
2	Aung, Tin	19	Quigley HA	227
3	Asaoka, Ryo	19	Acharya UR	220
4	Medeiros, FA	18	Cheng J	180
5	Murata, Hiroshi	17	Medeiros FA	142
6	Bowd, Christopher	16	Tham YC	142
7	Acharya, UR	15	Asaoka R	136
8	Elze, Tobias	15	Jonas JB	135
9	Li, Fei	14	He KM	132
10	Zangwill, LM	14	Ting DSW	132

AI: Artificial intelligence.

Table 3 Top 10 journals of publications on the use of AI in glaucoma from 2013 to 2022

Rank	Citing journals	Research fields	Count	IF (2022)
1	*Translational Vision Science & Technology*	Medicine/ophthalmology	40	3.0
2	*Scientific Reports*	Comprehensive journal	36	4.6
3	*American Journal of Ophthalmology*	Medicine/ophthalmology	26	4.2
4	*Plos One*	Comprehensive journal	25	3.7
5	*Ophthalmology*	Medicine/ophthalmology	24	13.7
6	*Biomedical Signal Processing and Control*	Engineering technology/engineering: biomedicine	21	5.1
7	*IEEE Access*	Engineering technology/computer: information system	20	3.9
8	*Multimedia Tools and Applications*	Engineering technology/computer: information system	18	3.6
9	*Journal of Glaucoma*	Medicine/ophthalmology	18	2.0
10	*British Journal of Ophthalmology*	Medicine/ophthalmology	18	4.1

AI: Artificial intelligence; IF: Impact factor in Journal Citation Reports.

institutions from Singapore (National University of Singapore, Singapore National Eye Centre, and Ngee Ann Polytechnic), 3 institutions from China (Chinese Academy of Sciences, Sun Yat-sen University, and Capital Medical University), 3 institutions from the United States (University of California San Diego, Harvard Medical School, and Columbia University), and one institution from Japan (University of Tokyo). The three leading institutions are the National University of Singapore, the Chinese Academy of Sciences, and Sun Yat-sen University, with 36, 29, and 26 articles respectively. It has been observed that research institutions in this field generally have low centrality. The Singapore National Eye Centre and the National University of Singapore were notable for their high centrality values, with centrality values of 0.15 and 0.13 respectively. This indicates the vital roles played by the Singapore National Eye Centre and the National University of Singapore in utilizing AI for glaucoma research.

Analysis of Authors and Cited Authors Table 2 provides a summary of the top 10 prolific authors and the top 10 cited authors. Weinreb RN, Aung Tin, and Asaoka Ryo were the top three authors in terms of publication output, with 20, 19, and 19 papers published, respectively. The top 10 authors in terms of publication output have collectively published 167 papers, which accounts for 22.3% of the total publication output. Fu HZ, Quigley HA, and Acharya UR were the top three cited authors with a total citation count of 230, 227, and 220, respectively. By comparing the rankings of authors and cited authors in Table 2, we observed that Asaoka Ryo, Medeiros FA, and Acharya UR had high rankings in both publication output and citation frequency, which suggests that these three authors have made significant contributions to the development of AI in glaucoma research.

Analysis of Journals and cited Journals Table 3 illustrated the ten journals with the highest number of published research articles in the field from 2013 to 2022. We can observe that the top three journals with the highest publication volume were *Translational Vision Science & Technology* (n=40, 5.3%), *Scientific Reports* (n=36, 4.8%), and *American Journal of Ophthalmology* (n=26, 3.5%).

Figure 4 depicts a dual map overlay of journals, showcasing the citing journals on the left and the cited journals on the right. The labels indicate the subjects covered by each journal. We use it to represent the disciplinary distribution of journals involved in AI research on glaucoma. It provides a

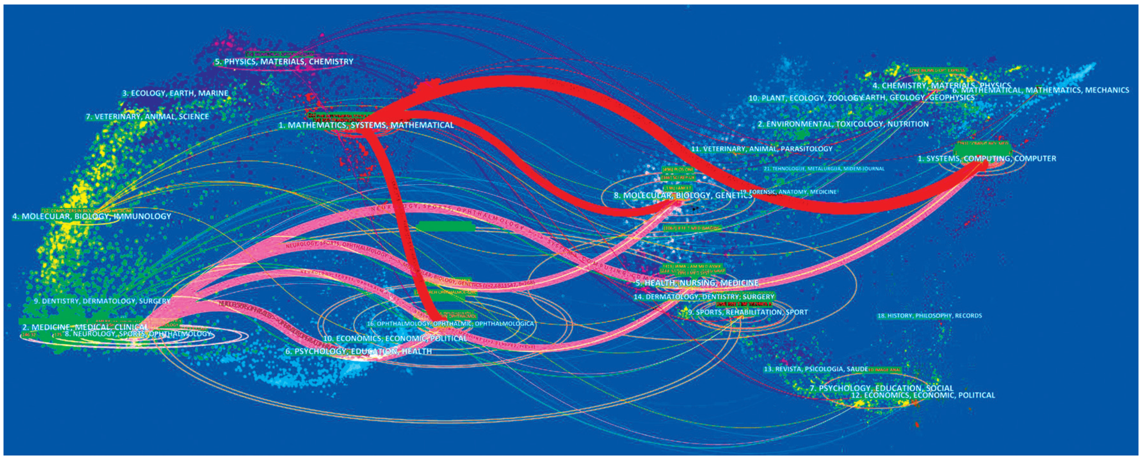


Figure 4 Dual map overlay of journals that contributed to publications on the use of AI in glaucoma from 2013 to 2022 AI: Artificial intelligence.

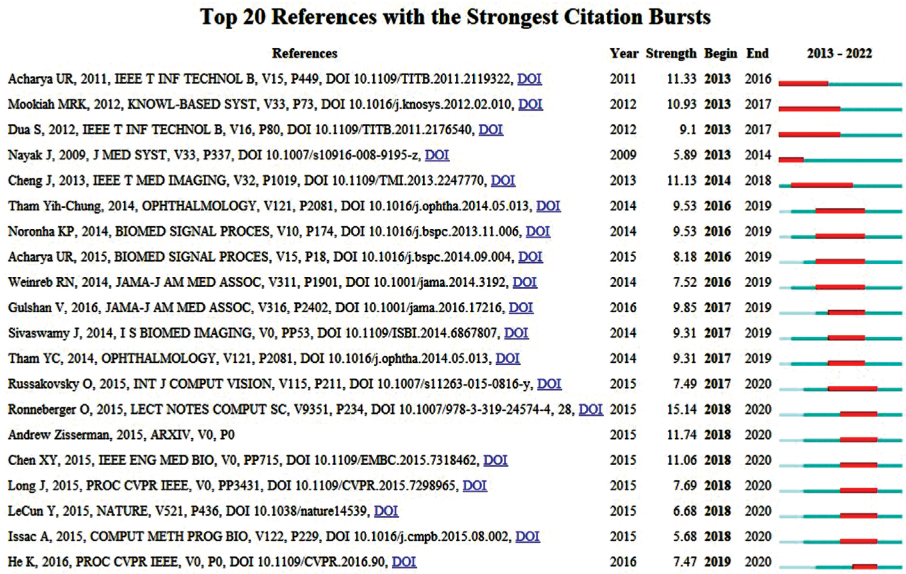
Table 4 Top 10 most cited references on the application of the use of AI in glaucoma from 2013 to 2022

Rank	Cited reference	Citation	Year	Journal	First author
1	Efficacy of a deep learning system for detecting glaucomatous optic neuropathy based on color fundus photographs[36]	108	2018	*Ophthalmology*	Li Z
2	Joint optic disc and cup segmentation based on multi-label deep network and polar transformation[37]	97	2018	*IEEE Transactions on Medical Imaging*	Fu H
3	Deep convolution neural network for accurate diagnosis of glaucoma using digital fundus images[38]	78	2018	*Information Sciences*	Raghavendra U
4	Development and validation of a deep learning system for diabetic retinopathy and related eye diseases using retinal images from multiethnic populations with diabetes[39]	76	2017	*Jama-Journal of The American Medical Association*	Ting DSW
5	Development and validation of a deep learning algorithm for detection of diabetic retinopathy in retinal fundus photographs[40]	74	2016	*Jama-Journal of The American Medical Association*	Gulshan V
6	Performance of deep learning architectures and transfer learning for detecting glaucomatous optic neuropathy in fundus photographs[41]	72	2018	*Scientific Reports*	Christopher M
7	Refuge challenge: a unified framework for evaluating automated methods for glaucoma assessment from fundus photographs[42]	69	2020	*Medical Image Analysis*	Orlando JI
8	Glaucoma detection using entropy sampling and ensemble learning for automatic optic cup and disc segmentation[43]	65	2017	*Computerized Medical Imaging and Graphics*	Zilly J
9	CNNs for automatic glaucoma assessment using fundus images: an extensive validation[44]	55	2019	*Biomedical Engineering Online*	Diaz-Pinto A
10	Development of a deep residual learning algorithm to screen for glaucoma from fundus photography[45]	53	2018	*Scientific Reports*	Shibata N

AI: Artificial intelligence.

clear understanding of the knowledge flow between various disciplines and highlights the frontiers and hotspots within each discipline. The colored lines from left to right represent citation paths. The three red citation paths demonstrate that research from systems, computing, computer journals, molecular, biology, genetics journals, and ophthalmology, ophthalmic, ophthalmological journals are frequently cited by research from mathematics, systems, mathematical journals. The four pink citation paths illustrate that research from systems, computing, computer journals, molecular, biology, genetics journals, health, nursing, medicine journals, and ophthalmology, ophthalmic, ophthalmological journals are frequently cited by research from neurology, sports, ophthalmology journals.

Analysis of References and Co-cited References When two publications are co-cited by a third citing publication, this is referred to as a co-citation relationship[35]. The more times a literature is cited, the more significant it is considered in a specific field. Therefore, the most frequently cited publications or highly influential articles can be considered as the knowledge foundation and primary focus of researchers in a field. Table 4 lists the top 10 cited papers[36-45], and the most frequently cited paper is a publication by Li *et al*[36] in 2018, which presented a deep learning algorithm for detecting referable glaucomatous optic disc neuropathy in color fundus photographs and showed that the algorithm had high sensitivity and specificity. This paper had been cited 108 times. The second most cited paper is a study by Fu *et al*[37] in 2018, which investigated optic disc and cup segmentation. The study proposed an M-Net deep learning architecture that combined multi-label deep networks and polar coordinate transformation to address the segmentation problem of the optic disc and cup. The study achieved satisfactory glaucoma screening results and has been cited 97 times. The third most cited paper is an article


Top 20 References with the Strongest Citation Bursts

References	Year	Strength	Begin	End	2013 - 2022
Acharya UR, 2011, IEEE T INF TECHNOL B, V15, P449, DOI 10.1109/TITB.2011.2119322, DOI	2011	11.33	**2013**	2016	
Mookiah MRK, 2012, KNOWL-BASED SYST, V33, P73, DOI 10.1016/j.knosys.2012.02.010, DOI	2012	10.93	**2013**	2017	
Dua S, 2012, IEEE T INF TECHNOL B, V16, P80, DOI 10.1109/TITB.2011.2176540, DOI	2012	9.1	**2013**	2017	
Nayak J, 2009, J MED SYST, V33, P337, DOI 10.1007/s10916-008-9195-z, DOI	2009	5.89	**2013**	2014	
Cheng J, 2013, IEEE T MED IMAGING, V32, P1019, DOI 10.1109/TMI.2013.2247770, DOI	2013	11.13	**2014**	2018	
Tham Yih-Chung, 2014, OPHTHALMOLOGY, V121, P2081, DOI 10.1016/j.ophtha.2014.05.013, DOI	2014	9.53	**2016**	2019	
Noronha KP, 2014, BIOMED SIGNAL PROCES, V10, P174, DOI 10.1016/j.bspc.2013.11.006, DOI	2014	9.53	**2016**	2019	
Acharya UR, 2015, BIOMED SIGNAL PROCES, V15, P18, DOI 10.1016/j.bspc.2014.09.004, DOI	2015	8.18	**2016**	2019	
Weinreb RN, 2014, JAMA-J AM MED ASSOC, V311, P1901, DOI 10.1001/jama.2014.3192, DOI	2014	7.52	**2016**	2019	
Gulshan V, 2016, JAMA-J AM MED ASSOC, V316, P2402, DOI 10.1001/jama.2016.17216, DOI	2016	9.85	**2017**	2019	
Sivaswamy J, 2014, I S BIOMED IMAGING, V0, PP53, DOI 10.1109/ISBI.2014.6867807, DOI	2014	9.31	**2017**	2019	
Tham YC, 2014, OPHTHALMOLOGY, V121, P2081, DOI 10.1016/j.ophtha.2014.05.013, DOI	2014	9.31	**2017**	2019	
Russakovsky O, 2015, INT J COMPUT VISION, V115, P211, DOI 10.1007/s11263-015-0816-y, DOI	2015	7.49	**2017**	2020	
Ronneberger O, 2015, LECT NOTES COMPUT SC, V9351, P234, DOI 10.1007/978-3-319-24574-4, 28, DOI	2015	15.14	**2018**	2020	
Andrew Zisserman, 2015, ARXIV, V0, P0	2015	11.74	**2018**	2020	
Chen XY, 2015, IEEE ENG MED BIO, V0, PP715, DOI 10.1109/EMBC.2015.7318462, DOI	2015	11.06	**2018**	2020	
Long J, 2015, PROC CVPR IEEE, V0, PP3431, DOI 10.1109/CVPR.2015.7298965, DOI	2015	7.69	**2018**	2020	
LeCun Y, 2015, NATURE, V521, P436, DOI 10.1038/nature14539, DOI	2015	6.68	**2018**	2020	
Issac A, 2015, COMPUT METH PROG BIO, V122, P229, DOI 10.1016/j.cmpb.2015.08.002, DOI	2015	5.68	**2018**	2020	
He K, 2016, PROC CVPR IEEE, V0, P0, DOI 10.1109/CVPR.2016.90, DOI	2016	7.47	**2019**	2020	

Figure 5 The top 20 references with the strongest citation bursts on the use of AI for glaucoma from 2013 to 2022 AI: Artificial intelligence.

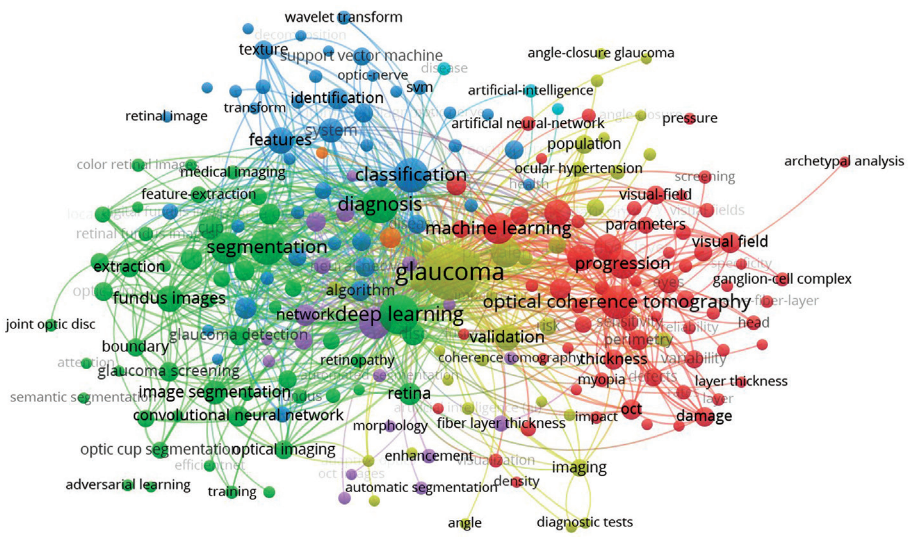


Figure 6 A network map of keywords on the use of AI in glaucoma from 2013 to 2022 AI: Artificial intelligence.

by Raghavendra *et al*[38] in 2018, which introduced a novel computer-aided diagnostic tool for precise glaucoma detection using deep learning techniques. The system demonstrates robustness and can serve as a supplementary tool for clinical decision validation by healthcare professionals[38], and it has been cited 78 times.

In order to effectively identify the research frontier, we utilized CiteSpace to identify references with citation bursts. We constructed a citation burst display of the top 20 references, as illustrated in Figure 5. Citation bursts indicate the references that have attracted researchers' interest during a specific time frame. The citation bursts in this study began in 2013 and can be traced back to a publication by Acharya *et al*[46] in 2011. The most recent citation burst was observed in 2019 and persisted until 2020.

Keywords Co-occurrence Analysis Keyword frequency analysis reveals the research hotspots in this study. Table 5 summarizes the top 20 keywords with the highest frequency. Among them, "deep learning", "glaucoma", and "diagnosis" appear over 100 times. The terms "optical coherence tomography", "image", "classification", "optic disc", "segmentation", "machine learning", "prevalence", "progression", "nerve fiber layer", "artificial intelligence", "fundus image", and "neural network" are also frequently mentioned, with occurrences exceeding 50 times. The high-frequency keywords "Deep learning", "glaucoma", "machine learning", "artificial intelligence", and "neural network" align with our research topic. Moreover, "classification" and "segmentation" are the most prominent research directions in the field. "Optical coherence tomography" is commonly employed for examination, while "optic disc" represents a pivotal research focus in this domain. We used VOSviewer to identify and analyze the keywords used in the publications. As shown in Figure 6, the keywords can be categorized into approximately 6 research clusters based on their colors, where each color represents a distinct research cluster.

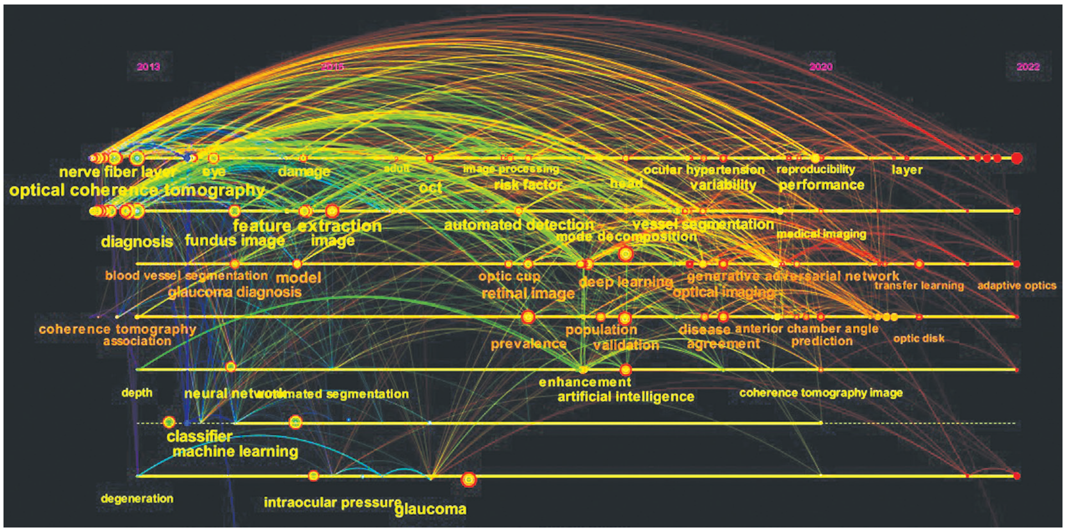


Figure 7 A CiteSpace visualization map of timeline viewer on the use of AI in glaucoma from 2013 to 2022 AI: Artificial intelligence.

Table 5 Top 20 keywords with the highest frequency on the use of AI in glaucoma from 2013 to 2022

Rank	Keyword	Count	Centrality	Rank	Keyword	Count	Centrality
1	Deep learning	146	0.04	11	Progression	62	0.04
2	Glaucoma	126	0.09	12	Nerve fiber layer	58	0.04
3	Diagnosis	105	0.08	13	Artificial intelligence	56	0.03
4	Optical coherence tomography	95	0.1	14	Fundus image	56	0.03
5	Image	88	0.03	15	Neural network	54	0.02
6	Classification	86	0.06	16	Feature	49	0.05
7	Optic disc	83	0.03	17	Open angle glaucoma	49	0.05
8	Segmentation	81	0.03	18	Convolutional neural network	44	0
9	Machine learning	80	0.09	19	Validation	44	0.02
10	Prevalence	65	0.02	20	Feature extraction	43	0.07

AI: Artificial intelligence.

To gain a better understanding of the application of AI in the field of glaucoma over the past 10y, we constructed emerging keywords that evolve over time based on the co-occurrence network analysis of keywords. Figure 7 presents a timeline view, providing a visual representation of the temporal characteristics of research hotspots in this field.

The concept of burst keywords refers to the sudden and frequent citation of specific terms within a certain timeframe, indicating a sharp increase in their occurrence frequency, which may persist for several years. CiteSpace is employed to identify burst keywords, which are considered indicators of research frontiers within a specific timeframe[47]. The blue line represents the time period from 2013 to 2022, while the red sections indicate the burst duration of keywords. As depicted in Figure 8, the top three keywords with the highest burst strength are "artificial neural network", "support vector machine", and "machine learning classifier". This highlights the widespread attention these research topics have garnered in recent years and their potential emergence as new research hotspots in the field of AI in glaucoma in the upcoming years. "Digital fundus image" and "texture" were the keywords with the longest burst

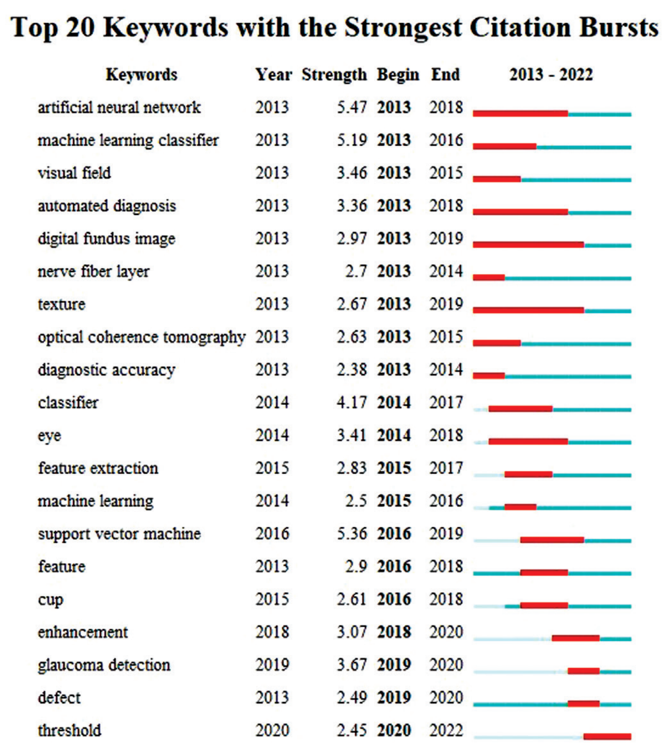


Figure 8 The top 20 keywords with the strongest citation bursts on the use of AI in glaucoma from 2013 to 2022 AI: Artificial intelligence.

duration (2012-2019), whereas "threshold" attains the highest popularity from 2020 to 2022.

DISCUSSION

It is challenging to stay sensitive to research hotspots, keep abreast of the latest research findings, and maintain a leading position in the research field amidst the era of explosive information growth. Bibliometric studies utilize mathematical and statistical tools to assess the interrelations and impact of publications within specific research fields, thereby Figure 8. The top 20 keywords with the strongest citation bursts on the use of AI in glaucoma from 2013 to 2022 providing advantages in summarizing the development of particular research areas and analyzing research hotspots[48-49].

This study provides a comprehensive overview of the application and development of AI in glaucoma through bibliometric analysis, presenting the progress made over the past decade and offering insights into future research hotspots. These findings can assist clinical practitioners and researchers in identifying outstanding authors, institutions, countries, and journals engaged in scholarly activities in this field. They provide a clear direction for AI research in glaucoma, fostering collaboration and communication among authors and institutions. Furthermore, they facilitate interdisciplinary cooperation, particularly in the development of AI and deep learning models, which hold significant and guiding implications for the diagnosis, treatment, and prognosis assessment of glaucoma. Overall, through this study, we aim not only to alleviate patient suffering but also to advance the discipline further.

To a certain extent, the quantity of scientific papers reflects the research development in a specific field. Between 2013 and 2022, the number of publications on AI-based glaucoma has shown an upward trend. In the recent five years, these publications constitute 88% of the total output, benefiting from the rapid development of AI. The World Economic 2016 Forum recognized the open AI ecosystem as one of the top ten most important emerging technologies, and novel deep learning frameworks are continuously being proposed and utilized. The effectiveness of AI applications has been supported by various studies[50]. The field of AI-based glaucoma applications has now become significant and holds broad prospects.

Among the 68 countries/regions included in this study, China, the United States, and India have the highest publication output, collectively accounting for 72% of all papers, indicating their important role in AI-based glaucoma research. Despite ranking first in terms of publication quantity, China's centrality is significantly lower than that of the United Kingdom, which published fewer papers. This indicates that although China has experienced an increase in publication output, it still lacks highly cited or high-quality articles, leading to a limited international influence.

The analysis of research institutions indicates that the studies conducted by the Singapore National Eye Centre and the National University of Singapore have had a significant impact on this research field. Furthermore, Singapore is represented by three institutions among the top ten research institutions, highlighting its growing importance in this area of research. While institutions such as the Chinese Academy of Sciences, Sun Yat-sen University, and the University of California San Diego, have produced numerous papers and gained some academic influence, they have not extensively collaborated or engaged in close exchanges with other academic institutions.

In the author co-occurrence analysis, Professor Weinreb RN emerged as the most prolific author. He is a well-known expert in the field of glaucoma in the United States and has made significant contributions to the understanding of glaucoma pathophysiology and treatment[51-53]. Moreover, he has played a crucial role in advancing the application of AI in glaucoma research. His team developed and evaluated a deep learning-based system for identifying and predicting visual field damage in glaucoma. The research findings indicate that the deep learning model achieves higher accuracy in identification and prediction compared to conventional measurement methods[54]. Professor Aung Tin, from the Singapore National Eye Centre, and his team proposed the use of superpixel-based segmentation techniques for optic disc and cup segmentation in glaucoma screening. The segmentation quality was assessed through self-assessment scoring, and the results showed that this method achieved a higher area under the curve compared to other methods in two datasets, making it suitable for glaucoma segmentation and screening[55]. Professor Asaoka Ryo from Japan and his team published a crucial paper in which they employed deep learning methods to differentiate between the visual fields of patients with angle-closure glaucoma and healthy eyes. The research findings indicated superior performance of the deep feedforward neural network classifier compared to other machine learning methods. This implies that deep learning methods can effectively discriminate between the visual fields of glaucoma patients and healthy eyes with high accuracy[56]. Consequently, we anticipate that the members of the aforementioned teams will produce more significant publications in the realm of AI-based glaucoma research. Strengthening collaboration with these esteemed teams is a favorable research direction.

In the author co-citation analysis, Professor Fu H, a Medical Imaging expert, proposed a circular perception integrated network utilizing deep learning for glaucoma screening in fundus images. By integrating global and local features, this method enhances screening accuracy. Experimental results exhibit superior performance compared to alternative algorithms, offering the potential for effective improvements in glaucoma diagnosis and treatment[57]. The most highly cited paper authored by Quigley HA is "The Number of People with Glaucoma Worldwide in 2010 and 2020"[58]. Professor Acharya UR is a renowned scholar in the field of Mathematical & Computational Biology, with multiple highly cited publications.

The journal most associated with AI applications in glaucoma is *Translational Vision Science & Technology*, which suggests that the majority of articles related to this field are likely to be published in this journal. However, the journal with the highest impact factor is *Ophthalmology* (IF2022=13.7), making it the only journal among the top ten to have an impact factor exceeding 10. It can be observed that most of the top ten journals for publishing research papers in this field are significant ophthalmology journals, but they also extend to the fields of Technology and Computer: Information System. Journal analysis provides researchers with valuable and reliable reference information, assisting them in identifying more suitable target journals during literature search or manuscript submission. Journal co-citation analysis enables a profound understanding of the interconnections between various research outcomes. The results demonstrate that AI applications in glaucoma research extend far beyond the discipline of ophthalmology, making advancements in fields such as computer science, mathematics, molecular biology, and genetics. This finding underscores the necessity of interdisciplinary collaboration for the progress of AI applications in the field of glaucoma.

Citation analysis and reference co-citation analysis are vital methods in bibliometric research that contribute to identifying noteworthy literature, assessing research progress, and predicting the forefront of research development. Highly cited articles are often indicative of high-quality research with strong innovation and significant impact within a specific field. Researchers in this field are encouraged to place greater focus on these research outcomes, enabling them to acquire reliable scientific evidence and data support, thereby propelling new discoveries, innovations, and technological advancements.

Utilizing co-occurrence analysis, we examined the keywords identified in AI-based glaucoma research to generate a network diagram portraying co-occurrence relationship. Through this analysis, we identified six potential research directions. The distinct density of nodes in different colors within the six clusters signifies evolving developments and highlights the evolving and diverse nature of research in these directions. Through the clustering timeline of keywords, emergent keywords in different time periods serve as indicators of various research hotspots. This temporal analysis enables the observation of evolving areas of active interest and the dynamic nature of research frontiers in AI-based glaucoma studies. Our findings reveal an initial emphasis on "segmentation", "classification", and "diagnosis" in earlier studies, followed by a shift towards the application of "deep learning" and "convolutional neural network" techniques. This transition signifies that initial research efforts in this field were primarily centered around the segmentation of glaucomatous pathological structures and glaucoma classification, followed by a subsequent focus on utilizing new technologies to improve the accuracy and efficiency of diagnostics, ultimately enabling early detection.

Burst keyword analysis enables the identification of current research hotspots and frontiers. Our research findings demonstrate that keywords related to AI technologies, such as "artificial neural network", "support vector machine", and "machine learning classifier", have emerged as popular research topics. Researchers are exploring the performance of different intelligent algorithms to enable their application in glaucoma screening, diagnosis, risk prediction, and other relevant areas. Raghavendra *et al*[59] introduced a glaucoma detection method based on Radon transform and nonparametric GIST descriptors. This approach demonstrates high accuracy and low cost, making it suitable for glaucoma screening. Juneja *et al*[60] introduced an AI-based glaucoma expert system that utilizes optic disc and cup segmentation. By employing convolutional neural networks, this system extracts hierarchical information from fundus images and accurately discerns glaucomatous and non-glaucomatous image patterns, effectively enabling automated glaucoma detection and diagnosis. Singh *et al*[61] developed a novel multimodal glaucoma prediction approach utilizing machine learning and deep learning techniques for classification. Research reports indicate that lowering intraocular pressure can mitigate the development of glaucoma and optic nerve damage[62-63]. Consequently, the current research focus in this field revolves around effectively utilizing AI for fast and accurate glaucoma diagnosis. Moreover, there is a growing clinical demand for employing AI to predict glaucoma progression and assess treatment effectiveness[64], making it a prominent research hotspot and priority for the future.

Currently, AI seems to possess indisputable potential[65-68]. In laboratory settings, it has already demonstrated sufficiently high-performance and high sensitivity, enabling its broader impact on the field of glaucoma. As AI continues to advance, there is promising potential for the overall progress of glaucoma towards accurate screening, diagnosis, and treatment. However, in practical applications, AI still encounters several limitations and challenges in both clinical and technical aspects. Research suggests that the conditions for replacing ophthalmologists with AI systems are not yet mature[69-70]. Future challenges in the application of AI to glaucoma may primarily arise in personalized data collection for glaucoma (*e.g.*, beyond clinical indicators, such as genetic information), data quality (*e.g.*, variations in data due to racial differences, patient compliance, and physician skill levels), data processing standards (inconsistencies in electronic health record structures), and the credibility of decision-making in assisting diagnosis. Importantly, deep learning-based AI models have encountered skepticism from clinicians due to a lack of interpretability, impeding the clinical application of these AI models[71-73]. To enhance physicians' confidence in making accurate diagnoses using AI systems, some AI systems need to be developed as explainable algorithms[74]. Hence, the key breakthrough for effectively applying deep learning-based AI in a clinical setting lies in the development of interpretable algorithms within the field of deep learning.

It is important to acknowledge that this bibliometric analysis study has inherent limitations that should be considered. First and foremost, it is important to note that we only utilized database as our database, thereby excluding other crucial databases such as PubMed, Embase, and Cochrane. This increases the possibility of missing out on relevant papers from these databases[75]. Second, we limited our inclusion criteria to articles published in English, overlooking potentially valuable studies in other languages. This may introduce research bias and diminish the overall credibility to some extent. Moreover, it should be acknowledged that it takes time for an article to accumulate a significant number of citations. Consequently, recently published high-quality articles might not have received the recognition they deserve. This delayed recognition of cutting-edge research also emphasizes the significance of future updates and research advancements. In conclusion, it is essential to recognize that the aforementioned factors may lead to inherent differences between the findings of this study and the actual research landscape. Moving forward, it is crucial to expand the literature search databases and conduct comprehensive investigations into the dynamic research trends within this field. This will enable a more authentic and objective representation of the research scenario.

As far as we know, this study represents the first scientific and systematic bibliometric research analyzing global research trends of AI in glaucoma from 2013 to 2022. In doing so, it achieves an objective and comprehensive understanding of the topic. Our research findings demonstrate that research on the application of AI in glaucoma is actively being conducted globally, making it a popular and promising area of study with substantial interdisciplinary exploration opportunities. It is essential for both countries and institutions to leverage their respective population advantages or core technologies in order to strengthen cross-disciplinary collaborations. Moving forward, the research focus in this field will transition from improving diagnostic accuracy to utilizing deep learning techniques for treatment assistance and utilizing big data for prognostic predictions. Challenges in applying AI to glaucoma may primarily arise in areas such as personalized data collection, data quality, data processing requirements, the reliability of diagnostic decision support, and the interpretability of deep learning models.

ACKNOWLEDGEMENTS

Foundation: Supported by National Natural Science Foundation of China (No.82074335).

Conflicts of Interest: Liu C, None; **Wang LY,** None; **Zhu KY,** None; **Liu CM,** None; **Duan JG,** None.

REFERENCES

1 Feng KM, Tsung TH, Chen YH, Lu DW. The role of retinal ganglion cell structure and function in glaucoma. *Cells* 2023;12(24):2797.

2 Tham YC, Li X, Wong TY, Quigley HA, Aung T, Cheng CY. Global prevalence of glaucoma and projections of glaucoma burden through 2040:a systematic review and meta-analysis. *Ophthalmology* 2014;121(11):2081-2090.

3 Varma R, Mei YL, Francis BA, Nguyen BB, Deneen J, Wilson MR, Azen SP, Los Angeles Latino Eye Study Group. Prevalence of open-angle glaucoma and ocular hypertension in Latinos: the Los Angeles Latino Eye Study. *Ophthalmology* 2004;111(8):1439-1448.

4 Friedman DS, Wolfs RC, O'Colmain BJ, Klein BE, Taylor HR, West S, Leske MC, Mitchell P, Congdon N, Kempen J, Eye Diseases Prevalence Research Group. Prevalence of open-angle glaucoma among adults in the United States. *Arch Ophthalmol* 2004;122(4):532-538.

5 Malihi M, Moura Filho ER, Hodge DO, Sit AJ. Long-term trends in glaucoma-related blindness in Olmsted County, Minnesota. *Ophthalmology* 2014;121(1):134-141.

6 Wu J, Fang H, Li F, *et al*. GAMMA challenge: Glaucoma grading from multi-modality images. *Med Image Anal* 2023;90:102938.

7 GBD Blindness and Vision Impairment Collaborators, Vision Loss Expert Group of the Global Burden of Disease Study. Causes of blindness and vision impairment in 2020 and trends over 30 years, and prevalence of avoidable blindness in relation to VISION 2020: the Right to Sight: an analysis for the Global Burden of Disease Study. *Lancet Glob Health* 2021;9(2):e144-e160.

8 Jayaram H, Kolko M, Friedman DS, Gazzard G. Glaucoma: now and beyond. *Lancet* 2023;402(10414):1788-1801.

9 Lim YJ, Bang JW, Weinreb RN, Zangwill LM, Suh MH. Temporal optic disc microvasculature dropout in glaucoma. *Invest Ophthalmol Vis Sci* 2023;64(11):6.

10 Prager AJ, Kang JM, Tanna AP. Advances in perimetry for glaucoma. *Curr Opin Ophthalmol* 2021;32(2):92-97.

11 Chauhan BC. Understanding the increasing role of optical coherence tomography in glaucoma diagnostics and disease progression. *JAMA Ophthalmol* 2023;141(9):890.

12 Jampel HD, Friedman D, Quigley H, Vitale S, Miller R, Knezevich F, Ding YL. Agreement among glaucoma specialists in assessing

progressive disc changes from photographs in open-angle glaucoma patients. *Am J Ophthalmol* 2009;147(1):39-44.e1.

13 Harwerth RS, Carter-Dawson L, Smith EL 3rd, Barnes G, Holt WF, Crawford ML. Neural losses correlated with visual losses in clinical perimetry. *Invest Ophthalmol Vis Sci* 2004;45(9):3152.

14 Liu Y, Simavli H, Que CJ, Rizzo JL, Tsikata E, Maurer R, Chen TC. Patient characteristics associated with artifacts in Spectralis optical coherence tomography imaging of the retinal nerve fiber layer in glaucoma. *Am J Ophthalmol* 2015;159(3):565-576.e2.

15 Burton MJ, Ramke J, Marques AP, *et al*. The lancet global health commission on global eye health: vision beyond 2020. *Lancet Glob Health* 2021;9(4):e489-e551.

16 Burton RJ, Albur M, Eberl M, Cuff SM. Using artificial intelligence to reduce diagnostic workload without compromising detection of urinary tract infections. *BMC Med Inform Decis Mak* 2019;19(1):171.

17 Yang X, Wang Y, Byrne R, Schneider G, Yang S. Concepts of artificial intelligence for computer-assisted drug discovery. *Chem Rev* 2019;119(18):10520-10594.

18 Szeskin A, Yehuda R, Shmueli O, Levy J, Joskowicz L. A column-based deep learning method for the detection and quantification of atrophy associated with AMD in OCT scans. *Med Image Anal* 2021;72:102130.

19 Wan C, Li H, Cao GF, Jiang Q, Yang WH. An artificial intelligent risk classification method of high myopia based on fundus images. *J Clin Med* 2021;10(19):4488.

20 Kessel K, Mattila J, Linder N, Kivelä T, Lundin J. Deep learning algorithms for corneal amyloid deposition quantitation in familial amyloidosis. *Ocul Oncol Pathol* 2020;6(1):58-65.

21 Xu J, Shen J, Wan C, Jiang Q, Yan Z, Yang W. A few-shot learning-based retinal vessel segmentation method for assisting in the central serous chorioretinopathy laser surgery. *Front Med* 2022;9:821565.

22 Mursch-Edlmayr AS, Ng WS, Diniz-Filho A, Sousa DC, Arnold L, Schlenker MB, Duenas-Angeles K, Keane PA, Crowston JG, Jayaram H. Artificial intelligence algorithms to diagnose glaucoma and detect glaucoma progression: translation to clinical practice. *Transl Vis Sci Technol* 2020;9(2):55.

23 Zheng C, Johnson TV, Garg A, Boland MV. Artificial intelligence in glaucoma. *Curr Opin Ophthalmol* 2019;30(2):97-103.

24 Park SJ, Lee EJ, Kim SI, Kong SH, Jeong CW, Kim HS. Clinical desire for an artificial intelligence-based surgical assistant system: electronic survey-based study. *JMIR Med Inform* 2020;8(5):e17647.

25 Agarwal A, Baskaran S, Panner Selvam MK, Barbăroșie C, Master K. Unraveling the footsteps of proteomics in male reproductive research: a scientometric approach. *Antioxid Redox Signal* 2020;32(8):536-549.

26 Feng LF, Yan PJ, Chu XJ, Zhang N, Li JY, Li JW, Guo KL, Lu CC, Li MX, Guo TK, Liu XR, Yang KH. A scientometric study of the top 100 most-cited publications based on Web-of-Science regarding robotic versus laparoscopic surgery. *Asian J Surg* 2021;44(2):440-451.

27 Wang H, Yi Z, Zhan H, Teng Y, Zhang S, Wu M, Geng B, Xia Y. A scientometric analysis of studies on patellar dislocation. *Orthop J Sports Med* 2022;10(11):23259671221137051.

28 Zhou YX, Cao XY, Peng C. Antimicrobial activity of natural products against MDR bacteria: a scientometric visualization analysis. *Front Pharmacol* 2022;13:1000974.

29 Wang X, Gong XF, Xiong KX, Guo DS, Liu LJ, Lin CM, Chang WY. Mapping of research in the field of forest therapy-related issues: a bibliometric analysis for 2007-2021. *Front Psychol* 2022;13:930713.

30 Shen JM, Chen J, Feng L, Feng C. A scientometrics analysis and visualisation of diabetic foot research from 1955 to 2022. *Int Wound J* 2023;20(4):1072-1087.

31 Wu H, Zhou Y, Xu L, Tong L, Wang Y, Liu B, Yan H, Sun Z. Mapping knowledge structure and research frontiers of ultrasound-induced blood-brain barrier opening: a scientometric study. *Front Neurosci* 2021;15:706105.

32 Hua N, Tan X, He Y, Sun M, Wang X. Medical decision-making for adolescents with depression: a bibliometric study and visualization analysis via CiteSpace. *Int J Ment Health Nurs* 2023;32(2):365-377.

33 Miao L, Shi J, Yu H, Song L, Zhu C, Shi D, Gao J. Studies on atrial fibrillation and venous thromboembolism in the past 20 Years: a bibliometric analysis via CiteSpace and VOSviewer. *J Am Heart Assoc* 2023;12(17):e029810.

34 Chen C, Hu Z, Liu S, Tseng H. Emerging trends in regenerative medicine: a scientometric analysis in CiteSpace. *Expert Opin Biol Ther* 2012;12(5):593-608.

35 Newman ME. Coauthorship networks and patterns of scientific collaboration. *Proc Natl Acad Sci U S A* 2004;101(Suppl 1):5200-5205.

36 Li Z, He Y, Keel S, Meng W, Chang RT, He M. Efficacy of a deep learning system for detecting glaucomatous optic neuropathy based on color fundus photographs. *Ophthalmology* 2018;125(8):1199-1206.

37 Fu H, Cheng J, Xu Y, Wong DWK, Liu J, Cao X. Joint optic disc and cup segmentation based on multi-label deep network and polar transformation. *IEEE Trans Med Imaging* 2018;37(7):1597-1605.

38 Raghavendra U, Fujita H, Bhandary SV, Gudigar A, Tan JH, Acharya UR. Deep convolution neural network for accurate diagnosis of glaucoma using digital fundus images. *Inf Sci* 2018;441:41-49.

39 Ting DSW, Cheung CY, Lim G, Tan GSW, *et al*. Development and validation of a deep learning system for diabetic retinopathy and related eye diseases using retinal images from multiethnic populations with diabetes. *JAMA* 2017;318(22):2211-2223.

40 Gulshan V, Peng L, Coram M, Stumpe MC, Wu D, Narayanaswamy A, Venugopalan S, Widner K, Madams T, Cuadros J, Kim R, Raman R, Nelson PC, Mega JL, Webster DR. Development and validation of a deep learning algorithm for detection of diabetic retinopathy in retinal fundus photographs. *JAMA* 2016;316(22):2402-2410.

41 Christopher M, Belghith A, Bowd C, Proudfoot JA, Goldbaum MH, Weinreb RN, Girkin CA, Liebmann JM, Zangwill LM. Performance of deep learning architectures and transfer learning for detecting glaucomatous optic neuropathy in fundus photographs. *Sci Rep* 2018;8(1):16685.

42 Orlando JI, Fu H, Barbosa Breda J, *et al*. REFUGE Challenge: a unified framework for evaluating automatedmethods for glaucomaassessment

from fundus photographs. *Med Image Anal* 2020;59:101570.

43 Zilly J, Buhmann JM, Mahapatra D. Glaucoma detection using entropy sampling and ensemble learning for automatic optic cup and disc segmentation. *Comput Med Imaging Graph* 2017;55:28-41.

44 Diaz-Pinto A, Morales S, Naranjo V, Köhler T, Mossi JM, Navea A. CNNs for automatic glaucoma assessment using fundus images: an extensive validation. *Biomed Eng Online* 2019;18(1):29.

45 Shibata N, Tanito M, Mitsuhashi K, Fujino Y, Matsuura M, Murata H, Asaoka R. Development of a deep residual learning algorithm to screen for glaucoma from fundus photography. *Sci Rep* 2018;8(1):14665.

46 Acharya UR, Dua S, Du X, Sree SV, Chua CK. Automated diagnosis of glaucoma using texture and higher order spectra features. *IEEE Trans Inf Technol Biomed* 2011;15(3):449-455.

47 Chen C, Dubin R, Kim MC. Emerging trends and new developments in regenerative medicine: a scientometric update (2000 - 2014). *Expert Opin Biol Ther* 2014;14(9):1295-1317.

48 Shen Z, Hu J, Wu H, Chen Z, Wu W, Lin J, Xu Z, Kong J, Lin T. Global research trends and foci of artificial intelligence-based tumor pathology: a scientometric study. *J Transl Med* 2022;20(1):409.

49 Zhao J, Lu Y, Qian Y, Luo Y, Yang W. Emerging trends and research foci in artificial intelligence for retinal diseases: bibliometric and visualization study. *J Med Internet Res* 2022;24(6):e37532.

50 Giardini ME, Livingstone IAT. Extending the reach and task-shifting ophthalmology diagnostics through remote visualisation. *Adv Exp Med Biol* 2020;1260:161-174.

51 Weinreb RN, Aung T, Medeiros FA. The pathophysiology and treatment of glaucoma: a review. *JAMA* 2014;311(18):1901-1911.

52 Weinreb RN, Khaw PT. Primary open-angle glaucoma. *Lancet* 2004;363(9422):1711-1720.

53 Weinreb RN. Ocular blood flow in glaucoma. *Can J Ophthalmol* 2008;43(3):281-283.

54 Christopher M, Bowd C, Belghith A, Goldbaum MH, Weinreb RN, Fazio MA, Girkin CA, Liebmann JM, Zangwill LM. Deep learning approaches predict glaucomatous visual field damage from OCT optic nerve head en face images and retinal nerve fiber layer thickness maps. *Ophthalmology* 2020;127(3):346-356.

55 Cheng J, Liu J, Xu Y, Yin F, Wong DW, Tan NM, Tao D, Cheng C, Aung T, Wong TY. Superpixel classification based optic disc and optic cup segmentation for glaucoma screening. *IEEE Trans Med Imaging* 2013;32(6):1019-1032.

56 Asaoka R, Murata H, Iwase A, Araie M. Detecting preperimetric glaucoma with standard automated perimetry using a deep learning classifier. *Ophthalmology* 2016;123(9):1974-1980.

57 Fu H, Cheng J, Xu Y, Zhang C, Wong DWK, Liu J, Cao X. Disc-aware ensemble network for glaucoma screening from fundus image. *IEEE Trans Med Imaging* 2018;37(11):2493-2501.

58 Quigley HA, Broman AT. The number of people with glaucoma worldwide in 2010 and 2020. *Br J Ophthalmol* 2006;90(3):262-267.

59 Raghavendra U, Bhandary SV, Gudigar A, Acharya UR. Novel expert system for glaucoma identification using non-parametric spatial envelope energy spectrum with fundus images. *Biocybern Biomed Eng* 2018;38(1):170-180.

60 Juneja M, Singh S, Agarwal N, Bali S, Gupta S, Thakur N, Jindal P. Automated detection of Glaucoma using deep learning convolution network (G-net). *Multimed Tools Appl* 2020;79(21):15531-15553.

61 Singh LK, Pooja, Garg H, Khanna M. Deep learning system applicability for rapid glaucoma prediction from fundus images across various data sets. *Evol Syst* 2022;13(6):807-836.

62 Heijl A, Leske MC, Bengtsson B, Hyman L, Bengtsson B, Hussein M, Early Manifest Glaucoma Trial Group. Reduction of intraocular pressure and glaucoma progression: results from the Early Manifest Glaucoma Trial. *Arch Ophthalmol* 2002;120(10):1268-1279.

63 Kass MA, Heuer DK, Higginbotham EJ, Johnson CA, Keltner JL, Miller JP, Parrish RK 2nd, Wilson MR, Gordon MO. The Ocular Hypertension Treatment Study: a randomized trial determines that topical ocular hypotensive medication delays or prevents the onset of primary open-angle glaucoma. *Arch Ophthalmol* 2002;120(6):701-713; discussion 829-830.

64 Medeiros FA. Biomarkers and surrogate endpoints in glaucoma clinical trials. *Br J Ophthalmol* 2015;99(5):599-603.

65 Esteva A, Robicquet A, Ramsundar B, Kuleshov V, DePristo M, Chou K, Cui C, Corrado G, Thrun S, Dean J. A guide to deep learning in healthcare. *Nat Med* 2019;25(1):24-29.

66 Shen D, Wu G, Suk HI. Deep learning in medical image analysis. *Annu Rev Biomed Eng* 2017;19:221-248.

67 Topol EJ. High-performance medicine: the convergence of human and artificial intelligence. *Nat Med* 2019;25(1):44-56.

68 Rajkomar A, Dean J, Kohane I. Machine learning in medicine. *N Engl J Med* 2019;380(14):1347-1358.

69 Li S, Zhao R, Zou H. Artificial intelligence for diabetic retinopathy. *Chin Med J* (*Engl*) 2021;135(3):253-260.

70 Ting DSW, Pasquale LR, Peng L, Campbell JP, Lee AY, Raman R, Tan GSW, Schmetterer L, Keane PA, Wong TY. Artificial intelligence and deep learning in ophthalmology. *Br J Ophthalmol* 2019;103(2):167-175.

71 Wu Z, Chen J, Li Y, Deng Y, Zhao H, Hsieh CY, Hou T. From black boxes to actionable insights: a perspective on explainable artificial intelligence for scientific discovery. *J Chem Inf Model* 2023;63(24):7617-7627.

72 Rudin C. Stop explaining black box machine learning models for high stakes decisions and use interpretable models instead. *Nat Mach Intell* 2019;1(5):206-215.

73 Salih A, Boscolo Galazzo I, Gkontra P, Lee AM, Lekadir K, Raisi-Estabragh Z, Petersen SE. Explainable artificial intelligence and cardiac imaging: toward more interpretable models. *Circ Cardiovasc Imaging* 2023;16(4):e014519.

74 Ahuja AS, Halperin LS. Understanding the advent of artificial intelligence in ophthalmology. *J Curr Ophthalmol* 2019;31(2):115-117.

75 Ma D, Yang B, Guan B, Song L, Liu Q, Fan Y, Zhao L, Wang T, Zhang Z, Gao Z, Li S, Xu H. A bibliometric analysis of pyroptosis from 2001 to 2021. *Front Immunol* 2021;12:731933.