· Intelligent Ophthalmology ·

Bibliometric analysis of artificial intelligence and optical coherence tomography images: research hotspots and frontiers

Hai-Wen Feng[1], Jun-Jie Chen[1], Zhi-Chang Zhang[2], Shao-Chong Zhang[3], Wei-Hua Yang[3]

[1]Department of Software Engineering, School of Software, Shenyang University of Technology, Shenyang 110870, Liaoning Province, China
[2]Department of Computer, School of Intelligent Medicine, China Medical University, Shenyang 110122, Liaoning Province, China
[3]Shenzhen Eye Hospital, Jinan University, Shenzhen 518040, Guangdong Province, China
Correspondence to: Wei-Hua Yang and Shao-Chong Zhang. Shenzhen Eye Hospital, Jinan University, Shenzhen 518040, Guangdong Province, China. benben0606@139.com; zhangshaochong@gzzoc.com; Zhi-Chang Zhang. Department of Computer, School of Intelligent Medicine, China Medical University, Shenyang 110122, Liaoning Province, China. zczhang@cmu.edu.cn
Received: 2023-04-20 Accepted: 2023-07-05

Abstract
● **AIM:** To explore the latest application of artificial intelligence (AI) in optical coherence tomography (OCT) images, and to analyze the current research status of AI in OCT, and discuss the future research trend.
● **METHODS:** On June 1, 2023, a bibliometric analysis of the Web of Science Core Collection was performed in order to explore the utilization of AI in OCT imagery. Key parameters such as papers, countries/regions, citations, databases, organizations, keywords, journal names, and research hotspots were extracted and then visualized employing the VOSviewer and CiteSpace V bibliometric platforms.
● **RESULTS:** Fifty-five nations reported studies on AI biotechnology and its application in analyzing OCT images. The United States was the country with the largest number of published papers. Furthermore, 197 institutions worldwide provided published articles, where University of London had more publications than the rest. The reference clusters from the study could be divided into four categories: thickness and eyes, diabetic retinopathy (DR), images and segmentation, and OCT classification.
● **CONCLUSION:** The latest hot topics and future directions in this field are identified, and the dynamic evolution of AI-based OCT imaging are outlined. AI-based OCT imaging holds great potential for revolutionizing clinical care.
● **KEYWORDS:** artificial intelligence; optical coherence tomography; bibliometric; deep learning; machine learning
DOI:10.18240/ijo.2023.09.09

Citation: Feng HW, Chen JJ, Zhang ZC, Zhang SC, Yang WH. Bibliometric analysis of artificial intelligence and optical coherence tomography images: research hotspots and frontiers. *Int J Ophthalmol* 2023;16(9):1431-1440

INTRODUCTION

Optical coherence tomography (OCT) imaging is an exceptionally advanced assessment technique employed for noninvasive, cross-sectional imaging of biological systems[1]. This sophisticated imaging modality is widely utilized in clinical ophthalmology and offers an unparalleled capacity to create a three-dimensional (3D) image of the area of interest, its primary application encompasses both the structures of the anterior and posterior segments of the eye. In relation to the anterior segment structures, OCT can be utilized to assess the anterior chamber angle, detect and monitor intraocular masses and tumors, as well as unveil abnormalities in the cornea, iris, and crystalline lens[2]. Regarding its application in the posterior segment structures, it proves especially effective in diagnosing eye conditions like glaucoma, age-related macular degeneration (AMD), and diabetic retinopathy (DR)[3].

In the 21st century, the use of artificial intelligence (AI) in medicine has become increasingly prominent, especially in terms of new breakthroughs made in the application of OCT in ocular imaging[4]. Recently, there has been substantial use of convolutional neural networks (CNNs) in low-level visual tasks, including denoising and other areas[5]. The combination of OCT imaging and AI is highly advantageous, and it is expected that the application of the next generation of AI and OCT will experience a surge of growth in the future[6].

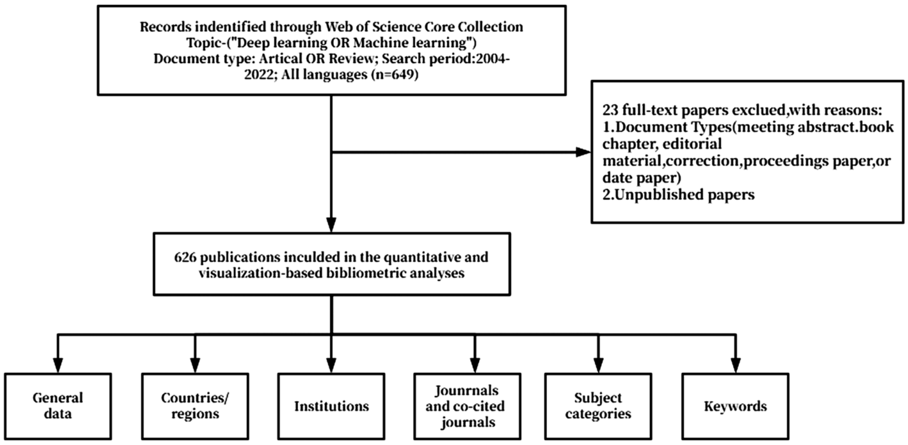

Figure 1 A frame flow diagram The diagram showed details selection criteria for AOIA publications from WoSCC database and the steps of bibliometric analysis**.** AOIA: Artificial intelligence related to optical coherence tomography image applications.

Therefore, it is essential to investigate the rapid development and current trends of AI in OCT images to guide the advancements in ophthalmology and further develop beneficial downstream industry markets[7]. AI is an immensely complex system integrating multiple disciplines, such as mathematics, statistics, probability, logic, and ethics. Its main components are deep learning (DL), machine learning (ML), CNNs and recurrent neural networks (RNNs)[8]. AI has been widely adopted in different industries, particularly when it comes to technology and medical image recognition[9]. In particular, remarkable strides have been made recently in harnessing AI to acquire and analyze diagnostic medical images more expeditiously and accurately than humans can[10].

To facilitate the research and development of OCT imaging utilizing AI, bibliometric analysis and review were conducted to gain insight into the applications, trends, and future prospects of the technology. The database spanning from June 1, 2004 to December 31, 2022 was searched, and a bibliometric analysis was conducted on the scientific papers regarding the use of AI in examining OCT eye images. Journals publishing AI biotechnology research were examined and the citations for popular research were counted. The references of cited studies were grouped to form a network and survey the subject knowledge base, while burst keywords were used to identify research hotspots. The objective of our study was to furnish researchers with an appreciation of how OCT imaging and AI can be combined by providing an instinctive, well-timed, and reasonable foundation to follow specialized fields of OCT imaging and DL[11].

MATERIALS AND METHODS

On June 1, 2023, we accessed the Science Core Collection Site to retrieve data from 2004-2022, which was independently authenticated by Chen JJ. We employed the following terms for the search: TS=(“deep learning” OR “machine learning” OR “convolutional neural network*” OR CNN* OR RNN OR “recurrent neural network*” OR “fully convolutional network*” OR FCN*) AND TS =(“eye examination” OR eye OR ophthalmology) AND TS=(OCT OR optical coherence tomography examination OR optical coherence tomography). The ScienceNet category was listed as “OCT image applications” to collect the relevant documents. As a result of the work, we gathered the following information: author, abstract, title, institution, journal, keywords, country/region, and references. This excluded certain material such as book chapters, data files, conference abstracts and conference papers, and duplicate articles and editorials, while unreported research not containing extensive analytical data was also omitted. Twenty-four duplicates were eliminated in the process. A summary of our research (search process and analysis) is given in Figure 1. We discussed the characteristics of publications by analyzing the countries, institutions, journals, and keywords. The H index was considered an essential metric to evaluate scientific research. We utilized bibliometric sites such as http://bibliometric.com/, as well as VOSviewer (Leiden University, Netherlands) and CiteSpace V (Drexel University, Philadelphia, PA, USA) to establish collaborative network and co-occurrence analysis visualizations of institutes/countries/keywords/journals. We conducted joint reference analysis and constructed knowledge maps with RStudio, while burst keywords were identified to generate duplicate keywords.

RESULTS

The results revealed that the science network has become increasingly collaborative and that the top three countries in terms of publications were the United States (217 publications), China (145 publications), and the United Kingdom (79 publications; Table 1). Figure 2 shows the cooperative relationship between countries. The most frequently referenced journals were *IEEE Transactions on Image Processing* (737 references) and *CVGIP: Image Understanding* (260

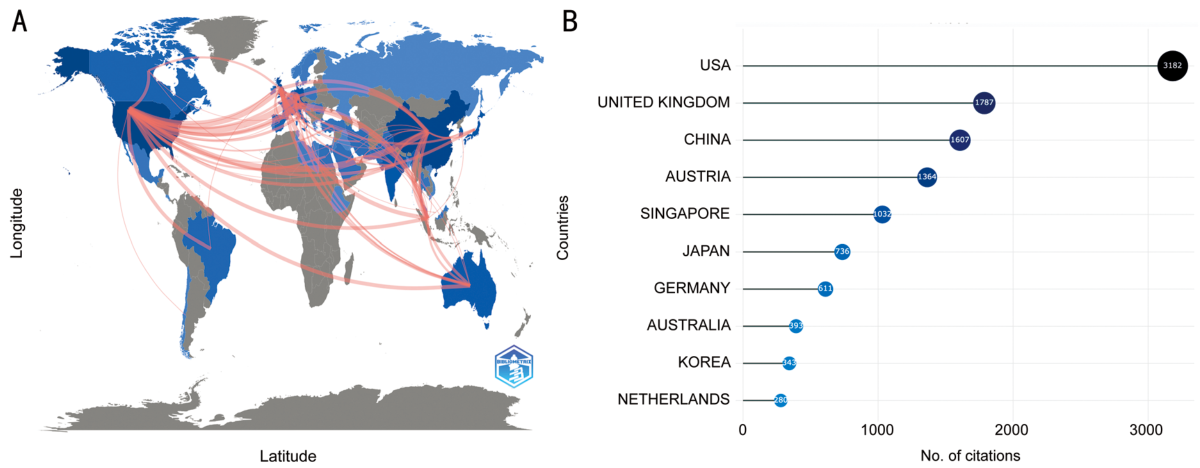

Figure 2 The cooperation of countries/regions contributed to publications A: Country collaboration map; B: Most cited countries.

Table 1 Top 10 countries/regions and relevant institutions

Rank	Countries/regions	Count	Total citations	H-index	Institutions	Total citations
1	USA	217	3182	22	University of London	48
2	China	145	1607	6	Moorfields Eye Hospital NHS Foundation Trust	42
3	UK	79	1787	27	Medical University of Vienna	39
4	Germany	62	611	19	University of California System	36
5	Japan	53	736	29	National University of Singapore	35
6	Austria	43	393	18	Singapore National Eye Center	33
7	South Korea	42	343	26	Duke University	29
8	Singapore	41	1032	17	Sun Yat-sen University	26
9	India	39	239	26	University of Bonn	20
10	Switzerland	37	43	16	Stanford University	19

references). The top keywords in the field were retinal OCT, ML, and image segmentation. The top institutions were the University of California Los Angeles, University of California San Diego, and the University of Houston. Finally, the most popular search hotspots were the United States, Europe, and China.

A literature search revealed that research on AI related to OCT image applications (AOIA) began in 2004. From 2004 to 2022, the number of papers published in this field grew steadily, with 598 papers identified thus far (Figure 3). These findings indicate that AOIA has established an important research trend, with a steady increase in publications each year.

Institutes, Countries, and Regions The results from our analysis revealed that 55 countries/territories had published AOIA studies (Table 1). United States was the leader with 217 publications, followed by the China with 145, the United Kingdom with 79, and Germany with 62. Table 1 presents the list of the top 10 most prolific countries in this field. China, the United States, the United Kingdom, and Germany demonstrated high degrees of centrality, and probably had a significant part in advancing the knowledge in this domain. Figure 4 highlights the institutional collaboration, with University of London publishing the most papers (n=48), followed by Moorfields Eye Hospital NHS Foundation Trust (n=42), Medical University of Vienna (n=39) and University of California System (n=36; Table 1).

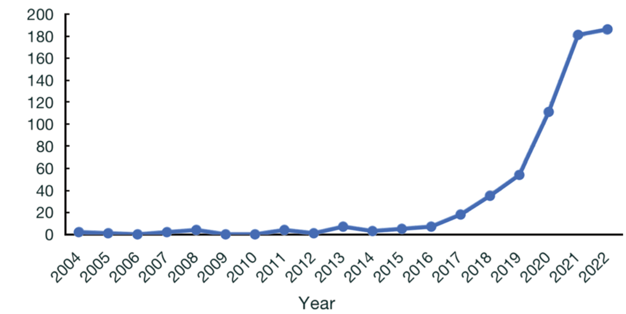

Figure 3 Trends in the number of publications on AOIA from 2004 to 2022 AOIA: Artificial intelligence related to optical coherence tomography image applications.

Figure 4 underscores the intricate and intimate interorganizational cooperation embodied in the data. By leveraging the VOSviewer platform, it was possible to evaluate the centrality of any given organization. As can be seen, a yellow circle is used to indicate the prominence of an organization, with the size being directly proportional to the degree of centrality. National University of Singapore and Singapore National Eye Center demonstrate the greatest centrality, indicating that these two organizations have been especially active in research in this field.

Journals In any given research domain, the relationships that scholarly journals have many times indicate the reciprocity of information and ideas, where the cited research is viewed

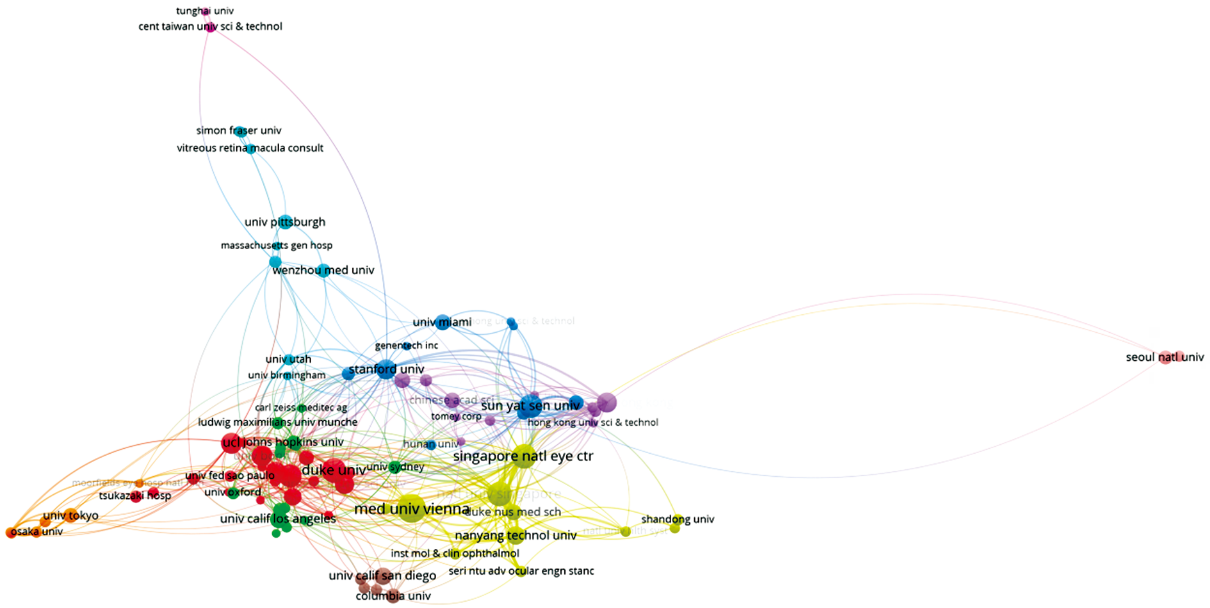

Figure 4 The cooperation of institutions contributed to publications.

Table 2 Top 10 references of AI and OCT image application

Rank	Source titles	Title of reference	Count	Interpretation of findings
1	NATURE	Clinically applicable deep learning for diagnosis and referral in retinal disease[7]	966	A novel deep learning architecture to a clinically heterogeneous set of three-dimensional OCT scans from patients referred to a major eye hospital.
2	IEEE TRANSACTIONS ON MEDICAL IMAGING	Joint optic disc and cup segmentation based on multi-label deep network and polar transformation[12]	391	A deep learning architecture, named M-Net, which solves the optic disc and optic cup segmentation jointly in a one-stage multi-label system.
3	BRITISH JOURNAL OF OPHTHALMOLOGY	Artificial intelligence and deep learning in ophthalmology[13]	377	A summary of the state-of-the-art deep learning systems described for ophthalmic applications, potential challenges in clinical deployment and the path forward.
4	BIOMEDICAL OPTICS EXPRESS	Automatic segmentation of nine retinal layer boundaries in OCT images of non-exudative AMD patients using deep learning and graph search[14]	310	A novel framework combining convolutional neural networks and graph search methods for the automatic segmentation of nine layer boundaries on retinal OCT images.
5	BIOMEDICAL OPTICS EXPRESS	ReLayNet: retinal layer and fluid segmentation of macular OCT using fully convolutional networks[15]	305	A new fully convolutional deep architecture, termed ReLayNet, for end-to-end segmentation of retinal layers and fluid masses in eye OCT scans.
6	PROGRESS IN RETINAL AND EYE RESEARCH	Artificial intelligence in retina[16]	288	Prediction and prognostic conclusions further expand the potential benefit of artificial intelligence in retina.
7	OPHTHALMOLOGY	Fully automated detection and quantification of macular fluid in OCT using deep learning[17]	237	Development and validation of a fully automated method to detect and quantify macular fluid in conventional OCT images.
8	BIOMEDICAL OPTICS EXPRESS	Deep-learning based, automated segmentation of macular edema in OCT[18]	185	Convolutional neural network can be trained to perform automated segmentations of clinically relevant image features.
9	PROGRESS IN RETINAL AND EYE RESEARCH	Deep learning in ophthalmology: The technical and clinical considerations[19]	175	Artificial intelligence, machine learning and deep learning will likely play a crucial role in clinical ophthalmology practice, with implications for screening, diagnosis and follow up of the major causes of vision impairment in the setting of ageing populations globally.
10	INVESTIGATIVE OPHTHALMOLOGY & VISUAL SCIENCE	Outcome of transplantation of autologous retinal pigment epithelium in age-related macular degeneration: a prospective trial[20]	161	To present the outcome of a consecutive series of patients who had foveal choroidal neovascularization in AMD and were treated with subretinal surgery combined with simultaneous transplantation of autologous retinal pigment epithelial cells.

AI: Artificial intelligence; AMD: Age-related macular degeneration; OCT: Optical coherence tomography.

as the knowledge frontier and the citing research indicates the knowledge foundation. To illustrate, the top 10 references from studies (2004–2022; Table 2[7,12-20]) and collaborations between related journals (Figure 4) are outlined, with *IEEE Transactions on Medical Imaging*, *Nature*, *British Journal of Ophthalmology*, and *Bidmedical Optics Express* exhibiting the highest degree of centrality as prominent journals that are favored for presenting investigations in the area. The journals involved possess a relatively balanced partnership, implying that research on the topic has gained attention from mainstream medical and biological journals.

DISCUSSION

Research Classification Based on earlier investigations, utilization of technologies involving DL in the area of medicine and OCT imaging is paramount, leading to numerous research outcomes. As illustrated in Figure 5, clustering the frequent keywords reveals that the seven most utilized keywords can be segregated into four distinct categories; these include thickness and eyes, DR and images and segmentation, OCT, and classification.

In the field of retinal thickness and eye detection, the retina is the layer of tissue at the back of the eye that receives and transmits light-induced images that enable people to see. Studying the thickness of the retina can help to diagnose a range of eye diseases, such as glaucoma, DR, high myopia in adolescents, and retinal detachment. In particular, retinal thickness is vital for determining the presence of glaucoma and DR. Vermeer *et al*[21] found that the root mean squared error at the upper and lower retina was 4–6 μm, with the internal interface error being slightly higher, *i.e.*, 6–15 μm. The OCT thickness map generated showed an accurate representation of the total retina thickness which allows for the easy identification of localized defects in the eye. Asaoka *et al*[22] investigated a DL model for its reliability in diagnosis using spectral-domain OCT-derived 8×8 macular retinal nerve fiber layer thickness and retinal ganglion cell complex layer thickness as inputs. These authors found that using an spectral-domain OCT glaucoma DL model significantly improved diagnostic accuracy. Venhuizen *et al*[23] created a fully automated system equipped with a CNN to precisely segment the entire retina region with OCT, capable of dealing with considerable retinal abnormalities and introducing a general U-net network structure to explain the changes within the retina, and the algorithm also impressively exhibited an ability to determine macular thickness precisely. Christopher *et al*[24] compared DL models with the average retinal nerve fiber layer thickness for identifying glaucoma visual field loss, and the DL model used could accurately predict the severity of glaucoma visual field loss through spectral-domain OCT imaging, which also helps clinicians provide more personalized visual field testing frequencies for individual patients. Escamez *et al*[25] employed ML algorithms to utilize the measurement of retinal nerve fiber layer thickness obtained through OCT to differentiate between healthy eyes and early-stage glaucoma.

In the category of DR, images and segmentation, image segmentation can be used to help detect retinal disease. It could help doctors identify features of the disease, such as shape, size, and location in the photographs. Furthermore, image segmentation can also be utilized to measure the amount and type of lesion in the image, thus helping to provide accurate information about DR. Srinivasan *et al*[26] found that the precise quantification of the thickness of the retina by OCT is crucial for the study of many ocular and neurodegenerative diseases and proposed a novel method of automated segmenting of the retinal layers in spectral-domain OCT images using sparse denoising, support vector machines, graph theory and dynamic programming to accurately delineate all existing retinal layer boundaries of both wild-type and rhodopsin knockout mice. Ting *et al*[13] have found that DL is remarkable for detecting diabetic macular edema (DME), AMD, and macular edema, and can also be applied to ocular imaging and telemedicine. Rahimy[27] applied DL to ophthalmology, with a focus on using DL models to accurately reveal and diagnose various eye disorders acting on the ocular posterior segment, especially DR, AMD, and glaucoma. Devalla *et al*[28] investigated the capabilities of AI in aiding the detection of glaucoma, utilizing DL techniques to develop different tools to identify, classify and enhance eye images for an effective diagnosis of the condition. Roberts *et al*[29] investigated how DL algorithms affected DME diagnosis of DME in intraretinal fluid and subretinal fluid under the background of anti-vascular endothelial growth factor therapy, and found best-corrected visual acuity and favorable antibody effect as well to be decreased with subretinal fluid. Krause *et al*[30] applied DL algorithms to retinal fundus photographs for the detection of DR and compared the performance of the algorithm in detecting artifacts and microaneurysms of DR to that of experts, thus improving its accuracy. Xu *et al*[31] investigated a more accurate method to quantitatively diagnose DME by using 3D macular thickness mapping and found that this mapping technique provides a more intuitive way to measure DME and obtain detailed statistical information.

In the OCT category, OCT is a noninvasive form of internal anatomy examination that enables high-resolution observation of internal tissue on a micron-scale. This technology allows doctors to get an in-depth view of the anatomy of the retina and detect changes associated with eye diseases such as glaucoma and cataract. By using OCT, we can have a clearer view of the internal structure of the eye and diagnose and treat eye conditions. Schlegl *et al*[17] demonstrated that DL in retinal image analysis shows remarkable accuracy in identifying the most common exudative macular disease and retinal fluid detected by OCT and offers encouraging prospects for improving the accuracy and reliability of ophthalmic research and clinical practice by automated analysis of conventional retinal OCT images. The assertions of Balyen and Peto[32] take into account the demographic and lifestyle shifts, increased life expectancy, and altered patterns of chronic illnesses such as diabetes, obesity, and glaucoma, predicting that there will be a continuous rise in demand for OCT imaging in the developed world's ophthalmic environment in the long run. Krishna *et al*[28] investigated DL models and applied them to 2D fundus and 3D OCT retinal images to accurately classify retinal markers, pathology, and disease and highlight the various studies, demonstrating the effectiveness of these models, and they discussed their advantages and disadvantages, providing a comprehensive review of current research in the field. Rong *et al*[33] are optimistic that OCT is emerging as a noninvasive approach to evaluate one of the most critical forms of retinal disease. Moraru *et al*[34] investigated the potential for implementing and using AI to assess retinal diseases and demonstrated the correlation between DL and OCT, the application of which is dependable in uncovering disorders of the retina and helps to improve the accurate diagnosis of posterior segmental eye diseases.

In the classification category, AI can be used to assist ophthalmologists in diagnosing diseases. By utilizing ML algorithms, doctors can analyze such data as fundus images, visual acuity test results, intraocular pressure measurements, and ocular examination results to then determine the type of illness. For example, DL algorithms can help in recognizing retinal abnormalities and can also determine according to symptoms what ophthalmic disease a patient is suffering from. Furthermore, AI can also analyze data from various types of ophthalmology-related data, and predict the development trends of diseases so that users can better identify and manage ophthalmic illnesses. Abràmoff *et al*[35] developed an AI algorithm to detect signs of DR and other forms of retinopathy and glaucoma in diabetic patients and to classify DME using advanced DL techniques, and they found that the system had 98% accuracy on the Messidor-2 dataset, showing high sensitivity (96.8%) and specificity (87.0%). Similarly, Gargeya and Leng[36] reported 97% accuracy using cross-validation reports on the same data set, and 94% and 95% accuracy on two independent test sets. Voets *et al*[37] from Google AI Healthcare recently revealed a remarkable DL system with remarkable diagnostic aptitude. Using a grand total of 128 175 retinal snapshots, a board of 54 United States approved ophthalmologists and ophthalmic residents trained DR and DME on the EyePACS-1 and Messidor-2 databases 3 to 7 times. It was then judged by at least seven United States board-certified ophthalmologists and found to have an impressive level of agreement, where EyePACS-1 showed area under the curve =0.991 and Messidor-2 area under the curve =0.990. Burgansky-Eliash *et al*[38] gathered eye data from 47 glaucoma patients and 42 healthy individuals. They leveraged an ML classifier to distinguish glaucoma from healthy eyes, and revealed that by using OCT output parameters, high accuracy was attained. Omodaka *et al*[39] advanced an ML-based algorithm to classify and evaluate retinal discs in patients with open angle glaucoma using 49 pairs of eyes as samples, and 91 quantitative data points, including 7 patient background features, 48 quantitative OCT values (optic disc topography and inner retinal nerve fiber layer thickness) and 36 laser point hemodynamic parameters, and an ML classification model with extremely high accuracy was constructed.

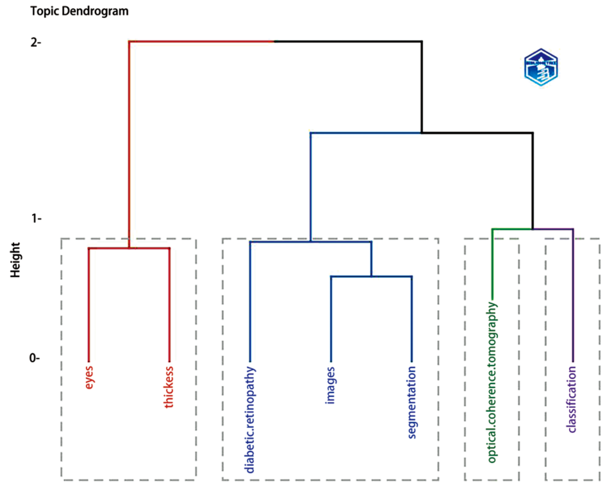

Figure 5 Factor analysis of the first 7 keywords.

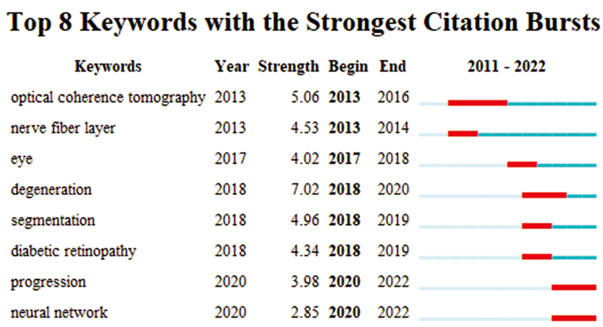

Figure 6 The keywords with the strongest citation bursts of publications on AOIA from 2010 to 2022 AOIA: Artificial intelligence related to optical coherence tomography image applications.

Research Frontiers and Hotspots Ordinarily, keywords are for focusing on current investigation ideas, while rising keywords represent leading edges of investigation and new tendencies. CiteSpace provided burst keywords, leading to the discovery of two frontiers of investigation: neural network (2020–2022) and progression (2020–2022) (Figure 6). It is assumed that these keywords are the paradigms for future research frontiers.

According to the first keyword "neural network (2020–2022)", particularly the development of neural networks has been swift since 2020. More and more researchers are leveraging neural networks for improving OCT diagnostic capabilities and image quality. This advanced combination can provide more information and enable more accurate diagnosis of fundus diseases. It also allows for earlier detection of potential diseases, providing an opportunity for timely intervention that could prevent further progression. Consequently, the utilization of neural networks in OCT is a rapidly growing trend that could significantly streamline the diagnostic process, reduce diagnostic errors, and improve the accuracy of disease diagnosis.

Fu *et al*[40] utilized a neural network model to assess the role of automated OCT segmentation in evaluating the impact of

C3 inhibition on geographic atrophy, identify OCT predictive biomarkers for geographic atrophy growth, and demonstrate that pegcetacoplan slows the progression of complete retinal pigment epithelium and outer retinal atrophy, reduces retinal pigment epithelium loss, protects photoreceptors, and slows the progression of healthy retina.

Xu *et al*[41] combined a CNN and a graph neural network, cascaded neural network, which can automatically segment and differentiate retinal arteriole and venule solely based on optical coherence tomography angiography (OCTA), offering the potential to enhance OCTA image information for the diagnosis of various eye diseases and systemic diseases, such as DR, hypertension, and cardiovascular diseases.

Fang *et al*[14] proposed a framework that integrates CNNs and graph search method for automated segmentation of the nine-layer boundaries in OCT images and utilized CNNs to determine characteristics of the specific retinal layer boundaries to instruct the relevant classifier in how to generate an initial eight-layer estimation, yielding satisfactory results.

To estimate best-corrected visual acuity using horizontal and vertical OCT data from various retinal diseases, Inoda *et al*[42] developed an AI model that demonstrated the potential to estimate best-corrected visual acuity *via* OCT in cases of AMD and retinal vein occlusion.

Ortiz *et al*[43] used OCT and AI to identify novel biomarkers for early multiple sclerosis diagnosis, revealing significant alterations in specific retinal layers among relapsing-remitting multiple sclerosis patients and achieving accurate automated diagnosis through a CNN, thereby supporting the potential incorporation of neuroretinal structure analysis into multiple sclerosis diagnostic criteria.

Schmidt-Erfurth *et al*[16] proposed that ML and particularly DL can be utilized to efficiently pinpoint, locate and quantify pathological components of diverse macular and retinal illnesses through the utilization of CNNs (object recognition that mimics patterns present in the human brain).

Lee *et al*[18] constructed a CNN to identify intraretinal fluid in OCT images and achieved a cross-validation Dice coefficient of 0.911 for image segmentation by evaluating 1289 OCT images, providing clinicians with a tool for automated detection of clinically important image features.

Asaoka *et al*[44] explored the potential of feedforward neural networks and other ML techniques such as random forest, gradient boosting, support vector machines, and neural networks and discovered that the area under the curve obtained by a deep fuzzy neural network classifier was significantly better than several other methods.

Another keyword, "progress (2020–2022)", is also widely mentioned. AI technologies can monitor the progression of eye disorders, including glaucoma, DME and others, by analyzing and comparing OCT images. By observing the features and patterns related to the disease in OCT images, AI can help doctors diagnose patients more effectively and provide treatments. Specifically, AI technologies can help doctors identify and track structural changes in OCT images to detect and monitor changes in the disease. For example, by using AI to recognize and analyze subtle changes in the images, the progression of glaucoma in a patient can be tracked and monitored. In addition, AI technologies can also help identify and predict future changes in a patient's condition and take effective therapeutic measures to prevent the disease from worsening and improve the patient's quality of life.

Morano *et al*[45] has developed an explainable DL method that can jointly identify relevant retinal lesions, identify pathological areas and corresponding lesions in images, provide meaningful information to enhance the diagnostic process, facilitate disease progression monitoring, and offer particular advantages in data-limited fields like medical imaging.

Raja *et al*[46] put forth a structure for overseeing glaucoma progression in an uncomplicated manner by investigating the weakening of retinal ganglion cells. The framework was rigorously appraised using the openly accessible Armed Forces Eye Institute dataset, with an F-1 score of 0.9577 in identifying the presence of glaucoma, a standard Dice score of 0.8697 for recognizing retinal ganglion cells areas, and an accuracy of 91.17% for evaluating the worsening of glaucoma.

Kamalipour *et al*[47] used longitudinal OCT and OCTA data, a supervised ML approach was used to detect glaucoma visual field progression and multiple visual field examinations and imaging of suspected and confirmed glaucoma patients found that combining OCT and OCTA parameters in the model had higher classification accuracy than using OCT or OCTA features alone.

There is an increasing emphasis on the utilization of AI and DL systems to detect features, development, and curative responses in retinal diseases, including utilizing OCT to achieve the above in retinal disorders such as neovascular AMD and DME[19].

Thompson *et al*[48] published a recent review of the most current applications of DL models in glaucoma and discussed their use in screening, diagnosis and detection of disease progression, and they proposed utilizing OCT and standard automated perimetry for providing effective measures for patients to avoid worsening of the disease.

Loo *et al*[49] found that carrying out the automated DL segmentation algorithm was superior to the conventional method, making it possible to correctly replicate, predict and monitor key outcome indicators in clinical trial progress, with significant advantages from a statistical standpoint.

In addition, the burst keywords from 2013 to 2019 are optical coherence tomography (2013–2016), nerve fiber layer (2013–2014), eye (2017–2018), degeneration (2017–2018), segmentation (2018–2019), diabetic retinopathy (2018–2019). Through these keywords, we can find that OCT technology has been widely applied since 2013, and since 2016, AI program beat Lee Sedol in the GO match, and AI has been widely concerned. Therefore, the combination of medicine and AI is getting closer and closer.

In conclusion, we conducted a systematic, unbiased, extensive review of the scientific literature on AOIA related to DL, ML, CNN, RNN, and fully convolutional networks. Furthermore, we recognized the research base, developments in the future and today's hot spots for this subject. Through our analysis, we found that thickness, eyes, DR, images, segmentation, OCT, and classification were the key knowledge bases. Progress and neural networks are considered to be the frontiers and trends of future research. Utilizing neural networks to model and monitor disease progression will become the major strategy of future disease treatment, which will enable medical professionals to accurately grasp the changes of disease progression and take effective treatment measures quickly, thus improving treatment efficiency and accuracy and consequently enhancing patients' quality of life.

In addition, OCT has become an important tool for the diagnosis of diseases such as glaucoma and DME. Its combination with AI is also becoming more and more widespread, and the use of AI to segment, analyze and predict OCT images has become the most commonly used method in recent years. OCT is a non-invasive detection technology that can image ocular tissues through optical principles, and can obtain high-resolution images of the eye without invading the patient's body. The development of this technology allows doctors to diagnose eye diseases more accurately and help patients with precise treatment. As an emerging technology, AI has the characteristics of autonomous learning, automatic processing and intelligent decision-making, which is expected to bring OCT technology to the extreme. After the combination of OCT and AI, OCT images can be automatically analyzed, which effectively improves the accuracy of ophthalmic diagnosis and reduces the work pressure of doctors. The combination of OCT technology and AI has brought revolutionary changes to the field of ophthalmology. Through our research, we believe that in the future, with the continuous progress of science and technology and the deepening of research, OCT technology and AI will have a more profound impact, bringing more value and innovation to the field of ophthalmic medicine.

However, the generated burst keywords in CiteSpace did not include "anterior segment OCT", possibly due to limited literature or lack of focused research on anterior segment tissues. Additionally, our data collection only included SCI publications from 2004 to 2022, excluding studies from Chinese and other non-SCI journals, and there were certain temporal or regional limitations. Considering that the publications collected between 2004 and 2022 might introduce public bias into our research, we adjusted our analysis to account for any potential influence caused by this bias and ensure the accuracy of our results.

ACKNOWLEDGEMENTS

Authors' contributions: Feng HW, Yang WH, Zhang ZC, and Zhang SC conceived the research and designed the research method. Feng HW and Chen JJ have prepared and standardized the contents and chapters. Chen JJ searched the references cited in the article. All authors have read and confirmed the final manuscript.

Foundations: Supported by Shenzhen Fund for Guangdong Provincial High-level Clinical Key Specialties (No. SZGSP014); Sanming Project of Medicine in Shenzhen (No.SZSM202011015); Shenzhen Science and Technology Planning Project (No.KCXFZ20211020163813019).

Conflicts of Interest: Feng HW, None; **Chen JJ,** None; **Zhang ZC,** None; **Zhang SC,** None; **Yang WH,** None.

REFERENCES

1 Huang D, Swanson EA, Lin CP, *et al*. Optical coherence tomography. *Science* 1991;254(5035):1178-1181.

2 Izatt JA, Hee MR, Swanson EA, Lin CP, Huang D, Schuman JS, Puliafito CA, Fujimoto JG. Micrometer-scale resolution imaging of the anterior eye *in vivo* with optical coherence tomography. *Arch Ophthalmol* 1994;112(12):1584-1589.

3 Puliafito CA, Hee MR, Lin CP, Reichel E, Schuman JS, Duker JS, Izatt JA, Swanson EA, Fujimoto JG. Imaging of macular diseases with optical coherence tomography. *Ophthalmology* 1995;102(2):217-229.

4 Kermany DS, Goldbaum M, Cai WJ, *et al*. Identifying medical diagnoses and treatable diseases by image-based deep learning. *Cell* 2018;172(5):1122-1131.e9.

5 Qayyum A, Anwar SM, Awais M, Majid M. Medical image retrieval using deep convolutional neural network. *Neurocomputing* 2017;266:8-20.

6 Hwang DK, Hsu CC, Chang KJ, *et al*. Artificial intelligence-based decision-making for age-related macular degeneration. *Theranostics* 2019;9(1):232-245.

7 De Fauw J, Ledsam JR, Romera-Paredes B, *et al*. Clinically applicable deep learning for diagnosis and referral in retinal disease. *Nat Med* 2018;24(9):1342-1350.

8 LeCun Y, Bengio Y, Hinton G. Deep learning. *Nature* 2015;521(7553): 436-444.

9 Litjens G, Kooi T, Bejnordi BE, *et al*. A survey on deep learning in medical image analysis. *Med Image Anal* 2017;42:60-88.

10 Shin HC, Roth HR, Gao MC, *et al*. Deep convolutional neural networks for computer-aided detection: CNN architectures, dataset

characteristics and transfer learning. *IEEE Trans Med Imaging* 2016;35(5):1285-1298.

11 Xu DY, Liu B, Wang J, Zhang ZC. Bibliometric analysis of artificial intelligence for biotechnology and applied microbiology: exploring research hotspots and frontiers. *Front Bioeng Biotechnol* 2022;10:998298.

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

13 Ting DSW, Pasquale LR, Peng L, *et al*. Artificial intelligence and deep learning in ophthalmology. *Br J Ophthalmol* 2019;103(2):167-175.

14 Fang LY, Cunefare D, Wang C, Guymer RH, Li ST, Farsiu S. Automatic segmentation of nine retinal layer boundaries in OCT images of non-exudative AMD patients using deep learning and graph search. *Biomed Opt Express* 2017;8(5):2732.

15 Roy AG, Conjeti S, Karri SPK, Sheet D, Katouzian A, Wachinger C, Navab N. ReLayNet: retinal layer and fluid segmentation of macular optical coherence tomography using fully convolutional networks. *Biomed Opt Express* 2017;8(8):3627-3642.

16 Schmidt-Erfurth U, Sadeghipour A, Gerendas BS, Waldstein SM, Bogunović H. Artificial intelligence in retina. *Prog Retin Eye Res* 2018;67:1-29.

17 Schlegl T, Waldstein SM, Bogunovic H, *et al*. Fully automated detection and quantification of macular fluid in OCT using deep learning. *Ophthalmology* 2018;125(4):549-558.

18 Lee CS, Tyring AJ, Deruyter NP, Wu Y, Rokem A, Lee AY. Deep-learning based, automated segmentation of macular edema in optical coherence tomography. *Biomed Opt Express* 2017;8(7):3440-3448.

19 Ting DSW, Peng L, Varadarajan AV, *et al*. Deep learning in ophthalmology: the technical and clinical considerations. *Prog Retin Eye Res* 2019;72:100759.

20 Binder S, Krebs I, Hilgers RD, *et al*. Outcome of transplantation of autologous retinal pigment epithelium in age-related macular degeneration: a prospective trial. *Invest Ophthalmol Vis Sci* 2004;45(11):4151-4160.

21 Vermeer KA, van der Schoot J, Lemij HG, de Boer JF. Automated segmentation by pixel classification of retinal layers in ophthalmic OCT images. *Biomed Opt Express* 2011;2(6):1743-1756.

22 Asaoka R, Murata H, Hirasawa K, *et al*. Using deep learning and transfer learning to accurately diagnose early-onset glaucoma from macular optical coherence tomography images. *Am J Ophthalmol* 2019;198:136-145.

23 Venhuizen FG, van Ginneken B, Liefers B, *et al*. Robust total retina thickness segmentation in optical coherence tomography images using convolutional neural networks. *Biomed Opt Express* 2017;8(7):3292-3316.

24 Christopher M, Bowd C, Belghith A, *et al*. 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.

25 Escamez CSF, Martinez SP, Fernandez NT. High interpretable machine learning classifier for early glaucoma diagnosis. *Int J Ophthalmol* 2021;14(3):393-398.

26 Srinivasan PP, Heflin SJ, Izatt JA, Arshavsky VY, Farsiu S. Automatic segmentation of up to ten layer boundaries in SD-OCT images of the mouse retina with and without missing layers due to pathology. *Biomed Opt Express* 2014;5(2):348-365.

27 Rahimy E. Deep learning applications in ophthalmology. *Curr Opin Ophthalmol* 2018;29(3):254-260.

28 Devalla SK, Liang Z, Pham TH, Boote C, Strouthidis NG, Thiery AH, Girard MJA. Glaucoma management in the era of artificial intelligence. *Br J Ophthalmol* 2020;104(3):301-311.

29 Roberts PK, Vogl WD, Gerendas BS, *et al*. Quantification of fluid resolution and visual acuity gain in patients with diabetic macular edema using deep learning: a post hoc analysis of a randomized clinical trial. *JAMA Ophthalmol* 2020;138(9):945-953.

30 Krause J, Gulshan V, Rahimy E, Karth P, Widner K, Corrado GS, Peng L, Webster DR. Grader variability and the importance of reference standards for evaluating machine learning models for diabetic retinopathy. *Ophthalmology* 2018;125(8):1264-1272.

31 Xu JJ, Zhou Y, Wei QJ, *et al*. Three-dimensional diabetic macular edema thickness maps based on fluid segmentation and fovea detection using deep learning. *Int J Ophthalmol* 2022;15(3):495-501.

32 Balyen L, Peto T. Promising artificial intelligence-machine learning-deep learning algorithms in ophthalmology. *Asia Pac J Ophthalmol* (*Phila*) 2019;8(3):264-272.

33 Rong YB, Xiang DH, Zhu WF, Yu K, Shi F, Fan Z, Chen XJ. Surrogate-assisted retinal OCT image classification based on convolutional neural networks. *IEEE J Biomed Health Inform* 2018;23(1):253-263.

34 Moraru A, Costin D, Moraru R, Branisteanu D. Artificial intelligence and deep learning in ophthalmology - present and future (Review). *Exp Ther Med* 2020;20(4):3469-3473.

35 Abràmoff MD, Lou YY, Erginay A, Clarida W, Amelon R, Folk JC, Niemeijer M. Improved automated detection of diabetic retinopathy on a publicly available dataset through integration of deep learning. *Invest Ophthalmol Vis Sci* 2016;57(13):5200-5206.

36 Gargeya R, Leng T. Automated identification of diabetic retinopathy using deep learning. *Ophthalmology* 2017;124(7):962-969.

37 Voets M, Møllersen K, Bongo LA. Reproduction study using public data of: development and validation of a deep learning algorithm for detection of diabetic retinopathy in retinal fundus photographs. *PLoS One* 2019;14(6):e0217541.

38 Burgansky-Eliash Z, Wollstein G, Chu TJ, *et al*. Optical coherence tomography machine learning classifiers for glaucoma detection: a preliminary study. *Invest Ophthalmol Vis Sci* 2005;46(11):4147-4152.

39 Omodaka K, An GZ, Tsuda S, *et al*. Classification of optic disc shape in glaucoma using machine learning based on quantified ocular parameters. *PLoS One* 2017;12(12):e0190012.

40 Fu DJ, Glinton S, Lipkova V, *et al*. Deep-learning automated

quantification of longitudinal OCT scans demonstrates reduced RPE loss rate, preservation of intact macular area and predictive value of isolated photoreceptor degeneration in geographic atrophy patients receiving C3 inhibition treatment. *Br J Ophthalmol* 2023:bjo-2022.

41 Xu XY, Yang PW, Wang HL, *et al*. AV-casNet: fully automatic arteriole-venule segmentation and differentiation in OCT angiography. *IEEE Trans Med Imaging* 2023;42(2):481-492.

42 Inoda S, Takahashi H, Arai Y, Tampo H, Matsui Y, Kawashima H, Yanagi Y. An AI model to estimate visual acuity based solely on cross-sectional OCT imaging of various diseases. *Graefes Arch Clin Exp Ophthalmol* 2023.Online ahead of print.

43 Ortiz M, Mallen V, Boquete L, *et al*. Diagnosis of multiple sclerosis using optical coherence tomography supported by artificial intelligence. *Mult Scler Relat Disord* 2023;74:104725.

44 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.

45 Morano J, Hervella ÁS, Rouco J, Novo J, Fernández-Vigo JI, Ortega M. Weakly-supervised detection of AMD-related lesions in color fundus images using explainable deep learning. *Comput Methods Programs Biomed* 2023;229:107296.

46 Raja H, Hassan T, Akram MU, Werghi N. Clinically verified hybrid deep learning system for retinal ganglion cells aware grading of glaucomatous progression. *IEEE Trans Biomed Eng* 2021;68(7): 2140-2151.

47 Kamalipour A, Moghimi S, Khosravi P, *et al.* Combining optical coherence tomography and optical coherence tomography angiography longitudinal data for the detection of visual field progression in glaucoma. *Am J Ophthalmol* 2023;246:141-154.

48 Thompson AC, Jammal AA, Medeiros FA. A review of deep learning for screening, diagnosis, and detection of glaucoma progression. *Transl Vis Sci Technol* 2020;9(2):42.

49 Loo J, Clemons TE, Chew EY, Friedlander M, Jaffe GJ, Farsiu S. Beyond performance metrics. *Ophthalmology* 2020;127(6):793-801.