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REVIEW ARTICLE

Artificial intelligence in glaucoma diagnosis and management: current applications, challenges, and future directions

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ABSTRACT

Background: Glaucoma is one of the leading causes of irreversible blindness worldwide and is often diagnosed at an advanced stage due to its asymptomatic early course. Recent advances in artificial intelligence (AI) have created new opportunities for improving the diagnosis, prediction, and management of glaucoma. This narrative review aims to provide an overview of current AI applications in glaucoma care, as well as recent developments and ongoing challenges.

Methods: A narrative review was conducted of studies published between 2019 and 2024, identified through a structured search of PubMed, Scopus, Web of Science, and Google Scholar. Studies focusing on AI applications in glaucoma diagnosis, disease progression prediction, and management were included.

Results: AI models, particularly deep learning and convolutional neural networks, have demonstrated high accuracy in detecting glaucomatous changes using fundus imaging, optical coherence tomography, and visual field data. These models also show promise in predicting disease progression and supporting clinical decision-making. Emerging technologies such as explainable AI, federated learning, and large language models aim to enhance interpretability, data security, and clinical applicability, although challenges related to data heterogeneity, limited external validation, and model transparency remain.

Conclusion: AI represents a promising approach for improving glaucoma care through enhanced diagnostic accuracy, risk stratification, and personalized management. Continued research, validation, and integration into clinical workflows are essential to ensure safe and effective real-world implementation.

Keywords: Artificial intelligence, glaucoma, deep learning, disease progression, ophthalmology.

Introduction

Glaucoma is a progressive optic neuropathy characterized by structural damage to the optic nerve and irreversible visual impairment, and it remains one of the leading causes of blindness worldwide [1-3]. Recent global estimates indicate that approximately 76 million individuals were affected by glaucoma in 2020, with projections rising to 111.8 million by 2040, reflecting a substantial and growing public health burden [4]. The condition is most commonly associated with high intraocular pressure (IOP), although other risk factors exist. Early stages are asymptomatic, with a gradual loss of peripheral vision

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that progresses to involve central vision in advanced disease [5,6]. Because of its silent progression, a large number of patients are diagnosed only when significant irreversible visual impairment has already begun [3].

Currently available approaches for diagnosis, such as optical coherence tomography (OCT), visual field methods, and assessment of the optic nerve head, are used, although these methods are resource demanding and with significant interobserver variation, rendering them less effective for early detection of the disease [7,8]. Subtle structural and functional alterations in early glaucoma may not be shown using "traditional" clinical approaches, resulting in late diagnosis and progression of the disease [9,10].

The application of artificial intelligence (AI) in ophthalmology has started transforming the field as it can quickly analyze large-scale and complex datasets with a good degree of accuracy [11,12]. Several machine learning (ML) and deep learning (DL) models demonstrated efficacy in detecting glaucomatous changes from fundus photographs, OCT images, and visual fields, with evidence of their applicability in real clinical settings mounting [13-16]. In more general retinal image classification tasks, some studies have reported performance on par with that of human experts [17]. Finally, there are AI applications that extend to the prediction of disease progression and surgical outcomes using longitudinal clinical data and electronic health records [18-21].

Despite its growing popularity, this fast-growing literature is often composed of reviews focused on a small number of algorithms or specific datasets, without much cross-pollination of findings across different clinical contexts. Furthermore, certain key issues - including data heterogeneity, lack of external validation, model interpretability, and challenges to real-world implementation - still remain inadequately addressed [22-25]. Consequently, this narrative review will discuss the current applications of AI in glaucoma diagnosis, management, and detection, highlight recent developments, discuss the remaining challenges, and point to future directions for integration of AI in real clinical practice.

Methodology

Relevant literature was identified through searches of PubMed, Scopus, Web of Science, and Google Scholar, covering studies published between 2019 and 2024. Search terms included combinations of keywords such as "glaucoma," "AI," "ML," "DL," "OCT," "fundus imaging," and "visual field," using Boolean operators (AND, OR) where appropriate.

The reference lists of selected articles were also reviewed to identify additional relevant studies not captured in the initial search.

Studies were included if they focused on the application of AI techniques in glaucoma diagnosis, detection, prediction, or management. Both original research articles and review papers were considered. Studies not directly related to glaucoma, non-English publications, conference abstracts without full-text availability, and studies lacking sufficient methodological detail were excluded.

Eligible studies were reviewed and organized into thematic categories, including diagnostic applications, disease progression prediction, management strategies, and emerging technologies in AI. A total of 40 studies were included in the final synthesis.

Results

AI in glaucoma diagnosis

The use of AI has shown much potential to enhance the accuracy, efficiency, and consistency of glaucoma diagnoses, especially by way of ML and DL techniques. The Convolutional Neural Networks (CNN) model is currently the predominant ML model structure for analyzing ophthalmological imaging, which includes fundus photographs, OCT scans, and visual field tests. CNNs function through hierarchical feature extraction, where early layers detect basic image features (e.g., edges and textures), while deeper layers identify complex anatomical structures such as the optic disc and cup-to-disc ratio, which are critical for glaucoma detection [7,22]. CNNs automatically extract multiple complex features and can also detect subtle structural changes associated with glaucomatous damage within the image data associated with glaucoma [11,12].

The most widely used imaging modality for detecting if a person has glaucoma using AI techniques is the fundus (colored) photography. Numerous studies note that various computer-based techniques (CNN) can distinguish between glaucomatous and non-glaucomatous retina images with a high level of accuracy using color fundus images. These models commonly analyze structural biomarkers such as cup-to-disc ratio enlargement, neuroretinal rim thinning, and optic disc hemorrhages [13-16,22]. Multiple architectures of DL, including multilevel CNNs and hybrid CNN-RNN models, have exhibited enhanced classification performance on both a technical and statistical basis across different datasets [26-28]. For example, when DL algorithms were created with large training datasets, they performed at least as well as trained ophthalmology experts on average; in some cases, higher than a trained ophthalmology expert [13,17,29,30]. Additional large-scale benchmark efforts, such as the AIROGS challenge, emphasize the robustness and generalizability of AI models in glaucoma screening across many differing datasets [31]. Additionally, there is a substantial amount of research surrounding the use of hybrid and ensemble DL techniques to improve classification accuracy and robustness even further, particularly when dealing with heterogeneous datasets [32-34].

OCT has also proven useful in the context of AI for glaucoma. AI methods that have adopted parameters like retinal nerve fiber layer (RNFL) and optic nerve head morphology from OCT have strong diagnostic power. In particular, AI models quantify RNFL thickness, ganglion cell complex measurements, and optic nerve head parameters to detect early glaucomatous damage [8,35]. More recently, the use of OCT probability map data and segmentation-free DL algorithms has improved diagnostic power and reduced reliance on manual feature extraction [35,36]. DL methods trained on OCT and OCTA images have shown higher classification accuracy and sensitivity in identifying early glaucomatous features [7,10,37]. Segmentation-free models are especially valuable as they reduce preprocessing errors and allow end-to-end learning directly from raw imaging data [36]. More advanced neural network models have been developed to address myopia as a confounder and improve diagnostic power in complex scenarios [38].

AI has followed a similar trajectory in functional assessment as observed in structural imaging. Visual field assessments using ML and AI can point to patterns of visual field loss and early change that may not easily be appreciated on standard interpretation [38]. ML models, including support vector machines and deep neural networks, are used to detect subtle spatiotemporal patterns in visual field progression [38,39]. Spatial pattern analysis and DL-based models have shown potential in detecting reanalysis of visual field change and improving diagnostic reliability [39].

One challenge going forward is limited datasets used in training many of the AI outcomes - often derived from more modest samples that do not represent the diversity of the real world [22,23]. Variability in imaging quality and differences in device specifications can further exacerbate this issue, particularly in the absence of standardized datasets. That said, there are signs of novel methodology and large-scale datasets improving diagnostic performance and clinical utility. AI functions best as an adjunct in diagnosis, but the application of its utility does not end here - it can facilitate the prediction of its progression, which is needed for timely treatment and longitudinal management.

AI in disease progression prediction

Beyond diagnosis, AI has also been used for predicting disease progression, which is important for early intervention and management of glaucoma patients. With the ever-changing landscape of glaucoma management, it is imperative to find cases with a propensity for worsening early on, given the condition's chronic, progressive, and irreversible nature, which can substantially affect the choice of treatment and health of the patient's vision over the years.

ML and DL models have been trained on longitudinal clinical datasets to predict progression, based on what they have seen occur before. These variables to make predictions draw on a variety of structural and functional variables, especially RNFL thickness or sectorial thickness, measures taken from nerve head analysis and visual fields, with extensive use of historical longitudinal data. Advanced models integrate multimodal inputs (imaging + clinical + temporal data) to improve predictive accuracy and enable personalized risk stratification [18,19,21]. DL approaches that integrate baseline and longitudinal imaging data have demonstrated superior performance in predicting visual field progression compared to conventional statistical methods [21].

Beyond imaging-based models, EHR data have also been harnessed for predicting glaucoma progression. ML models trained on large clinical datasets can risk-stratify individuals for surgical intervention or rapid disease progression. Predictive models using both systemic variables and treatment history have shown moderate to strong performance for identifying patients who may require surgical management [18,19]. Natural language processing (NLP) models further enhance prediction by extracting clinically relevant information from unstructured medical records. Recently developed models leveraging NLP and transformer-based techniques can directly extract clinically pertinent information from unstructured clinical notes as well [40].

AI-based models have also been developed to predict surgical outcomes and treatment response. ML algorithms can estimate the success of surgical procedures using preoperative and intraoperative parameters [41].

Despite these exciting advances, however, there are also important limitations. These predictive models have been generated in a number of cases using retrospective datasets and may not have been externally validated, raising questions about their translational capacity across populations and different clinical settings [11,22]. Variability in data quality, as well as integration of heterogeneous data to create a cohesive risk profile, is another challenge. However, as data availability and model development continue to improve, so will the role that AI plays in predicting progression and furthering iterations of precision medicine in ophthalmic encounters. Such predictive abilities enhance the justification for AI input into clinical interactions and decision-making.

AI in management and treatment

AI is being explored to help monitor, treat, and manage glaucoma across both intervention and chronic settings, moving beyond diagnosis and prediction to assist with clinical decision-making and personalizing treatment strategies. With the need for long-term monitoring of disease states, AI can offer models that reflect optimized treatment strategies while improving outcomes and efficiency in patient management and workflows.

AI systems may assist clinicians in selecting treatment strategies by integrating clinical, imaging, and demographic data from large-scale datasets. Patterns that interact with the treated individual's phenotype and treatment response to shape disease course can be detected using ML. These systems often rely on predictive modeling frameworks that combine supervised learning algorithms with longitudinal patient data to optimize individualized treatment pathways [18,19,21]. For example, predictive models have used electronic health record data to identify patients likely to need surgical intervention, allowing more timely treatment [18,19]. Predictive models that include preoperative clinical parameters and follow-up longitudinal data have been shown to have decent accuracy at predicting surgical outcomes, thus allowing improved patient selection and personalized surgical planning [41].

In surgical management, AI has demonstrated potential in predicting postoperative outcomes and guiding procedural planning. ML-assisted models have been used to estimate the success of glaucoma surgeries such as trabeculectomy, using preoperative and intraoperative parameters to improve patient selection and optimize outcomes [41]. These tools may help reduce surgical failure rates and enhance decision-making in complex clinical scenarios.

AI has also found a role in monitoring systems to assist with longitudinal disease management. Automatically analyzing sequential imaging and visual field data to detect treatment failure or disease progression so that therapy can be adjusted on time. In addition, AI-enabled platforms integrated into imaging systems may provide real-time decision support, improving consistency in clinical assessments and reducing clinician workload [11,22].

AI is also used for developing decision-support systems for selecting patient-specific treatment options. Multiple options are offered - AI-based models that can assist in treatment selection with the best fit for individual patient characteristics for different types of minimally invasive glaucoma surgery (MIGS) procedures [42].

Nonetheless, many challenges persist in deploying AI in clinical management, including variability in data quality, a lack of prospective validation, and issues regarding the interpretability and transparency of AI models. Regulatory and ethical concerns around these systems must also be resolved before they can find widespread use in the clinic [25,43]. Nonetheless, going forward, how AI tools will develop further and be integrated into the clinic to aid with the management and treatment of glaucoma will be critical. Further, as AI models progress in clinical management, new technology is forthcoming to enhance model interpretability, data security, and clinical applicability.

Emerging technologies

Recent advances in AI for glaucoma have extended beyond conventional ML and DL models to include emerging technologies that may improve interpretability, privacy, and clinical usability. Among the most relevant developments are explainable artificial intelligence (XAI), federated learning, and large language models (LLMs), all of which address important limitations in current AI applications and may facilitate broader clinical adoption.

XAI techniques, such as saliency maps and gradient-based attribution methods, allow visualization of image regions contributing to model predictions, thereby improving clinical interpretability [23]. One of the major concerns in AI-based glaucoma care is the "black-box" nature of many DL systems. Although these models often demonstrate strong diagnostic performance, their decision-making processes are not always transparent to clinicians. XAI has arisen as a key area of research to improve trustworthiness and utility of model outputs by enhancing their interpretability. Techniques such as feature attribution and visualization techniques can help determine which parts of the image, or which variables, most influenced a given model's output. In glaucoma, explainable ML has been applied to help clarify the contributions of RNFL thickness, IOP, and visual field data toward diagnostic classification, hence improving the interpretability of AI-assisted assessments [23,44]. More of this sort of greater explainability may lead to more clinician confidence, and therefore safer use of AI [1,25].

Federated learning has been proposed as another promising innovation in glaucoma AI, particularly in response to concerns about data privacy and limited data sharing across institutions. Instead of pooling images within the algorithm server, this federated approach allows an algorithm to be trained in a distributed manner across multiple sites, without the actual flow of sensitive data between patient databases. This geographical distribution may help the algorithms learn a more generalized set of features. Recent work shows the utility of such federated, learning-based glaucoma detection systems, improving institutional collaboration and reducing the risk of centralized exposure to sensitive patient data [24]. As multi-center datasets become increasingly important for robust AI development, federated learning may play a key role in expanding the scalability and external validity of glaucoma models.

LLMs are another emerging direction with potential applications in glaucoma care. Unlike image-based models, LLMs are designed to process and generate human-like language and may be used for analyzing unstructured clinical notes, summarizing patient information, and supporting diagnostic reasoning. In glaucoma, transformer-based NLP models have demonstrated the ability to predict disease progression requiring surgery from free-text clinical notes [30]. Exploratory studies have suggested that ChatGPT may exhibit diagnostic reasoning similar to ophthalmology trainees in select glaucoma case scenarios (indicating possible utility as a supportive educational or decision-assistance tool - rather than a stand-alone clinical system), but these applications are still early in stage and have limited clinical validation to date [40,45].

Despite the promise of these novel technologies, they remain in the early stages of clinical translation. Thus far, they require prospective validation and regulatory approval, with appropriate protection against bias; then, their performance in the real-world will need to be carefully assessed. Nonetheless, together with XAI, federated learning and LLMs represent important next directions in the evolution of AI for glaucoma, with potential to make future systems more transparent, safe, and clinically useful. A summary of representative studies of AI approaches in glaucoma is found in Table 1.

Discussion

This narrative review summarizes the expanding role and clinical applicability of AI in glaucoma, including the roles of diagnosis, prediction of disease progression, management, and newer technology. In the identified studies, AI-based models, particularly DL, showed consistently high diagnostic performance for the

Table 1. Representative studies on AI applications in glaucoma.

Study	AI method	Application area	Data type	Key finding
Aljohani and Aburasain [24]	Federated learning	Diagnosis	Multi-center data	Enabled privacy-preserving model training
Baxter et al. [18]	ML	Management/ Prediction	EHR	Predicted risk of surgical intervention
Birla et al. [41]	ML	Treatment	Clinical + Surgical	Predicted trabeculectomy outcomes
Bowd et al. [10]	DL	Diagnosis	OCTA	Enhanced classification of glaucoma using vessel density metrics
Delsoz et al. [45]	LLM (ChatGPT)	Decision support	Clinical cases	Demonstrated potential as a supportive diagnostic tool (limited validation)
Gong et al. [13]	DL	Diagnosis	Fundus / imaging	Demonstrated strong performance in glaucoma detection with AI-assisted models
Hu and Wang [40]	NLP / Transformer	Progression prediction	Clinical notes	Predicted progression requiring surgery
Li et al. [38]	Neural network	Diagnosis	OCT / RNFL	Improved diagnostic accuracy in myopic patients
Mohammadzadeh et al. [21]	DL	Progression prediction	Longitudinal imaging	Predicted visual field progression with high accuracy
Noury et al. [15]	DL	Diagnosis	Real-world datasets	Identified novel diagnostic regions with high accuracy across diverse datasets
Oh et al. [23]	XAI	Diagnosis	Clinical + Imaging	Improved interpretability of AI models
Qidwai et al. [42]	AI system	Treatment planning	Clinical data	Assisted in selecting optimal MIGS procedures
Ran et al. [7]	DL	Diagnosis	OCT	Improved detection of glaucomatous structural changes using OCT-based models
Sidhu and Mansoori [14]	CNN	Diagnosis	Fundus images	Effective classification of glaucomatous vs normal eyes
Wang et al. [39]	ML	Diagnosis/Monitoring	Visual field	Detected visual field progression using spatial pattern analysis
Wang et al. [19]	ML	Management/ Prediction	EHR	Identified patients at higher risk of disease progression

detection of glaucomatous changes using multimodal data based on fundus photography, OCT, and visual field analysis. These findings are consistent with prior studies reporting high sensitivity, specificity, and area under the curve values for AI-based glaucoma detection, with some models achieving performance comparable to experienced clinicians [11,12]

A common strength across the mentioned studies is AI's ability to rapidly analyze large-scale and high-dimensional datasets, which facilitates the uncovering of subtle structure-function changes not easily detected by human analysis alone. Convolutional neural networks applied to fundus and OCT imaging have been noted for their strong capabilities to detect glaucomatous damage [7,10]. Furthermore, longitudinal AI models incorporating temporal clinical and imaging data have demonstrated improved capability in predicting disease progression, enabling earlier and more targeted intervention to prevent irreversible vision loss [21].

Compared to previous reviews, this review provides a broader synthesis of AI applications across multiple stages of glaucoma care, rather than focusing exclusively on diagnostic performance. Previous reviews have largely emphasized detection and screening, whereas the present synthesis highlights the expanding role of AI in disease progression prediction, treatment decision-making, and surgical planning [22,43]. This reflects the growing scope of AI in ophthalmology, shifting from isolated image-based classification toward integrated clinical decision-support systems.

Despite these promising advances, multiple limitations also exist. The key one being the use of potentially non-representative cohorts from retrospective curated datasets raises the generalizability and external validity of many AI models [22,23]. Variability in imaging quality owing to differences in device specifications, as well as lack of a reference standard in the form of standardized datasets may influence model performance across clinical centers. Finally, the limited interpretability of DL models, the "black-box" problem, may hinder clinician trust and adoption of these systems in everyday use.

Ethical and regulatory challenges will be even more important in the introduction of AI to clinical care. Issues of privacy, algorithm bias, and accountability will all need to be addressed for AI implementations to be safe [23,24]. Emerging approaches such as federated learning and XAI offer potential solutions by enhancing data security and model transparency, although these technologies remain under active development.

From a clinical perspective, AI has the potential to transform glaucoma care through earlier detection, improved risk stratification, and personalized treatment strategies. AI-assisted diagnostic tools may help reduce clinician workload and provide better access to care in environments where specialist availability is scarce. Predictive models can also support clinicians to identify patients at a higher risk of having their disease progress and target interventions appropriately, leading to improved long-term outcomes.

Future research should focus on the development of large-scale, multi-center, and diverse datasets to improve the robustness and generalizability of AI models. Prospective validation studies are essential to assess real-world performance and clinical impact. Additionally, successful integration of AI into clinical workflows will require systems that complement, rather than replace, clinician expertise, ensuring safe and effective adoption. The development of emerging technologies and approaches such as XAI, federated learning, and LLMs may further bolster the transparency, scalability, and usability of this technology in glaucoma.

AI and its uses in the diagnosis and management of glaucoma are a fast-moving and promising area. Many advances have already been made, addressing current limitations and establishing robust clinical validation will be essential for achieving widespread and reliable implementation in routine ophthalmic practice.

Limitations of the review

This review has several important limitations that are relevant to the findings presented. First, as a pure narrative review, it was not done following a systematic review methodology and thus may suffer from selection bias in the identification and inclusion of studies. Although our search was structured, without defined protocols and quality assessment tools, there is the risk that the comprehensiveness and objectiveness of the searched literature are somewhat limited.

Second, no quantitative synthesis or meta-analysis was performed, and therefore, pooled estimates of diagnostic accuracy or predictive performance could not be generated.

Third, the studies differed substantially based on data sets used, techniques employed, and what metrics were used to evaluate them; this may limit the degree to which direct comparisons among studies can be made and may impact the generalizability of findings. Despite these limitations, this review provides a comprehensive and clinically relevant synthesis of current evidence on AI applications in glaucoma.

Conclusion

AI is rapidly becoming one of the most valuable tools available for glaucoma diagnosis, prognostication, and clinical management. The utilization of ML and DL in ophthalmic imaging and clinical data analysis has demonstrated improved diagnostic accuracy, efficiency, and risk stratification capabilities, enhancing the early detection and monitoring of glaucomatous changes.

However, many challenges still exist that limit the widespread clinical adoption of AI in the diagnosis and treatment of glaucoma, including but not limited to data heterogeneity, model generalizability and interpretability, and the need for solid clinical validation of these techniques. Addressing these limitations is essential to ensure the safe, reliable, and equitable integration of AI into routine clinical practice.

Overall, AI has the potential to significantly transform glaucoma care by enabling earlier diagnosis, supporting personalized treatment strategies, and improving long-term patient outcomes. Continued efforts in research, validation, and real-world implementation will be critical to fully realize these benefits and translate technological advances into meaningful clinical impact.

List of Abbreviations

AI	artificial intelligence
CNNs	conventional neural networks
DL	deep learning
EHRs	electronic health records
IOP	intra-ocular pressure
LLMs	large language models
ML	machine learning
OCT	optical coherence tomography
RNNs	recurrent neural networks
XAI	explainable artificial intelligence

Conflict of interests

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Supplementary content (if any) is available online.

References

1. Huang X, Islam MR, Akter S, Ahmed F, Kazami E, Serhan HA, et al. Artificial intelligence in glaucoma: opportunities, challenges, and future directions. Biomed Eng Online. 2023;22(1):126. https://doi.org/10.1186/s12938-023-01187-8
2. Haider A, Arsalan M, Lee MB, Owais M, Mahmood T, Sultan H, et al. Artificial intelligence-based computer-aided diagnosis of glaucoma using retinal fundus images. Expert Syst Appl. 2022;207:117968. https://doi.org/10.1016/j.eswa.2022.117968

3. Nair M, Tagare S, Venkatesh R, Odayappan A. Artificial intelligence in glaucoma. Indian J Ophthalmol. 2022;70(5):1868–9. https://doi.org/10.4103/ijo.IJO_1015_22
4. Allison K, Patel D, Alabi O. Epidemiology of glaucoma: the past, present, and predictions for the future. Cureus. 2020;12(11):e11686. https://doi.org/10.7759/cureus.11686
5. Zhang L, Tang L, Xia M, Cao G. The application of artificial intelligence in glaucoma diagnosis and prediction. Front Cell Dev Biol. 2023;11:1173094. https://doi.org/10.3389/fcell.2023.1173094
6. Ferro Desideri L, Rutigliani C, Corazza P, Nastasi A, Roda M, Nicolo M, et al. The upcoming role of Artificial Intelligence (AI) for retinal and glaucomatous diseases. J Optom. 2022;15(Suppl 1):S50–7. https://doi.org/10.1016/j.optom.2022.08.001
7. Ran AR, Tham CC, Chan PP, Cheng CY, Tham YC, Rim TH, et al. Deep learning in glaucoma with optical coherence tomography: a review. Eye (Lond). 2021;35(1):188–201. https://doi.org/10.1038/s41433-020-01191-5
8. Alghamdi M, Abdel-Mottaleb M. A comparative study of deep learning models for diagnosing glaucoma from fundus images. IEEE Access. 2021;9:23894–906. https://doi.org/10.1109/ACCESS.2021.3056641
9. Lee J, Kim YK, Park KH, Jeoung JW. Diagnosing glaucoma with spectral-domain optical coherence tomography using deep learning classifier. J Glaucoma. 2020;29(4):287–94. https://doi.org/10.1097/IJG.0000000000001458
10. Bowd C, Belghith A, Zangwill LM, Christopher M, Goldbaum MH, Fan R, et al. Deep learning image analysis of optical coherence tomography angiography measured vessel density improves classification of healthy and glaucoma eyes. Am J Ophthalmol. 2022;236:298–308. https://doi.org/10.1016/j.ajo.2021.11.008
11. Yousefi S. Clinical applications of artificial intelligence in glaucoma. J Ophthalmic Vis Res. 2023;18(1):97–112. https://doi.org/10.18502/jovr.v18i1.12730
12. Nunez R, Harris A, Ibrahim O, Keller J, Wikle CK, Robinson E, et al. Artificial intelligence to aid glaucoma diagnosis and monitoring: state of the art and new directions. Photonics. 2022;9(11):810. https://doi.org/10.3390/photonics9110810
13. Gong D, Hu M, Yin Y, Zhao T, Ding T, Meng F, et al. Practical application of artificial intelligence technology in glaucoma diagnosis. J Ophthalmol. 2022;2022:5212128.
14. Sidhu Z, Mansoori T. Artificial intelligence in glaucoma detection using color fundus photographs. Indian J Ophthalmol. 2024;72(3):408–11. https://doi.org/10.4103/IJO.IJO_613_23
15. Noury E, Mannil SS, Chang RT, Ran AR, Cheung CY, Thapa SS, et al. Deep learning for glaucoma detection and identification of novel diagnostic areas in diverse real-world datasets. Transl Vis Sci Technol. 2022;11(5):11. https://doi.org/10.1167/tvst.11.5.11
16. Schuman JS, De Los Angeles Ramos Cadena M, McGee R, Al-Aswad LA, Medeiros FA, Abramoff M, et al. A case for the use of artificial intelligence in glaucoma assessment. Ophthalmol Glaucoma. 2022;5(3):e3–13. https://doi.org/10.1016/j.ogla.2021.12.003
17. Pandey PU, Ballios BG, Christakis PG, Kaplan AJ, Mathew DJ, Ong Tone S, et al. Ensemble of deep convolutional neural networks is more accurate and reliable than board-certified ophthalmologists at detecting multiple diseases in retinal fundus photographs. Br J Ophthalmol. 2024;108(3):417–23. https://doi.org/10.1136/bjo-2022-322183
18. Baxter SL, Marks C, Kuo TT, Ohno-Machado L, Weinreb RN. Machine learning-based predictive modeling of surgical intervention in glaucoma using systemic data from electronic health records. Am J Ophthalmol. 2019;208:30–40. https://doi.org/10.1016/j.ajo.2019.07.005
19. Wang SY, Ravindranath R, Stein JD, Amin S, Edwards PA, Srikumaran D, et al. Prediction models for glaucoma in a multicenter electronic health records consortium: the sight outcomes research collaborative. Ophthalmol Sci. 2023;4(3):100445. https://doi.org/10.1016/j.xops.2023.100445
20. Tao S, Ravindranath R, Wang SY. Predicting glaucoma progression to surgery with artificial intelligence survival models. Ophthalmol Sci. 2023;3(4):100336. https://doi.org/10.1016/j.xops.2023.100336
21. Mohammadzadeh V, Wu S, Besharati S, Davis T, Vepa A, Morales E, et al. Prediction of visual field progression with baseline and longitudinal structural measurements using deep learning. Am J Ophthalmol. 2024;262:141–52. https://doi.org/10.1016/j.ajo.2024.02.007
22. Mursch-Edlmayr AS, Ng WS, Diniz-Filho A, Sousa DC, Arnould L, Schlenker MB, et al. Artificial intelligence algorithms to diagnose glaucoma and detect glaucoma progression: translation to clinical practice. Transl Vis Sci Technol. 2020;9(2):55. https://doi.org/10.1167/tvst.9.2.55
23. Oh S, Park Y, Cho KJ, Kim SJ. Explainable machine learning model for glaucoma diagnosis and its interpretation. Diagnostics (Basel). 2021;11(3):510. https://doi.org/10.3390/diagnostics11030510
24. Aljohani A, Aburasain RY. A hybrid framework for glaucoma detection through federated machine learning and deep learning models. BMC Med Informat Decis Making. 2024;24(1):115. https://doi.org/10.1186/s12911-024-02518-y
25. Bragança CP, Torres JM, Macedo LO, Soares CP. Advancements in glaucoma diagnosis: the role of AI in medical imaging. Diagnostics (Basel). 2024;14(5):530. https://doi.org/10.3390/diagnostics14050530
26. Aamir M, Irfan M, Ali T, Ali G, Shaf A, Alqahtani Saeed S, et al. An adoptive threshold-based multi-level deep convolutional neural network for glaucoma eye disease detection and classification. Diagnostics (Basel). 2020;10(8):602. https://doi.org/10.3390/diagnostics10080602
27. Arias-Serrano I, Velásquez-López PA, Avila-Briones LN, Laurido-Mora FC, Villalba-Meneses F, Tirado-Espin A, et al. Artificial intelligence based glaucoma and diabetic retinopathy detection using MATLAB - retrained AlexNet convolutional neural network. F1000 Res. 2024;12:14. https://doi.org/10.12688/f1000research.122288.2
28. Atalay E, Özalp O, Devecioğlu OC, Erdoğan H, Ince T, Yıldırım N. Investigation of the role of convolutional neural network architectures in the diagnosis of glaucoma using color fundus photography. Turk J Ophthalmol. 2022;52(3):193–200. https://doi.org/10.4274/tjo.galenos.2021.29726
29. Veena HN, Muruganandham A, Kumaran TS. Enhanced CNN-RNN deep learning-based framework

for the detection of glaucoma. Int J Biomed Eng Technol. 2021;36(2):133. https://doi.org/10.1504/IJBET.2021.116116

30. Xue Y, Zhu J, Huang X, Xu X, Li X, Zheng Y, et al. A multi-feature deep learning system to enhance glaucoma severity diagnosis with high accuracy and fast speed. J Biomed Inf. 2022;136:104233.
31. De Vente C, Vermeer KA, Jaccard N, Wang H, Sun H, Khader F, et al. AIROGS: artificial intelligence for robust glaucoma screening challenge. IEEE Trans Med Imag. 2024;43(1):542–57. https://doi.org/10.1109/TMI.2023.3313786
32. Serte S, Serener A. Graph-based saliency and ensembles of convolutional neural networks for glaucoma detection. IET Image Process. 2020;15(3):797–804. https://doi.org/10.1049/ipr2.12063
33. Sułot D, Alonso-Caneiro D, Ksieniewicz P, Krzyzanowska-Berkowska P, Iskander DR. Glaucoma classification based on scanning laser ophthalmoscopic images using a deep learning ensemble method. PLoS One. 2021;16(6):252339. https://doi.org/10.1371/journal.pone.0252339
34. Yang KO, Lee JM, Shin Y, Yoon IY, Choi JW, Lee WJ. Diagnosis of glaucoma based on few-shot learning with wide-field optical coherence tomography angiography. Biomedicines. 2024;12(4):741. https://doi.org/10.3390/biomedicines12040741
35. Thakoor KA, Li X, Tsamis E, Sajda P, Hood DC. Enhancing the accuracy of glaucoma detection from oct probability maps using convolutional neural networks. Annu Int Conf IEEE Eng Med Biol Soc. 2019; 2019:2036–40. https://doi.org/10.1109/EMBC.2019.8856899
36. Thompson AC, Jammal AA, Berchuck SI, Mariottoni EB, Medeiros FA. Assessment of a segmentation-free deep learning algorithm for diagnosing glaucoma from optical coherence tomography scans. JAMA Ophthalmol. 2020;138(4):333–9. https://doi.org/10.1001/jamaophthalmol.2019.5983
37. Bunod R, Lubrano M, Pirovano A, Chotard G, Brasnu E, Berlemont S, et al. A deep learning system using optical coherence tomography angiography to detect glaucoma and anterior ischemic optic neuropathy. J Clin Med. 2023;12(2):507. https://doi.org/10.3390/jcm12020507
38. Li L, Zhu H, Zhang Z, Zhao L, Xu L, Jonas RA, et al. Neural network-based retinal nerve fiber layer profile compensation for glaucoma diagnosis in myopia: model development and validation. JMIR Med Inf. 2021;9(5):e22664. https://doi.org/10.2196/22664
39. Wang M, Shen LQ, Pasquale LR, Petrakos P, Formica S, Boland MV, et al. An artificial intelligence approach to detect visual field progression in glaucoma based on spatial pattern analysis. Invest Ophthalmol Vis Sci. 2019;60(1):365–75. https://doi.org/10.1167/iovs.18-25568
40. Hu W, Wang SY. Predicting glaucoma progression requiring surgery using clinical free-text notes and transfer learning with transformers. Transl Vis Sci Technol. 2022;11(3):37. https://doi.org/10.1167/tvst.11.3.37
41. Birla S, Varshney T, Singh A, Sharma A, Panigrahi A, Gupta S, et al. Machine learning-assisted prediction of trabeculectomy outcomes among patients of juvenile glaucoma by using 5-year follow-up data. Indian J Ophthalmol. 2024;72(7):987–93. https://doi.org/10.4103/IJO.IJO_2009_23
42. Qidwai U, Qidwai U, Sivapalan T, Ratnarajan G. IMIGS: an innovative AI based prediction system for selecting the best patient-specific glaucoma treatment. MethodsX. 2023;10:102209. https://doi.org/10.1016/j.mex.2023.102209
43. Al-Aswad LA, Ramachandran R, Schuman JS, Medeiros F, Eydelman MB. Artificial intelligence for glaucoma: creating and implementing artificial intelligence for disease detection and progression. Ophthalmol Glaucoma. 2022;5(5):e16–25. https://doi.org/10.1016/j.ogla.2022.02.010
44. Vadduri M. Enhancing glaucoma diagnosis: deep learning models for automated identification and explainability using fundus images. J Theor Appl Inf Technol. 2024;102(13):5346–63.
45. Delsoz M, Raja H, Madadi Y, Tang AA, Wirostko BM, Kahook MY, et al. The use of ChatGPT to assist in diagnosing glaucoma based on clinical case reports. Ophthalmol Ther. 2023;12(6):3121–2. https://doi.org/10.1007/s40123-023-00805-x