Review Article

Transforming Glaucoma Care with Artificial Intelligence: A Comprehensive Review of Diagnosis, Monitoring, and Treatment Algorithms

Amanda Amberg, Alejandro Espaillat*

South Florida Eye Institute, 6233 N. University Drive, Fort Lauderdale, United States of America

Corresponding author:
Alejandro Espaillat, South Florida Eye Institute, 6233 N. University Drive, Fort Lauderdale, United States of America,
E-mail: drespaillat@evnmiami.com

Received: 14-Mar-2024, Manuscript No. amhsr-24-129463;
Editor assigned: 18-Mar-2024, Pre QC No. amhsr-24-129463 (PQ);
Reviewed: 01-Apr-2024, QC No. amhsr-24-129463;
Revised: 08-Apr-2024, Manuscript No: amhsr-24-129463 (R);
Published: 15-Apr-2024, DOI: 10.54608.annalsmedical.2024.S1

Abstract

This review article explores the transformative impact of Artificial Intelligence (AI) on glaucoma care, focusing on advancements in diagnosis, monitoring, and treatment algorithms. AI technologies have revolutionized the field of ophthalmology by enhancing the accuracy and efficiency of diagnosing glaucoma. Furthermore, AI-powered monitoring systems enable continuous and personalized patient care, facilitating early detection of disease progression. Integrating AI algorithms in treatment protocols promises individualized and optimized therapeutic strategies for better management of glaucoma. This comprehensive review elucidates AI applications' current state and future directions in transforming glaucoma care, emphasizing the potential benefits of improving patient outcomes.

Keywords: Glaucoma; Artificial intelligence; Diagnosis; Monitoring; Treatment algorithms.

Introduction

Glaucoma is a collection of eye conditions that gradually harm the optic nerve, ultimately leading to irreversible blindness, a significant cause of global vision loss [1,2]. The optic nerve tissue typically deteriorates due to the accumulation of aqueous humor, resulting in elevated Intra Ocular Pressure (IOP). This increased IOP damages the optic nerve, leading to varying degrees of lasting vision loss. The actual prevalence of glaucoma is likely underestimated, as the condition often affects peripheral vision initially while sparing central vision. Glaucoma manifests bilaterally in its early stages, although its impact can vary between the eyes [2]. Prompt diagnosis and effective management are crucial for a positive outcome due to the progressive condition. The Ocular Hypertension Treatment Study demonstrated that reducing baseline intraocular pressure by 20% in individuals with ocular hypertension reduced the risk of glaucoma by 50% [3]. Similarly, findings from the Early Manifest Glaucoma Trial showed that early intervention and a 25% decrease in intraocular pressure helped delay the progression of the disease [4].

In traditional clinical practice, diagnosing glaucoma involves an in-depth analysis of data gathered from different testing methods like Optical Coherence Tomography (OCT), Visual Fields (VF), pachymetry, gonioscopy, and Optic Disc Photography (ODP). The interpretation of these results guides clinicians in initiating treatment or determining the need for ongoing evaluations to arrive at a definitive diagnosis. Given the image-dependent nature of Ophthalmology, there is extensive potential for leveraging Artificial Intelligence (AI) to improve the diagnosis, treatment effectiveness, and other aspects of managing ocular diseases, particularly in the detection, diagnosis, treatment, and care of glaucoma [5]. Implementing predictive algorithms to forecast outcomes using varied treatment approaches can significantly improve treatment recommendations and patient compliance [6].

Literature Review

AI-based diagnostic tools for glaucoma

Although significant advancements have been made in glaucoma treatment, there remains a need for a comprehensive understanding of this disease. Leveraging AI to assess individual parameters and combinations, such as data extraction and analysis from ODP, VF, Retinal Nerve Fiber Layer (RNFL) thickness, and Ganglion Cell Layer (GCL) thickness, along with considerations for Intraocular Pressure (IOP) and pachymetry, can provide a reliable approach for swift glaucoma diagnosis. Fundus imaging of the optic nerve, OCT, and VF testing are the three primary imaging techniques commonly utilized in clinical assessments for glaucoma, with AI technologies already integrated into these systems [6].

Optic disc photography and AI

Fundus photography of the optic disc has been essential for documenting the optic nerve glaucomatous changes over time. ODP allows for a more detailed evaluation of anatomy, internal structure, and Cup-to-Disc Ratio (CDR), a critical indicator for glaucoma risk assessment [7]. Additionally, techniques such as stereo disc photography can further assess the dimensions and contours of the neuro-retinal rim and the depth of the cup compared to traditional two-dimensional photography. Challenges in analyzing disc photography include inconsistencies between different observers and reliance on qualitative interpretations by clinicians rather than quantitative data. Implementing a robust AI system that enhances objectivity could lead to more precise glaucoma diagnoses. In recent developments, progress in AI

How to Cite this Article: Amberg A et al. Transforming Glaucoma Care with Artificial Intelligence: A Comprehensive Review of Diagnosis, Monitoring, and Treatment Algorithms. Ann Med Health Sci Res. 2024;S1: 912-915.

has been directed toward accurately identifying and measuring optic disc and cup characteristics in fundus photographs to determine CDR values [8]. AI methods have been employed to measure optic disc and cup dimensions more precisely by extricating vascular information [9]. The proposed models would use an automated optic nerve head segmentation framework and quantification through morphological operations and active contours.

Classical image processing techniques for optic cup and disc segmentation, followed by a fusion network to integrate quantified parameters, funnel data to a Support Vector Machine (SVM) classifier to distinguish between glaucomatous and non-glaucomatous eyes [10]. Additionally, subsequent research on fundus images has extensively utilized classical image processing methods, including edge detection, morphological filtering, adaptive deformable filters, and active contours, to quantify optic disc features and aid in glaucoma diagnosis. As early as 2015, deep Convolutional Neural Network (CNN) models allowed seamless integrated and automatic qualification of fundus images [11]. Using two separate datasets of fundus images, a Deep Learning (DL) framework was able to train and compute the precise segmentation of optic disc and cup structures [11]. Advanced models have achieved more accuracy, detecting glaucoma by interpreting quantified retina and Optic Nerve Head (ONH) characteristics extracted from fundus images, and the deep hierarchical context analyzed the overall fundus image and the specific optic disc area by employing a unique disc-aware ensemble network for automated glaucoma screening [12]. This approach entailed four distinct deep streams operating at various levels and modules: The global image stream, segmentation-guided network, local disc region stream, and disc polar transformation stream. Ultimately, the output probabilities from these diverse streams are amalgamated to produce a cohesive and accurate diagnostic outcome.

Optical coherence tomography in AI

OCT machines are utilized in glaucoma testing to measure optic disc sizing, RNFL thickness, GCL thickness, neuro-retinal rim area, and cupping [13]. AI platforms can interpret these parameters to screen for glaucoma [14]. Some AI models employ linear or non-linear filtering, edge detection, and local texture analysis, known as classical image preprocessing [15]. Muhammad et al., utilized a hybrid DL approach on OCTs and achieved a sensitivity of 93.1% in identifying individuals suspected of having glaucoma [16]. This was achieved by integrating CNN to extract rich features from maps derived from OCTs. A random forest classifier was then used to train a model to predict the existence of glaucomatous damage. The algorithm was then compared against traditional optic nerve imaging metrics. Barella et al., generated an AI algorithm that used Machine Learning (ML) classifiers extracted from the RNFL and optic nerve head data [17]. Although the early study did not improve sensitivity and specificity utilization, favorable diagnostic accuracy was observed.

Christopher et al., generated an AI platform to analyze RNFL features through unsupervised ML on OCTs. Findings suggest a computational approach can extract and pinpoint structural characteristics that enhance glaucoma detection and its progression prediction [18]. Higher level AI models using deep CNN have taken AI interpretation to the highest level, and models can provide automatic end-to-end quantification of data to report highly accurate diagnoses [18]. DL models provide detailed quantifications of OCT layers, thus more accurately predicting glaucoma diagnoses [19].

Visual fields and AI

Visual field machines utilize automated perimetry diagnostic tools for detecting and quantifying visual field defects resulting from early glaucomatous changes, providing a means to track the stability or progression of the condition. Analyzing and categorizing VF changes can be challenging due to potential bias and variation among clinicians. AI technologies, such as unsupervised Gaussian Mixture Modeling (GMM), archetypal analysis, deep archetypal analysis, and Artificial Neural Networks (ANN), have been proposed to streamline this process [20]. These AI models aim to detect and classify VF defects into patterns, with notable success rates reported. Andersson et al., demonstrated that ANN achieved high sensitivity and specificity levels after appropriate training in assessing glaucoma-related visual field data performing on par with or outperforming human clinicians [21]. The integration of AI technology in interpreting and categorizing VF scans has shown promise in enhancing the accuracy and efficiency of glaucoma diagnosis [21].

Limitations and challenges of AI in glaucoma care

In medicine, the effectiveness and accuracy of AI algorithms hinge on the precise identification of specific disease entities. Glaucoma, for example, remains a condition with ongoing complexities and gaps in understanding. The diagnosis and management of glaucoma can vary significantly, particularly in the early stages of the disease, leading to discrepancies even among experts when it comes to treatment approaches for more advanced cases [22]. This variability poses challenges in establishing a standardized disease index or baseline, unlike in better defined conditions. Consequently, developing a robust AI based diagnostic model for glaucoma may need to be improved. Moreover, a critical consideration for AI development is the importance of diverse and unbiased training data sets [23]. AI systems use extensive data to identify and categorize diseases efficiently.

If the initial training set is balanced and diverse, the AI model's accuracy may be protected when applied to new data sets. Biases could become ingrained in the AI program, potentially resulting in overlooked nuances of early disease characteristics [24]. DL AI models exhibit inherent uncertainty. While these models primarily offer a probability-based diagnosis rather than absolute confirmation, they can sometimes err in straightforward cases by providing a high likelihood of an incorrect decision, potentially indicating a more severe disease condition than is present. The integration of AI in healthcare necessitates careful consideration of ethical concerns, including the assignment of liability in misdiagnosis, especially in telehealth environments; AI models operating at higher levels of autonomy must surpass the benchmark of "doing no harm" and demonstrate clear benefits to patient outcomes to be deemed appropriate for use. Privacy issues represent another ethical facet, as data sets to train AI models may implicate patient confidentiality and safety regulations [25].

Discussion

AI guided management of glaucoma

In regions with limited resources or inadequate access to eye care services, commonly termed "eye care deserts," integrating AI models presents an opportunity to address gaps in glaucoma management. By leveraging a synergy of AI technology and telehealth applications, non-physician healthcare professionals can support glaucoma diagnosis and care more actively. Implementing cost-effective screening protocols, overseen by technicians tasked with data collection, enables the evaluation of a larger patient population that would otherwise lack access to such services [26-28]. Further developments may harness AI capabilities to provide insights for glaucoma management, including recommendations for treatment options like traditional eye drops or surgical interventions. Tao et al., published a study demonstrating that AI survival models can predict the progression to glaucoma surgery by gathering information from Electronic Health Records (EHR) and clinical data [29]. The ability to predict progression outcomes of this nature will drastically reduce the cost burden for glaucoma patients, as surgical intervention can occur earlier in the disease course, providing more favorable surgical outcomes [30,31].

Advanced AI-driven personalized treatment plans are advancing, potentially revolutionizing glaucoma management. This advancement relies on AI models utilizing sophisticated algorithms integrating various data sources, such as imaging technology, EHR, and demographics. While research on AI applications in glaucoma surgery and training is ongoing, Nespolo and colleagues have demonstrated the successful use of an AI CNN in vitreoretinal surgery [32]. This AI system has the potential to offer real-time intraoperative guidance and analyze instrument movements post-surgery, showcasing the promising prospects of AI in reducing intraocular surgical errors and enhancing training processes.

Summarizing AI integrations for glaucoma

Glaucoma, known as the "silent thief of sight," is a leading cause of irreversible blindness globally. The disease's progressive nature, characterized by a gradual loss of peripheral vision, often goes undetected by patients [33]. Traditional diagnosis of glaucoma involves a combination of clinical assessments and various imaging techniques. However, consistency in defining the disease stages can result in significant variability among healthcare providers in diagnosis and management. Furthermore, limited access to care due to physician shortages in certain regions underscores the increasing importance of integrating AI into glaucoma treatment and diagnosis.

Conclusion

AI can analyze large datasets, identify complex patterns, and forecast disease progression. The use of AI is poised to revolutionize the management of glaucoma entirely. However, there are obstacles to ensuring dataset diversity, addressing bias, and establishing standardized definitions for the disease. The integration of AI can significantly enhance the accuracy of glaucoma diagnosis, monitoring, and treatment, offering personalized and effective care for individuals affected by the condition. Ongoing developments in this field aim to improve patient outcomes and reshape the management of this prevalent and complex eye disorder.

References

1. GBD 2019 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.
2. Kang JM, Tanna AP. Glaucoma. Med Clin North Am. 2021;105(3):493-510.
3. Kass MA, Heuer DK, Higginbotham EJ, Johnson CA, Keltner JL, et al. 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.
4. Leske MC, Heijl A, Hyman L, Bengtsson B. Early manifest glaucoma trial: Design and baseline data. Ophthalmology. 1999;106(11):2144-2153.
5. Huang X, Islam MR, Akter S, Ahmed F, Kazami E, et al. Artificial intelligence in glaucoma: Opportunities, challenges, and future directions. Biomed Eng Online.2022;22(1):126.
6. Zheng C, Johnson TV, Garg A, Boland MV. Artificial intelligence in glaucoma. Curr Opin Ophthalmol. 2019;30(2):97-103.
7. Kim YW, Yun YI, Choi HJ. Screening fundus photography predicts and reveals risk factors for glaucoma
8. 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.
9. Yousefi S. Clinical applications of artificial intelligence in glaucoma. J Ophthalmic Vis Res. 2023;18(1):97.
10. Sharifi M, Khatibi T, Emamian MH, Sadat S, Hashemi H, et al. Development of glaucoma predictive model and risk factors assessment based on supervised models. BioData Min. 2021;14:1-5.
11. Coyner AS, Swan R, Campbell JP, Ostmo S, Brown JM, et al. Automated fundus image quality assessment in retinopathy of prematurity using deep convolutional neural networks. Ophthalmol Retina. 2019;3(5):444-450.
12. Fu H, Cheng J, Xu Y, Zhang C, Wong DW, et al. Disc-aware ensemble network for glaucoma screening from fundus image. IEEE Trans Med Imaging. 2018;37(11):2493-2501.
13. Raja H, Akram MU, Khawaja SG, Arslan M, Ramzan A, et al. Data on OCT and fundus images for the detection of glaucoma. Data in brief. 2020; 29:105342.
14. Wu JH, Nishida T, Weinreb RN, Lin JW. Performances of machine learning in detecting glaucoma using fundus and retinal optical coherence tomography images: A meta-analysis. Am J Ophthalmol. 2022; 237:1-2.
15. Akter N, Fletcher J, Perry S, Simunovic MP, Briggs N, et al. Glaucoma diagnosis using multi-feature analysis and a deep learning technique. Sci Rep. 2022;12(1):8064.

16. Muhammad H, Fuchs TJ, De Cuir N, De Moraes CG, Blumberg DM, et al. Hybrid deep learning on single wide-field optical coherence tomography scans accurately classifies glaucoma suspects. J Glaucoma. 2017; 26(12):1086-1094.

17. Barella KA, Costa VP, Gonçalves Vidotti V, Silva FR, Dias M, et al. Glaucoma diagnostic accuracy of machine learning classifiers using retinal nerve fiber layer and optic nerve data from SD-OCT. J Ophthalmol. 2013;2013.

18. Zhang Y, Wang N, Liu H, Christopher M, Christopher B 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. 2022;129(1):e4-5.

19. Ran AR, Tham CC, Chan PP, Cheng CY, Tham YC, et al. Deep learning in glaucoma with optical coherence tomography: A review. Eye. 202; 35(1):188-201.

20. Yousefi S, Balasubramanian M, Goldbaum MH, Medeiros FA, Zangwill LM, et al. Unsupervised Gaussian mixture-model with expectation maximization for detecting glaucomatous progression in standard automated perimetry visual fields. Transl Vis Sci Technol. 2016; 5(3):2.

21. Andersson S, Heijl A, Bizios D, Bengtsson B. Comparison of clinicians and an artificial neural network regarding accuracy and certainty in performance of visual field assessment for the diagnosis of glaucoma. Acta Ophthalmol. 2013;91(5):413-417.

22. Wagner IV, Stewart MW, Dorairaj SK. Updates on the Diagnosis and Management of Glaucoma. Mayo Clin Proc Innov Qual Outcomes. 2022;6(6):618-635.

23. Seker E, Talburt JR, Greer ML. Preprocessing to address bias in healthcare data. Stud Health Technol Inform.2022; 327-331.

24. Nazer LH, Zatarah R, Waldrip S, Ke JX, Moukheiber M, et al. Bias in artificial intelligence algorithms and recommendations for mitigation. PLOS digital health. 2023; 2(6):e0000278.

25. Rickert J. On Patient Safety: The Lure of Artificial Intelligence: Are We Jeopardizing Our Patients' Privacy?. Clin Orthop Relat Res.2020;478(4):712-724.

26. Jaccard, N. AI for glaucoma care. Glaucoma Today.2022;7.

27. De Vente C, Vermeer KA, Jaccard N, Wang H, Sun H, et al. AIROGS: Artificial Intelligence for Robust Glaucoma Screening Challenge. IEEE Trans Med Imaging. 2024;43(1):542-557.

28. Lemij HG, de Vente C, Sánchez CI, Vermeer KA. Characteristics of a large, labeled data set for the training of artificial intelligence for glaucoma screening with fundus photographs. Ophthalmol Sci. 2023; 3(3):100300.

29. Tao S, Ravindranath R, Wang SY. Predicting glaucoma progression to surgery with artificial intelligence survival models. Ophthalmol Sci. 2023; 3(4):100336.

30. Buisson M, Navel V, Labbé A, Watson SL, Baker JS, et al. Deep learning *versus* ophthalmologists for screening for glaucoma on fundus examination: A systematic review and meta-analysis. Clin Exp Ophthalmol. 2021;49(9):1027-1038.

31. Xiao X, Xue L, Ye L, Li H, He Y. Health care cost and benefits of artificial intelligence-assisted population-based glaucoma screening for the elderly in remote areas of China: A cost-offset analysis. BMC Public Health. 2021;21(1):1065.

32. Nespolo RG, Yi D, Cole E, Wang D, Warren A, et al. Feature tracking and segmentation in real time *via* deep learning in vitreoretinal surgery: A platform for artificial intelligence-mediated surgical guidance. Ophthalmol Retina. 2023; 7(3):236-242.

33. Lee SS, Mackey DA. Glaucoma–risk factors and current challenges in the diagnosis of a leading cause of visual impairment. Maturitas. 2022;163:15-22.