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Artificial Intelligence–Driven Multimodal Imaging for Early Glaucoma Detection: A Transformative Approach in Modern Ophthalmology

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Short Communication

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Abstract

Glaucoma is a chronic, progressive optic neuropathy and one of the leading causes of irreversible blindness worldwide. Due to its asymptomatic progression in early stages, timely diagnosis remains a major clinical challenge. Recent advancements in artificial intelligence (AI) and multimodal ocular imaging have significantly enhanced early detection strategies. Deep learning algorithms can analyze complex datasets derived from optical coherence tomography (OCT), optical coherence tomography angiography (OCTA), fundus photography, and visual field testing to identify subtle structural and functional abnormalities. The integration of AI with multimodal imaging improves diagnostic accuracy, supports disease monitoring, and facilitates personalized clinical decision-making. This short communication discusses recent developments, clinical relevance, limitations, and future perspectives of AI-assisted multimodal imaging in early glaucoma detection.

Keywords: Artificial Intelligence; Glaucoma; Multimodal Imaging; Oct; Octa; Deep Learning; Early Diagnosis; Ophthalmology

Introduction

Glaucoma is one of the leading causes of irreversible blindness globally and represents a significant public health burden [1]. It is characterized by progressive degeneration of retinal ganglion cells and optic nerve damage, leading to irreversible visual field loss [2]. Because the disease often remains asymptomatic in its early stages, early detection is critical for preventing permanent visual impairment [3].

Conventional diagnostic methods, including intraocular pressure measurement, optic nerve head assessment, visual field testing, and optical coherence tomography (OCT), have improved glaucoma detection. However, early-stage disease remains difficult to identify due to subtle and heterogeneous clinical presentations [4]. The increasing availability of high-resolution imaging technologies has resulted in large volumes of ophthalmic data, requiring advanced analytical tools for accurate interpretation.

Artificial intelligence (AI), particularly deep learning, has emerged as a powerful technology capable of analyzing complex medical datasets with high speed and accuracy [5]. When combined with multimodal imaging techniques such as OCT, OCT angiography (OCTA), and fundus photography, AI offers a comprehensive approach to identifying early glaucomatous changes [6].

Short Communication

Glaucoma continues to be a major cause of vision loss worldwide, largely due to delayed diagnosis. Traditional

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diagnostic approaches rely on multiple clinical and imaging modalities, each with inherent limitations. AI-based systems have demonstrated strong potential in overcoming these limitations by enabling automated and objective analysis of ophthalmic images [7].

Deep learning algorithms trained on large datasets of fundus photographs and OCT scans have shown high diagnostic performance in detecting glaucomatous optic neuropathy [7,8]. Multimodal imaging further enhances diagnostic capability by integrating structural, vascular, and functional information, thereby improving sensitivity and specificity compared to single-modality approaches [6,8].

AI-assisted multimodal imaging also facilitates disease monitoring by enabling the detection of subtle longitudinal changes that may not be easily recognized through conventional clinical assessment. This allows for earlier intervention and more effective management strategies [8]. Additionally, AI-based screening tools have the potential to expand access to eye care, particularly in rural and underserved populations, by enabling rapid identification of high-risk individuals.

Despite these advantages, several challenges remain. Variability in imaging quality, lack of algorithm transparency (the “black box” problem), limited external validation, and concerns regarding patient data privacy continue to restrict widespread clinical implementation [9]. Furthermore, biases in training datasets may affect the generalizability of AI systems across diverse populations. Therefore, AI should be considered a supportive tool that enhances, rather than replaces, clinical expertise.

Conclusion

Artificial intelligence integrated with multimodal imaging represents a transformative advancement in the early detection and management of glaucoma. By combining structural, vascular, and functional information, AI improves diagnostic precision, supports disease monitoring, and enhances clinical decision-making. Although technical and ethical challenges persist, ongoing research and careful validation are expected to accelerate the safe integration of these technologies into routine ophthalmic practice. The collaboration between clinicians and AI systems holds significant promise in reducing preventable blindness and improving patient outcomes through earlier and more accurate glaucoma detection.

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