· Editorial ·

Artificial intelligence in ophthalmology

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The concept of artificial intelligence (AI) was first introduced in the 1950s, referring to "the machine simulation of human mental reasoning, decision making, and behavior"[1-2]. Computers perform tasks that typically require human intelligence. AI comprises machine learning (ML) and deep learning (DL) components. ML uses high-quality exemplary data samples to train its models. Patterns or rules recognized in the learning data are then applied to new data to discern features or make predictions. DL is a type of ML that utilizes multiple layers of artificial neural networks to understand intricate patterns from extensive data sets.

AI has been implemented in various medical fields. One area where AI has shown tremendous potential is in ophthalmology, as it relies heavily on imaging and visual data[3]. Recently, a new AI-based method was developed to establish a human retinal aging clock using longitudinal fundus images and genome-wide association analysis[4]. The overall potential of AI includes screening, diagnostic grading, therapy guidance with automated detection of disease activity, recurrences, quantification of therapeutic effects, prognosis, and identification of relevant targets for novel therapeutic approaches[5]. And, of course, an upgraded AI chatbot can pass professional board certification exams[6].

Ophthalmology has quickly adopted AI technologies. The number of published articles on AI in ophthalmology has grown considerably over the last decade, reflecting the topic's increasing interest and importance[7]. However, no specific journal is dedicated to AI in ophthalmology, and articles on AI are scattered across various journals with different scopes and audiences. Therefore, the new "Intelligent Ophthalmology" section in the *International Journal of Ophthalmology* is a big step forward. This article briefly overviews AI's leading applications, challenges, and opportunities in ophthalmology.

Ophthalmic imaging, including fundus digital photography and optical coherence tomography (OCT), is a critical method for diagnosing and monitoring the progression of ocular disorders. OCT has been extensively used to diagnose and manage diseases like age-related macular degeneration (AMD), diabetic retinopathy (DR), and glaucoma. OCTs of the macula and the optic nerve are a promising modality for DL applications for several reasons; there is a large and growing number of OCTs available for training DL systems, the structure of these OCTs is consistent and three-dimensional, and there is a potential to discover new disease biomarkers from details. Interpreting OCT images can be challenging, especially for large-scale screening and longitudinal monitoring. Therefore, applying ML and DL methods to OCT images can enhance the accuracy and efficiency of OCT-based diagnosis[8].

Clinical Use and Benefit of Artificial Intelligence in Ophthalmology The first section will discuss AI's applications in DR and AMD, two of the most common retinal disorders that cause vision loss, and pediatric ophthalmology. AI has shown promising results in accurately detecting and classifying these diseases, enabling timely intervention and management. Myopic fundus changes, especially prevalent in Asian countries, can equally be classified[9]. The second section will focus on AI's role in glaucoma, another leading cause of blindness globally, where AI can aid in earlier diagnosis and disease monitoring, leading to better outcomes. The third section will explore AI's potential in anterior eye diseases. Finally, we consider AI aspects of telehealth provision.

DR is a significant cause of visual impairment and blindness, affecting millions worldwide. Early detection and treatment of DR can prevent vision loss and improve quality of life. However, many patients miss timely eye examinations due to barriers such as cost, access, and awareness. Hence, increasing interest is in developing AI-based algorithms for automated DR detection. The first Food & Drug Administration (FDA)-approved autonomous diagnostic system used fundus images to diagnose and classify DR[10]. Several cutting-edge AI DR screening technologies are commercially available and have shown promising results[11]. DL is typically employed in AI-based DR screening systems; it can automatically extract features from retinal images and distinguish between normal and abnormal cases without human intervention or prior knowledge, thereby enhancing the accuracy and efficiency of DR screening. AI-based DR screening systems' clinical impact and cost-effectiveness compare well to traditional methods[8].

With the aging population, there is an urgent clinical need for a robust AI system to screen these patients for further evaluation. DL is adequate and accurate for classifying regular versus AMD OCT images[3]. This has implications for utilizing OCT in automated screening and developing computer-aided diagnosis tools in the future. AI will be part of the decision-making regarding scientific investigation, diagnosis, and therapeutic management[12]. A preclinical study explores the safety and efficacy of an AI-enabled tool for treatment decisions in neovascular AMD[13]. Quantitative OCT imaging biomarkers can predict visual outcomes and treatment needs in a treat & extend regimen in neovascular AMD[14]. Macular OCTs are a suitable and challenging data source for DL research. The combination of DL and OCT technologies is reliable in detecting retinal diseases and improving the diagnostic performance of posterior segment ocular diseases[12]. Prediction and prognostic conclusions further expand the potential benefit of AI in the retina, enabling personalized health care and large-scale management[8]. ML and DL can identify, localize, and quantify pathological features in nearly every macular and retinal disease. In addition, they have potential applications in pediatric ophthalmology, such as the automated detection of retinopathy of prematurity, with results comparable to those of experts[15].

Information from structural and functional testing of the optic nerve and macula makes glaucoma a particularly appropriate field for AI application[16]. DL can analyze different types of ocular images, such as fundus photographs, OCT scans, visual field tests, and gonioscopy videos, and provide automated diagnosis, classification, and prediction of glaucoma. DL can also enhance our understanding of the glaucomatous process by generating activation maps highlighting the critical regions of interest in the images[17]. Diagnosis and disease monitoring involves integrating information from the clinical examination with subjective data from visual field testing and objective biometric data, including pachymetry, corneal hysteresis, and optic nerve and retinal imaging. This intricate process is further complicated by the lack of clear definitions for the presence and progression of glaucomatous optic neuropathy, which makes it vulnerable to clinician interpretation error. AI and AI-enabled workflows are plausible solutions[18].

AI has many applications for the anterior segment of the eye, which can improve diagnosis, treatment, and outcomes for various ocular conditions[19-20]. Here are four applications related to cataract management[21]. AI can be applied as a telediagnostic platform to screen and diagnose patients with cataracts using slit-lamp and fundus photographs. It utilizes DL to detect and classify referable cataracts appropriately. Some of the latest intraocular lens formulas have used AI to enhance prediction accuracy, achieving superior postoperative refractive results compared to traditional formulas. AI can augment cataract surgical skill training by identifying different phases of cataract surgery on video and optimizing operating theater workflows by accurately predicting the duration of surgical procedures. AI can effectively predict the progression of posterior capsule opacification and the eventual need for YAG laser capsulotomy. These advances in AI could transform and optimize cataract management and enable the delivery of efficient ophthalmic services. AI has proven a highly effective tool for disease diagnosis, image interpretation, and corneal topographic mapping[19].

The combination of telehealth and AI provides synchronous solutions to challenges facing ophthalmologists and healthcare providers worldwide[22]. The success of ophthalmology in both areas can be attributed to many investigative techniques that rely on imaging. Analyzing such images is time-consuming, costly, and prone to human error. AI can improve health equity by facilitating teleophthalmology services and reducing the burden on ophthalmologists. AI-based systems are crucial in streamlining the screening, staging, and treatment planning of sight-threatening eye conditions, offloading the most tedious tasks from the experts, allowing for better population coverage, and bringing the best possible care to every patient[5].

Moreover, AI can assist in identifying patients with preventable vision loss and direct them to physicians, especially in developing countries with fewer trained professionals and physicians who are challenging to reach[23]. Therefore, detecting and treating DR, AMD, glaucoma, and other ophthalmic disorders through automated application systems will soon be inevitable[19]. AI-based screening programs are as cost-effective as traditional methods while maintaining similar clinical effectiveness levels[24].

The number of AI and ML algorithms approved by the US FDA has accelerated dramatically in recent years. As of January 2023, the FDA has approved over 520 AI and ML algorithms for medical use[25]. AI applications have various factors that affect their performance and value, such as the real-world context, the data quality and quantity, the AI variables, the algorithms, and the application's purpose and use. Biases and errors can occur in any of these factors. Therefore, to evaluate an AI application, it is essential to use evidence-based medicine principles - a standard that is only sometimes met[26].

Ethical Aspects, Translation, and Conclusion Given the rise of AI in medicine and ophthalmology, defining its accuracy and reliability will guide future research in this area and enhance its real-life adaption[27].

The potential challenges with DL application in ophthalmology include clinical and technical challenges, data quality, explain ability of the algorithm results, medicolegal issues, and physician and patient acceptance of the AI "black box" algorithms. Bioethical challenges of AI implementation in medicine can be categorized into six main categories: machine training ethics, machine accuracy ethics, patient-related ethics, physician-related ethics, shared ethics such as liability and culpability, accountability and responsibility, and the roles of regulators. These categories reflect the multiple stakeholders involved in the ethical issues surrounding AI in medicine and ophthalmology[10].

AI could revolutionize how ophthalmology is practiced in the future. Generalist medical AI (GMAI)-models can carry out diverse tasks using very little or no task-specific labeled data[28]. The rapidly developing, highly flexible, reusable AI models will likely usher in newfound medical capabilities. Collaboration among researchers, clinicians, industry partners, regulators, and patients are essential for successfully integrating AI into patient care[11,29]. Therefore, the future directions and opportunities for AI-based screening systems include integrating multimodal data sources, incorporating clinical outcomes, and improving user experience. They must demonstrate clinically acceptable performance, enhance the generalizability of AI models across heterogeneous populations, and improve end-user trust[21]. Open-access data sets and software could alleviate these issues and encourage further applications[15]. Translating research findings into clinical practice is a significant challenge of AI implementation in health care. Regulatory and organizational challenges must still be mastered for AI's practical usage. The scientific basis is a fundamental element of modern medicine. Therefore, principles of evidence-based medicine and human judgment must transparently assess the objectivity (independence from uncontrolled influencing factors), reliability (dependability), and validity (validity) of AI-based ophthalmological applications to prevent patient risk.

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