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Research Progress in the Application of Artificial Intelligence in the Diagnosis and Treatment of Glaucoma

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Abstract

In today's digital age, artificial intelligence (AI) is developing rapidly in various fields around the world and has become an important force leading reform and innovation in various industries. AI has promoted the development of AI ophthalmology and provided a new model for the diagnosis and treatment of eye diseases. Glaucoma is a common irreversible blinding eye disease. Its early diagnosis and treatment can prevent the occurrence and development of the disease to a certain extent, improve patient prognosis, and reduce the global blindness rate. Starting from the direction of AI, this article reviews the relevant research and application in the diagnosis and treatment of glaucoma, aiming to provide new ideas for the AI diagnosis and treatment of glaucoma.

Keywords

Artificial intelligence (AI); Glaucoma; Diagnosis and treatment

The term AI was first proposed by John McCarthy at the Dartmouth Conference in 1956 [1]. It is a multidisciplinary science dedicated to simulating human thinking and decision-making logic and extending human intelligence. The application of artificial intelligence in the medical field mainly includes machine learning (ML) and deep learning (DL). As an important branch of machine learning, deep learning is a further development on the basis of machine learning, with stronger generalization ability and the ability to process more complex data sets. The advantage of DL is that it can automatically learn features from raw data, thus eliminating the need for manual feature engineering. DL is mainly based on artificial neural networks (ANNs), a computing model inspired by the function of the human brain. Like the human brain, it is composed of many computing cells or "neurons", each of which can perform logical operations and connect to each other to make decisions [2]. DL technology is mainly divided into convolutional neural networks (CNNs), recurrent neural networks (RNNs), generative adversarial networks (GANs), long short-term memory (LSTM) models and hybrid models [3]. Glaucoma is the second leading cause of blindness in the world and can lead to visual impairment and optic nerve coloboma. In 2020, the number of people with glaucoma worldwide exceeded 76 million, and this number is expected to exceed 110 million by 2040 [4]. Due to the large population base and the aging of society, the number of glaucoma patients in China is much higher than in other parts of the world. Clinically, due to the extremely hidden occurrence and development of glaucoma, some patients are already in the late stage of glaucoma when they seek medical treatment. Therefore, early screening, diagnosis, and monitoring and treatment of glaucoma are particularly important. The main basis for the diagnosis of glaucoma includes intraocular pressure, optic nerve changes, visual field, angle opening, corneal biomechanical properties and other factors. The imaging examination methods involved include: fundus color photography, optical coherence tomography (OCT),

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anterior chamber angle ultrasound biomicroscopy (UBM), anterior segment optical coherence tomography (AS-OCT) and visual field. This article aims to explore the current research and application of AI in the diagnosis and treatment of glaucoma and to look forward to its clinical prospects.

1. Development of AI in ophthalmology

In recent years, artificial intelligence (AI) theory and technology, led by deep learning, have developed rapidly. Due to its advantages in image processing and data analysis, artificial intelligence has developed rapidly in the medical field. Since ophthalmology relies heavily on image results, ophthalmology has become one of the fastest-growing fields in the application of artificial intelligence in the medical field. In addition, the diagnosis of a single eye disease often requires a combination of multiple examinations to be determined. The large amount of data and the variety of types show that ophthalmology is very suitable for combining artificial intelligence technology. At present, in the field of ophthalmology, especially in diabetic retinopathy (DR), age-related macular degeneration (AMD), glaucoma and other aspects, medical image analysis assisted by artificial intelligence has achieved good results. Ting et al. used deep learning to perform intelligent analysis of retinal images of multi-ethnic diabetic patients [5]. Burlina et al. [6] used color fundus photography to train an artificial intelligence model, which can identify mid- and late-stage AMD from non-AMD and early AMD fundus images, and there is no significant difference with the gold standard.

2. Research progress of AI in glaucoma diagnosis and treatment

2.1 Fundus color photography

Fundus photography can be used to observe the optic disc morphology and cup-to-disc ratio (C/D). In 2015, the C/D data in fundus images was first used to train AI models. Subsequently, a large number of researchers used DL models to detect glaucomatous optic neuropathy (GON). Diaz et al. [7] used five different deep learning models trained using image networks and used fundus images to allow them to autonomously assess glaucoma and verify their performance in the automatic glaucoma screening system.

However, the fully fine-tuned transfer learning method is very time-consuming and needs further optimization. Therefore, Li et al. [3] applied a hierarchical fine-tuning method to effectively solve this problem and enhance the prediction ability. Their deep learning method based on ResNet101 was combined with color fundus photographs to automatically and reliably detect GON. Finally, GON was identified from fundus images with high accuracy, sensitivity, specificity and AUC, achieving performance comparable to or exceeding that of human experts with rich clinical experience. Medeiros et al. [8] believed that for DL algorithms, the RNFL area close to the optic disc is an important part for predicting glaucoma. The application of CNN-based diagnosis of glaucoma in fundus images of different environments and image quality verified its high sensitivity, specificity and universality in detecting GON. Combined with the popularity of fundus color photography in clinical practice and the above research results, the use of AI algorithms to interpret fundus color photography has high practicality for early screening and diagnosis of glaucoma.

2.2 OCT

Optical coherence tomography (OCT) is widely used for the diagnosis and monitoring of glaucoma, a progressive optic neuropathy characterized by thinning of the retinal nerve fiber layer (RNFL) and irreversible vision loss. The peripapillary RNFL thickness obtained by OCT scanning is a routine assessment method used by clinicians to diagnose and monitor glaucoma. Considering that imaging quality will affect the interpretation of clinical results, Shi et al. [9] corrected the artifacts of the retinal nerve fiber layer thickness map based on deep learning, thereby improving the accuracy of glaucoma progression analysis. Kim et al. [10] attempted to use the retinal nerve fiber layer thickness and visual field of OCT to analyze and diagnose glaucoma, and compared the differences between four machine learning models, and then found that the random forest model performed best.

Accurate assessment of the anterior chamber angle (ACA) is very important for the classification and diagnosis of glaucoma. Currently, slit-lamp gonioscopy is the gold standard for assessing the anterior chamber angle, but it has poor repeatability and a long learning curve. AS-OCT examination uses invisible light to obtain clear cross-sectional images of the anterior segment of the eye and performs non-contact, qualitative/quantitative assessment and measurement of the anterior segment and chamber angle [11]. Xu et al. [12] used automated OCT to assess ACA, which

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can help the community screen for primary angle-closure glaucoma, reduce the burden of manual gonioscopy, and help improve patient compliance and clinical efficiency during follow-up. Li et al. [13] also performed DL training on the collected AS-OCT images. The results showed that the DL training set can achieve a high level of diagnostic efficacy in recognizing the chamber angle morphology.

2.3 UBM

UBM examination is a contact imaging examination method that uses high-frequency ultrasound to examine the anterior segment tissue structure and has good repeatability. However, because it is a contact examination, there is a risk of infection. In addition, patients with conjunctivitis, keratitis, and those who have undergone intraocular surgery are not suitable for examination. In addition, the examination time is long and the requirements for the operator are high. Therefore, it is not often used for screening in clinical practice. Wang Wensai et al. used deep learning to identify the open state of the anterior chamber angle on the collected UBM images to assist in the diagnosis of glaucoma. At the same time, they also compared the transfer learning results of different network models [14]. Yu et al . [15] collected UBM images, located the apex of the angle recess, and automatically identified the angle opening and closing state through grayscale feature analysis. The ACA was divided into open angle, narrow angle, and closed angle, which can be used to identify the anterior chamber angle morphology and diagnose glaucoma.

2.4 Visual field testing

In clinical practice, commonly used automatic perimeters include the Humphrey perimeter and the Octopus perimeter [16]. Visual field results are widely used as the gold standard for determining whether a patient has typical glaucomatous damage [17]. The progression of visual field loss in visual field examination reflects the control of glaucoma progression and is particularly critical for the analysis of glaucoma progression. Li et al. [17] used a deep convolutional neural network to distinguish between glaucomatous and non-glaucomatous visual fields. Compared with human ophthalmologists and traditional rules, they found that the CNN-based algorithm had higher accuracy, indicating that the CNN-based algorithm is superior to humans in glaucoma diagnosis and can help doctors screen and diagnose glaucoma in the future. Dixit et al. [18] showed that compared with traditional glaucoma progression algorithms, the convolutional LSTM network they developed can better predict the visual field progression of glaucoma patients. Asaoka et al. [19] used a deep learning classifier to distinguish the visual field results of pre-glaucoma patients and normal people, but they believe that the key to using AI to predict the visual field progression of glaucoma patients in the future lies in whether a multi-task learning model can be constructed.

Each link in the diagnosis and treatment of glaucoma is extremely challenging, and the personal experience of the attending physician directly determines the effectiveness of the treatment. If the attending physician is inexperienced, the diagnosis may lead to missed diagnosis and diagnostic bias of glaucoma, and the treatment may lead to insufficient or excessive treatment of glaucoma, which may lead to further progression of the disease. Recently, Li et al. [20] conducted a study using a deep learning system (DLS) to assist junior ophthalmologists in diagnosing 13 major fundus diseases and evaluate its diagnostic performance. The results showed that there was good consistency between the DLS group and the experimental group. DLS provides a new method for the automatic detection of fundus diseases while helping junior ophthalmologists improve the accuracy of diagnosis and reduce the risk of missed diagnosis. This study not only achieved the purpose of clinical application, but also achieved the purpose of teaching junior ophthalmologists.

3. Difficulties and challenges

As we all know, my country has a large population, the pathogenesis of glaucoma is complex, and there are many types of diseases. How to use artificial intelligence to conduct comprehensive and accurate analysis of it, so as to diagnose and further treat it is the key link of our future research. At present, most studies are based on AI for single ophthalmic imaging examinations. As a complex eye disease that requires multiple examinations for comprehensive evaluation, how to construct a multimodal diagnosis and treatment model for glaucoma will be the focus of the future research by ophthalmologists and engineers. Clinically, some glaucoma patients often have other eye diseases, such as cataracts, retinal diseases, and corneal diseases. In this case, the image acquisition quality and analysis results will be affected, which requires computer engineers and ophthalmologists to work together for further research in the future. It is worth paying attention to the establishment of an AI comprehensive eye disease analysis model including glaucoma. In today's digital information age, how to ensure the security of patient information is also a link we need

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to focus on. Imaging data has certain biometric value. How to ensure information security and avoid privacy leakage need to be treated with caution. Judging from many current studies, experts have not yet reached a consensus on the acceptable model for the clinical application of artificial intelligence. More efforts and exploration are needed to seek common ground while reserving differences and reach a consensus.

4. Future outlook

With the advent of the 5G era, clinical data between medical institutions at all levels around the world are gradually being shared. The further development of AI requires data sharing among countries and regions, building a larger, public database that covers more disease types and ethnic groups, and continuously improving the accuracy of AI algorithms. The AI ophthalmology model is already a development trend in contemporary ophthalmic medicine, and its development potential is undeniable. It is believed that in the future, AI can provide more patients with early screening and diagnosis opportunities for glaucoma, help clinicians accurately monitor the progression of glaucoma, and become an important milestone in the development of ophthalmology.

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