Editorial

Understanding the advent of artificial intelligence in ophthalmology

Introduction

While some physicians view artificial intelligence (AI) as a threat to their careers, imagining a machine taking over for a human being, large tech companies such as Google, Microsoft, and Apple are investing billions of dollars into research and development of AI. Many in the medical industry are now beginning to view AI as the most promising technology for medicine. While the potential of AI is just beginning to be uncovered, many ophthalmology practices are already using AI and its subfields [machine learning (ML) and deep learning (DL)] to revolutionize vision care. While it is highly improbable that AI will ever replace the need for an ophthalmologist, AI can be used to augment vision care and greatly improve efficiency. According to Schmidt-Erfurth et al.1 "Methods based on machine learning and particularly deep learning are able to identify, localize and quantify pathological features in almost every macular and retinal disease". It is vital to understand how ML and DL work, understand current applications in ophthalmology, and prepare for the future of AI.

Machine learning and deep learning

AI is a subfield of computer science that aims to create intelligent machines.1 ML is a subset of AI which focuses on the learning feature of intelligence. It imitates the neural structure of the nervous system by creating artificial neural networks (ANNs) which is a network of units called artificial neurons organized into layers. Layers of neurons transform the signal as it travels from the input layer to the output layer. A large amount of image data needs to be provided to the system which then learns to detect patterns from that data in a training session. During the training phase, the computer must be told what it is looking for, i.e. there must be a descriptive label for each image. DL is an improvement over ANN, consisting of more layers that permit higher levels of abstraction and improved predictions from data. The basic idea is that a neural network, instead of just acting as a classifier, can also serve as the feature extractor as well.1 Therefore, a single deep neural network performs both tasks and can learn to both extract features that are suitable for a given classification problem and to classify them.1

DeepMind Health and Moorfields Eye Hospital

Perhaps the best “proof of concept” for the use of AI in ophthalmology is seen from the study partnered between DeepMind Health (parent company: Alphabet) and Moorfields Eye Hospital NHS Foundation Trust. Researchers on this project noticed that in ophthalmology the rate of imaging through optical coherence tomography (OCT) is rapidly increasing and OCT is increasingly being viewed as the gold standard of initial assessment of sight threatening diseases.2 However, interpreting such large sets of imaging data is very time intensive for the ophthalmologist and can lead to delays in care for patients facing treatable eye conditions. A UK based study has shown that patients are suffering preventable vision loss due to delay in care and the study indicates there is an association between patient need and lack of health service capacity.3 Thus, researchers at DeepMind Health and Moorfields Eye Hospital hoped that AI tools could be trained to interpret OCT scans as accurately as humans, thereby reducing the burden of the ophthalmologist and giving them a better chance to treat sight-threatening diseases.

The outcome of the study conducted by DeepMind Health and Moorfields is very promising. Researchers created a training set for their classification network using 14,884 OCT scan volumes of 7621 patients and then tested their AI framework on a dataset from 997 patients (including a wide range of retinal pathologies) not included in the original training dataset.2 As De Fauw et al. noted in their study published in Nature Medicine, “Our framework (5.5% error rate) performed comparably to the two best retina specialists (6.7% and 6.8% error rate) and significantly outperformed the other six experts in the “OCT only” setting”.2 This framework was evaluated at 32 different Moorfields Eye Hospital sites using 37 individual OCT devices and focused on 53 key diagnoses.2 While the technology demonstrated here by

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DeepMind Health and Moorfields Eye Hospital has not yet undergone randomized clinical trials (RCTs), the preliminary data shows a potential widespread application of very successfully using such AI technology to diagnose a variety of retinal pathologies.

Artificial intelligence in glaucoma

Currently, half of those with glaucoma go undiagnosed until the disease has reached advanced stages.\(^4\) This is because patients can be asymptomatic in the early stages of the disease. Screening of large populations can be difficult as it requires individual examination by a specialist; however, the hope is that automatic screening using AI could alleviate this issue.\(^4\) Kim et al.\(^5\) developed an ML-based model using three types of records: retinal nerve fiber layer (RNFL) thickness, visual field (VF) test parameters, and general ophthalmic examination. Using ML for glaucoma, Kim et al.\(^5\) report a classification accuracy of 0.98, a sensitivity of 0.983, and a specificity 0.975. In some cases of early glaucoma, the algorithm misdiagnosed highly myopic patients.\(^5\) However, the algorithm’s accuracy rate of early glaucoma was still 91.7%.\(^5\) It is possible the accuracy of the algorithm could be further improved by adding the refraction of the eye and OCT indices.\(^5\)

The above algorithm, while successful, requires many inputs. Ahn et al.\(^6\) developed a model that requires only fundus images. Using a DL convolution neural network (CNN) approach, the model Ahn et al.\(^6\) developed achieved a 92.2% accuracy on the training data. While the algorithm developed by Kim et al.\(^5\) overall showed a higher accuracy and specificity than the model developed by Ahn et al.,\(^6\) the model developed by Ahn et al. is very convenient and shows great potential as it only requires fundus photography. With further refinement, such AI based algorithms can become a valuable tool in aiding ophthalmologists in diagnosing glaucoma. Furthermore, such algorithms could be used to screen large populations and identify those in need of further evaluation by an ophthalmologist.

Looking to the future

Although the use and development of AI in medicine is in its infancy, an AI based device has already been U.S. Food and Drug Administration (FDA) approved to detect diabetic retinopathy.\(^7\) The goal moving forward will be to put AI frameworks such as DeepMind Health’s through rigorous RCTs and gain regulatory approval. Beyond the collaborative AI framework of DeepMind Health and Moorfields there are many promising uses of AI in ophthalmology. For example, Hogarty et al. discuss in their article that AI based triage systems could be very useful in the primary care setting, particularly in rural areas, to help determine when referral to an ophthalmologist is truly necessary.\(^8\) Furthermore, a study by Long et al. in,\(^9\) demonstrated in a multi-hospital clinical trial on congenital cataracts that an AI based framework showed a 98.25% accuracy within the identification networks and a 92.86% accuracy for treatment suggestions. AI has shown diverse uses that can serve the goal of providing excellent care in ophthalmology.

DL AI systems are being developed for wet age-related macular degeneration (AMD) to predict the timing and extent of disease progression by identifying anatomic OCT-based features.\(^10,11\) The system predicts which patients will need frequent anti-vascular endothelial growth factor (anti-VEGF) treatment from a longitudinal series of OCT scans acquired during the initiation phase.\(^11\) Schlegl et al.\(^12\) developed a DL-based system to automatically detect and quantify intraretinal cystoid fluid (IRC) and subretinal fluid (SRF). This system accurately characterized the pattern of intraretinal fluid in patients with wet AMD or retinal vein occlusion (RVO) and distinguished between IRC and SRF.\(^12\) The authors conclude that DL in retinal image analysis provides an accurate means “for the differential detection of retinal fluid types across the most prevalent exudative macular diseases and OCT devices”.\(^12\)

The use of AI systems is now extending beyond retinal diseases and glaucoma. AI systems are being developed and evaluated to diagnose and grade cataract in pediatric patients based on an analysis of slit-lamp images\(^10,13\) and diagnose keratoconus based on Scheimpflug tomography.\(^14\) Given the increasing applications of AI in ophthalmology it becomes essential that an ophthalmologist learn about and begin to embrace the use of AI. While some may fear that AI might threaten their jobs, AI actually has the potential of increasing demand for the ophthalmologist.

One of the challenges with the use of AI based systems in medicine, including ophthalmology, concerns the ‘black-box’ problem where physicians are unable to trust the decisions of such systems because the AI decision-making process is often-times opaque. Even if the inputs and outputs are known, the algorithms used to arrive at a decision are often proprietary or not easily understood. Either the vendor of the AI systems will not reveal how their system works or the system will use neural networks of significant complexity level that only computer scientists can understand.\(^15,16\) Hence the human user, in this case the physician, is unable to comprehend how the AI system arrived at its conclusion. This can place the physician in a difficult position because the ultimate responsibility falls on a human decision maker as they will be held responsible for any negative consequences of an incorrect decision, even if recommended by the AI system.\(^16\) To address this concern there is a push towards explainable AI systems (XAI).\(^15\) These systems are programmed to describe their purpose and decision-making process in a way that can be understood by the average user. XAI is expected to provide accountability and transparency in ML. For physicians to trust AI, systems must not lock their secrets inside a black box. XAI provides this transparency.

DL AI systems are likely to enable ophthalmologists to identify previously unknown patterns of disease that would improve our understanding of disease development, assist with early-stage diagnosis, staging, and prognosis.\(^10\) Although more studies on patient outcomes are needed, there is
justifiable hope and expectation that the use of AI in ophthalmology will improve patient outcomes across an increasing range of ophthalmic diseases.

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