Artificial intelligence in ophthalmology: The optimization of medical care and future challenges

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ABSTRACT
Introduction: The concentrated evolution of various digital and telecommunication technologies in 2020 due to the emergence of a need to adapt to a new lifestyle, has raised opportunities for their use in medicine and in new models of care based on the growth of artificial intelligence (AI). AI seeks to mirror the human intellect through innovations capable of completing tasks, with Deep Learning, a technology that uses an artificial neural network, as a primordial subdivision. Progress in computational power, refinement of algorithms and learning architectures, the availability of unlimited data, and public access to deep neural networks, have made AI technology a promising reality in healthcare, specifically in the diagnosis and treatment of eye diseases. Objectives: To evaluate the benefits and importance of Artificial Intelligence in the diagnosis and treatment of ophthalmic diseases for the future. Methods: This is a bibliographic research of the narrative review type in which were used, mostly, scientific productions from the period 2018 to 2023 in the electronic databases: PubMed/MEDLINE and Scielo, containing the descriptors: artificial intelligence AND ophthalmology AND machine learning AND diagnosis. We found 21 from the search for the descriptors and 9 were elected who answered the guiding question; these, selected after the process of exclusion of works that associated other themes with the title, were written in a language other than English/Portuguese and paid articles. Results: The diagnosis for ophthalmic diseases is based on clinical evaluation and use of numerous equipment for image capture, being an expensive and time-consuming method. Research using AI would facilitate the process, taking Phelcom® equipment as an example. However, this study requires initial financial resources and a vast manpower, in addition to regulatory approval, the readjustment of algorithms to different data sets, and the black box problem. Conclusion: Artificial intelligence will provide benefits for the diagnosis and treatment of ophthalmic diseases by reducing the discordance and interobserver variability in the classification of diseases, such as glaucoma and diabetic retinopathy. However, it faces major structural challenges for its implementation.

Keywords: Artificial Intelligence, Ophthalmology, Diagnosis, Telemedicine.

1 INTRODUCTION

The concentrated evolution of various digital and telecommunication technologies in 2020 due to the emergence of a need to adapt to a new lifestyle, has raised opportunities for their use in medicine and in new models of care based on the growth of digital innovations. Artificial intelligence (AI) has emerged as the main frontier in computer science research, considered the fourth industrial revolution in human history. This allows the Processing patient information with greater accuracy and at high speed when compared to a single physician.

AI is a type of science that aims to mirror human intelligence through machines, making them capable of completing tasks – recognizing speech, identifying images and solving problems. Being an umbrella term for all algorithms based on computer software used to complete a given task. With technological evolution over the years, AI subdivisions have been created. The most widely used are Machine learning (ML) and Deep learning (DL).

In the past, there was a need for the computer to be pre-programmed with a set of instructions or algorithms to complete a task. This commonly conceived of the illusion of an intelligent machine. However, a mistake occurred, as the equipment simply followed the instructions. The adaptations in these machines were limited to those foreseen and accounted for in the pre-programming. In addition, because programming was performed by humans, their knowledge and competence was limited by the technological understanding of those who programmed it. The high efficiency and the reach of the total capacity of these machines for the completion of tasks is achieved before the process of machine learning, better known as ML.

ML is a system in which the machine builds its programming and acquires information in order to complete a task on its own. The first phase of this process is to assign a function to be completed, for example, the separation of fundus photographs in diabetic retinopathy (DR) and non-DR. The machine will require a high number of background photographs to learn (training dataset), as well as an isolated database for validation (validation dataset), to accomplish this task. Given this, experts need to perform the long task of rigorously and accurately classifying each image with the correct grouping of RD or non-RD. Once completed, a basic learning framework for algorithms is selected. The training data is entered into the machine, and the machine develops its own conclusions and compares them with the correct results previously entered. If its answers have a high error rate, the machine reevaluates its algorithms and adjusts its tunable internal parameters, necessitating, for the most part, learning one image feature at a time.

The machine is then fed the same training information again and produces a new set of responses. This method occurs indefinitely until the plateau of the products or the desired result is reached. The final conclusions of sensitivity, specificity and accuracy can be analyzed with the validation dataset for external efficiency assessments.

The neural network used in ML is a new, more sophisticated subdivision of AI. DL is an admirable technology that utilizes an artificial neural network (ANN). The ANNs mirror the structure of a biological neural network, which uses a representation learning mechanism with multiple data abstraction, without the need for manual insertion of predefined resources.

The RNAs were inspired by the neural network of the human being. An RNA involves promoting the input of impulses and stimuli into various layers of neurons that have been created through an ML process. Each individual layer in an RNA learns different attributes with different weights for different stimuli. This provides the machine with the adaptation to complex processes. It's the multiple layers that give RNA the name of deep learning, better known as DL.

Progress in computational power, the refinement of algorithms and learning architectures, the availability of a large amount of data, and public access to deep neural networks have made AI a promising reality in healthcare. AI is already applied in many medical areas, such as radiology, dermatology and cardiology, but in ophthalmology its application will bring major changes in the means of diagnosis and treatment for eye conditions such as corneal ectasias, age-related macular degeneration (AMD), diabetic retinopathy (DR), glaucoma, etc.

The usual diagnosis for ophthalmic diseases relies on clinical evaluation and image capture using numerous equipment, thus generating an expensive and time-consuming process. In ophthalmology, LD can utilize images, such as digital photographs of the fundus of the eye, cornea, and the visual field, and perform automated screening and diagnosis of common vision-threatening diseases with high efficiency. In addition to being able to more accurately diagnose diseases which depend on the knowledge of the observer, and therefore it is necessary to evaluate their applications in this area.

2 PURPOSE AND JUSTIFICATIONS

To evaluate the benefits and importance of artificial intelligence in the diagnosis and treatment of ophthalmic diseases in the face of interobserver variability. In addition to characterizing how artificial intelligence can optimize the diagnosis of ophthalmic diseases. Given the extensive current technological evolution, it is necessary to elucidate how artificial intelligence will be present in the future of medicine and optimize knowledge on the subject to encourage more field research in the future.

3 DEVELOPMENT

3.1 METHODOLOGY

This is a bibliographic research of the narrative review type in which were used, mostly, scientific productions from the period 2018 to 2023 in the electronic databases: Scielo-Brasil (Scientific Electronic Library Online) and MedLine/Pubmed (US National Library of Medicine), containing the descriptors: artificial intelligence AND ophthalmology AND machine learning AND diagnosis.

A total of 21 articles were found based on the search for descriptors and 11 articles were chosen that answered the guiding question.

Documentary research has been consistently compiled and summarized in articles that discuss the implementation of artificial intelligence in medicine, specifically in the area of ophthalmology, in order to corroborate in the screening and diagnosis of eye diseases under a critical and analytical eye. However, this search does not include the exhaustion of the theme or sources of information, nor does it have the intention of strategies for more sophisticated and exhaustive searches, but rather to conduct a reflection on this issue for the future society. Thus, in this study were listed as theoretical support, the reading of texts rich in scientific basis, as well as theoretical principles that support pillars on the medical scenario. Articles written before this period or with little relevance to the researched theme were excluded, with results without significance for the research and paid articles. Thus, 9 articles in English and Portuguese that addressed the theme with demonstrative results of relevance were selected.

4 DISCUSSION AND RESULTS

The current applications of AI in the field of ophthalmology and its various subspecialties:

4.1 RETINA

Screening for diabetic retinopathy (DR) is essential for early detection and treatment, preventing vision loss. DR is an ideal field for AI, which can help overcome obstacles to detection, improve access, and prevent vision loss. Early AI and DR research focused on lesion identification and evolved into the categorization of RD with a predominant focus on standard colored eye fundus imaging. In addition to fundus photography as a mold, detection of the disease was analyzed using optical coherence tomography (OCT) images, ultra-wide field (UWF) images, and even retinal images captured by smartphones. The intraretinal fluid found by OCT can be accurately recognized using RNA. The UWF photo grants viewing up to 200° of the background, potentially detecting additional peripheral diseases related to diabetes.

Datasets can be used to develop high-performance DL systems for labeling fundus images. Studies using color photographs of unaltered eye funduses and with altered optic discs, of patients of different ethnicities, have demonstrated the learning power of high-complex RNAs. As a result, they obtained a high performance for the semantic labeling of images, with high sensitivity and specificity, evidencing how machine learning can organize large databases of medical images and facilitate the ophthalmologist's workflow, automatically classifying the images for screening and laterality.

Another parameter that can influence the decision to use automated models for the diagnosis of ophthalmic diseases, in addition to accuracy, is cost. Economic analysis study models showed that the expense for screening DR in automated or semi-automated models in the face of human evaluation would have a lower cost - a decrease of approximately 20% of the current annual cost of screening.

The access and availability of imaging tools are challenges for the effective detection of RD, the use of images that have a high quality are of utmost importance for diagnostic quality. The current use of advanced background cameras has facilitated teleophthalmology, bringing modern eye care to remote regions, and even AI coupled with this technology, being able to highlight whether it is an altered image or not. There are AI RD detection platforms commercially available today.

Age-related macular degeneration (AMD) is a common cause of vision loss affecting approximately 196 million patients worldwide. Early diagnosis and initial treatment can reduce vision loss. Given the lethality of the disease, AI can assist in mass scanning of OCT and retinal images without direct human evaluation. In addition to predicting its evolution through the application of an AI algorithm that can accurately quantify the volume of intraretinal fluids in patients with neovascular AMD, with the potential to monitor the response to treatment, for example. Deep learning has been used to explore other aspects associated with AMD, such as the sub-retinal, pigmentary epithelial detachment, loss of ellipsoidal area, drusen, fibrosis and subretinal hyperreflective material.7

4.2 CORNEA

Although AI has been widely investigated in the posterior segment, the employment of AI in anterior segment disease and diagnostic investigation is now at the forefront of the ophthalmic literature.

The use of a neural network to measure with high accuracy the severity of hyperemia or conjunctival opacity through a pre-existing categorization is one of the applications of AI in this field.

Corneal opacities are important causes of blindness, and their main etiology is infectious keratitis. This is a painful and severe bacterial infection of the cornea that threatens vision. An immediate clinical diagnosis by an ophthalmologist can often help prevent patients with this disease from progressing to corneal melting or even perforation. However, many rural areas do not have an ophthalmologist. In addition, slit lamp examinations are commonly used to determine the causative pathogen; However, its diagnostic accuracy is low even for experienced ophthalmologists. The rapid development of DL algorithms and artificial intelligence through image processing can provide instant screening and immediate recommendation for patients with red and sore eyes.

A study conducted using 5 RNA databases showed promising results for the diagnosis of bacterial keratitis. The diagnostic accuracy of these models (ranging from 69 to 72%) is comparable to that of an ophthalmologist (66% to 74%). In addition to screening to diagnose a possible corneal alteration, research involving the use of LD and specialized neural networks used facial recognition algorithms tailored to determine the likelihood for a specific pathogen that causes keratitis (bacteria, fungi, acantamoeba and herpes simplex virus - HSV). The study had as a result of the algorithm created a high overall diagnostic accuracy - accuracy/area under the curve for acanthamoeba was 97.9%/0.995, bacteria was 90.7%/0.963, fungi was 95.0%/0.975 and HSV was 92.3%/0.946, by the validation of the K-fold group, and was robust even for low-resolution web images.4 It is concluded that these models are promising tools for the diagnosis of corneal diseases in first-line medical care units without ophthalmologists.

In view of the pathologies of the lacrimal apparatus, lacrimal scintigraphy (LS) is an objective and reliable method of studying the drainage system and tear flow. The development of ML and DL algorithms using LS images to classify tear duct pathology in patients with epiphora is possible. Thus, the system would obtain an accuracy comparable to a trained oculoplastic specialist.

Other applications in the anterior segment would be before dry eye and keratoconus. Meibomian glands play a critical role in the health of the ocular surface, being the most frequent cause of dry eyes. Meibography, or photographic documentation of the glands of the eyelids with transillumination or light infrared, is a common test for the diagnosis, treatment and management of these dysfunctions. The development of a DL approach to digitally segment meibomian gland atrophy and calculate percentage atrophy on meibography images by providing quantitative information of gland atrophy would achieve a high meiboscore classification accuracy, outperforming the principal clinical investigator and clinical team.

Keratoconus is a non-inflammatory corneal disease described as having stromal thinning and astigmatism. A DL algorithm can be developed from the analysis of corneal topography results collected retrospectively over time in order to discover keratoconus. The algorithm should measure the thickness of the three main layers, namely the epithelium, the Bowman layer and the middle layer, in patients with keratoconus and healthy eyes. Becoming able to identify and label the eyes with the pathology and stage of the disease.

4.3 CATARACT

Cataracts are a disease that causes blindness in approximately 18 million people worldwide. Because it is an age-related pathology, it is mostly inevitable, but treatment requires a high cost, so low-income countries are the most affected by blindness due to the lack of health infrastructure and the aging of the population.

In populations of underdeveloped countries, high-volume cataract surgery campaigns have been a solution for the treatment of this pathology, and the cost-effectiveness and efficiency ratio is extremely important. Supplies must be planned and shifted for each campaign, and the optimized provision of intraocular lenses (IOLs) is required to achieve the best outcomes. With the evolution of IOLs it was possible to correct refractive errors concomitantly with the opacity of the lens, and a specific lens was selected for the patients.

Studies conducted in patients of Ethiopian cataract campaigns with records of target IOL and the one that was implemented, as well as the evaluation of the diopter difference between both, in the campaigns applying ML to obtain this optimization of the IOL inventory and minimize avoidable refractive errors obtained promising results. The IOL inventory reproduced by ML ensured that more than 99.5% of patients received their target IOL, using only 39% of surplus IOLs.

By using ML to limit IOLs with incorrect potency, particularly IOLs with insufficient potency in cataract surgery campaigns, it will be possible to observe significant improvement in refractive results, and in addition to reducing the excess of lenses needed, there will be a simultaneous reduction in campaign costs. 2

4.4 GLAUCOMA

Glaucoma, the second most common cause of irreversible blindness worldwide, is a progressive optic neuropathy characterized by the degeneration of retinal ganglion cells and their axons, resulting in the eventual loss of the visual field and alteration of the optic disc. The therapeutic strategies of this pathology are intended to decrease the intraocular pressure (IOP) in order to prevent or avoid the progression of the disease. Treatment follow-up is usually performed through IOP measurements performed during consultations, but these measurements represent a small portion of all circadian variation in IOP. The worsening of glaucoma in patients who appear to have their IOP levels controlled may be explained in part by this lack of evaluation.

It is estimated that half of patients with glaucoma have IOP peaks at 6 AM, after detection by means of a 24-hour IOP curve. However, obtaining the measurements for the performance of this curve are not easily obtained in clinical practice, consequently the daytime IOP curve is adopted for the evaluation of patients. The measurement of isolated IOP during medical hours is not reliable, as they often underestimate the IOP peaks, which may be related to the progression of the disease.

Studies using ML - a classification tree used to determine a multivariate algorithm from the measurements of the daytime curve - to predict the risks of elevation of this pressure based on three measurements (8.9 and 11 AM) showed a sensitivity of 100% and a specificity of 86%, with accuracy of 93%. It is concluded that this method can solve challenges in obtaining the 24-hour IOP curve, in addition to predicting the risks of IOP peaks in the early morning. Or The proposed model presented a sensitivity of 100% and a specificity of 86%, with an accuracy of 93%.

Early detection of glaucoma helps reduce eventual vision loss. Evaluation of the optic disc is a method of analyzing the progression of the disease. Digital imaging of the optic nerve is a common screening technique and is used effectively in many tele-glaucoma programs. AI algorithms have been developed to recognize optic nerve changes through SD-OCT and optical disc photography and thus predict changes in the glaucomatous field. ML can be used to improve the identification of early glaucoma changes in the optic nerve through imaging.

4.5 FUTURE CHALLENGES

While AI can bring many benefits to medicine today, there are still challenges in the process. Screening requires a vast manpower and financial resources from health systems around the world – developed countries and in low/middle-income countries. The implementation of AI in healthcare also has hurdles such as the Black Box problem, overfitting and regulatory approval. The Black Box problem represents the lack of skills of DL algorithms to demonstrate how they arrive at their conclusions. Overfitting is when AI algorithms, trained on one dataset, have restricted applicability to other datasets. For regulatory approval, the FDA classified new AI tools based on three criteria: risk to patient safety, existence of a quality algorithm, and the degree of human intervention.

Another challenge in the process of AI models in ophthalmology is the limited availability of large volumes of data for rare diseases and for common diseases that are not routinely photographed in practice. In addition, there are diseases such as glaucoma and ROP in which there may be disagreement and interobserver variability in the definition of the physical manifestation of the disease genotype, in addition to the interposition of diseases, which would lead to a possible misdiagnosis through ML.

The use of computing technologies also involves cyberattacks. Research has pointed out that conventional models of DL based on imaging domains, such as fundus photography, ultra-wide field fundus photography, and optical coherence tomography, are extremely vulnerable to adversarial attacks, which may be undetectable to humans. These disturbances proved to be a problem for the effectiveness of the result produced by AI. DL medical system designers and approval agencies must be careful to protect themselves against these intrusions.

However, if these problems are addressed with due attention, other, more urgent challenges faced by health providers and policymakers will be solved by these technological developments, such as: universal, equitable and sustainable health coverage for the growing and aging population.

5 CONCLUSIONS

Given the interobserver variability, artificial intelligence has been shown to be a viable technique to improve ophthalmological treatment. Medical professionals can count on a more accurate, effective and cost-effective way to identify eye diseases with the use of ML and LD. Ophthalmology is a specialty conducive to the incorporation of AI.

The extensive use of multimodal digital imaging and diagnostic tests captured over time across all ophthalmic subspecialties provides a treasure trove of opportunities for ML, given that artificial intelligence's ability to analyze massive amounts of data quickly and accurately is one of its key benefits. With the use of sophisticated algorithms it is possible to thoroughly examine photos and clinical data, finding minimal patterns that can point to specific eye disorders, as well as quantify diseases. This helps in early identification and more accurate diagnosis, providing more efficient treatment and better outcomes for patients.

In addition, the use of LD and ML results in a large reduction in spending on ophthalmic medicine. The analysis of exams and photographs is an example of repetitive and routine operation that can be automated so that professionals can focus on more difficult and relevant tasks. This reduces labor expenses and decreases patient waiting time, increasing the productivity and efficiency of hospital services.

The potential to develop predictive models that aid in the early detection of eye disorders is another significant advantage. Algorithms can identify people who are more likely to develop specific eye problems based on medical histories, genetic information, and other pertinent data, enabling early, individualized therapies. In addition to improving the quality of life for patients, this helps health systems remain sustainable by avoiding the need for future, more complex and expensive treatments.

Despite all the improvements and advantages offered by artificial intelligence in ophthalmology, it is critical to highlight that technology should not replace professional knowledge and clinical judgment. Although AI is a potent auxiliary tool, ophthalmologists still play a critical role in evaluating outcomes and developing a treatment strategy for each patient, according to their needs and personal history.

In conclusion, artificial intelligence and machine learning solutions have initiated the evolution from a research environment to a clinical tool that will be invaluable to ophthalmologists in all clinical settings. In addition to presenting considerable advantages in the detection of eye disorders and cost reduction in the field of ophthalmic medicine through ML and DL. The future of ophthalmic medicine will certainly be positively impacted by the responsible and ethical use of these technologies in conjunction with the clinical expertise of specialists. In view of this, it is extremely important that all physicians are aware of the recent progress in the development of AI, given the influence it will have on the spread of healthcare in the future.

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