Scholars Journal of Applied Medical Sciences
Abbreviated Key Title: Sch J App Med Sci
ISSN 2347-954X (Print) | ISSN 2320-6691 (Online)
Journal homepage: https://saspublishers.com

OPEN ACCESS

Ophthalmology

Artificial Intelligence and Deep Learning in Ophthalmology: A Review of Advancements and Challenges

Benita Alex[1*], Ashwini Amol Diwan[1], Joel Jeffrey[2], David Jeffrey[3]

[1]Primary Health Care Corporation, Doha, Qatar
[2]IIT Palakkad
[3]BTech ECE, NIT Calicut

DOI: https://doi.org/10.36347/sjams.2024.v12i11.024 | **Received:** 11.10.2024 | **Accepted:** 15.11.2024 | **Published:** 18.11.2024

***Corresponding author:** Benita Alex
Primary Health Care Corporation, Doha, Qatar

Abstract **Review Article**

Artificial intelligence and deep learning are upcoming areas of interest in the field of computer science. It's becoming increasingly popular in the field of medicine, specifically in ophthalmology. It has the potential to improve the screening, diagnostic and treatment aspects of many ocular conditions like corneal diseases, glaucoma, age-related macular degeneration, and diabetic retinopathy. The concept, application, and terminology are relatively new and unfamiliar to medical professionals. Ophthalmology was quick to adopt different methods of artificial intelligence and deep learning to improve the diagnostic areas as it involves many digitalized images and data collection.

Keywords: Artificial Intelligence, Deep Learning, Ophthalmology, Diabetic Retinopathy, Age-Related Macular Degeneration.

INTRODUCTION

With advances in computer and computational science, the artificial intelligence and deep learning methods are making their way forward in the field of medicine, more importantly in ophthalmology. Artificial intelligence technology and methods are specifically useful in ophthalmology because of the fact that the decision-making in this field is highly dependent on image acquisition and analysis [1]. Recently these sophisticated methods are used to construct deep learning models to perform high dimensional analyses. They are used to automate screening and diagnosis of many ocular conditions like diabetic retinopathy and age-related macular degeneration in addition to other anterior segment disease [2]. In ophthalmology deep learning has been used for analyzing fundus photographs, OCT and visual field images with accurate and reliable performance in detecting diabetic retinopathy, glaucoma suspect, and macular degeneration. Deep learning based ocular imaging can be utilized as a part of telemedicine to quickly screen and reliably diagnose different ocular conditions in primary care level and as a method of community screening [3]. The major benefits of deep learning in ophthalmology is in screening for which definite guidelines exist and screening demands manpower and financial resources in both developed and in low-income countries [4].

Applications

Diabetic retinopathy

Diabetes is a global epidemic with patients projected to increase to 600 million by 2040 as reported by international diabetes Federation with about 30% having diabetic retinopathy [5].

Regular screening, prompt referral and adequate treatment are important aspects of DR prevention. The screening can be done by healthcare professionals including ophthalmologists screening technicians and clinical photographers. The methods adopted are direct ophthalmoscopy, slit lamp bio microscopy, indirect ophthalmoscopy, mydriatic and non-mydriatic retinal photography and telemedicine screening [6].

Deep learning has transformed the screening methodology of diabetic retinopathy and many researchers have had excellent results with various methods [7]. Abràmoff *et al.,* demonstrated that these systems were able to achieve sensitivity of 96.8% and specificity of 87% respectively, in detecting referable DR [8]. Recently Gulshan *et al.,* 9came up with another system with excellent diagnostic accuracy which utilized 10,000 images from publicly available data bases which were graded by experienced ophthalmologists [9]. Multiple artificial intelligence based systems are approved for clinical use in the field of diabetic retinopathy. Some of them like IDx-DR (IDx LLC, Coralville, IA, USA) and Eye Art (Eyenuk, Inc., Woodlands Hills, CA, USA) have already been approved by USA food and drug administration and are under clinical use [10]. Various studies have pointed out significant cost savings that are attributed to the use of artificial intelligence-based algorithms in screening of diabetic retinopathy [11]. These intelligence systems are likely to be used in large scale diabetic retinopathy screening programs in the future. But there are some limitations which should be solved before integrating it to the routine screening programs. Retinal images usually contain other features of ocular or systemic diseases which may cause concern especially when considering medicolegal aspects [11]. Some of the systems only detect diabetic retinopathy while some others detect age-related macular degeneration also [12].

Most methods utilize fundus images which help to determine the present status of retinopathy and presence of features like microaneurysms, and exudates help to classify the retinopathy. For these various techniques like retinal blood vessel segmentation and lesion segmentation are made use of. This high-performance detection technique utilized standard images to detect, and segment affected parts of the retina. The deep learning techniques are used for detection as well as grading purposes utilizing artificial neural networks with multiple processing layers to detect high resolution features from the data [10].

Recently these methods have been improved with the use of high-resolution OCT images and significant research studies are being carried out. OCT images are superior to fundus images to develop systems which can undertake micrometer resolutions and improved penetrations onto the retina which helps in the grading and treatment decisions [11].

The deep learning techniques heavily depend on data sets that are used. The accuracy of the data set and its quality will influence the results obtained by these techniques. Kaggle's Eye PACS and APTOS datasets are most commonly used for detection and grading of diabetic retinopathy. These data sets contain fundus images taken with different cameras and settings and consist of more than 88,000 images [7]. These methods for detection and grading are evaluated using different measures like accuracy, sensitivity, and specificity. For detection of diabetic retinopathy two groups of data sets, one group consisting of images with diabetic retinopathy and the other images without retinopathy, are used. The methods used for diabetic retinopathy grading utilize a different convoluted neural network and transfer learning. Also pre-processing techniques are used for better feature extraction [9].

Age-related macular degeneration

Age-related macular degeneration (AMD) is an important cause of blindness in the elderly. With the increase of aging population, there should be increased awareness and screening of this condition. A study by Ting *et al.,* suggested an improvised deep learning system for detecting referable AMD [13]. Burlina *et al.,* demonstrated accuracy of between 88.4% and 91.6% with respect to referable AMD [14]. In the beginning color fundus photographs of patients were utilized in the deep learning systems, but lately OCT images are being trained and tested [15]. In a previous study a deep learning algorithm was developed to assess the risk of progression from intermediate to late AMD [16]. The researchers identified certain biomarkers to assess this risk of progression of which most relevant where drusen volume, area and average thickness [16]. Another study by Russakoff *et al.,* also used deep learning algorithms to study the progression of early AMD to neo vascular AMD based on OCT biomarkers [17]. Developing OCT biomarkers and analysis and quantification is most important in improving the screening program. Deep learning model is promising in differentiating AMD images from normal OCT images [15]. The incorporation of deep learning and OCT images in patients with AMD has the potential to identify the progression to neovascular AMD and helps to promptly refer patients who need treatment [18].

In a study by Heo TY *et al.,* deep learning based artificial intelligence tool was used to differentiate between dry and neovascular age-related macular degeneration [19]. They also did comparison of diagnostic accuracy of the AI tool with that of ophthalmology residents. Two different fundus photography systems were used to give ultra-wide field fundus digital images. Convolutional neural network techniques were used to classify macular degeneration in macular images. Cross validation was done for evaluating the deep learning models. The tested artificial intelligence model was able to detect features of AMD such as drusen, bleeding, elevation of the center of macula [20].

Other macular diseases

OCT is very useful in the management of macular disorders and provides microscopic view of retina in vivo which is not visible to the naked eye [3]. Macular OCT is very useful for deep learning techniques because of better image quality and three-dimensional structure. A large number of OCT images are required to train the deep learning systems. A study by Pace T *et al.,* demonstrated efficiency of deep learning systems to identify macular hole [21]. OCT was widely used for the diagnosis and classification of macular holes. Convolutional neural networks were recently used to automatically detect macular holes using ultra-wide field images. The Visual Geometry Group network (VGG, Department of Engineering Science, The University of

Oxford, Oxford, UK) with 16 convolutional layers was used for the identification of macular hole [21].

Glaucoma

Glaucoma is caused by increased intraocular pressure which results in damage to retinal ganglion cells and optic nerve damage in the form of excavation and cupping. Researchers have used deep learning methods to distinguish glaucomatous nerve fiber layer damage from normal scans using OCT images. Also, studies are underway using different neural networks to identify disc appearance that can lead to glaucoma. As these methods are developed, ophthalmologists can use these techniques for diagnosing glaucoma and monitor progression [3].

Retinopathy of prematurity

Due to high number of preterm births, retinopathy of prematurity is commonly encountered. Retinopathy of prematurity screening is done by experienced ophthalmologist trained in the examination of newborns, or by telemedicine evaluation using digital fundus photographs. The main barriers to retinopathy of prematurity screening are the lack of experienced personnel and subjective nature of the diagnosis [3]. Significant interobserver variation exists in making the diagnosis. Early attempts are being made to apply deep learning methods in this context which could potentially improve the identification and to improve the outcome of screening. Recently Brown *et al.,* reported as fully automated deep learning system which is useful to diagnose plus disease with high accuracy [22].

Potential challenges

Even though artificial intelligence-based models have high accuracy, there are potential clinical and technical challenges before they can be clinically implemented and used in clinical practice [3]. Many of the studies have used data sets from homogeneous populations. Training and testing of deep learning techniques is subject to many variabilities like width of field, field of view, image magnification and quality. Including more diverse data sets and including ethnically different data sets and improving the hardware can overcome these challenges. Another challenge is the limited availability of data sets for common diseases in ophthalmology due to lack of routine imaging in clinical practice. Furthermore, there are subjective differences and interobserver differences in certain diseases like glaucoma and retinopathy of prematurity which pose difficulty in training the AI algorithms [3]. There is a possibility of dependency of physicians to technology and also a chance of patient dissatisfaction in relying on deep learning excessively. In case a physician disagrees with the results obtained after applying these innovative techniques, it can be challenging, and patients' treatment is affected which may lead to medicolegal aspects of care. These potential flaws demand call for continuous improvement in deep learning technology [23].

CONCLUSION

Deep learning based artificial intelligence methods using fundus and OCT images have revolutionized the field of ophthalmic imaging as it is immensely useful in screening and has provided clinically acceptable diagnostic performance in detecting many retinal diseases particularly diabetic retinopathy and retinopathy of prematurity. Nevertheless, large patient data sets from various ethnic groups are necessary for enhancing these systems. Applying these into clinical practice has the potential to improve patient access to screening and diagnosis and reduce the health care cost in certain fields where the incidence of disease is very high. However, the legal regulations to its application and solving such matters are of utmost importance. Future research is pivotal in gauging its efficacy and cost effectiveness before deploying in clinical practice. Despite all the shortcomings deep learning is likely to transform the practice of medicine and ophthalmology in the forthcoming decades.

REFERENCES

1. Jin, K., & Ye, J. (2022). Artificial intelligence and deep learning in ophthalmology: Current status and future perspectives. *Advances in ophthalmology practice and research*, *2*(3), 100078. https://doi.org/10.1016/j.aopr.2022.100078
2. Gulshan, V., Peng, L., Coram, M., Stumpe, M. C., Wu, D., Narayanaswamy, A., Venugopalan, S., Widner, K., Madams, T., Cuadros, J., Kim, R., Raman, R., Nelson, P. C., Mega, J. L., & Webster, D. R. (2016). Development and Validation of a Deep Learning Algorithm for Detection of Diabetic Retinopathy in Retinal Fundus Photographs. *JAMA*, *316*(22), 2402–2410. https://doi.org/10.1001/jama.2016.17216
3. Ting, D. S. W., Pasquale, L. R., Peng, L., Campbell, J. P., Lee, A. Y., Raman, R., Tan, G. S. W., Schmetterer, L., Keane, P. A., & Wong, T. Y. (2019). Artificial intelligence and deep learning in ophthalmology. *The British journal of ophthalmology*, *103*(2), 167–175. https://doi.org/10.1136/bjophthalmol-2018-313173
4. Ting, D. S. W., Cheung, C. Y., Lim, G., Tan, G. S. W., Quang, N. D., Gan, A., Hamzah, H., Garcia-Franco, R., San Yeo, I. Y., Lee, S. Y., Wong, E. Y. M., Sabanayagam, C., Baskaran, M., Ibrahim, F., Tan, N. C., Finkelstein, E. A., Lamoureux, E. L., Wong, I. Y., Bressler, N. M., Sivaprasad, S., … Wong, T. Y. (2017). Development and Validation of a Deep Learning System for Diabetic Retinopathy and Related Eye Diseases Using Retinal Images From Multiethnic Populations With Diabetes. *JAMA*, *318*(22), 2211–2223. https://doi.org/10.1001/jama.2017.18152
5. Yau, J. W., Rogers, S. L., Kawasaki, R., Lamoureux, E. L., Kowalski, J. W., Bek, T., Chen, S. J., Dekker, J. M., Fletcher, A., Grauslund, J., Haffner, S., Hamman, R. F., Ikram, M. K., Kayama, T., Klein,

B. E., Klein, R., Krishnaiah, S., Mayurasakorn, K., O'Hare, J. P., Orchard, T. J., … Meta-Analysis for Eye Disease (META-EYE) Study Group (2012). Global prevalence and major risk factors of diabetic retinopathy. *Diabetes care*, *35*(3), 556–564. https://doi.org/10.2337/dc11-1909

6. Ting, D. S., Cheung, G. C., & Wong, T. Y. (2016). Diabetic retinopathy: global prevalence, major risk factors, screening practices and public health challenges: a review. *Clinical & experimental ophthalmology*, *44*(4), 260–277. https://doi.org/10.1111/ceo.12696
7. LeCun, Y., Bengio, Y., & Hinton, G. (2015). Deep learning. *Nature*, *521*(7553), 436–444. https://doi.org/10.1038/nature14539
8. Abràmoff, M. D., Lou, Y., Erginay, A., Clarida, W., Amelon, R., Folk, J. C., & Niemeijer, M. (2016). Improved Automated Detection of Diabetic Retinopathy on a Publicly Available Dataset Through Integration of Deep Learning. *Investigative ophthalmology & visual science*, *57*(13), 5200–5206. https://doi.org/10.1167/iovs.16-19964
9. Gulshan, V., Peng, L., Coram, M., Stumpe, M. C., Wu, D., Narayanaswamy, A., Venugopalan, S., Widner, K., Madams, T., Cuadros, J., Kim, R., Raman, R., Nelson, P. C., Mega, J. L., & Webster, D. R. (2016). Development and Validation of a Deep Learning Algorithm for Detection of Diabetic Retinopathy in Retinal Fundus Photographs. *JAMA*, *316*(22), 2402–2410. https://doi.org/10.1001/jama.2016.17216
10. Abràmoff, M. D., Lavin, P. T., Birch, M., Shah, N., & Folk, J. C. (2018). Pivotal trial of an autonomous AI-based diagnostic system for detection of diabetic retinopathy in primary care offices. *NPJ digital medicine*, *1*, 39. https://doi.org/10.1038/s41746-018-0040-6
11. Xie, Y., Nguyen, Q. D., Hamzah, H., Lim, G., Bellemo, V., Gunasekeran, D. V., Yip, M. Y. T., Qi Lee, X., Hsu, W., Li Lee, M., Tan, C. S., Tym Wong, H., Lamoureux, E. L., Tan, G. S. W., Wong, T. Y., Finkelstein, E. A., & Ting, D. S. W. (2020). Artificial intelligence for teleophthalmology-based diabetic retinopathy screening in a national programme: an economic analysis modelling study. *The Lancet. Digital health*, *2*(5), e240–e249. https://doi.org/10.1016/S2589-7500(20)30060-1
12. Ting, D. S. W., Cheung, C. Y., Lim, G., Tan, G. S. W., Quang, N. D., Gan, A., Hamzah, H., Garcia-Franco, R., San Yeo, I. Y., Lee, S. Y., Wong, E. Y. M., Sabanayagam, C., Baskaran, M., Ibrahim, F., Tan, N. C., Finkelstein, E. A., Lamoureux, E. L., Wong, I. Y., Bressler, N. M., Sivaprasad, S., … Wong, T. Y. (2017). Development and Validation of a Deep Learning System for Diabetic Retinopathy and Related Eye Diseases Using Retinal Images From Multiethnic Populations With Diabetes. *JAMA*, *318*(22), 2211–2223. https://doi.org/10.1001/jama.2017.18152
13. Ting, D. S. W., Cheung, C. Y., Lim, G., Tan, G. S. W., Quang, N. D., Gan, A., Hamzah, H., Garcia-Franco, R., San Yeo, I. Y., Lee, S. Y., Wong, E. Y. M., Sabanayagam, C., Baskaran, M., Ibrahim, F., Tan, N. C., Finkelstein, E. A., Lamoureux, E. L., Wong, I. Y., Bressler, N. M., Sivaprasad, S., … Wong, T. Y. (2017). Development and Validation of a Deep Learning System for Diabetic Retinopathy and Related Eye Diseases Using Retinal Images From Multiethnic Populations With Diabetes. *JAMA*, *318*(22), 2211–2223. https://doi.org/10.1001/jama.2017.18152
14. Burlina, P. M., Joshi, N., Pekala, M., Pacheco, K. D., Freund, D. E., & Bressler, N. M. (2017). Automated Grading of Age-Related Macular Degeneration From Color Fundus Images Using Deep Convolutional Neural Networks. *JAMA ophthalmology*, *135*(11), 1170–1176. https://doi.org/10.1001/jamaophthalmol.2017.3782
15. Borrelli, E., Serafino, S., Ricardi, F., Coletto, A., Neri, G., Olivieri, C., Ulla, L., Foti, C., Marolo, P., Toro, M. D., Bandello, F., & Reibaldi, M. (2024). Deep Learning in Neovascular Age-Related Macular Degeneration. *Medicina (Kaunas, Lithuania)*, *60*(6), 990. https://doi.org/10.3390/medicina60060990
16. Schmidt-Erfurth, U., Waldstein, S. M., Klimscha, S., Sadeghipour, A., Hu, X., Gerendas, B. S., Osborne, A., & Bogunovic, H. (2018). Prediction of Individual Disease Conversion in Early AMD Using Artificial Intelligence. *Investigative ophthalmology & visual science*, *59*(8), 3199–3208. https://doi.org/10.1167/iovs.18-24106
17. Russakoff, D. B., Lamin, A., Oakley, J. D., Dubis, A. M., & Sivaprasad, S. (2019). Deep Learning for Prediction of AMD Progression: A Pilot Study. *Investigative ophthalmology & visual science*, *60*(2), 712–722. https://doi.org/10.1167/iovs.18-25325
18. Lee, C. S., Baughman, D. M., & Lee, A. Y. (2017). Deep learning is effective for the classification of OCT images of normal versus Age-related Macular Degeneration. *Ophthalmology. Retina*, *1*(4), 322–327. https://doi.org/10.1016/j.oret.2016.12.009
19. Heo, T. Y., Kim, K. M., Min, H. K., Gu, S. M., Kim, J. H., Yun, J., & Min, J. K. (2020). Development of a Deep-Learning-Based Artificial Intelligence Tool for Differential Diagnosis between Dry and Neovascular Age-Related Macular Degeneration. *Diagnostics (Basel, Switzerland)*, *10*(5), 261. https://doi.org/10.3390/diagnostics10050261
20. Simonyan, K., & Zisserman, A. (2014). Very deep convolutional networks for large-scale image recognition. *arXiv preprint arXiv:1409.1556*.
21. Pace, T., Degan, N., Giglio Md, R., Tognetto Md, D., & Accardo, A. (2022). A Deep Learning Method for Automatic Identification of Drusen and Macular Hole from Optical Coherence Tomography. *Studies*

in health technology and informatics, *294*, 565–566. https://doi.org/10.3233/SHTI220525

22. Brown, J. M., Campbell, J. P., Beers, A., Chang, K., Ostmo, S., Chan, R. V. P., Dy, J., Erdogmus, D., Ioannidis, S., Kalpathy-Cramer, J., Chiang, M. F., & Imaging and Informatics in Retinopathy of Prematurity (i-ROP) Research Consortium (2018). Automated Diagnosis of Plus Disease in Retinopathy of Prematurity Using Deep Convolutional Neural Networks. *JAMA ophthalmology*, *136*(7), 803https://doi.org/10.1001/jamaophthalmol.2018.1934
23. Moraru, A. D., Costin, D., Moraru, R. L., & Branisteanu, D. C. (2020). Artificial intelligence and deep learning in ophthalmology - present and future (Review). *Experimental and therapeutic medicine*, *20*(4), 3469–3473. https://doi.org/10.3892/etm.2020.9118