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Chapter - 10

A Research Perspective and Analysis of AI in Ophthalmology : Optimizing Diabetic Retinopathy Diagnosis

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ABSTRACT

Background: Diabetic retinopathy may be a leading reason for visual impairment globally, resulting from delayed diabetes related retinal injury. Early identification is crucial and at the same time traditional screening methods are time-consuming and demand a skilled ophthalmologist. AI-driven demonstrative devices have emerged as a game-changing solution, utilising machine learning algorithms to automate and improve DR screening, reducing the workload of healthcare professionals. The development of AI model in DR treatment has been supported by extensive research, including Convolutional Neural Network (CNN) trained on retinal fundus images. Aim: This present study is to explore the application of AI in diagnosing Diabetic Retinopathy (DR), centring headways in deep learning and computerized screening strategies.AI integration in *healthcare has transformed ophthalmology by enhancing accuracy and efficiency in DR detection, particularly in resource constrained settings. Methodology: This review synthesizes findings from several review papers on AI based DR screening, surveying the execution of different deep learning models. Key techniques incorporate administered learning procedures connected to expansive datasets of retinal pictures, highlight extraction for injury distinguishing proof and approval of AI models against ophthalmologist diagnosis. Moreover, real world applications such as, Googles Automated Retinal Disease Assessment (ARDA), illustrate the potential of AI in clinical settings. ARDA was created in collaboration with healthcare experts to improve DR screening, tending to challenges of accessibility and accuracy. Results: Studies have shown that AI models have achieved diagnostic accuracies comparable to, and sometimes exceeding, those of human specialists. Algorithms based on extensive image datasets displays high sensitivity and specificity in detecting DR stages, from mild non-proliferative DR to vision threatening conditions. AI driven screening reduces symptomatic errors, streamlines workflow and increases screening accessibility, particularly in underserved regions. The ARDA system reflects the impact of AI, enabling healthcare workers to detect DR in an effective manner via automated retinal image examinations, reducing reliance on specialized personnel. Conclusion: AI has come to play an important role in DR diagnosis as a scalable and effective substitute for conventional screening practices. The incorporation of deep learning in ophthalmology enables early detection, timely interventions and enhanced patient outcomes. With future developments potentially further optimizing AI models with multimodal imaging and real time diagnosis, AI has poised to further enhance its influence on global healthcare systems in their efforts.*

Keywords: Artificial Intelligence (AI), Diabetic Retinopathy (DR), Machine Learning, Retinal Imaging, Convolutional Neural Networks (CNNs), Automated Retinal Disease Assessment (ARDA).

INTRODUCTION

Artificial intelligence, or AI, is a branch of computer science that creates theories, models, inventions, and application systems for the purpose of imitating, enhancing, and expanding human concepts in machines. One of the subdivisions of AI is Machine Learning, ML, which builds intelligent systems based on statistical techniques. The paradigm remarkably learns and improves the efficiency of its execution, even accuracy, without being specifically programmed, through either a supervised or unsupervised learning approach(Kong & Song, 2024). Deep learning (DL), a novel branch of ML, has found application in diagnosis in speech recognition, image recognition, and even natural language processing. Deep learning (DL) has reintroduced the traditional history of unbiased and facilitative, retinal image analysis, originating in the 1990s. Therefore, a wide range of innovations has been developed in various therapeutic fields including radiology, dermatology, ophthalmology etc., for medical image analysis applications to all the fields. Such artificial intelligence (AI) architectures using these devices have also been demonstrated to increase diagnostic accuracy rates and decrease the cost and numbers of DR screening patients (1). The capacity to learn features, as well as to perform the recognition tasks, even when these tasks are based on data made available across the layers of (artificial neurons), by exploiting the deep layers which can store at different depths the information representations derived from an input and generating a symptomatic output, in part explains the success. Since that amazing goal, dozens of examiners have pointed DL at Rehabilitation and medical work tasks and converted it to the bot of high-quality diagnosis, therapy and screening of a large variety of pathologies over the last years. DL has also been applied to the identification of COVID-19 in chest X-ray, in the annotation of thyroid ultrasound, and in the detection and ranking of lung nodule in computed tomography (CT) images(Grzybowski et al., 2020).

This article seeks to outline the role of AI in diagnosing and treating diabetic retinopathy, given that AI is already being harnessed for a myriad of other conditions. One of the major complications of diabetes is Dr, which is an eye disease that can severely hinder vision. The event of DR is caused by prolonged hyperglycemia resulting in damage to the retinal capillaries which engenders the perception of flags as well as light. The occurrence of DR is alarmingly high in the working-age population globally and it is estimated that by the year 2030, there will be 191 million sufferers of DR(Nakayama et al., 2023).

The rates of proliferative diabetic retinopathy, extreme non-proliferative DR, macrovascular DME, and VTDR (Vision threatening Diabetic Retinopathy) are on the rise. It is estimated that the number of patients suffering from sight threatening VTDR globally will surge to about 44.8 million from 28.5 million in 2020 by the year 2045. There is a growing concern for the ever-increasing rates of DR, which is set to become a global health risk in the near future. Screening patients also presents an opportunity to reduce the rates of visual impairment as well as offer great insight into sight threatening stages of DR for necessary follow-up and treatment strategies. DR burden is highest in developing countries due to reasons that are at no exception publicly and clinically unknown, low- and medium-income countries (LMICs) DR appears to be more frequent because less health-care facilities compared with high-income countries(London, n.d.). Patients with clear/undetermined diabetes mellitus were enrolled in a study of diabetic retinopathy incidence rates and incidence of eye-threatening diabetic retinopathy (VTDR) in India. In order to ensure information authenticity and reliability, the present study is constructed as cross-sectional shape and quality assurance and control is made to be strictly implemented. Diabetic retinopathy and VTDR status were the main outcome variables and were given weights over risk factors selection and overestimation of prevalence in a general weighted format and also recognizing the risk factors. Representatives from ten chosen states and one union territory underwent sampling; the rural and urban domains were further subdivided, leading to the creation of a total of 22 strata. The study indicates that there was a substantial burden of VTDR in India which in turn demonstrates the need for future plans where the heterogeneity of VTDR burden is taken into consideration in order to effectively screen and treat diabetic retinopathy in the country(Raman et al., 2022). People suffering from diabetes in a specific region are the subjects of national DR screening campaigns. These campaigns are considered to be an effective public health initiative aimed at eliminating vision loss caused by DR. In order to minimize loss of sight, which is a highly simple task, regular DR examination is crucial. Time and financial limitations are major issues for both endocrinologists and ophthalmologists. Fundus photograph-based screening might be sufficient due to the small number of enrolled ophthalmologists, especially masters of retinal diseases; however, this could have a major impact. DR is the most common ocular vascular infection characterized by features such as microaneurysms, haemorrhages, exudates, and neovascularization.. Programmed screening for infection would involve first physically marking these injuries on fundus images. After this, a preliminary candidate selection is performed using machine learning(Grzybowski et al., 2023). But when a national survey was conducted in 2013, only 30% of DM patients had been undergoing annual dilated fundus exams by an ophthalmologist. which is unanimously accepted as the gold standard for DR diagnosis. The significantly high annual DR screening rate among diabetic patients can be explained by multiple factors. A number of reasons could have accounted for the high annual DR screening rate among DM patients. One major reason? Patients often do not recognize the value of routine ocular examinations, since DR is often asymptomatic in its early stages. Second, patients often don't experience enlarged fundus inspections. Also, the patients are not going for their routine fundus checks because of the misconception that sufficient blood glucose control will remove the risk for DR to improve or metastasize. Enhancing the clinical relevance and patient comfort of routine eye exams remain even though educating patients about screening for diabetic complications is the key to tackling these challenges. Artificial intelligence (AI) research in restoration imaging has recently become a topic of interest [due to] several reasons. Apart from the broader health consequences, availability of image data, robotization for detection, preliminary successes and the confidence to exploit AI for DR detection, use of AI for DR detection has produced the encouraging results that some AI systems demonstrate or exceed human performance with regard to accuracy. These factors have come together to render DR not only a baseline (and therefore inevitable) point in the use of AI in health care, for medical diagnosis and treatment, or whatever. The focus on DR extends beyond demonstrating the potential of AI to contribute an option for enhancing diagnostic and therapeutic outcomes for a range of illnesses, but it also constitutes a pretty basic need for global health(Kong & Song, 2024).

REVIEW OF LITERATURE

(Grzybowski et al., 2020) The reviewed paper highlights the developing concern of diabetic retinopathy (DR) as a major worldwide eye wellbeing issue, especially due to the expanding predominance of diabetes and a maturing populace. AI, particularly through machine learning and deep learning, has risen as a promising apparatus in computerizing DR discovery. A few AI-driven screening innovations have illustrated vigorous symptomatic execution, with a few as of now accessible commercially. However, their widespread integration into healthcare faces significant challenges, including moral concerns, patient privacy, medico-legal suggestions, and the require for a viable clinical arrangement show. Whereas AI-driven screening holds incredible potential in anticipating visual impairment caused by DR, as it was a restricted number of these advances are right now in commercial utilize. Future investigate must address basic issues such as making strides quiet acknowledgment, guaranteeing information security, and making AI models more interpretable (settling the "black box "issue). The fruitful selection of AI in ophthalmology will depend on overcoming these obstructions and guaranteeing the consistent integration of AI-based arrangements into clinical practice.

(Nakayama et al., 2023) This study investigates how AI is utilized in teleophthalmology for diabetic retinopathy (DR) screening, comparing existing frameworks, reasonableness issues, and execution challenges. Out of 132 surveyed articles, as it were nine met the criteria, covering telemedicine frameworks, AI calculations, financial affect, and picture quality. Whereas AI-powered telemedicine can make strides get to DR screening, the consider highlights key gaps—most inquire about centres on high-income nations, with small representation from low-income locales. Also, no ponders surveyed post-deployment inclinations or social impacts. For AI in DR screening to be genuinely successful, future efforts must centre on diminishing biases, improving data diversity, and guaranteeing reasonable and impartial execution around the world. Financial and social studies will be significant in directing the capable selection of AI-driven healthcare arrangements.

(Padhy et al., 2019) AI in medicine is quickly advancing, advertising awesome potential for mass screening and early conclusion. In diabetic retinopathy (DR), AI-powered instruments analyse fundus images to help clinicians in distinguishing and evaluating the disease effectively. This not as it were speeds up determination but moreover decreases the require for exceedingly prepared pros, making screening more open. AI-driven healthcare technologies point to minimize patient visits, lower costs, and optimize doctors' workloads. Whereas AI improves decision-making, it isn't however able of replacing clinicians completely. Progressing headways in AI are refining DR location calculations, clearing the way for more precise and effective screening arrangements.

(Rajalakshmi et al., 2018) This study assesses the adequacy of AI-based automated software for recognizing diabetic retinopathy (DR) and sight-threatening DR (STDR) utilizing fundus photography captured with a smartphone-based gadget. A total of 296 patients with type 2 diabetes were evaluated, comparing AI-based evaluating with ophthalmologists' assessments. The AI software illustrated tall affectability (95.8% for DR, 99.1% for STDR), demonstrating its solid capacity to distinguish cases. In any case, specificity was lower (around 80%), meaning some wrong positives happened. In spite of this, the AI instrument appeared significant understanding with ophthalmologists, proposing it may serve as a proficient beginning screening apparatus for mass DR detection. In general, AI-powered smartphone retinal imaging offers an adaptable, cost-effective arrangement for early DR screening, especially in resource-limited settings. In any case, ophthalmologists remain essential for confirming diagnoses and overseeing treatment.

(Tan & Wong, 2023) Diabetic retinopathy (DR) remains a major worldwide health challenge, with its burden moving progressively toward low- and middle-income nations. Progresses in imaging, pharmacologic treatments, and artificial intelligence (AI) are shaping the long run of DR management. Key advancements incorporate optical coherence tomography (OCT), anti-VEGF medicines, AI-based screening, and novel treatments like quality treatment. By 2030, AI is anticipated to play an indeed more prominent part in DR determination and forecast, whereas more current imaging modalities will give more comprehensive illness evaluations. Also, research is growing past vascular complications to focus on retinal neural dysfunction as a basic perspective of DR. In any case, guaranteeing that these headways are similarly available over all financial settings is basic to decreasing visual impairment rates around the world. Future efforts must focus on bridging the crevice between tall- and low-resource locales, overhauling classification frameworks, and making inventive medicines broadly accessible to guarantee equitable eye care for all.

(Abdalla & Mohanraj, 2025) Artificial intelligence (AI) and machine learning (ML) are revolutionizing diabetic retinopathy (DR) care by enhancing screening precision, improving early discovery, and empowering personalized treatment techniques. These technologies analyse vast datasets to anticipate disease movement with high accuracy, permitting clinicians to form more educated choices whereas reducing their workload. AI-based screening tools like IDx-DR and Eye-Art can be conveyed in essential care and remote settings, improving accessibility for underserved populations. By automating screening and streamlining workflows, AI makes a difference guarantee convenient determination and optimized treatment pathways. However, challenges stay, counting technological scalability, moral concerns like algorithmic inclination, information protection, and the requirement for strong regulatory system. For AI to completely realize its potential in DR care, collaboration between researchers, clinicians, policymakers, and technologists is significant. With continued progressions, AI and ML can significantly reduce vision impairment and the global burden of DR, shaping the future of ophthalmic healthcare.

(Pieczynski et al., 2021) With the increasing prevalence of diabetes mellitus (DM), diabetic eye disease (DED) is getting to be a major worldwide concern. Early diagnosis through imaging-based screening strategies remains the leading technique for avoiding vision misfortune. Telemedicine and AI-powered screening strategies are changing DR location by making it more available and proficient. The survey found that fundus cameras (both stable and portable), ultra-wide-field (UWF) imaging, and optical coherence tomography (OCT) are broadly utilized for DR screening. AI calculations play a pivotal part in automating image assessment, allowing non-specialists to capture and analyse retinal pictures utilizing smartphones and AI-enhanced adapters. This advancement clears the way for large-scale in-home testing, lessening dependence on specialized healthcare providers. Looking ahead, ophthalmic care is anticipated to become increasingly AI-driven and inaccessible, with pre-specialist diagnostics recognizing healthy eyes and as it were referring cases that require encourage consideration. This move will optimize healthcare assets, making DR screening more cost-effective, versatile, and open to a broader population.

(Banerjee et al., 2025) The study provides the analysis of the market antidiabetic brands in Nagpur, India, which is a lacking area of concern. The investigation further focuses on western and northern parts of Nagpur, highlighting the anti-diabetic medicine prescriptions at pharmacies. Moreover, this report provides the complete list of the prescribed anti-diabetic medicines, such as Jaunmet XR CP Tablet and Glychiphage SR 1mg Tablet, and the respective frequencies of prescription for other items on the list. This demographic study provides the information on groups of ages prescribed brands in anti-diabetic therapy. All in all, the literature research offers relevant and informative data about the prevailing preferences and market of anti-diabetic brands in Nagpur.

(Yao et al., 2021) The study further reports the variation in diabetic retinopathy prevalence in diabetic patients according to age, region and diabetes duration and severe diabetic retinopathy. Nevertheless, it has some limitations such as small sample size, failure to study dyslipidemias and cardiovascular diseases, and cross-sectional nature. The study implies that ocular diseases and hyperglycaemia may in turn co-occur because of some changes in the blood-retinal barrier, which increases the risk of the first disease to appear in the presence of the second. These factors also can affect the association between eye diseases.

(Steinmetz et al., 2021) Cataracts and under corrected refractive errors are the main causes of blindness and vision impairment across the globe during the twentieth century (1990 to 2019), according to the Lancet Global Health study. The number of people affected has increased with the population growth and aging: over 15 million people aged 50+ blind due to cataracts and 86 million people with uncorrected refractive errors. It urges for development of additional affordable eye care services, early screening and treatment availability to address future global requirements.

(*Is There a Glycemic Threshold for Mortality Risk*, n.d.) In the Paris Prospective Study, linking 7,018 non-diabetic men to mortality, there is no clear cutoff point for fasting, or 2-hours glucose concentrations which increase mortality risk. Mortality from all causes, and from coronary heart disease, in fact increased with increasing glucose levels in a continuing fashion. At fasting glucose of 5.5 mmol/l and 2-hour glucose of 5.0 mmol/l, the lowest mortality rates were observed. The risks of mortality rose to a significant degree even for modest hyperglycaemia. Traditional diagnostic glucose cut off values based on retinopathy data are challenged in this study.

(Jasuja et al., 2013) The Framingham Heart Study also discovered that the higher we are as men in estrone (or estradiol) levels correlate, the more likely he is to be diabetic. Elevated estrone was also longitudinally a significant predictor of incident diabetes over 6.8 years, with a twofold increase in estrone levels suggesting a certain twofold increased odds of developing T2DM of 77–93%. The study offers some suggestion that in men, estrone may be a better biomarker of diabetes risk than estradiol, meaning that in some cases, hormonal regulation contributes to the progression of metabolic disease.

(Lee & Afshari, 2025)This article looks into the changing global burden of blindness and vision impairment from the perspective of demographic, socioeconomic and technological transformations. It notes that although rates of blindness, standardized for age, have fallen in the bulk of areas, ageing populations and longer life expectancies are responsible for mounting the absolute numbers. Largely unchanged still are cataracts, age-related macular degeneration, diabetic retinopathy (DR), glaucoma, and uncorrected refractive errors as causes of vision loss. The report comments on the need for scalability and an increasing chasm in eye care between rich and poor nations. Therefore, it highlights the need to provide early screening, affordable therapies, and AI enabled solutions, to reduce the long-term effects of avoidable blindness particularly in the less privileged locations.

RESEARCH GAP

Despite AI's unfathomable potential in diabetic retinopathy (DR) screening, a few issues still need to be resolved. In low- and middle-income countries where DR diagnosis state of the art is not available despite an increase in DR cases, there is a significant gap in representation. Furthermore, whereas AI models perform well in controlled studies, real-world arrangement brings issues like algorithmic bias and fairness, which are frequently ignored. Another challenge is integrating AI into existing healthcare systems, as numerous studies focus on the innovation itself instead of how it can be consistently utilized in routine medical practice. Moral concerns, such as patient information protection and regulatory approval, to require clearer rules. A key impediment of AI in DR screening is its dark box nature, meaning clinicians do not continuously get it how the calculation makes decisions, which can affect believe and appropriation. Besides, financial possibility remains uncertain, as there's limited research on whether AI-based screening is really cost-effective within the long run. Most AI progressions centre on diagnosis, but little work has been done on personalized AI-driven treatment methodologies to anticipate disease progression and direct patient care. To make AI a genuinely transformative instrument for DR administration, future research must centre on making these frameworks more straightforward, open, and consistently coordinates into healthcare around the world.

OBJECTIVE

The purpose of the present study was to explore the application of AI in DR diagnosis (i.e., LRV/LRV for deep learning and computerised screening) for DR. The application of AI in healthcare, for example, ophthalmology, has already enhanced the DR detection performance with increased speed.

RESEARCH METHODOLOGY

The reviewed studies utilised literature reviews, AI model advancement, clinical trials, and telemedicine applications for diabetic retinopathy (DR) screening. A few papers conducted precise reviews utilizing databases like PubMed, EMBASE, and MEDLINE, analysing studies on AI-driven diagnosis, telemedicine, and imaging procedures. Experimental studies centred on machine learning and deep learning models, preparing CNNs on huge retinal picture datasets and comparing AI evaluating with ophthalmologists' appraisals. Clinical trials, counting a study on 301 diabetic patients utilizing smartphone-based fundus imaging, assessed AI's adequacy in real-world settings. WHO'S report on vision was also studied which provides an insight on the economic burden that can likely be caused due to vision impairment and also emphasizes on the global vision impairment ultimately leading to increased DR cases. Key challenges identified include algorithmic bias, moral concerns, regulatory issues, and integration into healthcare frameworks. This study underscores the need for adaptable, impartial AI arrangements to improve DR screening, especially in underserved regions.

RESULTS AND DISCUSSIONS

RESULTS

In 2022, 828 million people worldwide were estimated to have diabetes and 212 million of which (i.e. 25 % of the global disease burden) were in India. Other high burden countries are the United States (42M), Pakistan (36M), China (148M) and Brazil (22M). Of people with diabetes, 12.5 percent have diabetes retinopathy (DR) and 4 percent have vision threatening DR. The prevalence of DR in Bangladesh is 25% because there are not many eye doctors in the country. Out of the 2.2 billion people who have vision impairment, 3.9 million have DR and is responsible for contributing to the vision loss.

DR related vision loss alone results in $411 billion a year of lost productivity and it's estimated that the DR itself costs somewhere in the range of $166 billion. AI solutions like King's College prediction model, Google's ARDA, AI Optics' Sentinel Camera had up to 97.5% sensitivity and 98.5% specificity, and have also reduced the screening cost by $140 per patient. For comparison, when men have DR, they have slightly higher rates than women, and DR risk increases dramatically with age and time since diabetes.

DISCUSSION

The results show the extreme necessity of readily accessible and inexpensive means to address DR especially in LMIC where the prevalence of diabetes is growing but people with diabetes have restricted access to specialists. AI technologies have become a game change in providing effective real time screenings in rural and basic care settings. Initiatives such as Google's ARDA in India and Thailand and Orbis' AI powered screenings in Bangladesh show how ophthalmology practices using scale-able solutions reduce ophthalmologist's workload and accelerates the diagnosis. Personalised care is also guaranteed using AI, meaning that high risk patients are attended to immediately. Despite these, few barriers have been overcome: algorithmic bias, ethical issues, integration in the healthcare system and generalisability in resource constrained environments. Despite the obvious visual loss, even in the presence of a diabetic eye problem, AI can fully revolutionise diabetic eye care.

FIGURES

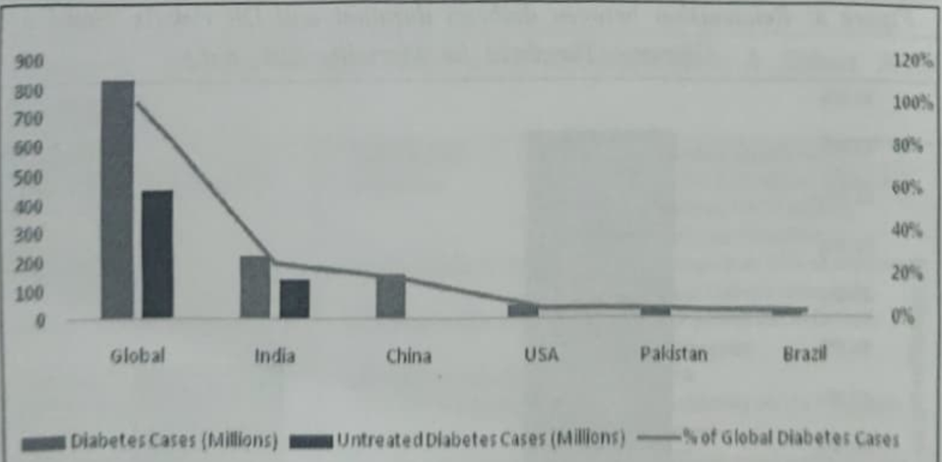

Figure 1: Graphical representation of diabetes prevalence in LMICS and globally(*India Accounts for 25% of Global Diabetes Cases, Study Finds 82.8 Crore Affected - CNBC TV18*, 2024)

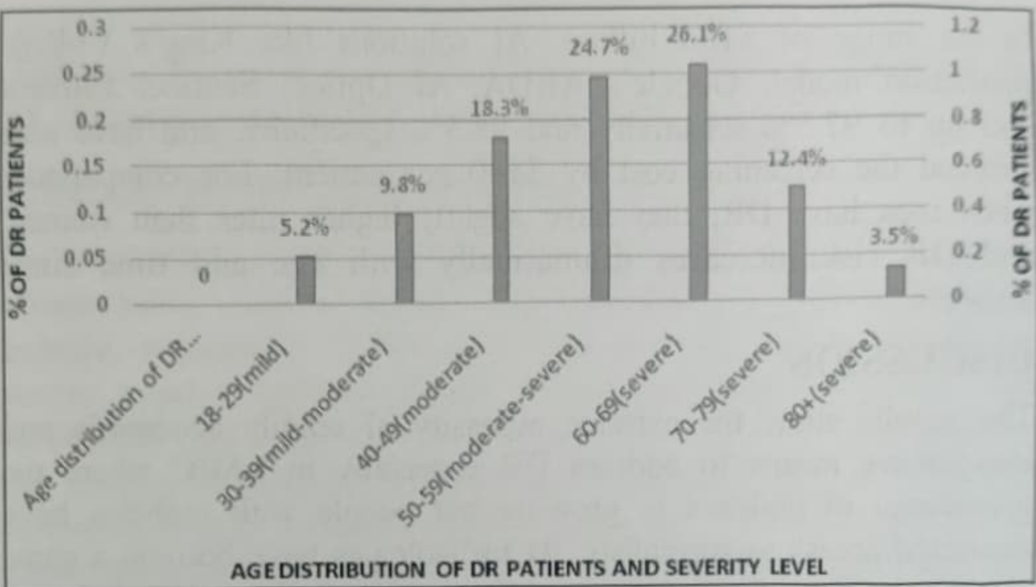

Fig.2: Age Distribution of DR patients and its severity level with increase in age.

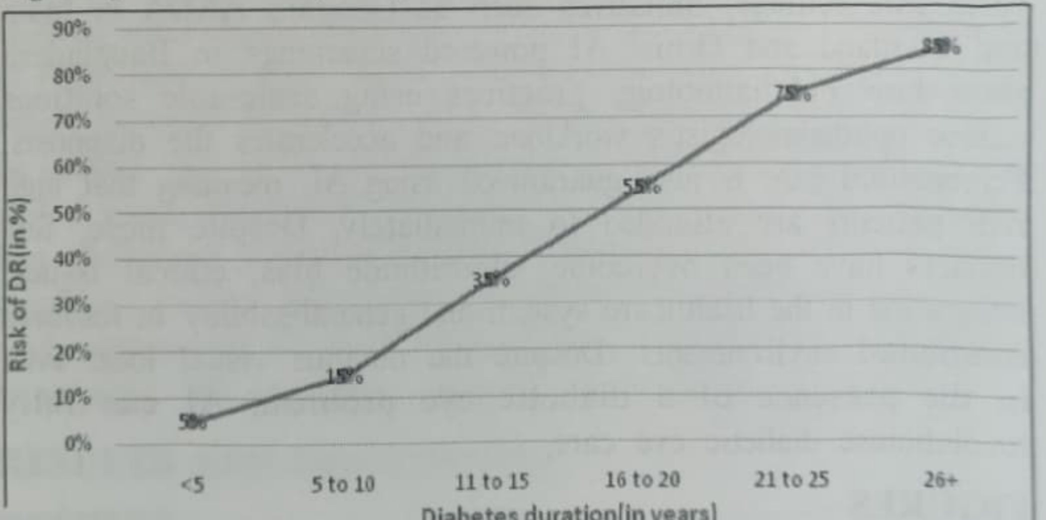

***Figure 3:** Relationship between diabetes duration and DR risk.(Is There a Glycemic Threshold for Mortality Risk, n.d.)*

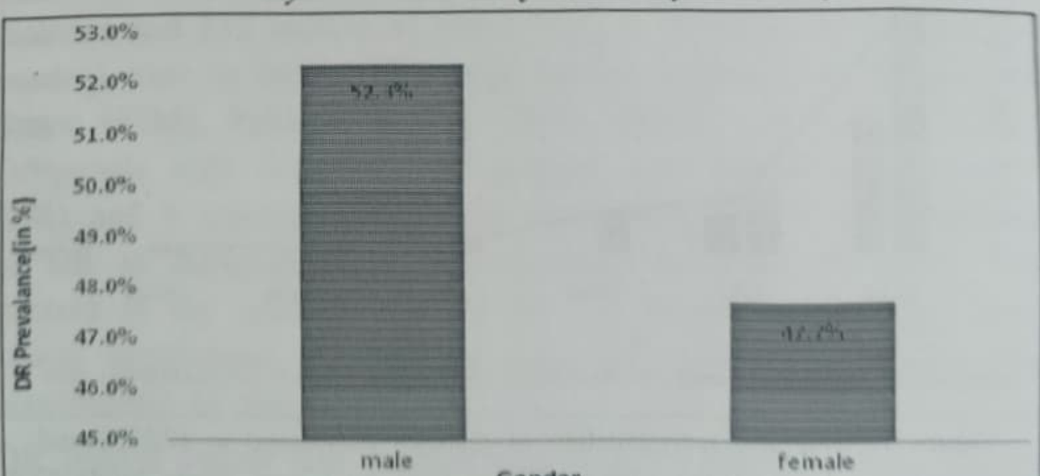

***Figure 4:** Gender differences in DR incidence.(Jasuja et al., 2013)*

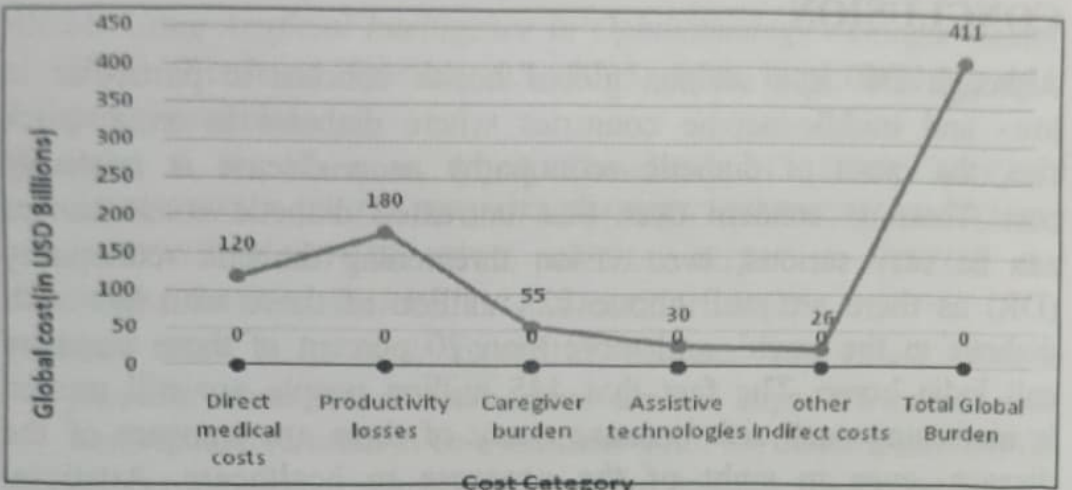

Figure 5: Economic Burden of vision impairment due to DR.(WHO, 2019)

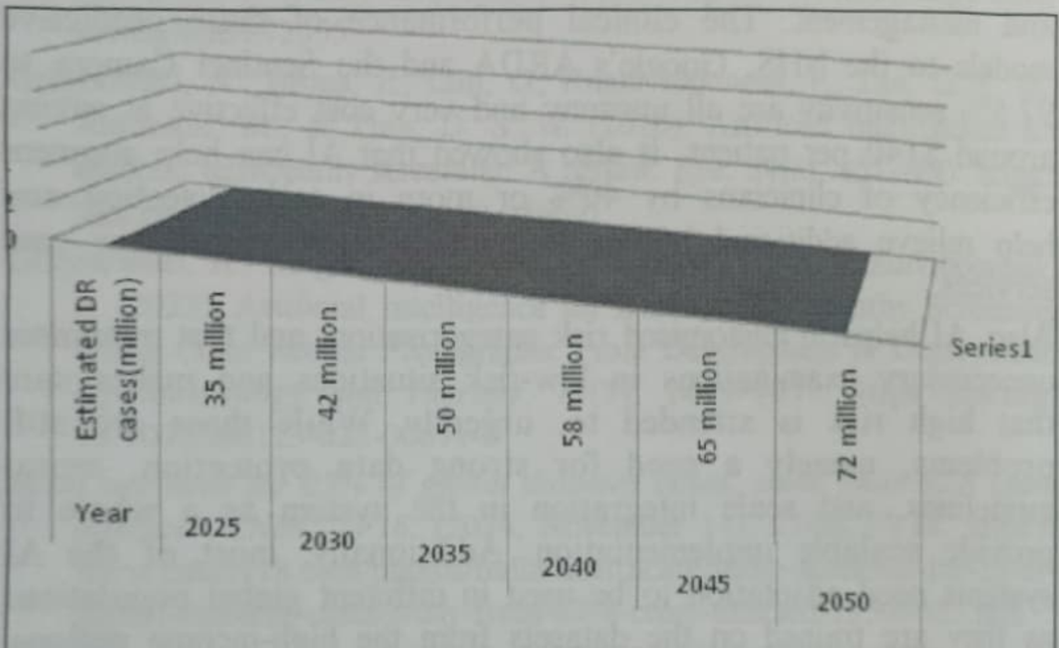

Figure 6: Projected increase in DR cases (2025-2050)(Lee & Afshari, 2025)

TABLES

Category	Global figures	Country Specific data
Global Diabetes Cases (2022)	828 million	India: 212 million, China: 148 million, US:42 million, Pakistan:36 million
Prevalence of DR	12.5% of diabetic patients	Bangladesh: 25% of diabetics have Diabetic retinopathy
Vision Impairment Cases	2.2 billion people affected	3.9 million due to Diabetic retinopathy
Financial Burden of Vision Loss	$411 billion annually	N/A
AI Screening Sensitivity	Up to 97.5% (EyePACS dataset)	Sensitivity 96.1% - Messidor 2 dataset
AI Screening Cost Savings	$140 per patient (US study)	Millions saved annually- NHS UK
Efficiency Gains from AI	40% increase (Orbis data)	Reduced unnecessary ophthalmologist visits

TABLE 1: Key findings from the study

CONCLUSION

Although DR is a serious global health concern in particular in low- and middle-income countries where diabetes is on a quick rise, the onset of diabetic retinopathy as a disease is relatively new. There is concern over that untreated diabetic consequences can be very serious, even vision threatening diabetic retinopathy (DR) as there are well above 828 million of those who live with diabetic in the world, and more than 20 percent of those numbers call India home. The fact that 445 million people are still treated is increasing such risk because many of them are unaware of the disease, even in sight of the progress in healthcare. Artificial intelligence has greatly changed the landscape of DR screening and management. The clinical performance of these predictive models to the NHS, Google's ARDA and the Sentinel Camera to 97.5% sensitivity are all uncanny and very cost effective at saving around $140 per patient. It also showed that AI can help augment efficiency of clinicians by 40% or more in early detection and help relieve additional burden on already overburdened eye care services.

Also, AI helps in customised risk categorisation, and that minimises unnecessary examinations in low-risk situations and makes sure that high risk is attended to, urgently. While these are still problems, namely a need for strong data protection, moral guidelines, and scale integration in the system as a whole to provide scalable implementation. Additionally, most of the AI systems need adaptation to be used in different global populations as they are trained on the datasets from the high-income regions. However, the promise is evident. In particular, AI driven DR screening helps to make eye care more egalitarian, accessible, and cheap primarily in regions of patient's poverty. With continuity of innovation and appropriate use of AI, it can greatly reduce preventable blindness and transform the global treatment of diabetic eye care.

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