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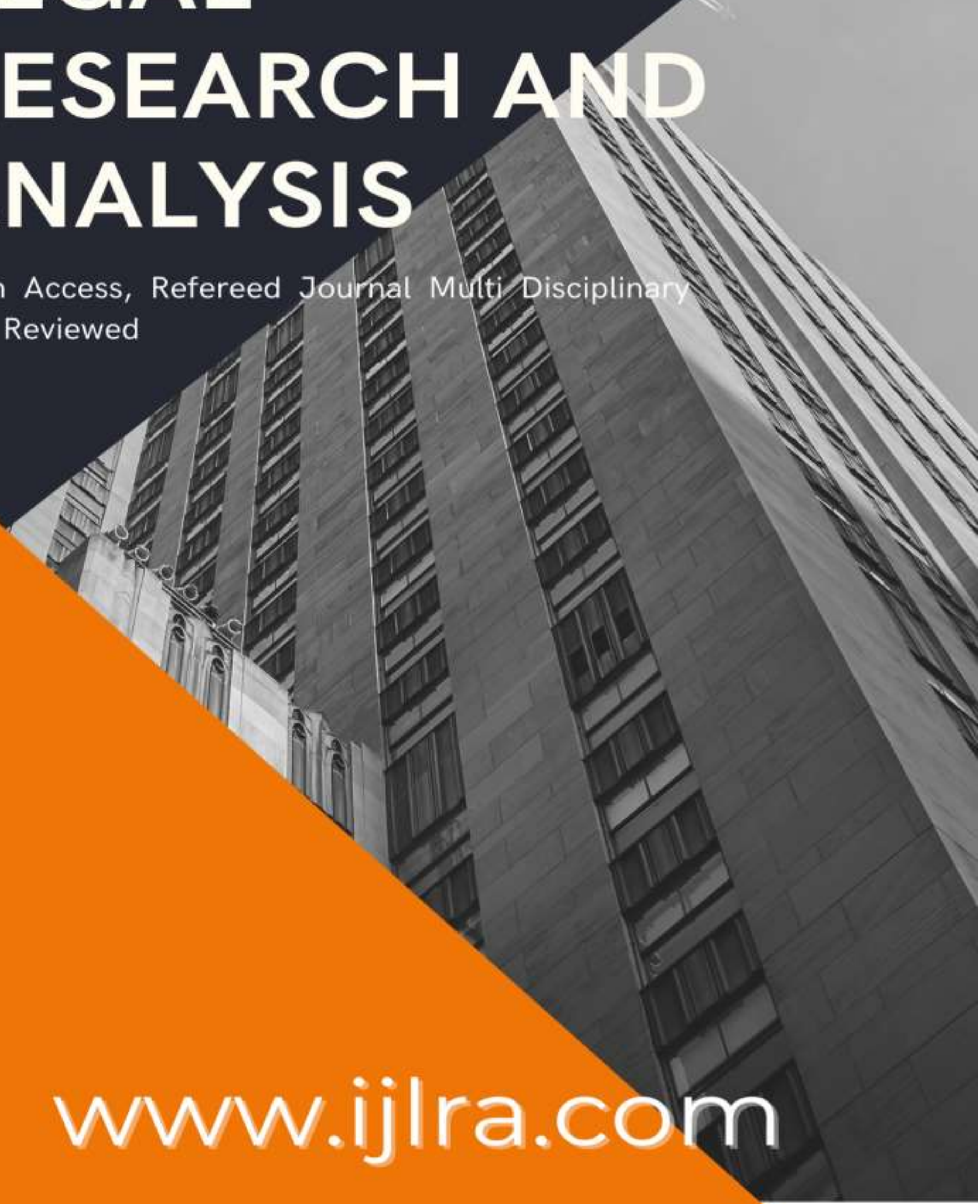

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LEVERAGING AI FOR DIABETIC RETINOPATHY SCREENING IN RURAL INDIA: CHALLENGES & SCALABILITY

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In India, where the prevalence of diabetes is still rising quickly, diabetic retinopathy (DR) is a major preventable cause of blindness worldwide. DR is a microvascular complication of diabetes that affects the blood vessels in the retina and, if left untreated, can result in irreversible vision loss. Access to regular DR screening and eye care is still uneven throughout India, particularly in rural and underserved areas where the majority of the population lives, even though it can be prevented with prompt screening and intervention. Rural communities have been underserved by traditional screening models, which rely on specialized ophthalmologists and costly imaging equipment. By automating parts of DR detection and diagnosis, artificial intelligence (AI), in particular deep learning and convolutional neural network (CNN)-based systems, has surfaced as a potential solution to these access and scalability issues.[1] The promise and drawbacks of using AI for DR screening in rural India are examined in this article, along with the implications for clinical practice, community health, economics, scalability, and ethical deployment.

By 2040, an estimated 600 million people will have diabetes mellitus (DM). Global healthcare systems will face a major challenge due to the substantial morbidity and care burden linked to the systemic complications of diabetes mellitus. An essential public health requirement is early detection and intervention to slow the progression of diabetes and its complications. Diabetic kidney disease or nephropathy (DKD), diabetic neuropathy (DN), diabetic retinopathy (DR), cardiovascular disease (CVD), peripheral artery disease (PAD), lower-extremity amputations (LEA), and other systemic complications are common in patients with diabetes. One in five diabetes patients in the US do not know they have the disease, despite the importance of prompt screening and treatment for these complications. Two to five patients are unaware that they

[1] 'Leveraging Artificial Intelligence for Diabetic Retinopathy Screening and Management: History and Current Advances: Seminars in Ophthalmology: Vol 40, No 8 - Get Access' <https://www.tandfonline.com/doi/full/10.1080/08820538.2024.2432902?af=R>.

have severe chronic kidney disease (CKD).[2] Our health system is heavily burdened by insufficient screening, incorrect diagnoses, and low patient awareness. Therefore, it is crucial to investigate practical and affordable ways to identify complications related to diabetes, particularly in less developed regions. Often referred to as a “window” to the vascular system, the retina may provide a quick and non-invasive way to evaluate the state of the systemic vasculature.[3]

The application of artificial intelligence (AI) technology in clinical settings has advanced significantly. Many AI models, including machine learning methods, have been used in the identification, prediction, and screening of diseases, with an emphasis on how well they analyze multi-modal images. AI may be used in clinical research with the goal of increasing diagnostic precision and clinical productivity. Numerous studies in the field of ophthalmology have developed and validated the use of AI algorithms on retinal imaging for a variety of purposes, including the diagnosis and treatment of conditions like glaucoma, age-related macular degeneration, diabetic retinopathy, and other retinal diseases.[4]

Diabetic Retinopathy in the Indian Context

Diabetes, mainly Type 2, is now of major public health concern in India. Studies in different parts of the country reveal a high and increasing prevalence in both urban and rural areas, with a higher prevalence being reported from urban areas. Most of this evidence comes from south and central India. In South India, the prevalence of diabetes among adults is estimated to be around 20% in urban areas and nearly 10% in 6 rural areas. These figures show a steep increase compared to studies nearly a decade earlier.

According to the Prevalence of Diabetes in India (PODIS) Study, 3.3% of adults over the age of 25 had diabetes, and another 3.6% had pre-diabetes with fasting blood glucose levels above normal.[5]

[2] Ramachandran Rajalakshmi and others, ‘Leveraging Artificial Intelligence for Diabetic Retinopathy Screening and Management: History and Current Advances’ (2025) 40 Seminars in Ophthalmology 719.
[3] Kinalyne Perez and others, ‘Investigation into Application of AI and Telemedicine in Rural Communities: A Systematic Literature Review’ (2025) 13 Healthcare 324.
[4] Rohan Chawla and others, ‘Artificial Intelligence for Advancing Eye Care in Resource-Poor Settings: Assessing the Predictive Accuracy of an AI-Model for Diabetic Retinopathy Screening in India’ (2025) 9 Global Epidemiology 100209.
[5] admin, ‘The Role of AI in Early Detection of Eye Diseases in India’ (*Laxmi Eye Hospital*, 3 January 2025) <https://www.laxmieye.org/blog/the-role-of-ai-in-early-detection-of-eye-diseases-in-india/>

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According to current estimates, there are 65.1 million diabetics in India, and by 2035, that number is expected to increase to 109 million. 62.4 million Indians had diabetes and 77.2 million had pre-diabetes in 2011, according to a large study (14,000 participants) conducted in four Indian states by the ICRM (INDIAB Study).[6]

Numerous factors contribute to the "epidemic" of diabetes in India. Low birth weight, genetic predisposition, and changes in lifestyle brought on by fast urbanization have all contributed to this circumstance. Insulin resistance and hyperinsulinemia brought on by low birth weight can result in "thin-fat Indians", or adults with a higher percentage of body fat for any given BMI than Europeans. Low birth weight rates are high (25–40%) in India, which may be a factor in the sharp rise in NCDs given dietary and physical activity changes. Nearly 75% of type 2 diabetics in India have a first-degree relative with the disease, indicating that Asian Indians have a strong genetic predisposition to the disease, according to studies. These elements raise the risk of diabetes even more when combined with a sedentary lifestyle and a diet high in glycaemic index.[7]

The percentage of individuals with diabetes in India experiencing diabetic retinopathy ranges between 18% and 26%. Several small-scale surveys on diabetes have been conducted across various regions of the country; however, there is a lack of data from a nationally representative sample. There are no available estimates regarding the actual number of individuals blinded by diabetic retinopathy in India, as most national blindness surveys were carried out one to two decades ago, and other studies were limited to small local areas, making their results non-generalizable.

Research indicates that prompt identification and treatment are crucial for preventing vision loss and blindness due to DR. While the genetic risk cannot be altered, several lifestyle factors such as obesity, diet, and physical activity is highly changeable, resulting in a decreased risk of DR. A prospective study in India focused on patients with impaired glucose tolerance demonstrated that maintaining a consistent lifestyle. Alteration halted the advancement to

[6] Qianhui Yang and others, 'Use of Artificial Intelligence with Retinal Imaging in Screening for Diabetes-Associated Complications: Systematic Review' (2025) 81 eClinicalMedicine <https://www.thelancet.com/journals/eclinm/article/PIIS2589-5370(25)00021-5/fulltext?rss=yes>.

[7] 'Situational Analysis Report _Inner Pages Final' <https://iiphh.org/wp-content/uploads/2024/05/Diabetic%20Retinopathy%20Report%20of%20a%20situation%20analysis%20in%20India.pdf.

diabetes, allowing swift progression from impaired glucose tolerance to diabetes in the groups that did not receive intervention.[8]

Information Technology: A New Prospect in services for Diabetic Retinopathy

The local community is currently tremendously benefiting from the applications of information technology. Information technology integration and telemedicine are now highly advantageous due to developments in both the medical field and the medical equipment business. In India, healthcare organizations in the public and private sectors have launched numerous initiatives. On an experimental basis, the Indian Space Research Organization (ISRO) has been assisting tertiary hospitals in establishing connections with remote areas like the Northeast. The rural population can receive high-quality medical treatment by sharing satellite hardware and bandwidth.

Information technology and ophthalmology

Since the majority of diagnoses are based on images, one of the quickly evolving medical specialties that is better suited for telemedicine is ophthalmology. Nowadays, the majority of ophthalmic equipment is integrated with IT (information technology), which enables image capture and transfer while adhering to necessary standards like digital imaging and communications in medicine (DICOM). In a similar vein, even in remote areas with higher bandwidth of 2 MBPS access, the government is attempting to guarantee IT penetration.[9]

Tele-ophthalmology is being successfully used at several levels to facilitate patient screening and to make eye care, particularly specialized eye issues, more accessible. The following tiers of DR screening make good use of information technology:

Primary level: Several eye care programs are adopting the vision center paradigm envisioned by the global initiative VISION 2020: The Right to Sight. These Vision Center's main goal is to offer complete treatment by skillfully combining information technology to deliver high-quality eye care right to rural resident's doorsteps. The base hospital's ophthalmologist consults with patients who are examined at the vision center. Patients are referred to the base hospital if they need additional care.

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8 'Love Your Eyes Actions' (*International Agency for the Prevention of Blindness*) <https://www.iapb.world/love_your_eyes_actions>.

9 Rajwinder Kaur and others, 'Artificial Intelligence-Based Apps for Screening and Diagnosing Diabetic Retinopathy and Common Ocular Disorders' (2025) 15 World Journal of Methodology <https://www.wjgnet.com/2222-0682/full/v15/i4/107166.htm>.

Strategies: Using a standard digital camera connected to a slit lamp, the technician can take fundus pictures of the diabetic patients and send them to the base hospital for review.

***Secondary level:* Diabetes center's remote diagnosis method**

Experiments are being conducted to position the fundus. Camera at the diabetic's office and transmitting pictures via the internet to the base hospital. By working with additional professionals, such as diabetologists, to conduct efficient screening, this method has the advantage of expanding the screening. Patients wouldn't need to travel to a tertiary eye hospital in order to receive this professional consultation.

Screening in a mobile van

By sending skilled professionals to the screening level to take high-quality pictures, mobile tele-ophthalmology makes it possible to identify blinding eye conditions like DR in diabetes patients early. Patients who have been diagnosed with diabetes are screened in a mobile van that travels to remote areas or doctor's offices.

A mobile van has a video slit light to take pictures of the anterior segment, or front of the eye, and a non-mydriatic camera to take pictures of the fundus, or retina. This equipment is linked to both the video-conferencing device and a computer. The Reading and Grading Center at the base hospital receives the images that are thus taken.[10]

Professionals with training read and grade these pictures. The software automatically extracts the severity level and therapy recommendations in a report format from the grader's input for each image. This information is sent back right away to the camp site, where the report is produced and handed to the patient, who subsequently receives counseling based on the report. The entire process takes around an hour to complete.

How AI-Based Screening Operates

Deep learning algorithms based on extensive datasets of retinal fundus images are typically used by AI systems for DR screening in order to detect disease symptoms. These technologies classify the severity of retinopathy, segment aberrant characteristics like microaneurysms or exudates, and evaluate digital images taken by fundus cameras. Convolutional neural networks (CNNs), such as ResNet, EfficientNet, and hybrid deep learning frameworks, are used by well-known models to minimize computational complexity while balancing sensitivity and

[10] 'Artificial Intelligence for Diabetic Retinopathy in Low-Income and Middle-Income Countries: A Scoping Review | BMJ Open Diabetes Research & Care' <https://drc.bmj.com/content/11/4/e003424>.

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specificity.[11]

Validation and Performance Metrics

When it comes to identifying referable DR- disease stages that call for immediate specialized care- AI-based systems have proven to perform on par with qualified doctors. Sensitivity and specificity values in the region of over 90% have been observed. For instance, when compared to independent ophthalmologist evaluations, an AI model created in India called MadhuNetrAI demonstrated a sensitivity of approximately 93% and specificity of approximately 95% for referable DR identification.

The Artificial Intelligence-driven Diabetic Retinopathy Screening System (AIDRSS) was assessed in another multicentric study using over 10,000 fundus pictures in Kolkata. The results showed 100% sensitivity for referable DR detection and 92% sensitivity and 88% specificity overall. The high accuracy levels show that AI can consistently identify people who need to be sent to a specialist, which is especially helpful in primary care and community settings where specialists are hard to come by.[12]

Effective Pilot Projects and National Projects

Governmental and Scientific Partnerships

Through government-sponsored programs, India has started implementing AI-based DR screening on a large scale. Recently, AIIMS and Wadhwani AI released the MadhuNetrAI mobile app, which can quickly identify diabetic retinal illness in settings with limited resources. As part of a larger effort to democratize eye care outside of large cities, this device has purportedly achieved over 95% detection accuracy in validation testing. Furthermore, AI screening is being included into larger community health campaigns through pilot programs supported by health organizations such as the Ministry of Health and Family Welfare, who hire qualified staff to do screenings in both urban and rural districts. Additionally, these programs produce real-time data on the geographic distribution and occurrence of diseases, which is essential for resource allocation and planning.

AI Deployment and Armed Forces Medical Services (AFMS)

The Armed Forces Medical Services (AFMS) has implemented AI-powered community

[11] Ramachandran Rajalakshmi and others, 'Leveraging Artificial Intelligence for Diabetic Retinopathy Screening and Management: History and Current Advances' (2025) 40 Seminars in ophthalmology 719.
[12] Chawla and others (n 4).

screening initiatives that use portable imaging and MadhuNetrAI to benefit both rural and retired communities. This technique offers a reproducible strategy for national adoption by combining AI screening with organized training of healthcare personnel.[13]

Difficulties in Implementing AI in Rural Areas

Despite AI's potential, a number of obstacles prevent its widespread adoption and long-term effects, particularly in rural areas.

- *Resource and Infrastructure Limitations:* Unreliable electricity, equipment damage from voltage fluctuations, and environmental factors that deteriorate image quality are common challenges faced by rural facilities. According to a study conducted in basic healthcare settings, screening sessions were immediately disturbed by power outages and variable voltage, necessitating the purchase of voltage stabilizers and backup generators to keep things running. The percentage of gradable fundus photos is decreased by poor ambient lighting and ergonomic problems, which also negatively impact picture acquisition.[14] The efficacy of AI models, which rely on high-quality input photos, is jeopardized if these practical obstacles are not overcome.
- *Socioeconomic Obstacles to Involvement:* Patient participation and community engagement are still issues. High refusal rates in facility-based screening models are caused by transportation constraints, ignorance of DR, and attitudes on eye health, especially among older adults with mobility challenges.
- *Validation, Algorithmic Bias, and Data Quality:* The representativeness of training data is a crucial issue in the use of AI. When dealing with diverse patient populations across various areas and ethnic groups, models built on small or non-diverse datasets run the risk of being less accurate. In order to reduce bias, research on global AI screening systems has highlighted the necessity of transparency in training datasets and validation across populations.[15]
- *Referrals and Care Continuity:* AI screening does not provide treatment on its own. Finding DR cases is just the beginning. Even after AI identifies diseases that need to be referred, specialized care and treatment facilities may be far away in rural locations,

[13] Areeb Ansari and others, 'The Role of Artificial Intelligence in the Diagnosis and Management of Diabetic Retinopathy' (2025) 14 Journal of Clinical Medicine 5150.
[14] Ansari and others (n 13).
[15] Manish Pharswan, 'Comparing the Implementation of Different Diabetic Retinopathy Screening Models in Primary Health Care Settings in Northern India: Pragmatic Three-Arm Observational Study' (*SeriesScience International | Open Access Journals | Peer Reviewed Articles*, 30 April 2024) <https://seriesscience.com/diabetic-retinopathy-screening/>.

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producing a "diagnosis desert" where detection may not result in better results. If referral systems are not improved at the same time, this disparity may unintentionally make inequality worse.

- *Retrospective versus prospective studies versus randomized controlled trials: The* great majority of DR studies have been retrospective, meaning they use previously labeled data to train and test algorithms, even though they have very large numbers of patients and extensive benchmarking against expert performance. We won't be able to fully comprehend the usefulness of AI systems until we do prospective research, since real-world data that differs from that used for algorithm training is likely to cause performance issues. To present, very few randomized controlled trials using AI systems for DR have been conducted. Clinical outcomes should be included as trial endpoints in future research to show longer-term benefits.[16]
- *Metrics don't reflect clinical applicability: The* phrase "AI chasm" was used to highlight the fact that clinical efficacy isn't always correlated with accuracy. Many physicians find it difficult to interpret the AUC of a receiver operating characteristic curve, which is not always the appropriate statistic to illustrate clinical usefulness.[17]
- *Difficulty comparing multiple algorithms*: Since the performance of each study is reported using different approaches on different populations, it is difficult to compare algorithms across studies objectively.
- *Machine learning science challenges:* AI algorithms may have flaws such as bias and inapplicability outside of the training environment. Dataset shift, inadvertently fitting confounders instead of the genuine signal, and the difficulty of generalizing to other populations are other considerations to take into account.[18]
- *Difficulties in generalizing to new populations and environments:* Due to variations in the populations to be screened, fundus cameras, and photographers' abilities, most AI systems for DR are far from reaching dependable generalizability. Appropriately planned external validation, which involves testing an AI system using suitably sized datasets gathered from institutions other than those that contributed the data for model training, is necessary for accurate evaluation of real-world clinical performance and generalization.

[16] Rajiv Raman and others, 'Using Artificial Intelligence for Diabetic Retinopathy Screening: Policy Implications' (2021) 69 Indian Journal of Ophthalmology 2993.
[17] Raman and others (n 16).
[18] 'Leveraging Artificial Intelligence Tools to Bridge the Healthcare Gap in Rural Areas in India' <https://japi.org>.

- *Logistical issues in adopting AI systems:* The majority of healthcare data are not easily accessible for machine learning, which is a major contributing factor to many of the existing difficulties in applying AI algorithms to clinical practice. Variations in DR screening, particularly differences in screening settings, lead to logistical challenges when implementing AI.
- *Achieving strong regulation and strict quality control:* The creation of the required regulatory frameworks is crucial to the safe and efficient implementation of AI algorithms. Given the current rate of innovation and the substantial dangers involved, this presents a difficulty. The regulatory implications of any enhancements and upgrades that manufacturer of AI products are anticipated to make throughout the course of the product's life should also be taken into account.[19]

Legal, Ethical, and Equity Aspects

- *Algorithmic Fairness:* AI systems must be developed and verified to function equally across all demographic groupings. Certain populations may be systematically misclassified as a result of biases in training data. It is crucial to guarantee varied representation in datasets and open reporting of subgroup performance.
- *Data Security and Privacy:* Since retinal imaging data is personal health information, patient permission, secure data handling, and adherence to data protection regulations are unavoidable. Ethical guidelines and informed consent procedures are crucial since rural communities may not be as aware of their rights regarding digital privacy.
- *Accessibility and Affordability:* Even with AI technologies, there are still financial obstacles, such as the cost of retinal cameras and related equipment. Financing options that reduce or subsidize expenses for patients and rural health centers will be necessary for scaling solutions.[20]

Methods for Expanding AI-Powered DR Screening

Strengthening Infrastructure: To guarantee reliable screening operations, it is crucial to address power dependability, make investments in long-lasting imaging equipment, and provide backup systems (generators, voltage regulators). Collaborations with private sector suppliers and municipal governments can help with maintenance and save upfront expenses.

[19] Bhovi Bhavani, 'The Impact of Artificial Intelligence in Healthcare Management' (2025).
[20] Dr Pooja Tripathi and others, 'Advancements in Virtual Health Screening for Diabetic Retinopathy: A Review of AI-Driven Approaches' (2025) 11.

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Models of Community: Centered Engagement Screening programs must incorporate community health workers, local leaders, and awareness-raising efforts regarding diabetes complications and the advantages of early DR identification in order to boost participation.[21] Building trust and acceptance requires adapting communication tactics to local languages and cultural situations.

Hybrid Human-AI Systems: These models, in which AI supports skilled technicians and clinicians, may be more successful than fully autonomous AI. In order to reduce false negatives and handle edge cases that AI models might overlook, human oversight makes sure that cases that are borderline or of poor quality are properly reviewed.

Integrated Referral Networks: AI screening programs need to be directly connected to organized referral networks. This enables health systems to assess impact rather than merely detection rates. It includes transportation assistance, referral coordination between primary sites and district hospitals, and feedback loops that verify whether patients finish specialist visits.

Policy and Ethical Frameworks: Data privacy, algorithmic openness, and validation criteria should be highlighted in national guidelines for AI in healthcare. Before deploying AI tools, regulatory agencies must make sure they are thoroughly and equitably assessed. The increasing emphasis on monitoring and safety compliance is demonstrated by initiatives like MadhuNetrAI, which is undergoing regulatory certification.[22]

Conclusion

By automating image processing, enabling screenings without onsite professionals, and producing real-time insights into disease incidence, artificial intelligence has emerged as a promising solution to assist reduce the gap in diabetic retinopathy screening in rural India. High performance and usefulness are demonstrated by pilot implementations such as AIDRSS and

[21] 'Beyond the Blind Spots: Using AI to Prevent Blindness in Diabetics | AI for Social Impact – Wadhwani AI' <https://www.wadhwaniai.org/beyond-the-blind-spots-using-ai-to-prevent-blindness-in-diabetics/>.
[22] 'India Launches AI-Driven Community Screening Tool For Diabetes-Related Vision Loss' (*www.ndtv.com*) <https://www.ndtv.com/health/india-launches-ai-driven-community-screening-for-diabetic-retinopathy-9830102>.

MadhuNetrAI.[23] However, infrastructure preparedness, community involvement, ethical deployment, and robust referral networks are all necessary for successful scalability in addition to algorithm accuracy.

AI must be carefully included to achieve long-lasting effects, supporting human healthcare professionals, resolving systemic issues, and coordinating with national health agendas. AI-enabled DR screening might significantly lower preventable blindness in India’s rural heartlands with concerted efforts from legislators, medical professionals, technologists, and communities.

This AI-based method has the potential to completely transform the diagnosis of eye diseases by making it quicker, more accessible, and less expensive- especially in places with poor access to medical care. The method lessens the workload for medical practitioners by automating the diagnostic process, freeing them to concentrate on more complicated situations while the AI model effectively handles routine diagnostics. Preventing serious consequences like vision loss requires early detection of diseases like diabetic retinopathy and eye disorders brought on by hypertension. Users are empowered by the system to receive an early diagnosis, which allows them to seek prompt medical attention. Patients in underserved or rural locations, where access to specialists is restricted, will particularly benefit from this. Furthermore, the system’s utilization of a sizable and varied dataset guarantees that it can deliver precise outcomes for various eye conditions, enhancing overall diagnostic precision. In the long run, an AI-powered approach could improve patient outcomes through early intervention and therapy while drastically lowering healthcare expenditures related to conventional diagnostic techniques.

[23] ‘AI-Powered Eye Disease Detection System: Revolutionizing Healthcare with Deep Learning’ <https://indiaai.gov.in/case-study/ai-powered-eye-disease-detection-system-revolutionizing-healthcare-with-deep-learning>.