EJPMR, 2026, 13(4), 119-128 **Review Article** **Impact Factor: 8.158**

EUROPEAN JOURNAL OF PHARMACEUTICAL AND MEDICAL RESEARCH

www.ejpmr.com

ISSN (O): 2394-3211
ISSN (P): 3051-2573
Coden USA: EJPMAG

ARTIFICIAL INTELLIGENCE (AI) ENABLED PERSONALIZED MEDICINE - SHAPING THE FUTURE OF OCULAR THERAPEUTICS

Shanthi Priya R.[1], Senthil Prabhu R.*[2], Umamaheswari D.[2], Selva Kumari N.[1], Sherley Rozzario J.[1], Venkatarathinakumar T.[3]

[1]Under Graduate Scholar, Department of Pharmaceutics, College of Pharmacy, Madurai Medical College, Madurai-20, Tamilnadu, India.
[2*]Assistant Professor, Department of Pharmaceutics, College of Pharmacy, Madurai Medical College, Madurai-20, Tamilnadu, India.
[3]Principal, College of Pharmacy, Madurai Medical College, Madurai-20, Tamilnadu, India.

***Corresponding Author: Senthil Prabhu R.**
Assistant Professor, Department of Pharmaceutics, College of Pharmacy, Madurai Medical College, Madurai-20, Tamilnadu, India.

DOI: https://doi.org/10.5281/zenodo.19327376

How to cite this Article: Shanthi Priya R.[1], Senthil Prabhu R.*[2], Umamaheswari D.[2], Selva Kumari N.[1], Sherley Rozzario J.[1], Venkatarathinakumar T.[3] (2026). Artificial Intelligence (Ai) Enabled Personalized Medicine - Shaping The Future Of Ocular Therapeutics. European Journal of Pharmaceutical and Medical Research, 13(4), 119–128.

Article Received on 03/03/2026 **Article Revised on 23/03/2026** **Article Published on 01/04/2026**

ABSTRACT
Ocular diseases such as glaucoma, diabetic retinopathy, and age-related macular degeneration are among the leading causes of visual impairment and blindness worldwide, posing a significant global healthcare challenge. Effective management of these conditions is often complicated by the eye's complex anatomical and physiological barriers, which limit drug penetration and therapeutic efficiency. Conventional ophthalmic formulations frequently experience rapid precorneal drug loss, poor corneal permeability, and low bioavailability, resulting in reduced treatment effectiveness and the need for frequent dosing. Artificial intelligence (AI) is increasingly transforming healthcare by enabling advanced data analysis, predictive modeling, and improved clinical decision-making. In ophthalmology, AI technologies such as machine learning and deep learning are being applied to enhance disease diagnosis, support drug development, and optimize therapeutic strategies. The integration of AI with modern ocular drug delivery systems is emerging as a promising approach to improve treatment precision and patient outcomes. Recent advances in AI also support the development of advanced ophthalmic therapies. AI-based models can predict drug behavior, optimize formulation parameters, and improve targeted drug delivery. In addition, AI is being integrated with emerging approaches such as gene correction, optogenetics, biomarker analysis, and personalized medicine. AI-driven diagnostic and screening tools further enable earlier detection and monitoring of retinal diseases, facilitating timely and more effective treatment. This review highlights the role of advanced AI tools in ocular drug development and therapeutic innovation.

KEYWORDS: Artificial Intelligence; Personalized Medicine; Glaucoma; Diabetic Retinopathy; Machine Learning/Deep Learning; IoNT /IoT; EyeArt; DeepMind; IBM Watson Health.

INTRODUCTION
Ocular drug delivery remains one of the most challenging areas in pharmaceutical sciences due to the eye's unique anatomy, protective barriers, and dynamic physiological processes that limit drug bioavailability and therapeutic efficacy. Conventional ophthalmic formulations such as eye drops, ointments, and intravitreal injections often suffer from rapid precorneal elimination, low retention time, and poor penetration, necessitating frequent dosing and resulting in suboptimal clinical outcomes for diseases such as glaucoma, diabetic retinopathy, and age-related macular degeneration. These limitations have driven the development of advanced drug delivery systems incorporating nanocarriers, implants, and stimuli-responsive platforms to improve targeted delivery, controlled release, and patient adherence.[1]

Artificial intelligence (AI) has emerged as a transformative technology across healthcare, offering unprecedented capabilities in data analysis, predictive modeling, and system optimization. In ophthalmology, AI techniques particularly machine learning (ML) and deep learning (DL) have advanced rapidly, demonstrating expert-level performance in disease detection, image analysis, and clinical decision support. These approaches leverage large and complex biomedical datasets to uncover patterns beyond human interpretation, enhancing diagnostic accuracy and enabling personalized treatment strategies.

The integration of AI into ocular drug delivery and therapeutic development promises to address longstanding challenges in formulation design, prediction of drug-barrier interactions, and optimization of treatment regimens. AI-driven algorithms can analyze multimodal clinical and molecular data to identify novel drug targets, predict pharmacokinetic behaviors, and guide the development of precision delivery systems that overcome anatomical and physiological constraints. Furthermore, AI-powered tools are being used to accelerate drug discovery, improve biomarker-based screening, and support adaptive clinical trial designs, thereby potentially reducing development timelines and enhancing therapeutic success rates.[2]

By converging advances in pharmaceutical technology with cutting-edge computational intelligence, the field is entering a new era of personalized and efficient ocular therapeutics. This review explores the current landscape of advanced AI tools in ocular preparation, highlights their applications and impact on ophthalmic care, and outlines future opportunities and challenges in achieving truly intelligent ocular drug delivery systems.

1. ANATOMICAL AND PHYSIOLOGICAL BARRIERS IN OCULAR DRUG DELIVERY SYSTEM

Tear Film and Precorneal Factors

The tear film is the first barrier encountered by topically administered drugs. It consists of three layers: a lipid layer, an aqueous layer, and a mucin layer. The tear film is continuously renewed through blinking and lacrimal secretion, resulting in rapid dilution and removal of instilled drugs. The normal tear turnover rate is approximately 1–2 µL per minute, which significantly limits drug residence time on the ocular surface.

Corneal Barrier

The cornea is the primary route for drug absorption into the anterior segment of the eye. It consists of five layers: epithelium, Bowman’s membrane, stroma, Descemet’s membrane, and endothelium. The corneal epithelium contains tight junctions that restrict the passage of hydrophilic drugs, while the stromal layer limits the diffusion of lipophilic compounds.

Conjunctival and Scleral Barrier

The conjunctiva covers a larger surface area than the cornea and is more permeable to drugs. However, it is highly vascularized, which leads to systemic absorption and reduced ocular bioavailability.

Blood–Ocular Barrier

The blood–aqueous barrier (BAB) and blood–retinal barrier (BRB) restrict the entry of drugs from systemic circulation into intraocular tissues. These barriers are particularly significant for posterior segment diseases, where systemic drug delivery often fails to achieve therapeutic concentrations in the retina.[3]

Limitations of Conventional ocular drug delivery systems

Conventional ocular drug delivery systems such as eye drops, ointments, gels, and suspensions suffer from several important limitations that reduce their therapeutic effectiveness. The most significant drawback is their low ocular bioavailability, with typically less than 1–5% of the administered drug reaching the target ocular tissues. This is mainly due to rapid precorneal drug loss caused by blinking, tear turnover, and reflex tearing, which quickly wash the drug away from the ocular surface. In addition, a large portion of the instilled dose is lost through nasolacrimal drainage, further decreasing ocular availability and sometimes leading to unwanted systemic side effects.

Another major limitation is the poor corneal permeability of many drugs. The cornea acts as a complex physiological barrier, making it difficult for both hydrophilic and lipophilic drugs, especially those with high molecular weight, to penetrate effectively. As a result, achieving therapeutic drug levels often requires frequent administration, which can reduce patient compliance, particularly in chronic conditions such as glaucoma. Moreover, conventional systems provide inaccurate and variable dosing, as the delivered dose depends on drop size, formulation viscosity, and patient technique, leading to inconsistent therapeutic outcomes.[4]

Conventional ocular formulations also show limited ability to deliver drugs to the posterior segment of the eye, including the retina and vitreous humor, making them ineffective for treating diseases such as diabetic retinopathy and age-related macular degeneration. Drug instability due to light exposure, pH variations, and enzymatic activity in tear fluid further compromises efficacy. Additionally, the presence of preservatives may cause ocular irritation, toxicity, or allergic reactions, while semisolid dosage forms like ointments and gels often lead to blurred vision and discomfort, reducing patient acceptance. Overall, these limitations highlight the need for advanced and targeted ocular drug delivery systems.[5]

2. Ocular Diseases: Clinical Overview and Therapeutic Challenges

2.1. Diabetic Retinopathy

Diabetic retinopathy (DR) is a leading cause of vision impairment and blindness worldwide, particularly among individuals with long-standing diabetes mellitus. The condition results from progressive damage to the retinal microvasculature, which can lead to visual deterioration and irreversible blindness if not detected and treated early. Early diagnosis and timely intervention are therefore essential to prevent disease progression. Traditionally, DR screening relies on manual evaluation of retinal fundus images by ophthalmologists, a process that can be time-consuming and subject to variability among observers.[6]

Recent advances in artificial intelligence (AI), particularly deep learning techniques such as convolutional neural networks (CNNs), have significantly improved the automated detection of DR from retinal images. These AI models can analyze complex retinal features and identify disease patterns with high accuracy. Several studies have demonstrated that AI-based systems can achieve diagnostic performance comparable to experienced ophthalmologists in identifying referable diabetic retinopathy. Among the clinically validated AI tools, the **EyeArt** system has shown strong performance in detecting referable DR, demonstrating sensitivity greater than 90% in large clinical evaluations. Another important development is the deep learning model created by **Google Health**, which analyzes retinal fundus photographs and has demonstrated diagnostic accuracy comparable to that of board-certified ophthalmologists.[7]

AI-assisted screening systems offer several advantages, including rapid image analysis, improved diagnostic consistency, and the ability to support large-scale screening programs. These technologies are particularly valuable in regions with limited access to specialized ophthalmic care. In countries with a high prevalence of diabetes, such as India, AI-enabled screening programs using mobile retinal imaging units have improved early detection of DR and facilitated timely referral for treatment, ultimately contributing to better patient outcomes.[8]

2.2. Age-Related Macular Degeneration

Age-related macular degeneration (AMD) is a leading cause of visual impairment among the elderly and primarily affects the macula, the central region of the retina responsible for sharp vision. Progressive degeneration of this region results in gradual loss of central vision and, in advanced stages, may lead to severe visual disability. Early and accurate diagnosis is essential for effective disease management. Traditionally, AMD is diagnosed through clinical examination and retinal imaging techniques such as optical coherence tomography (OCT), which provides detailed cross-sectional images of retinal structures. However, interpretation of OCT images requires specialized expertise and can be time-consuming.[9,10]

Recent advances in artificial intelligence (AI) have enabled automated detection and classification of AMD using OCT images. Deep learning models, particularly convolutional neural networks (CNNs), can analyze complex retinal features and distinguish between healthy and diseased tissues. By training on large imaging datasets, these models can identify early signs of AMD and differentiate between intermediate and advanced stages, including dry (atrophic) and wet (neovascular) forms. Several clinical studies have shown that AI-based diagnostic systems can achieve accuracy comparable to experienced retinal specialists.[11]

The integration of AI into AMD screening and diagnosis offers significant clinical advantages. AI algorithms can rapidly analyze large numbers of OCT scans, enabling automated triaging of patients who require urgent clinical evaluation and reducing the workload of ophthalmologists. A notable example is the collaboration between Moorfields Eye Hospital and **DeepMind**, which developed an AI system capable of diagnosing multiple retinal diseases, including AMD, from OCT scans with high diagnostic accuracy. Such AI-enabled screening programs are particularly valuable in regions with limited access to specialized eye care, where mobile imaging systems combined with AI analysis can facilitate early detection and timely referral for treatment.[12]

2.3. Glaucoma

Glaucoma represents a group of chronic optic neuropathies characterized by progressive damage to the optic nerve, commonly associated with elevated intraocular pressure. It is one of the leading causes of irreversible blindness worldwide and remains a major public health concern, particularly among older adults. The disease often progresses without noticeable symptoms in its early stages, making early detection and continuous monitoring essential to prevent permanent vision loss.

Artificial intelligence (AI) has recently emerged as an important tool in improving glaucoma diagnosis and management. AI-based systems can analyze ophthalmic imaging and clinical data to identify structural and functional changes associated with the disease. In particular, deep learning models applied to optical coherence tomography (OCT) images can detect subtle abnormalities in the optic nerve head and retinal nerve fiber layer, sometimes with diagnostic performance comparable to experienced ophthalmologists.[13]

In addition to structural assessment, AI techniques are increasingly used to analyze visual field data for monitoring disease progression. Unlike conventional statistical methods, machine learning algorithms can evaluate large longitudinal datasets and identify complex patterns of visual field deterioration. This capability allows earlier detection of functional damage and improved prediction of disease progression. AI-driven glaucoma screening and monitoring systems are also being implemented in clinical and community settings. These technologies support early identification of individuals at risk and facilitate timely referral and treatment, which may ultimately reduce the burden of glaucoma-related blindness.[14]

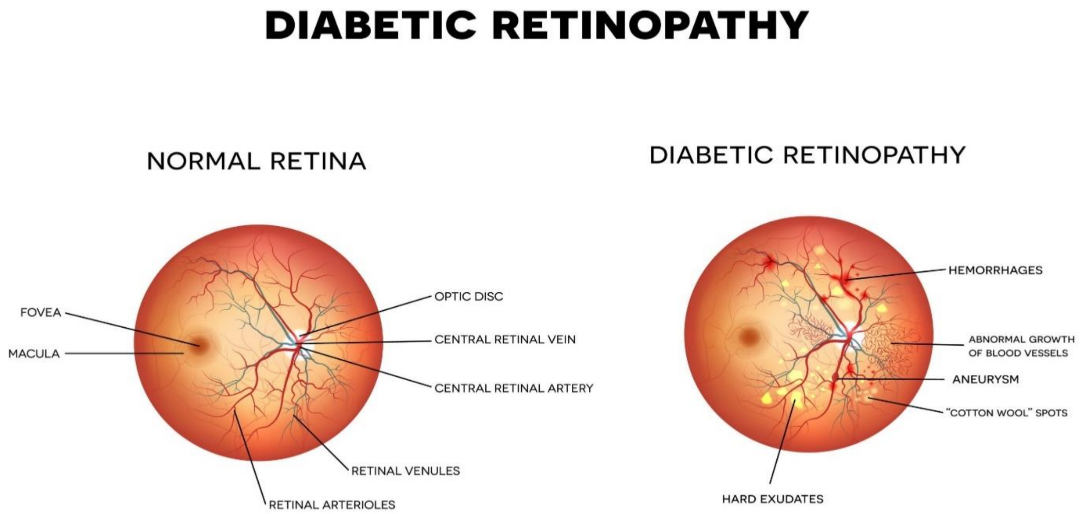

Fig. 2: Diabetic retinopathy.

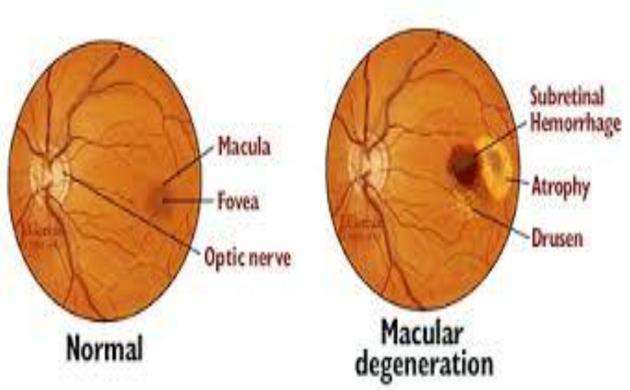

Fig. 3: Acute macular degeneration.

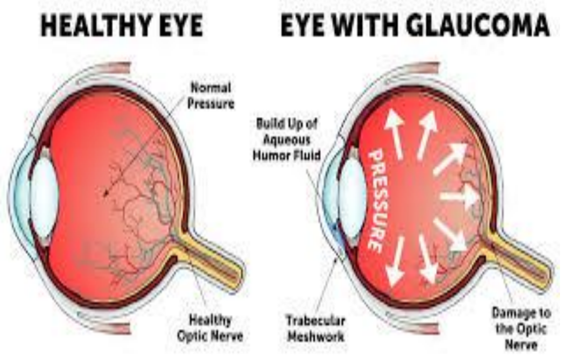

Fig. 4: Glaucoma.

3. AI-Driven Ophthalmic Drug Dispensing: Enhancing Accuracy and Patient Safety

Artificial intelligence (AI) is increasingly being integrated into healthcare systems to improve the safety, accuracy, and efficiency of clinical processes. Drug dispensing in hospitals represents a critical step in patient care, where errors can lead to treatment failure, adverse drug reactions, or other serious complications.[15] Although conventional and semi-automated dispensing systems have improved medication management, challenges such as prescription misinterpretation, human error, and inefficient inventory control still remain. AI-based drug dispensing systems use machine learning algorithms, intelligent automation, and data-driven decision support to enhance the dispensing process. These systems can automatically verify prescriptions, detect potential drug–drug or drug–allergy interactions, and confirm the correct medication, dose, and formulation before dispensing. By reducing reliance on manual verification, AI helps minimize dispensing errors and improves overall medication safety.[16,17]

In addition to error prevention, AI also supports efficient pharmacy workflow management. Predictive algorithms can analyze patient data and historical usage patterns to forecast drug demand, optimize inventory distribution across hospital departments, and prevent medicine shortages or wastage. In ophthalmic pharmacy settings, where treatment regimens may involve specialized formulations and precise dosing, AI-enabled dispensing platforms provide additional benefits. Technologies such as machine learning, computer vision, and automated verification systems assist pharmacists in validating prescriptions and monitoring medication distribution. These tools streamline workflow, reduce dispensing errors, and allow pharmacists to focus more on clinical decision-making and patient counseling, ultimately improving the safety and effectiveness of ophthalmic drug therapy.[18]

4. Advanced Therapeutics and AI in Ophthalmology

4.1 AI-Powered Screening for Rare and Common Retinal Diseases

Artificial intelligence is increasingly improving the detection and monitoring of both prevalent and rare retinal disorders. Rare inherited retinal diseases such as vitelliform dystrophy and macular telangiectasia type 2 often present with subtle retinal abnormalities that can be difficult to recognize during routine clinical examination. Advanced AI algorithms trained on large imaging datasets can analyze retinal photographs and optical coherence tomography (OCT) scans to identify early pathological changes that might otherwise remain unnoticed. Early identification of these conditions allows timely clinical intervention and improved disease management.

AI also plays an important role in glaucoma screening and monitoring. Early stages of glaucoma are characterized by mild structural and functional changes that are frequently overlooked in conventional assessments. Delayed diagnosis may lead to irreversible vision loss, while excessive false-positive referrals can increase healthcare burden and patient anxiety. AI-based image analysis systems provide automated evaluation of retinal structures and can detect early glaucomatous changes with high diagnostic accuracy.

An example is **Altris AI**, which performs advanced optic disc analysis using OCT images. The system evaluates several parameters, including optic disc size, cup area, cup-to-disc ratio, cup volume, rim absence angle, and the Disc Damage Likelihood Scale (DDLS). By integrating data from different OCT platforms, the tool enables consistent monitoring of optic nerve and macular pathology and supports more individualized clinical assessment.

4.2 AI in Clinical Trials and Biomarker Discovery

Artificial intelligence is becoming an important tool in ophthalmic clinical research and drug development. AI algorithms are capable of analyzing extensive imaging datasets, including OCT and fundus photographs, to identify novel imaging biomarkers associated with disease onset and progression. These biomarkers can assist researchers in monitoring disease development and evaluating therapeutic responses during clinical trials.

AI technologies also contribute to improved clinical trial design by automating the screening of patient eligibility criteria and ensuring appropriate participant selection. Furthermore, AI can analyze real-world data obtained from electronic health records to generate real-world evidence. Such data complement traditional randomized clinical trials by providing valuable information about disease progression, long-term treatment outcomes, and real-world therapeutic effectiveness.

4.3 Oculomics

Oculomics refers to the use of detailed ocular imaging data to gain insights into both eye health and systemic diseases. By combining advanced imaging techniques with artificial intelligence-based analysis, oculomics enables the identification of biomarkers that reflect physiological changes occurring throughout the body.

AI-driven oculomic analysis has demonstrated potential in several areas. These include early identification of neurodegenerative disorders such as Alzheimer’s disease through retinal structural changes, assessment of cardiovascular and cerebrovascular risk by evaluating retinal microvascular patterns, and detection of subtle abnormalities in corneal nerve fibers or retinal vascular architecture that may indicate early disease development.

4.4 Optogenetics

Optogenetics represents an innovative therapeutic strategy aimed at restoring vision in individuals with advanced retinal degenerative diseases such as retinitis pigmentosa. This technique involves introducing genes encoding light-sensitive proteins (opsins) into surviving retinal neurons, enabling these cells to respond to light stimuli even in the absence of functional photoreceptors.

Several experimental therapies, including RhyGaze and Nanoscope Therapeutics’ MCO-010, deliver opsin genes through intravitreal injection. These therapies allow remaining retinal cells to function as artificial photoreceptors and transmit visual signals to the brain. Unlike conventional gene therapy approaches, optogenetics does not depend on the presence of viable photoreceptor cells. Recent preclinical and early clinical studies have demonstrated encouraging improvements in visual perception among treated patients.

4.5 Gene Correction

Gene editing technologies are emerging as promising therapeutic strategies for inherited retinal disorders and other ocular diseases. Techniques such as CRISPR-Cas9, base editing, prime editing, and CRISPR-associated transposase systems allow targeted modification of disease-causing genetic mutations.

Base and prime editing approaches enable precise nucleotide modifications without creating double-strand DNA breaks, thereby reducing the risk of unintended genetic alterations. By correcting pathogenic mutations directly within the genome, gene editing technologies offer the possibility of long-term or potentially curative treatment for several retinal disorders.

4.6 Cell Reprogramming

Cell reprogramming strategies aim to regenerate damaged retinal tissue by converting existing cells into functional retinal cell types. These approaches may involve generating photoreceptors or retinal pigment epithelial cells that are essential for maintaining normal visual function.

Two main approaches are currently being investigated. In vitro reprogramming involves transforming cells in a laboratory environment before transplantation into the eye. In contrast, in vivo reprogramming directly converts resident retinal cells into new functional cells within the ocular environment. Both approaches hold promise for restoring visual function in degenerative retinal diseases.

4.7 Cloning Vectors for Ophthalmic Therapeutic Delivery

Efficient delivery systems are essential for successful gene-based and pharmacological therapies in ophthalmology. Viral vectors, such as adeno-associated viruses (AAV) and lentiviruses, are widely used because of their high transduction efficiency and ability to target specific retinal cell types.

Non-viral delivery systems, including lipid-based and polymer-based nanoparticles, offer alternative approaches with improved safety profiles and easier large-scale production. In addition, advanced drug delivery technologies such as sustained-release implants and microneedle-based injections allow localized and controlled release of therapeutic agents within ocular tissues, improving treatment efficacy and reducing dosing frequency.

5 Emerging Pharmacological Approaches for the Management of Ophthalmic Diseases

5.1 New Anti-VEGF Agents

Anti-vascular endothelial growth factor (anti-VEGF) therapy remains the primary treatment for several retinal vascular diseases. Recently developed agents such as brolucizumab and faricimab demonstrate improved durability compared with earlier therapies, allowing longer intervals between injections. AI-based predictive models may further assist clinicians by optimizing dosing schedules, monitoring therapeutic response, and identifying patients who may not respond adequately to treatment.

5.2 Tyrosine Kinase Inhibitors (TKIs)

Tyrosine kinase inhibitors represent another therapeutic strategy for retinal vascular diseases. Drugs such as axitinib and vorolanib inhibit intracellular signaling pathways involved in VEGF-mediated angiogenesis. These agents can be incorporated into sustained-release formulations to provide long-lasting therapeutic effects while reducing the need for repeated intravitreal injections.

5.3 Port Delivery System (PDS)

The port delivery system is a surgically implanted, refillable device designed to continuously deliver anti-VEGF medication to the eye. This technology provides a sustained therapeutic effect and significantly reduces the frequency of intravitreal injections required for chronic retinal diseases. However, appropriate surgical technique and careful monitoring are necessary to minimize complications such as infection.

5.4 Nanotechnology in Drug Delivery

Nanotechnology-based drug delivery systems are gaining increasing attention in ophthalmology. Nanoparticles, liposomes, and polymer-based carriers can improve drug solubility, enhance ocular penetration, and provide sustained drug release. Artificial intelligence can further support the development of these systems by predicting pharmacokinetic behavior, optimizing formulation parameters, and improving targeted delivery.

Future advances are expected to integrate AI with multimodal clinical data, including imaging, genomic information, and patient history, enabling precision-based ophthalmic therapy. Emerging technologies such as optogenetics, gene editing, and cell reprogramming may significantly improve treatment outcomes for degenerative retinal diseases, while advanced delivery systems could reduce treatment burden and improve patient adherence. Additionally, the expanding field of oculomics may broaden the role of ophthalmology in detecting systemic diseases, while AI-driven screening and clinical trial optimization continue to improve research and patient care.

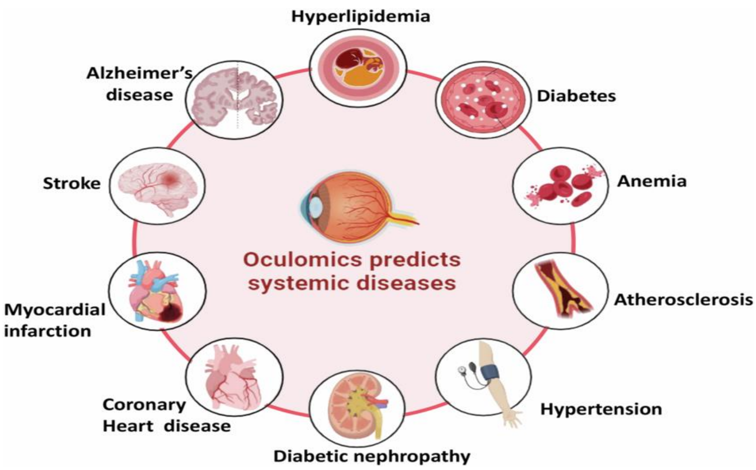

Fig. 5: Oculomics.

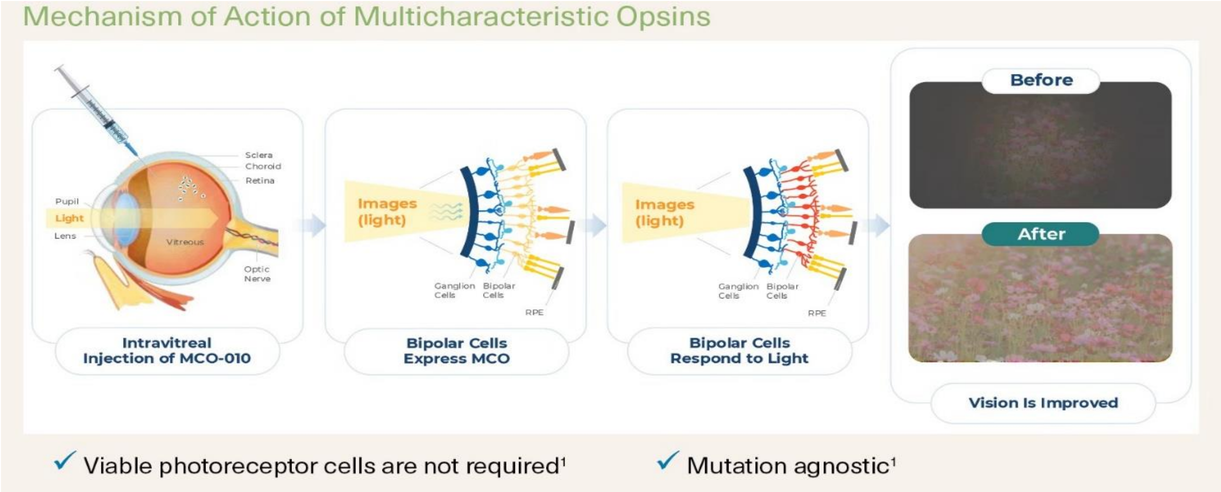

Fig. 6: Mechanism of action of Opsins.

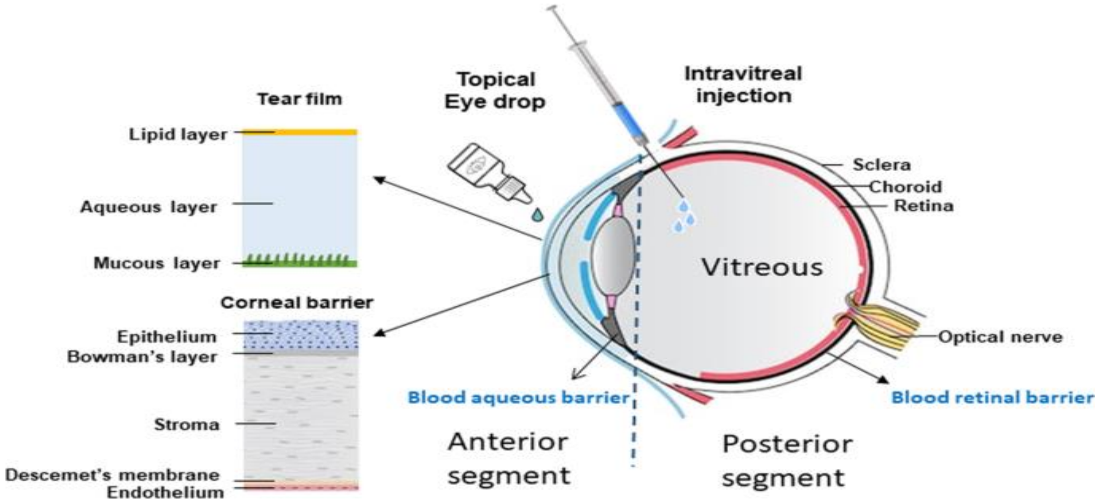

Fig. 7: Anti-VEGF Agent.

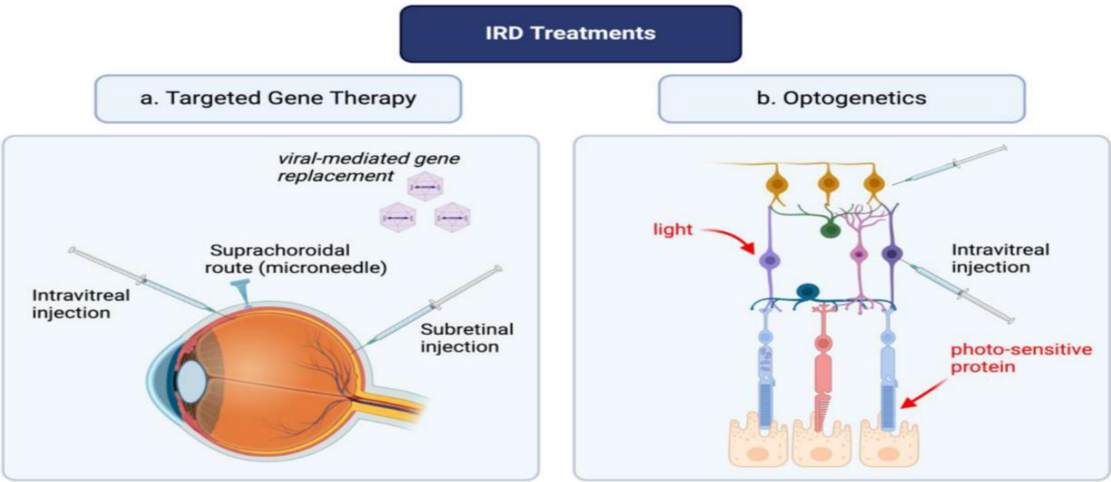

Fig. 8: Optogenetics.

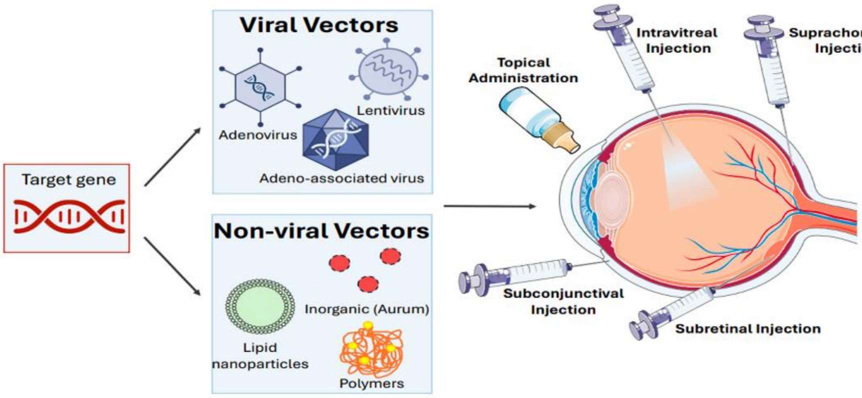

Fig. 9: Cloning Vectors for Ophthalmic Therapeutic Delivery.[39,40]

Table 1: Application of AI Tools in Ophthalmic Dosage Forms.[27,28,29]

S. No	Dosage Form	Name of AI Tool	Origin	Logo	Application
1	Eye drops	IBM Watson Health	USA	IBM Watson	• Predict patient adherence • optimize dosing schedules
2	Intravitreal injection	EyeArt AI	USA	EyeArt	• Enhances screening efficiency, reducing missed referrals.
3	Topical gel	DeepMind AI	UK	DeepMind	• Classifies AMD stages from OCT images with high precision
4	Sustained-release implant	Altris AI	USA	altris AI	• Assesses optic nerve damage and guides individualized treatment
5	Nanoparticle-based drops	NVIDIA Clara	USA	NVIDIA.	• Supports optimization of nanoparticle formulations for better delivery
6	3D printed ocular inserts	Custom AI Design Tools	Switzerland	3D PRINTING LOGO DESIGN	• Combines AI with 3D printing to create patient-specific inserts
7	Hydrogel ocular delivery	Google Health AI	USA	Google Health	• Integrates AI screening with hydrogel-based drug delivery
8	Microneedle ocular patch	Microsoft Azure AI	USA	Azure	• Improves local drug delivery efficiency and reduces variability

9	Lens drug delivery	EyeBrain AI	India		• AI predicts lens behavior and patient-specific drug release
10	Port Delivery System	RetinAI	Israel		• Integrates OCT and clinical data for personalized PDS management

Future Perspectives

The integration of artificial intelligence (AI) with advanced ocular drug delivery systems is expected to significantly transform ophthalmic therapeutics. With increasing computational power and availability of large clinical datasets, AI models are likely to evolve from supportive analytical tools to integrated systems that assist in formulation development and therapeutic optimization. One promising development is the use of AI-driven digital twins for ocular pharmacokinetics. These virtual patient models can simulate processes such as corneal permeability, vitreous diffusion, and drug clearance, enabling researchers to predict therapeutic outcomes before clinical testing. Such predictive modeling may accelerate formulation development and improve dose optimization for both anterior and posterior segment diseases.[30,31]

AI is also expected to enhance advanced therapeutic approaches, including gene and cell-based therapies. Intelligent algorithms can assist in optimizing viral vector design, predicting off-target genetic effects, and modeling long-term expression in retinal tissues. In addition, AI-guided optimization of sustained-release implants and nano-ophthalmic carriers may allow longer dosing intervals and improved patient adherence.[32] Another emerging area is the integration of oculomics with AI-driven precision medicine, where retinal imaging data are combined with genomic and clinical information to guide personalized treatment strategies for chronic conditions such as glaucoma, diabetic retinopathy, and macular degeneration. Furthermore, AI-enabled smart delivery systems, including biosensor-based implants and intelligent contact lenses, may enable real-time monitoring and controlled drug release.[33,34]

Despite these advancements, challenges such as data standardization, algorithm transparency, regulatory approval, and ethical considerations remain important. Continued collaboration among pharmaceutical scientists, ophthalmologists, data scientists, and regulatory bodies will be essential to ensure the safe and effective integration of AI into future ophthalmic therapeutics.[35]

CONCLUSION

Artificial intelligence is rapidly transforming the landscape of ocular drug preparation and advanced ophthalmic therapeutics. By enabling predictive modeling, intelligent formulation design, and data-driven personalization, AI addresses many of the longstanding challenges associated with conventional ocular drug delivery systems, including limited bioavailability, frequent dosing requirements, and variability in therapeutic response. Beyond formulation optimization, AI plays an increasingly significant role in biomarker identification, disease stratification, gene therapy enhancement, and clinical decision support. The integration of machine learning, deep learning, and computational modeling with nano-ophthalmic systems and biologic therapies offers a pathway toward safer, more effective, and patient-specific treatments.

While regulatory, technical, and ethical challenges remain, the continued evolution of AI technologies holds substantial potential to improve therapeutic precision and accelerate innovation in ophthalmic care. The future of ocular preparation is likely to be characterized by intelligent, adaptive, and personalized drug delivery platforms that integrate seamlessly with diagnostic and monitoring systems. As interdisciplinary collaboration strengthens, AI-driven ophthalmology may move from enhancement of existing practices to a fundamentally new paradigm in ocular therapeutics.

REFERENCES

1. Rajpurkar P, Chen E, Banerjee O, Topol EJ. **AI in health and medicine.** *Nature Medicine*, 2022.
2. Topol EJ. High-performance medicine: the convergence of human and artificial intelligence. *Nature Medicine*, 2019.
3. Esteva A, Kuprel B, Novoa RA, Ko J, Swetter SM, Blau HM, et al. Dermatologist-level classification of skin cancer with deep neural networks. *Nature*, 2017.
4. Levin LA, Nilsson SFE, Ver Hoeve J, Wu SM, Kaufman PL, Alm A. Adler’s physiology of the eye. 11th ed. Elsevier, 2011.
5. Barrett KE, Barman SM, Brooks HL, Yuan JXJ. Ganong’s review of medical physiology. 26th ed. Mc Graw Hill, 2019.

6. Gulshan V, Peng L, Coram M, Stumpe MC, Wu D, Narayanaswamy A, et al. Development and validation of a deep learning algorithm for detection of diabetic retinopathy in retinal fundus photographs. *JAMA.*, 2016.
7. Rajalakshmi R, Subashini R, Anjana R, Mohan V. *Automated diabetic retinopathy detection in smartphone-based fundus photography using AI.* Eye, 2018.
8. Ting DSW, Cheung CYL, Lim G, Tan GSW, Quang ND, Gan A, et al. Development and validation of a deep learning system for diabetic retinopathy and related eye diseases using retinal images. *JAMA.*, 2017.
9. De Fauw J, Ledsam JR, Romera-Paredes B, Nikolov S, Tomasev N, Blackwell S, etal. Clinically applicable deep learning for diagnosis and referral in retinal disease. *Nature Medicine*, 2018.
10. Deimazar G, Sabbaghi H, Ahmadieh H, Sheikhtaheri A. *Artificial intelligence for detection of age-related macular degeneration based on fundus images: systematic review.* Surv Ophthalmol., 2025.
11. Verma P, Wang J, et al. *Multimodal AI in retinal disease diagnosis and prognostics.* BMC Ophthalmol., 2025.
12. Tien Y, Lee CS, Baughman DM, et al. *Deep learning is effective for automated AMD vs normal OCT classification*, 2016.
13. Asaoka R, Murata H, Iwase A, Araie M. Detecting preperimetric glaucoma with standard automated perimetry using a deep learning classifier. *Ophthalmology*, 2016.
14. Hood DC, Raza AS. On improving the use of OCT imaging for detecting glaucomatous damage. *Br J Ophthalmol*., 2014.
15. Shanthi Priya R, Senthil Prabhu R, Umamaheswari D, Selva Kumari N, Sherley Rozzario J, Venkatarathinakumar T. Artificial intelligence powered automation: Advancing drug dispensing systems. *World Journal of Pharmacy and Pharmaceutical Sciences*, 2025.
16. Senthil Prabhu, R., Sabitha Ananthi, D., Uma Maheswari, D., & Raja Soundarya, S. (2022). Internet of Nano Things (IoNT) and Machine Learning (ML) – Innovations in drug discovery and healthcare system. International Journal of Frontiers in Science and Technology Research, 2(1): 1–8.
17. Pooja, B., Abinaya, R., & Senthil Prabhu, R. (2025, September 13). Exploring the world of AI – The impact in pharmaceutical science. Magna Scientia Advanced Research and Reviews, 15(1): 29–41.
18. Ting DSW, Pasquale LR, Peng L, Campbell JP, Lee AY, Raman R, et al. Artificial intelligence and deep learning in ophthalmology. *British Journal of Ophthalmology*, 2019.
19. Schmidt-Erfurth U, Sadeghipour A, Gerendas BS, Waldstein SM, Bogunović H. Artificial intelligence in retina. *Progress in Retinal and Eye Research*, 2018.
20. Preethi, J., Gunaseelan, J., Punniyamoorthy, M., & Jothika, R., Senthil Prabhu, R. (2025). AI-enabled in-vitro characterization: Shaping the future of solid dosage forms. International Journal of Pharmacy and Pharmaceutical Science.
21. Senthil Prabhu, R., Priyanka, R., & Rajasoundarya, S. (2021). Artificial Intelligence – Emerging trends in management of pandemics. The Pharmaceutical and Chemical Journal.
22. Gaudana R, Ananthula HK, Parenky A, Mitra AK. Ocular drug delivery. *AAPS Journal*, 2010.
23. Urtti A. Challenges and obstacles of ocular pharmacokinetics and drug delivery. *Advanced Drug Delivery Reviews*, 2006.
24. Agarwal P, Rupenthal ID. Modern approaches to ocular drug delivery. *Drug Discovery Today*, 2016.
25. del Amo EM, Urtti A. Current and future ophthalmic drug delivery systems: A shift toward posterior segment drug delivery. *Advanced Drug Delivery Reviews*, 2008.
26. Patel A, Cholkar K, Agrahari V, Mitra AK.Ocular drug delivery systems: An overview. *World Journal of Pharmacology*, 2013.
27. Yu KH, Beam AL, Kohane IS. Artificial intelligence in healthcare. *Nature Biomedical Engineering*, 2018.
28. Jiang F, Jiang Y, Zhi H, Dong Y, Li H, Ma S, et al. Artificial intelligence in healthcare: past, present and future. *Stroke and Vascular Neurology*, 2017.
29. Patel VL, Shortliffe EH, Stefanelli M, Szolovits P, Berthold MR, Bellazzi R, et al. The coming of age of artificial intelligence in medicine. *Artificial Intelligence in Medicine*, 2009.
30. Mesko B, Hetenyi G, Gyorffy Z.Will artificial intelligence solve the human resource crisis in healthcare? *BMC Health Services Research*, 2018.
31. Panch T, Szolovits P, Atun R. Artificial intelligence, machine learning and health systems. *Journal of Global Health*, 2018.
32. Milea D, Najjar RP, Jiang Z, Ting D, Vasseneix C, Xu X, et al. Artificial intelligence to detect papilledema from ocular fundus photographs. *New England Journal of Medicine*, 2020.
33. Sahel JA, Boulanger-Scemama E, Pagot C, Arleo A, Galluppi F, Martel JN, et al. Partial recovery of visual function in a blind patient after optogenetic therapy. *Nature Medicine*, 2021.
34. Yadav KS, Rajpurohit R, Sharma S. Nanotechnology-based drug delivery systems for ocular diseases. *Journal of Controlled Release*, 2019.
35. Cheng H, Wong JLY, Quek CWN, et al. Ophthalmic drug discovery and development using artificial intelligence and digital health technologies. *NPJ Digital Medicine*, 2025.