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Emerging Therapeutic Strategies and Innovations in Age-Related Macular Degeneration: Current Perspectives and Future Directions

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ABSTRACT: Age-related macular degeneration is a major cause of central visual loss which is irreversible to the older population of the world. It is caused by a complicated interaction of the oxidative stress, inflammatory reactions, dysregulation of the complement system, and genetic and environmental risk factors that eventually lead to the degeneration of the retinal pigment epithelium and photoreceptor cells. The current development in imaging techniques such as optical coherence tomography fundus fluorescein angiography and fundus autofluorescence have significantly enhanced early disease diagnosis and disease surveillance. The present forms of therapy, which include mainly anti-vascular endothelial growth factor therapy, photodynamic therapy, laser photocoagulation, and nutritional supplementation, have significantly improved visual recovery, particularly in the exudative wet type of Age-related macular degeneration. However, there are still limited therapeutic solutions of the dry age-related macular degeneration. New therapeutic strategies, such as complement, tyrosine kinase, gene- and cell-based therapeutic agents as well as new sustained-release delivery systems, bring new perspectives to long-term management of the disease. At the same time, advances in imaging biomarkers, artificial intelligence and low-vision restoration are transforming the clinical practice. The future research with prioritization to predictive models and precision medicine will make possible personalized, sustained, and preventive interventions and thus can be utilized to drive the management of Age-related macular degeneration towards a higher level of visual retention and better patient quality of life.

KEYWORDS: Age-Related Macular Degeneration (AMD), Anti-VEGF Agents, Neovascularization, Vascular Endothelial Growth Factor (VEGF), Retinal Pigment Epithelium (RPE), Wet AMD Therapy, Retinal Atrophy

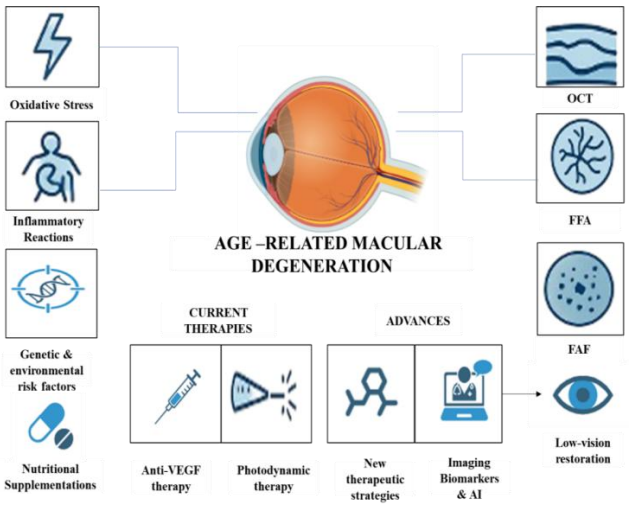

Figure: Graphical abstract of Emerging Therapeutic Strategies and Innovations in Age-Related Macular Degeneration: Current Perspectives and Future Directions

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Caption: This figure summarizes AMD's pathogenic factors, diagnostic advances (OCT, FFA, FAF), and evolving therapies. Recent strategies now include imaging biomarkers, artificial intelligence and low-vision restoration modalities.

I. INTRODUCTION

Age-related maculopathy (also known as age-related macular degeneration (ARMD)) is a progressive, degenerative retinal pathology of central retina (macula) that mostly occurs in people over the age of 50 years of age. High-accuracy visual acuity is mediated by the macula, which is located near the retinal Centre, thus providing the basis of reading, driving, and facial recognition functions [1, 2]. ARMD is characterized by loss of structure and function of the retinal pigment epithelium (RPE), photoreceptor cells, and Bruch's membrane resulting in the eventual loss of central visual function and sparing of peripheral vision to a great extent. The pathology is clinically divided into two major phenotypes; the dry (non-exudative or atrophic) and wet (exudative or neovascular) ones [3, 4]. The dry form which forms about 85-90 percent of all manifestations is marked by a progressive accumulation of drusen lipid protein complexes below the RPE and the development of geographic atrophy in retinal layers. Contrarily, the wet form, though rarely seen, explains the prevalence of cases of severe visual deficits that ensue after aberrant choroidal neovascularization and subsequent leakage or haemorrhage in the area beyond the retina [5]. The etiology of this disease follows a complex process of senescence and genetic predisposition, oxidative stress and inflammatory responses, and a web of extrinsic risk factors, such as smoking, unhealthy diet, and exposure to ultraviolet radiation [6, 7]. Genetic studies have established strong correlations with polymorphs in complement factor H (CFH), ARMS2 and HTRA1 thus identifying the dysregulation of the complement cascade in the etiology of the diseases [8]. As the world population trends towards older ages, age related macular degeneration has become the leading cause of permanent central blindness in the industrialized states thus becoming an important burden to eye health and life quality in general among the geriatric population [9, 10].

Age-related macular degeneration (ARMD) is an epidemiological issue that is rising to become a massive health problem in the community and its prevalence is increasing at an alarming rate worldwide. Latest estimates worldwide show that more than 200,000,000 people had ARMD in 2020, which is expected to increase to close to 300,000,000 by 2040, the majority of which can be explained by the age-related demographic shift and the change of lifestyle [11, 12]. The highest disease burden is observed in the regions with higher life expectancy like Europe, North America, Australia and some parts of East Asia. However, it is simultaneously increasing in prevalence in the developing countries in the stage of demographic and epidemiological transition [13, 14]. In adults over the age of 60, the occurrence of early - stage ARMD (presence of drusen and retinal pigment epithelium (RPE) changes without impairment of vision) is 8-12 percent [15]. Late-stage ARMD, including neovascular and atrophic forms, on the contrary, affects about 125-250/100,000 of this population group. The overall incidence is a little higher in female compared to male part of which is explained by the fact that women live longer. The global impact of age-associated macular degeneration (AMD) is not limited to visual dysfunction, but there is also a big socioeconomic and psychosocial cost [16, 17].

The visual impairments caused by AMD are linked with higher rates of falls, fracture, depressive states, isolation, and dependency and hence makes a significant impact on reducing the quality of life among the elderly. Fiscally, AMD is causing billions of dollars in revenue in direct healthcare expenditures and indirect productivity losses every year [18, 19]. As an example, anti-vegetal endothelial growth factor (anti-VEGF) therapy spending is a significant amount of ophthalmic budget in high-income nations that cover neovascular AMD. Since the life expectancy in low- and middle-income countries is limited and access to novel therapeutic interventions is limited, it is estimated that the burden of age-related macular degeneration (ARMD) is going to increase significantly over the next several decades [20]. A coordinated strategy that includes preventive lifestyle strategies, early case identification, equal access to therapeutic services, and population-based interventions aimed at ageing populations is required to fight this health issue of the populace. ARMD is thus a major cause of visual impairment worldwide, and is one of the areas that has received much ophthalmic research, health-policy development, and geriatric clinical care [21, 22].

II. PATHOPHYSIOLOGY OF ARMD

2.1 Molecular mechanisms: oxidative stress, inflammation, complement system

Age-related macular degeneration (AMD) is a pathology triggered by a group of closely interconnected molecular pathways, including oxidative stress, inflammation and complement system malfunctions. The retina is particularly

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undergoing oxidative damage as the organ has been found to have a high oxygen demand as well as unremitting exposure to photic energy, which leads to an overproduction of reactive oxygen species (ROS) [23, 24]. These ROS cause dysfunction to the retinal pigment epithelial (RPE) cells and disrupt the integrity of mitochondria, thus limiting the viability of photoreceptors. Oxidative insults trigger chronic inflammation which involves the activation of microglial cells and macrophages that increase the release of pro-inflammatory cytokines (interleukin6 IL6) and tumor necrosis factor-alpha (TNF -a) worsening retinal tissue destruction [25]. At the same time, the innate immune complement cascade is hyperactivated which is explained by the polymorphism in the genes coding the complement components, in particular, the complement factor H (CFH) and C3. The deposits of membrane attack complexes due to an aberrant complement activation result in the formation of drusens under the retinal pigment epithelium that subsequently activates the inflammatory signaling pathway as well as induces apoptosis of the cells [26]. A self-reinforcing loop is formed between oxidative stress, inflammatory mediators and the complement dysregulation that speed up retinal degeneration; in its extreme phases leading to choroidal neovascularization typical of the exudative form of age-related macular degeneration. Such molecular clues highlight the feasibility of therapeutic approaches that should work on the reduction of oxidative stress, the regulation of the inflammatory reaction, and the control of the activity of complement so that the development of the disease could be delayed or even averted [27, 28].

2.2 Genetic and environmental risk factors

Age related macular degeneration (AMD) is a multidimensional disease, which develops due to the interaction between the personal genetic factors and external environmental factors [29]. Polymorphisms of the important constituents of the complement cascade such as complement factor H (CFH), complement component 3 (C3) and the ARMS2 / HTRA1 locus in the 10q26 chromosome have been strongly linked with the increased disease susceptibility; these allelic variants are responsible of hampering immune control mechanisms and enhancing the inflammatory and oxidative reaction in the retinal milieu **(Figure 1)** [30]. Other genetic determinants which regulate lipid metabolism, extracellular matrix integrity and angiogenic regulation also play a role in the way a disease has a path to follow. On the other hand, aging and other environmental conditions trigger accrual oxidative stress and cellular senescence, which compromises retinal activities [31]. The increased risk that is caused by cigarette smoking is very high, since it initiates oxidative stress and vascular dysfunction [32]. The lack of antioxidants and omega-3 fatty acids in the diet, as well as the insufficiency of their intake, increases the susceptibility, although the intake of leafy greens, vitamins C and E, and zinc can have protective effects [33]. Oxidative and inflammatory retinal damage is enhanced by other risk factors such as obesity, hypertension, hypercholesterolemia and long-term exposure to ultraviolet or blue radiation. This means that genetic predisposition and changeable environmental conditions interact with each other in a synergistic manner to determine the presence and severity of the disease with the paramount importance of lifestyle change and early genetic counseling to prevent the development of age-related macular degeneration and to suppress that of age-related macular degeneration [34, 35].

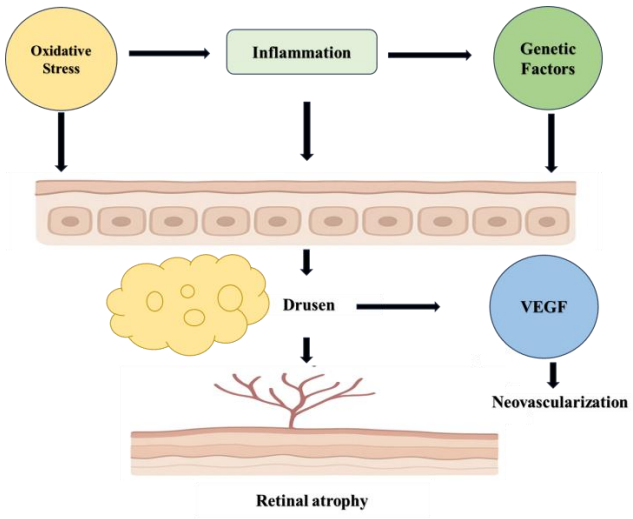

Figure 1: Schematic pathway of ARMD pathogenesis showing key molecular players and tissue changes

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Caption: Oxidative stress, chronic inflammation, and genetic susceptibility contribute to retinal pigment epithelium (RPE) dysfunction. Accumulation of drusen further aggravates RPE damage and promotes VEGF upregulation, leading to choroidal neovascularization in wet AMD. Progressive RPE degeneration results in retinal atrophy characteristic of dry AMD.

III. CLINICAL PRESENTATION AND DIAGNOSIS

3.1 Signs, symptoms, diagnostic imaging (OCT, FFA, autofluorescence)

The age-related macular degeneration (AMD) is often associated with visual disturbances in the central area that significantly affect the normal daily life. The patients tend to complain of blurred or distorted central vision (metamorphopsia), the inability to read fine print, to recognize face features, or to perform any task that requires narrowed visual focus [36]. As the disease advances, central scotomas will develop (in the foveal region) that is the area of reduced or no vision but the peripheral vision is not usually affected. Initial signs are characterised by drusen which are yellowish extracellular deposits located at the bottom of the retina pigment epithelium with subtle pigment changes [37]. Further progression of advanced AMD can be a neovascular (wet) phenotype (choroidal neovascularization, subretinal haemorrhage), or as an atrophic (dry) one (progressive geographic atrophy of the retinal pigment epithelium and layers of the photoreceptor) [38].

Diagnostic imaging cannot be done away with, as it serves to confirm a diagnosis, to distinguish between disease subtypes, as well as to track progression or response to therapy [39]. The optical coherence tomography (OCT) is a noninvasive modality that offers high-resolution cross-sectional retinal imaging, allowing visualization of the drusen, pigment epithelial detachments, and intraretinal or subretinal fluid accumulations, which are being used as signs of active neovascular age-related macular degeneration (ARMD) [40]. Fundus fluorescein angiography (FFA) defines choroidal neovascular membranes and demonstrates typical leakage patterns, pooling, and staining, and thus, plans anterior of anti-vascular endothelial growth factor (VEGF) [41]. Fundus autofluorescence (FAF) is a technique used to capture endogenous lipofuscin-based fluorescence in the retinal pigment epithelium (RPE), which is a sensitive fluorescence indicator of cellular stress and initial RPE pathology allowing one to monitor atrophic disease. All these imaging modalities will give complementary information about both the structure and the functionality of the retina, enabling effective distinction of the dry and the wet forms of ARMD, timely therapeutic intervention, and the long-term monitoring to prevent the irreversible loss of central visual function and maintain the quality of visual perception **(Table 1)** [42].

Table 1: Comparison between dry and wet ARMD (clinical features, progression, diagnostic markers)

Feature	Dry (Non-Exudative) ARMD	Wet (Exudative or Neovascular) ARMD	References
Pathology	Degeneration of retinal pigment epithelium (RPE) and accumulation of drusen	Formation of abnormal choroidal neovascular membranes beneath RPE or retina	[43]
Prevalence	Accounts for about 85–90% of ARMD cases	Accounts for about 10–15% of ARMD cases	[44]
Onset	Gradual and slowly progressive	Rapid and often severe onset	[9]
Visual Symptoms	Mild to moderate central vision loss; metamorphopsia may be absent early	Sudden distortion of vision (metamorphopsia), central scotoma, rapid vision loss	[45]
Fundus Findings	Drusen, RPE mottling, geographic atrophy in advanced stages	Subretinal or intraretinal fluid, hemorrhage, exudates, fibrotic scar formation	[46]
OCT Findings	Drusen elevation, thinning of outer retina and RPE	Presence of subretinal/intraretinal fluid, RPE detachment, CNV complex	[47]
FFA Findings	Minimal or no leakage; may show window defects	Leakage from neovascular membranes and late staining	[48]

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FAF Findings	Areas of decreased autofluorescence due to RPE loss	Irregular autofluorescence with hyperintense areas of active CNV	[49]
Feature	Dry (Non-Exudative) ARMD	Wet (Exudative or Neovascular) ARMD	[50]
Pathology	Degeneration of retinal pigment epithelium (RPE) and accumulation of drusen	Formation of abnormal choroidal neovascular membranes beneath RPE or retina	[43]

IV. CURRENT THERAPEUTIC APPROACHES

4.1 Anti-VEGF agents, photodynamic and laser therapy, combination therapies, nutritional supplements

Therapeutic treatment of Age -Related Macular Degeneration (AMD) is mostly guided towards the reduction of the onset of the disease, prevention of irreversible loss of the central visual acuity and maintenance of functional visual integrity [51]. Intravitreal administration of antiangular endothelial growth factor (anti-VEGF) drugs are the existing state of the art in the neovascular (wet) form of AMD [52]. Other antivascular endothelial growth factor (VEGF) antagonists like ranibizumab, aflibercept and bevacizumab inhibit aberrant choroidal neovascularization, vascular permeability and macular oedema. These interventions have significantly increased visual outcomes having resulted in stabilization or increased vision in most of the treated patients when treated at regular intervals **(Figure 2)** [53]. However, the necessity of regular intravitreal injections poses a significant burden on the therapeutic process, which is why there is currently continued research on extended-release preparations and sustained-release administration systems [54].

Photodynamic therapy (PDT) using verteporfin is a form of targeted treatment; it will entail intravenous delivery of the photosensitizer and lazer excitation and thus selective occlusion of aberrant neovascular membranes and sparing of adjacent retinal tissue [55]. Although it is accompanied by a decrease in utilization along with the emergence of anti-vascular endothelial growth factor (VEGF) therapy, PDT still has clinical use in specific settings, especially polypoidal choroidal vasculopathy or when used in synergistic combination therapy [56]. Laser photocoagulation is a modality that used to be considered as one of the standards, but is currently used only when lesions are extrafoveal and well-defined, i.e., to seal permeable vessels and limit the disease development [57]. The combination regimens, including anti-VEGF therapy and PDT, can be used simultaneously to increase the therapeutic effect, decrease the recurrence, and minimize the number of intravitreal injections (**Table 2)** [58].

In the case of atrophic age -related macular degeneration (ARMD), nutritional supplementation using the Age -Related Eye Disease Study (AREDS) and its more recent formulation, AREDS2, is the focus of therapeutic approaches. These diets include antioxidants such as vitamins C and E, zinc, copper, lutein, and zeaxanthin, the aim of which is to slow the process of the advancement of disease stages [59]. The addition of complimentary lifestyle interventions, which includes quitting smoking, high intake of leafy greens and omega 3 fatty acids in the diet, and enough ultraviolet protection also helps in preserving the retinal integrity and residual visual function of patients with ARMD [60].

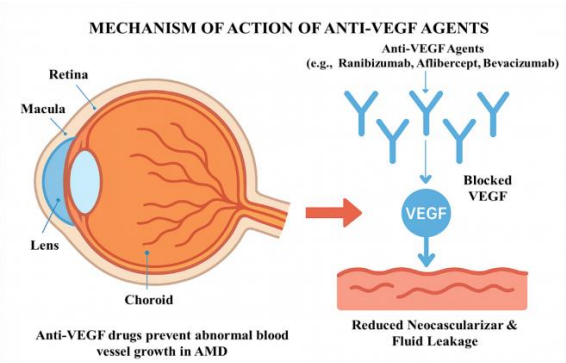

Figure 2: Mechanism of action of anti-VEGF agents.

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Caption: Anti-VEGF drugs bind and neutralize VEGF, preventing abnormal blood vessel growth. This reduces neovascularization and fluid leakage in the retina.

Table 2: Summary of approved anti-VEGF drugs (structure, mechanism of action, dosage, efficacy)

Drug	Type / Structure	Mechanism	Dosage	Efficacy / Notes	References
Ranibizumab (Lucentis)	Antibody fragment (Fab)	Blocks VEGF-A	0.5 mg monthly	Proven efficacy, improves/stabilizes vision	[61]
Bevacizumab (Avastin)	Full antibody	Inhibits VEGF-A	1.25 mg every 4–6 weeks (off-label)	Cost-effective, similar results to Lucentis	[62]
Aflibercept (Eylea)	Fusion protein (VEGF Trap)	Binds VEGF-A, VEGF-B, PlGF	2 mg every 8 weeks after loading	Longer duration, excellent fluid control	[63]
Brolucizumab (Beovu)	Single-chain antibody fragment	Potent VEGF-A blocker	6 mg every 8–12 weeks	Longer action, risk of inflammation	[64]
Faricimab (Vabysmo)	Bispecific antibody	Inhibits VEGF-A & Ang-2	6 mg every 8–16 weeks	Dual action, extended dosing, effective outcomes	[65]

V. EMERGING THERAPIES

5.1 Investigational Pharmacological Agents in ARMD

A number of new therapeutic approaches are currently being explored as a means to treat the underlying molecular pathways of Age-Related Macular Degeneration (ARMD) [66]. Complement inhibitors are tailored to regulate hyper stimulated complement cascade that triggers the retinal inflammation and cell destruction. C3 and C5 inhibitors (Pegcetacoplan and Avacincaptad pegol, respectively) have shown potential in slowing down the atrophy of the geographic in the dry ARMD [67]. Intracellular VEGF receptor signalling inhibitors (TKIs) such as sunitinib and axitinib, also exhibit greater durability and lower occurrence of intravitreal injections; sustained-release preparations of these compounds are currently in clinical trials of wet ARMD [68]. The application of the gene therapy methods is expected to get long-term VEGF inhibition with the help of the viral vectors (such as RGX-314 or ADVM-022), which encode the anti-VEGF proteins, and may even replace the recurrent injections into the eye with one injection. Cell based therapies, e.g. transplantation of retinal pigment epithelium (RPE) cells made using the stem cell are aimed at replacing the damaged retinal architecture and functional capacity in severe cases of dry ARMD. All these new modalities are indicators of a transition to disease modification, increased treatment periods, and possibly permanent retinal protection [69].

5.2 Novel delivery systems and devices

The progress of new drugs used in the treatment of Age-Related Macular Degeneration (ARMD) is directed towards the decrease in frequency of injections, higher efficacy and patient compliance [70]. Sustained-release implants, including ranibizumab which is a sustained-release drug via the Port Delivery System (PDS) offer sustained intravitreal drug release of up to six months and reduce treatment burden [71]. Biodegradable microspheres and nanoparticles allow localized and sustained release of anti-VEGF or corticosteroids and hence therapeutic levels with reduced current injections. Sensitive drugs are better absorbed into the eye by hydrogel based systems and liposomal preparation [72]. A suprachoroidal and subretinal delivery devices enable the specific delivery of medication to posterior ocular tissues which result in improved drug penetration and less systemic exposure. Also, minimal invasive transscleral delivery is currently being researched using microneedle and iontophoresis [73]. Gene therapy vectors are other innovative strategies, which provide the maintained intraocular synthesis of therapeutic proteins in one dosage. Together, these innovative systems promise to revolutionize the ARMD management through the prolongation of the period of treatment and improvement of visual results in the long-term perspective [74].

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5.3 RNA-based therapeutics, CRISPR-Cas9 gene editing

CRISPR-Cas9 gene editing and RNA-based therapeutics represent the revolutionary methods of age-related macular degeneration (ARMD) treatment that has the potential to provide the opportunity to precisely treat and modify the disease over time. RNA-based therapeutics can be used to target disease-driving genes and pathways in a variety of ways including RNA interference (RNAi) and antisense oligonucleotides (ASOs) [75]. These molecules have the ability to selectively repress or tune the expression of angiogenesis and inflammatory process-linked pathways proteins such as vascular endothelial growth factor (VEGF) and complement pathway-linked proteins [74]. VEGF inhibitors including bevasiranib, AGN -211745 (siRNA based-VEGF inhibitors) and others have shown promising preclinical findings, but clinical translation work is still in progress. Furthermore, mRNA based therapeutics have potential in providing protective or regenerative type of proteins to retinal cells, which could potentially restore the performance of degenerative stages [76].

CRISPR-Cas9 genome-editing system is an exceptionally exact approach of either fixing or silencing pathogenic genes that have been associated with ARMD, including CFH, ARMS2, and HTRA1. Its accuracy enables irreversible genetic alteration of retinal cells and has a potential of curing the disease once [77]. Recent research is being conducted on adeno associated viral (AAV) vectors in the delivery of CRISPR to the retinal pigment epithelium (RPE) as a safe and targeted editing [78]. Combined, both RNA-based and CRISPR technologies promise a new dawn of gene-targeted treatment of ARMD, which may treat the underlying causes of this condition instead of just suppressing the subsequent downstream pathological phenomena [79].

VI. INNOVATIONS IN DISEASE MANAGEMENT

6.1 Advances in imaging, biomarkers, artificial intelligence in ARMD diagnosis

The last progress in imaging technologies, biomarkers, and artificial intelligence (AI) have significantly improved the management and treatment of Age-Related Macular Degeneration (ARMD) [80]. Optical Coherence Tomography (OCT) has advanced on better depth resolution and swept -source imaging, which allows the microstructure of the retina, morphology of drusen, and membrane of neovascular structure to be viewed in greater detail. OCT -Angiography (OCT -A) provides noninvasive images of retinal and choroidal vessels and enables the detection of subclinical choroidal neovascularization [81]. Fundus Autofluorescence (FAF) helps to detect the dysfunction of the pigment epithelium (RPE) and anticipate the development of atrophy. New biomarkers, including components of complement (C3, C5), cytokines of inflammation, lipofuscin deposits, and genetic alterations (CFH, ARMS2/HTRA1) are useful in risk evaluation and in individual treatment [82]. The use of artificial intelligence (AI) and deep-learning algorithms is changing the ARMD screening process, as specific algorithms are able to identify early lesions, define the disease stage, and predict disease progression based on the large retinal images datasets [83]. AI-assisted OCT interpretation is able to increase the accuracy of the diagnosis and reduce the workload of clinicians. It is expected to provide specific diagnosis, early intervention, and efficient treatment planning through the fusion of imaging data with molecular and genetic biomarkers with the help of AI-controlled analytics. All these advances are changing the paradigm of ARMD care to a more predictive, preventive and personalized approach [84].

6.2 Low vision aids and rehabilitation

Low vision aids and rehabilitation forms an important part of the care of patients with Age-Related Macular Degeneration (ARMD), particularly at its late stages where the patient no longer has any central vision. Its major goal is to maximize residual vision and improve the functional independence [85]. High-powered reading spectacles, magnifiers (either handheld, stand-mounted, or spectacle-mounted), and telescopic lenses are all invaluable assistive devices that help patients to carry out the most important activities that are reading, writing and recognizing faces [86]. The use of technology has also brought about electronic low-vision aids, such as closed-circuit television (CCTV) readers, portable digital magnifiers, smart phone-based applications that have adjustable magnification, contrast and text-to-speech capabilities that significantly support reading, movement and navigation [87].

Non-optical devices, including large-print materials, high-contrast markings, audiobooks, and increased lighting are also used in order to enhance the level of visual comfort and usability [88]. Vision rehabilitation programs focus on eccentric fixation training that entails using healthier peripheral retina regions in performing the visual tasks and orientation and mobility training to ensure that spatial awareness and safety are preserved [89]. Occupational therapy will help the patients to adapt to their living conditions, and psychological counseling will help them emotionally, to overcome frustration or depression, or even social withdrawal due to the loss of the sight [90]. It is important to refer to

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low- vision and rehabilitation services at an early age since early intervention can not only improve the functional performance but it brings about independence, confidence and overall better life of an individual affected by ARMD [91].

6.3 Teleophthalmology and digital health monitoring tools

Teleophthalmology together with digital health monitoring tools is gradually being considered as a paradigm shift at the care of Age-Related Macular Degeneration (ARMD), enabling remote, accessible, and continuous care of patients. Teleophthalmology uses high-tech digital imaging systems and safe communication networks that will allow retina experts to remotely assess the fundus photographs and optical coherence tomography (OCT) scan of the patients [92]. This approach allows the early diagnosis, screening, and follow-up, particularly among people living in the rural or underserved areas where ophthalmological care is limited. Remote screening programs have the potential to identify subtle phenotypic changes the existence of which is preceded by severe visual acuity loss to prevent adverse clinical outcomes due to the timely delivery of therapeutic procedures [93].

The digital health monitoring tools i.e., home-based visual functional analysis application, hand-held retinal imaging tools, and artificial-intelligence-enhanced analytical tools provide real-time disease surveillance and personalized disease management [94]. Amsler grid system, preferential hyperacuity perimetry, and home-based OCT application are some of the applications that empower patients to self-monitor themselves and quickly report visual changes. The combination of these tools and cloud-based repositories and electronic health records systems allows sharing data and predictive analytics in AI [95]. Teleophthalmology, together with digital monitoring, complement each other and enhance proactive disease management, reduce outpatient load, enhance treatment compliance, and stimulate patient interaction during the process of long-term ARMD treatment [96].

VII. FUTURE DIRECTIONS

7.1 Challenges, unmet needs, areas for research

Regardless of impressive advances in treatment, there are still many challenges and unmet needs regarding the treatment of Age-Related Macular Degeneration (ARMD). Though anti-VEGF agents have transformed the management of neovascular ARMD, they necessitate high-frequency intravitreal injections that have a heavy burden on the patient, caregiver and healthcare system resulting in non-adherence and poor outcomes. In addition, there is currently no efficient treatment available specifically to dry (geographic atrophy) ARMD that would lead to permanent blindness of millions of people across the globe. The problem of early detection is that most of the imaging technologies and the reliable biomarkers of disease progression are not perceived, and their availability is limited. The differences in the reactions to anti-VEGF therapy support a dire necessity of individualized treatment plans based on the genetic, molecular, and phenotypic profiles. Moreover, there are new resistance mechanisms, chronic inflammation, and dysregulation of the complement pathway that requires a higher level of mechanistic knowledge.

The development of long acting drug delivery systems, combination therapies and neuroprotective or regenerative methods like gene and stem cell therapy should be explored in future studies in order to repair retinal integrity. The implementation of artificial intelligence (AI), machine learning, and biomarker-based predictive models in the diagnostic processes will guarantee the possibility of earlier intervention and optimization of treatment on a case-by-case basis. The increased availability of high-quality imaging, screenings across the world, and online health apps will also improve disease surveillance. ARMD care has the potential to progress, by attending to these unmet needs, to be a response involving not only reactive management but active prevention; to take this cause of blindness and turn it into a much easier, chronic condition with better vision and quality life.

7.2 Predictive modeling, precision medicine approaches

Although there are good developments in regards to the method of diagnosis and therapeutic interventions, there are still a lot of challenges and unmet needs that are still facing Age-Related Macular Degeneration (ARMD). Although anti-VEGF agents have significantly improved the visual outcome of patients with neovascular ARMD the need to administer the drugs intravitreally on a regular basis has provided patients and health care systems with a significant burden and the therapeutic effect is often not optimal as a result of a lack of adherence. There is also no effective intervention so far developed against dry (geographic atrophy) form of ARMD, the most frequent form that results in permanent destruction of the retina. Early diagnosis is still undermined due to the lack of access to sophisticated imaging tools, the lack of universal biomarkers, and screening regimens among the high-risk groups. The observed

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heterogeneity of patient reactions to current treatments makes the need to create personalized treatment approaches based on biomarkers significant.

The future research efforts should focus on new approaches that can be used to overcome these constraints. The emerging potential lines of research are in development of long-acting delivery vehicles, sustained-release anti-VEGF formulations, and combination therapies simultaneous targeting angiogenesis, inflammation and oxidative stress. The future of retinal architecture and functional capacity repair has a great potential in gene therapy, stem-cell-based regenerative therapies, and neuroprotective agents. Furthermore, the integration of artificial intelligence (AI) and predictive modeling into clinical processes can help diagnose earlier, optimize treatment plans, and have a more accurate control over the process of disease progression. Finally, by solving these gaps with precision medicine and innovation based on technology, ARMD can possibly change into a preventable and manageable chronic disease.

VIII. CONCLUSION

Age-Related Macular Degeneration (ARMD) remains a leading cause of visual impairment worldwide, yet recent advances have transformed its diagnosis and management. Current perspectives emphasize early detection through advanced imaging, biomarker identification, and AI-driven analysis. Anti-VEGF therapy has revolutionized wet ARMD treatment, while emerging complement inhibitors offer hope for dry ARMD. However, challenges persist, including treatment burden, variable response, and lack of curative options. Future developments are expected to focus on long-acting drug delivery systems, gene and cell therapies, and combination treatments that target multiple disease pathways. Integration of precision medicine, predictive modeling, and digital health tools will enable personalized and proactive management. As research continues to bridge gaps in understanding disease mechanisms, ARMD care is moving toward sustained vision preservation, improved patient quality of life, and the eventual goal of complete prevention or regeneration of retinal function.

Conflict of Interest
The authors have no conflict of interest

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Data Availability
All the data presented in this manuscript are original and have not been published elsewhere.

Authors' Contributions
The authors confirm contribution to the paper as follows: IH: Writing and reviewing the paper; SH: Study conception and design; TS & BR: Data Collection, MMI: Writing the paper. All authors reviewed the results and approved the final version of the manuscript.

REFERENCES

1. Dehghan, S., et al., *Human-induced pluripotent stem cells-derived retinal pigmented epithelium, a new horizon for cells-based therapies for age-related macular degeneration.* Stem Cell Res Ther, 2022. **13**(1): p. 217.
2. Md. Moidul, I., K. Jyotibikash, and R. Sarjana, *Upholding Data Integrity in the Pharmaceutical Industry.* Applied Drug Research, Clinical Trials and Regulatory Affairs, 2025. **11**: p. 1-4.
3. Somasundaran, S., et al., *Retinal pigment epithelium and age-related macular degeneration: A review of major disease mechanisms.* Clin Exp Ophthalmol, 2020. **48**(8): p. 1043-1056.
4. Md Moidul, I., et al., *Solid Lipid Nanoparticles: Preparation Methods and Therapeutic Potential in Oral Cancer.* Clinical Cancer Drugs, 2025. **11**: p. 118-132.
5. M, K. and M. G, *A comprehensive review on early detection of drusen patterns in age-related macular degeneration using deep learning models.* Photodiagnosis and Photodynamic Therapy, 2025. **51**: p. 104454.
6. Lee, K.S., et al., *Cellular senescence in the aging retina and developments of senotherapies for age-related macular degeneration.* J Neuroinflammation, 2021. **18**(1): p. 32.
7. Md Moidul, I. and R. Sarjana, *Revolutionizing Oral Cancer Treatment: Immunotherapeutic Approaches.* Current Cancer Therapy Reviews, 2025. **21**(3): p. 278-286.

| ISSN: 2455-1864 | www.ijrai.org | editor@ijrai.org | A Bimonthly, Scholarly and Peer-Reviewed Journal |

||Volume 8, Issue 6, November–December 2025||

DOI:10.15662/IJRAI.2025.0806015

8. Ismail, F., et al., *Association of ARMS2, HTRA1 and CFH genes polymorphisms in patients with age-related macular degeneration in the Malaysian population.* Egyptian Journal of Medical Human Genetics, 2024. **25**(1): p. 79.
9. Vyawahare, H. and P. Shinde, *Age-Related Macular Degeneration: Epidemiology, Pathophysiology, Diagnosis, and Treatment.* Cureus, 2022. **14**(9): p. e29583.
10. Md Moidul, I. and R. Sarjana, *Artificial Intelligence in the Development and Optimization of Nanocarriers.* Current Nanoscience, 2025. **21**(3): p. 355-357.
11. Edarous, D.H., et al., *Epidemiology of age-related macular degeneration among elderly in geriatric homes, East Cairo, Egypt.* BMC Public Health, 2025. **25**(1): p. 2495.
12. Md Moidul, I., et al., *Targeting Cancer with Graphene Quantum Dots (GQDs): A Novel Approach.* Clinical Cancer Drugs, 2025. **11**: p. 1-11.
13. Wang, P., et al., *Global burden and cross-country inequalities in diseases associated with high body mass index from 1990 to 2019: Result from the Global Burden of Disease Study 2019.* J Glob Health, 2024. **14**: p. 04200.
14. Md Moidul, I., et al., *Emerging Trends in Novel Drug Delivery Systems for the Effective Treatment of Oral Cancer.* Current Cancer Therapy Reviews, 2025. **21**(5): p. 679-694.
15. Mukherjee, S., et al., *Validation of Deep Learning–Based Automatic Retinal Layer Segmentation Algorithms for Age-Related Macular Degeneration with 2 Spectral-Domain OCT Devices.* Ophthalmology Science, 2025. **5**(3): p. 100670.
16. Huang, Y., et al., *Global, regional, and national burden of age-related macular degeneration, 1990-2019: an age-period-cohort analysis based on the Global Burden of Disease 2019 Study.* Front Public Health, 2024. **12**: p. 1486168.
17. Md Moidul, I., V. Abhishek, and R. Sarjana, *PAMAM Dendrimers: Revolutionizing the Targeted Cancer Therapy.* Clinical Cancer Drugs, 2024. **10**: p. 12-15.
18. Singh, R.R. and P. Maurya, *Visual impairment and falls among older adults and elderly: evidence from longitudinal study of ageing in India.* BMC Public Health, 2022. **22**(1): p. 2324.
19. Islam, M.M., et al., *Formulation Development, Box-Behnken Design-Based Optimization and Evaluation of Cisplatin-Loaded Chitosan Nanoparticles Embedded in Mucoadhesive Buccal Film for Targeted Oral Cancer Therapy.* Journal of Pharmaceutical Innovation, 2025. **20**(6): p. 276.
20. *Global burden of vision impairment due to age-related macular degeneration, 1990-2021, with forecasts to 2050: a systematic analysis for the Global Burden of Disease Study 2021.* Lancet Glob Health, 2025. **13**(7): p. e1175-e1190.
21. Chaudhuri, M., et al., *Age-Related Macular Degeneration: An Exponentially Emerging Imminent Threat of Visual Impairment and Irreversible Blindness.* Cureus, 2023. **15**(5): p. e39624.
22. Islam, M.H., et al., *Graphene and CNT-based smart fiber-reinforced composites: a review.* Advanced Functional Materials, 2022. **32**(40): p. 2205723.
23. Ochoa Hernández, M.E., et al., *Role of Oxidative Stress and Inflammation in Age Related Macular Degeneration: Insights into the Retinal Pigment Epithelium (RPE).* Int J Mol Sci, 2025. **26**(8).
24. Islam, M., A. Vashishat, and M. Kumar, *Advancements beyond limb loss: exploring the intersection of AI and BCI in prosthetic evaluation.* Current Pharmaceutical Design, 2024. **30**(35): p. 2749-2752.
25. Maurya, M., et al., *Oxidative stress in retinal pigment epithelium degeneration: from pathogenesis to therapeutic targets in dry age-related macular degeneration.* Neural Regen Res, 2023. **18**(10): p. 2173-2181.
26. Armento, A., M. Ueffing, and S.J. Clark, *The complement system in age-related macular degeneration.* Cellular and Molecular Life Sciences, 2021. **78**(10): p. 4487-4505.
27. Zhao, B., et al., *Oxidative stress and epigenetics in ocular vascular aging: an updated review.* Molecular Medicine, 2023. **29**(1): p. 28.
28. Harmanjot, K., et al., *Exosomes in Oncology: Advancing Gene Therapy and Targeted Drug Delivery Systems.* Clinical Cancer Drugs, 2025. **11**: p. 58-71.
29. Heesterbeek, T.J., et al., *Risk factors for progression of age-related macular degeneration.* Ophthalmic Physiol Opt, 2020. **40**(2): p. 140-170.
30. Williams, B.L., et al., *Chromosome 10q26-driven age-related macular degeneration is associated with reduced levels of HTRA1 in human retinal pigment epithelium.* Proc Natl Acad Sci U S A, 2021. **118**(30).
31. García-Onrubia, L., et al., *Matrix Metalloproteinases in Age-Related Macular Degeneration (AMD).* Int J Mol Sci, 2020. **21**(16).
32. Ruan, Y., S. Jiang, and A. Gericke, *Age-Related Macular Degeneration: Role of Oxidative Stress and Blood Vessels.* Int J Mol Sci, 2021. **22**(3).
33. Seddon, J.M., D. De, and B. Rosner, *The role of nutritional factors in transitioning between early, mid, and late stages of age-related macular degeneration: prospective longitudinal analysis.* Am J Clin Nutr, 2024. **120**(6): p. 1387-1398.

| ISSN: 2455-1864 | www.ijrai.org | editor@ijrai.org | A Bimonthly, Scholarly and Peer-Reviewed Journal |

||Volume 8, Issue 6, November–December 2025||

DOI:10.15662/IJRAI.2025.0806015

34. Saigal, K., et al., *Modifiable Lifestyle Risk Factors and Strategies for Slowing the Progression of Age-Related Macular Degeneration.* Vision (Basel), 2025. **9**(1).
35. Moidul Islam, J., et al., *Therapeutic Trends in Diabetes Management: A Review on Oral Hypoglycemic Agents (OHAs) Utilization in Tertiary Care.* Cardiovascular & Hematological Disorders-Drug Targets, 2025. **25**: p. 1-17.
36. Roque, A.B., et al., *The effects of age-related macular degeneration on quality of life in a Brazilian population.* International Journal of Retina and Vitreous, 2021. **7**(1): p. 20.
37. Wong, J.H.C., et al., *Exploring the pathogenesis of age-related macular degeneration: A review of the interplay between retinal pigment epithelium dysfunction and the innate immune system.* Front Neurosci, 2022. **16**: p. 1009599.
38. Marchesi, N., et al., *Different Therapeutic Approaches for Dry and Wet AMD.* Int J Mol Sci, 2024. **25**(23).
39. Bodaghi, A., N. Fattahi, and A. Ramazani, *Biomarkers: Promising and valuable tools towards diagnosis, prognosis and treatment of Covid-19 and other diseases.* Heliyon, 2023. **9**(2): p. e13323.
40. Langlo, C.S., A. Amin, and S.S. Park, *Optical coherence tomography retinal imaging: narrative review of technological advancements and clinical applications.* Ann Transl Med, 2025. **13**(2): p. 17.
41. Ugarte, M., *Pseudophakic Cystoid Macular Oedema*, in *Cataract Surgery: Pearls and Techniques*, C. Liu and A. Shalaby Bardan, Editors. 2021, Springer International Publishing: Cham. p. 173-189.
42. Schmitz-Valckenberg, S., et al., *Fundus autofluorescence imaging.* Progress in Retinal and Eye Research, 2021. **81**: p. 100893.
43. Okubo, A., et al., *Numerous retinal pigment epithelial elevations and drusen associated with unusual dilated choroidal vessels seen at choriocapillaris level in macular area.* Am J Ophthalmol Case Rep, 2020. **18**: p. 100634.
44. Schultz, N.M., et al., *Global Burden of Dry Age-Related Macular Degeneration: A Targeted Literature Review.* Clin Ther, 2021. **43**(10): p. 1792-1818.
45. Newman, N.J. and V. Biousse, *Approach to Vision Loss.* Continuum, 2025. **31**(2): p. 328-355.
46. Chen, L., et al., *Stages of Drusen-Associated Atrophy in Age-Related Macular Degeneration Visible via Histologically Validated Fundus Autofluorescence.* Ophthalmol Retina, 2021. **5**(8): p. 730-742.
47. Fragiotta, S., et al., *Structural biomarkers influencing drusenoid pigment epithelial detachment lifecycle and the development of late macular degeneration.* Ophthalmology Science, 2025: p. 100977.
48. Chen, L., et al., *Fundus Autofluorescence in Neovascular Age-Related Macular Degeneration: A Clinicopathologic Correlation Relevant to Macular Atrophy.* Ophthalmology Retina, 2021. **5**(11): p. 1085-1096.
49. Kaminska, K., et al., *Bi-allelic variants in three genes encoding distinct subunits of the vesicular AP-5 complex cause hereditary macular dystrophy.* The American Journal of Human Genetics, 2025. **112**(4): p. 808-828.
50. Fernandes, A.R., et al., *Exudative versus Nonexudative Age-Related Macular Degeneration: Physiopathology and Treatment Options.* Int J Mol Sci, 2022. **23**(5).
51. Grotz, S., et al., *Early disruption of photoreceptor cell architecture and loss of vision in a humanized pig model of usher syndromes.* EMBO Mol Med, 2022. **14**(4): p. e14817.
52. Hang, A., et al., *Intravitreal Anti-Vascular Endothelial Growth Factor Therapies for Retinal Disorders.* Pharmaceuticals (Basel), 2023. **16**(8).
53. Lombardo, M., et al., *Aflibercept, ranibizumab, and bevacizumab for macular neovascularization secondary to age-related macular degeneration: a retrospective OCT-angiography study.* International Journal of Retina and Vitreous, 2025. **11**(1): p. 111.
54. Rowe, L.W., et al., *Beyond the injection: delivery systems reshaping retinal disease management.* Expert Opin Pharmacother, 2025. **26**(8): p. 939-952.
55. Garg, S.J. and M. Hadziahmetovic, *Verteporfin Photodynamic Therapy for the Treatment of Chorioretinal Conditions: A Narrative Review.* Clin Ophthalmol, 2024. **18**: p. 1701-1716.
56. Lee, J., et al., *Seven-year outcomes of combined treatment of anti-vascular endothelial growth factor with photodynamic therapy for polypoidal choroidal vasculopathy; according to polypoidal lesion regression.* BMC Ophthalmology, 2023. **23**(1): p. 511.
57. Flores, R., et al., *Age-Related Macular Degeneration: Pathophysiology, Management, and Future Perspectives.* Ophthalmologica, 2021. **244**(6): p. 495-511.
58. Wallsh, J.O. and R.P. Gallemore, *Anti-VEGF-Resistant Retinal Diseases: A Review of the Latest Treatment Options.* Cells, 2021. **10**(5).
59. Chew, E.Y., et al., *Long-term Outcomes of Adding Lutein/Zeaxanthin and ω-3 Fatty Acids to the AREDS Supplements on Age-Related Macular Degeneration Progression: AREDS2 Report 28.* JAMA Ophthalmology, 2022. **140**(7): p. 692-698.
60. Ma, L., et al., *Effect of Lutein and Zeaxanthin on Macular Pigment and Visual Function in Patients with Early Age-Related Macular Degeneration.* Ophthalmology, 2012. **119**.

| ISSN: 2455-1864 | www.ijrai.org | editor@ijrai.org | A Bimonthly, Scholarly and Peer-Reviewed Journal |

||Volume 8, Issue 6, November–December 2025||

DOI:10.15662/IJRAI.2025.0806015

61. DelGuidice, C.E., et al., *Optimization and method validation for the quantitative analysis of a monoclonal antibody and its related fab fragment in human plasma after intravitreal administration, using LC–MS/MS.* Journal of Chromatography B, 2021. **1164**: p. 122474.
62. Zong, Y., et al., *Ophthalmic Use of Targeted Biologics in the Management of Intraocular Diseases: Current and Emerging Therapies.* Antibodies (Basel), 2024. **13**(4).
63. Wei, X., et al., *GB10, a novel antibody fusion protein targeting VEGF/Ang-2, exhibits promising therapeutic efficacy for neovascular eye diseases.* Biomedicine & Pharmacotherapy, 2025. **192**: p. 118690.
64. Coney, J.M., et al., *Switching to brolucizumab: injection intervals and visual, anatomical and safety outcomes at 12 and 18 months in real-world eyes with neovascular age-related macular degeneration.* Int J Retina Vitreous, 2023. **9**(1): p. 8.
65. Panos, G.D., et al., *Faricimab: Transforming the Future of Macular Diseases Treatment - A Comprehensive Review of Clinical Studies.* Drug Des Devel Ther, 2023. **17**: p. 2861-2873.
66. Wang, X., et al., *Molecular Targeting of Intracellular Bacteria by Homotypic Recognizing Nanovesicles for Infected Pneumonia Treatment.* Biomater Res, 2025. **29**: p. 0172.
67. Cruz-Pimentel, M. and L. Wu, *Complement Inhibitors for Advanced Dry Age-Related Macular Degeneration (Geographic Atrophy): Some Light at the End of the Tunnel?* J Clin Med, 2023. **12**(15).
68. Xu, M., et al., *Progress and Challenges of Anti-VEGF Agents and Their Sustained-Release Strategies for Retinal Angiogenesis.* Drug Des Devel Ther, 2022. **16**: p. 3241-3262.
69. Hussain, R.M., et al., *Vascular Endothelial Growth Factor Antagonists: Promising Players in the Treatment of Neovascular Age-Related Macular Degeneration.* Drug Des Devel Ther, 2021. **15**: p. 2653-2665.
70. Fabre, M., et al., *Recent Advances in Age-Related Macular Degeneration Therapies.* Molecules, 2022. **27**(16).
71. Ranade, S.V., et al., *The Port Delivery System with ranibizumab: a new paradigm for long-acting retinal drug delivery.* Drug Deliv, 2022. **29**(1): p. 1326-1334.
72. Tsung, T.H., Y.H. Chen, and D.W. Lu, *Updates on Biodegradable Formulations for Ocular Drug Delivery.* Pharmaceutics, 2023. **15**(3).
73. Wu, K.Y., et al., *Suprachoroidal Injection: A Novel Approach for Targeted Drug Delivery.* Pharmaceuticals (Basel), 2023. **16**(9).
74. Hushmandi, K., et al., *Gene therapy for age-related macular degeneration: a promising frontier in vision preservation.* Cell Commun Signal, 2025. **23**(1): p. 233.
75. Ahmad, I., *CRISPR/Cas9-A Promising Therapeutic Tool to Cure Blindness: Current Scenario and Future Prospects.* Int J Mol Sci, 2022. **23**(19).
76. Hassan, M.S.A., et al., *Targeting the Eye: RNA-Based Therapies, Interferences, and Delivery Strategies.* Pharmaceutics, 2025. **17**(10).
77. Chang, Y.J., et al., *CRISPR editing demonstrates rs10490924 raised oxidative stress in iPSC-derived retinal cells from patients with ARMS2/HTRA1-related AMD.* Proc Natl Acad Sci U S A, 2023. **120**(19): p. e2215005120.
78. Huang, J., et al., *Adeno-Associated Virus Vectors in Retinal Gene Therapy: Challenges, Innovations, and Future Directions.* Biomolecules, 2025. **15**(7).
79. Blasiak, J., et al., *A New Generation of Gene Therapies as the Future of Wet AMD Treatment.* Int J Mol Sci, 2024. **25**(4).
80. Gao, Y., et al., *Recent advances in the application of artificial intelligence in age-related macular degeneration.* BMJ Open Ophthalmol, 2024. **9**(1).
81. Liu, Y.V., et al., *Quantifiable In Vivo Imaging Biomarkers of Retinal Regeneration by Photoreceptor Cell Transplantation.* Transl Vis Sci Technol, 2020. **9**(7): p. 5.
82. Rajanala, K., F. Dotiwala, and A. Upadhyay, *Geographic atrophy: pathophysiology and current therapeutic strategies.* Front Ophthalmol (Lausanne), 2023. **3**: p. 1327883.
83. Parmar, U.P.S., et al., *Artificial Intelligence (AI) for Early Diagnosis of Retinal Diseases.* Medicina (Kaunas), 2024. **60**(4).
84. Bai, J., et al., *Accuracy and feasibility with AI-assisted OCT in retinal disorder community screening.* Front Cell Dev Biol, 2022. **10**: p. 1053483.
85. Gopalakrishnan, S., S. Velu, and R. Raman, *Low-vision intervention in individuals with age-related macular degeneration.* Indian J Ophthalmol, 2020. **68**(5): p. 886-889.
86. Leat, S., *2020 CAO Clinical Practice Guideline: Optometric Low Vision Rehabilitation FULL GUIDELINES.* Canadian Journal of Optometry, 2020. **82**(1): p. 19-62.

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||Volume 8, Issue 6, November–December 2025||

DOI:10.15662/IJRAI.2025.0806015

87. Wolffsohn, J. and R. Peterson, *A review of current knowledge on Electronic Vision Enhancement Systems for the visually impaired.* Ophthalmic & physiological optics : the journal of the British College of Ophthalmic Opticians (Optometrists), 2003. **23**: p. 35-42.
88. Deemer, A.D., J.E. Goldstein, and P.Y. Ramulu, *Approaching rehabilitation in patients with advanced glaucoma.* Eye, 2023. **37**(10): p. 1993-2006.
89. Rák, T., et al., *Low Vision Rehabilitation and Eye Exercises: A Comprehensive Guide to Tertiary Prevention of Diabetic Retinopathy.* Life (Basel), 2025. **15**(6).
90. Degirmenci Oz, S., E. Sezer, and D. Yildirim, *The effect of occupational therapy on anxiety, depression, and psychological well-being in older adults: a single-blind randomized-controlled study.* European Geriatric Medicine, 2024. **15**(1): p. 217-223.
91. van Nispen, R.M., et al., *Low vision rehabilitation for better quality of life in visually impaired adults.* Cochrane Database Syst Rev, 2020. **1**(1): p. Cd006543.
92. Than, J., et al., *Teleophthalmology and retina: a review of current tools, pathways and services.* Int J Retina Vitreous, 2023. **9**(1): p. 76.
93. Wang, Z., J. Kempen, and G. Luo, *Using Smartphones to Enhance Vision Screening in Rural Areas: Pilot Study.* JMIR Form Res, 2024. **8**: p. e55270.
94. Daich Varela, M., et al., *Digital health and wearable devices for retinal disease monitoring.* Graefes Arch Clin Exp Ophthalmol, 2025. **263**(2): p. 279-289.
95. Faes, L., L. Bachmann, and D. Sim, *Home monitoring as a useful extension of modern tele-ophthalmology.* Eye, 2020. **34**.
96. Merino, M., et al., *Value-based digital health: A systematic literature review of the value elements of digital health care.* DIGITAL HEALTH, 2024. **10**: p. 20552076241277438.