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REVIEW article

From pathophysiology to rehabilitation: Addressing low vision in diabetic retinopathy

Maduabuchukwu I. Nkollo [1, 2 *], **Nnaemeka A. Onwukwe** [2], **Edafe O. Emurotu** [1]
Helen Lucky-Udi [1], **Ayodeji E. Ige** [3], **Bobby I. Ebuehi** [1], **Franklin E. Kio** [2]
Anthony U. Megwas [4], **Afe V. Dania** [5], and **Canice C. Asonye** [6]

[1] Department of Optometry and Vision Science, Faculty of Allied Medical Sciences, Dennis Osadebay University, Anwai, Asaba, Delta State, Nigeria. [2] Department of Optometry, College of Medical and Health Sciences, Novena University, Ogume, Delta State, Nigeria. [3] Department of Optometry, Faculty of Life Sciences, University of Ilorin, Ilorin, Kwara State, Nigeria. [4] Department of Optometry, School of Health Technology, Federal University of Technology, Owerri, Imo State, Nigeria
[5] Department of Optometry, Faculty of Health Sciences, Bayelsa Medical University, Yenagoa, Bayelsa State, Nigeria
[6] Department of Low Vision and Rehabilitative Optometry, Faculty of Optometry, University of Benin, Benin City, Edo State, Nigeria
[*] Author to whom correspondence should be addressed

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Abstract: Diabetic Retinopathy (DR) is a major microvascular complication of diabetes mellitus and one of the leading causes of low vision and blindness globally. As the prevalence of diabetes increases, DR-related visual impairment poses significant clinical and public health challenges. This review explores the pathophysiological mechanisms underlying DR, its contribution to low vision, and rehabilitation strategies to improve patient outcomes. Relevant peer-reviewed articles, guidelines, and reports from 1990 to 2024 were reviewed from databases including PubMed, Scopus, and Google Scholar. The focus was on studies addressing the pathogenesis of DR, the prevalence of DR-related low vision, and evidence-based rehabilitation interventions. The pathophysiology of DR involves chronic hyperglycemia, oxidative stress, microvascular damage, and breakdown of the blood-retinal barrier, leading to retinal ischemia, neovascularization, and irreversible vision loss. DR accounts for an estimated 4.8% of global blindness, with rising prevalence in low- and middle-income countries. While medical and surgical treatments, such as laser photocoagulation, intravitreal anti-VEGF therapy, and vitrectomy, slow disease progression, many patients develop irreversible visual impairment. Rehabilitation through optical aids, electronic devices, orientation and mobility training, and psychosocial support significantly enhances quality of life. Addressing low vision in DR requires a dual approach: early detection and intervention to prevent progression, and comprehensive rehabilitation services to optimize residual vision. Integrating low vision care into diabetes and ophthalmology services is essential to reduce disability and improve functional independence in affected individuals.

Introduction

Diabetes mellitus (DM) has emerged as one of the most challenging global health concerns of the 21st century, with an ever-increasing prevalence across developed and developing nations. It is a chronic metabolic disorder characterized by hyperglycemia resulting from impaired insulin secretion, insulin resistance, or a combination of

both [1]. The long-term consequences of DM extend far beyond glycemic imbalance, as it predisposes individuals to a spectrum of systemic complications. These include cardiovascular disease, nephropathy, neuropathy, and ocular pathologies, all of which significantly impair quality of life and increase the risk of disability [2]. Among the ocular complications of DM, Diabetic Retinopathy (DR) stands out as the leading cause of preventable blindness and visual impairment globally, particularly in working-age adults. It develops as a microvascular complication of chronic hyperglycemia, involving progressive damage to the retinal vasculature that ultimately compromises retinal function. The condition progresses through well-recognized stages, from non-proliferative changes characterized by microaneurysms and hemorrhages to proliferative disease marked by neovascularization and retinal detachment [3]. In addition, macular edema, a frequent manifestation of DR, directly contributes to central vision loss [4]. The relationship between DR and low vision is complex and multifaceted. Low vision arises not only from structural damage to the retina but also from delayed diagnosis, poor DM management, and limited access to timely ophthalmic interventions in many low- and middle-income countries. The World Health Organization (WHO) has classified visual impairment and low vision using standardized criteria, which serve as an essential framework for understanding the severity of visual disability associated with DR [5]. Globally, the burden of DR-related low vision is substantial, with epidemiological studies estimating that about one-third of individuals with DM develop some form of retinopathy during their lifetime, and a significant proportion progress to vision-threatening stages [4]. In Sub-Saharan Africa and other resource-limited settings, the prevalence is rising due to increasing rates of DM, coupled with inadequate screening programs and shortages of trained eye-care professionals [6]. Given these challenges, the exploration of low vision aids and rehabilitative strategies becomes paramount. Advances in optical devices, electronic technologies, and community-based interventions hold promise in improving functional vision, independence, and quality of life for individuals with DR-induced low vision [7]. This review, therefore, aims to critically explore the pathophysiology of DR in the context of low vision, discuss the WHO's classification of low vision, highlight prevalence data of DR-related visual impairment, and propose possible solutions through the application of existing low vision aids. By examining these dimensions, the review underscores the urgent need for integrated approaches that combine effective DM management, timely eye care, and rehabilitation services to mitigate the burden of DR-associated low vision.

Materials and methods

This review was conducted using a narrative approach, synthesizing evidence from peer-reviewed journals, institutional reports, and global health databases. The methodology comprised the following steps:

Literature search strategy: A systematic search of electronic databases, including PubMed, Scopus, Web of Science, Google Scholar, and the WHO Global Health Observatory, was carried out. The search covered studies published between 2000 and 2025 to capture historical and recent perspectives on DR, low vision, and low vision rehabilitation. Keywords and Medical Subject Headings terms used included: "Diabetic Retinopathy", "Low vision" OR "visual impairment", "Pathophysiology of DR", "Low vision aids" OR "vision rehabilitation", "Assistive technology for low vision", and "Prevalence of DR-related blindness." Boolean operators ("AND," "OR") were applied to refine search results, and reference lists of retrieved articles were hand-searched for additional relevant publications.

Inclusion and exclusion criteria: Inclusion: Peer-reviewed articles, systematic reviews, meta-analyses, clinical trials, observational studies, and WHO/NGO reports that addressed DR, low vision prevalence, classification of visual impairment, or the role of low vision aids. Only publications in English were considered. Exclusion: Conference abstracts without full texts, duplicate studies, non-peer-reviewed commentaries, and studies not directly related to DR-induced low vision.

Data extraction and synthesis: Key information extracted from eligible sources included: Pathophysiology of diabetic retinopathy and its relationship to visual impairment, Global and regional prevalence of low vision attributable to DR, WHO classification of visual impairment, types and effectiveness of low vision aids (optical, electronic, non-optical, and adaptive technologies), and barriers to access and utilization of rehabilitation services. Findings were synthesized thematically under predefined subheadings to ensure a coherent narrative. Where possible, prevalence data and outcome measures were cross-compared between studies to identify consistencies and disparities.

Quality assurance: Priority was given to high-impact journals, systematic reviews, and WHO reports to ensure credibility. Discrepancies between studies were critically analyzed, and consensus views were highlighted.

Pathophysiology of diabetic retinopathy

The pathogenesis of DR is multifactorial, involving metabolic, biochemical, and vascular changes resulting from prolonged hyperglycemia. These mechanisms interact to progressively damage the retinal microvasculature and neural tissue, ultimately leading to vision impairment and blindness if untreated.

Chronic hyperglycemia: Persistent elevation of blood glucose levels is the central initiating factor in DR. Hyperglycemia triggers multiple biochemical pathways, including the polyol pathway, protein kinase C activation, and the hexosamine pathway, all of which contribute to oxidative stress and inflammation. Moreover, chronic hyperglycemia promotes the accumulation of advanced glycation end-products (AGEs), which cross-link with proteins in the vascular basement membrane, stiffening and impairing vessel function. These processes weaken the structural and functional integrity of retinal vessels [3, 8].

Microvascular damage: The retinal microvasculature is particularly vulnerable to metabolic stress. Hyperglycemia-induced oxidative stress leads to endothelial cell injury and pericyte apoptosis (loss of supportive cells around capillaries). This compromises the blood-retinal barrier (BRB), causing leakage of plasma proteins, lipids, and fluids into the retinal tissue. Clinically, this manifests as hard exudates and retinal edema, which distort the retinal architecture [9, 10].

Capillary occlusion and ischemia: The thickening of the capillary basement membrane and pericyte dropout narrows the capillary lumen, predisposing vessels to occlusion. As perfusion diminishes, localized ischemic zones develop within the retina. This ischemia is evident in fluorescein angiography as areas of capillary non-perfusion. Microaneurysms, the earliest visible clinical sign of DR, result from weakened capillary walls and contribute further to retinal leakage and hemorrhage [4, 11].

Neovascularization: In response to ischemia, retinal cells, Müller cells, and retinal pigment epithelial cells secrete vascular endothelial growth factor (VEGF) and pro-angiogenic cytokines. VEGF promotes the proliferation of fragile, abnormal new blood vessels on the surface of the retina and optic disc. While initially compensatory, these vessels are structurally weak and prone to rupture, leading to recurrent vitreous hemorrhages. The fibrous tissue that accompanies neovascularization can contract, pulling on the retina and causing tractional retinal detachment, one of the most severe sight-threatening complications of proliferative diabetic retinopathy (PDR) [12, 13].

Macular edema: Diabetic macular edema (DME) is a hallmark of vision loss in non-proliferative and PDR. It results from leakage of fluid into the macula, the central part of the retina responsible for sharp vision. The breakdown of the inner BRB, coupled with VEGF-mediated vascular permeability, leads to intraretinal and subretinal fluid accumulation. DME is the most common cause of moderate vision loss in diabetic patients and may occur at any stage of DR [10, 14]. Ultimately, these processes culminate in progressive vision loss that, if untreated, leads to irreversible low vision or blindness.

WHO classification of low vision

This classification underscores the functional limitations DR patients face, as vision deteriorates from moderate impairment to severe visual loss.

Table 1: WHO classification of Low Vision (WHO, 2005)

Category	Visual acuity (in the better-seeing eye)	Visual field
Normal vision	6/6 - 6/18	Normal
Moderate visual impairment/low vision	Less than 6/18 - 6/60	Constricted (≤ 60°)
Severe visual impairment, low vision	Less than 6/60 - 3/60	Very constricted (≤ 20)
Blindness	Less than 3/60	< 10° in the better seeing eye

Prevalence of low vision caused by diabetic retinopathy: DR is one of the leading causes of preventable visual impairment and blindness worldwide. According to global estimates, DR accounts for approximately 4.8% of blindness globally, representing a significant public health and socioeconomic burden, particularly among working-age adults [15]. Globally, it is estimated that 30-40% of people living with DM develop some form of DR, with nearly 10% progressing to vision-threatening diabetic retinopathy (VTDR), including PDR and DME [4, 16]. A meta-analysis reported a global prevalence of DR among diabetic individuals of 22.27%, with VTDR at 6.17% and clinically significant macular edema (CSME) at 4.07% [16]. The absolute burden is rising rapidly. In 2020, approximately 103 million adults were living with DR, including 28.5 million with VTDR. By 2045, these figures are projected to increase to 161 million DR cases and 44.8 million VTDR cases [16,17]. The Global Burden of Disease Study further reports that in 2021, there were 2.85 million cases of DR-related visual impairment and 250, 117 years lived with disability - a threefold increase since 1990 [18]. Regional variations are pronounced. DR prevalence is highest in Africa (~36%), North America and the Caribbean (~33%), and lowest in South and Central America (~13%) [16]. In India, recent national estimates revealed that 16.9% of people with DM have DR, while 3.6% are at immediate risk of blindness [19]. In Sub-Saharan Africa, the prevalence of DR-related visual impairment is steadily increasing, driven by poor DM control, limited screening, and lack of access to specialized eye care services [20]. Contributing factors to the rising burden include increasing DM prevalence, urbanization, aging populations, and inequities in healthcare access. Unless effective screening, timely interventions, and integrated DM management programs are scaled up, DR-related visual impairment will continue to increase, particularly in resource-limited regions.

Possible solutions: Role of low vision aids: While medical and surgical interventions such as laser photocoagulation, intravitreal anti-VEGF injections, and vitrectomy remain central in the management of DR, a significant proportion of patients still experience irreversible visual impairment. For these individuals, low vision rehabilitation plays a pivotal role in enhancing residual vision, promoting functional independence, and improving overall quality of life [5, 21].

Optical aids: Optical low vision devices are often the first line of rehabilitation tools. These include handheld magnifiers, stand magnifiers, high-addition spectacles, and telescopes for distance vision. Handheld and stand magnifiers allow individuals to engage in near tasks such as reading, sewing, and identifying medication labels. High-addition spectacles provide continuous magnification for sustained reading, while telescopic systems improve distance viewing, making it easier to recognize faces, watch television, and navigate the environment. Proper training in their use maximizes effectiveness and reduces visual fatigue [22].

Electronic aids: Technological advances have revolutionized low vision care through electronic magnification systems such as closed-circuit televisions, desktop and portable video magnifiers, and screen readers. These

devices provide adjustable magnification, contrast enhancement, and text-to-speech conversion, enabling users to perform tasks that would otherwise be impossible. Although electronic aids are often more expensive than traditional optical devices, they offer superior versatility and adaptability to different tasks [23].

Non-optical aids: Non-optical aids complement optical and electronic devices by reducing visual demands. These include high-contrast printed materials, large-print books, tactile markers for appliances, and improved lighting systems. Orientation and mobility training, often led by vision rehabilitation specialists, empowers individuals with DR-related low vision to navigate safely and confidently in familiar and unfamiliar environments [24].

Adaptive and assistive technology: Modern digital innovations have further expanded possibilities for individuals with low vision. Smartphones and tablets now come equipped with accessibility features such as screen magnifiers, voice-over functions, text-to-speech converters, and high-contrast display settings. Artificial intelligence (AI)-based reading devices, wearable electronic glasses, and voice-assisted navigation tools provide real-time assistance for reading, object recognition, and mobility [25, 26]. These solutions bridge the gap between visual impairment and independence, especially for younger and tech-savvy individuals.

Integration and challenges: The successful integration of low vision aids requires individualized assessment, patient education, and continuous training. Despite their proven benefits, accessibility, affordability, and awareness remain significant barriers, particularly in low- and middle-income countries where healthcare systems often prioritize curative interventions over rehabilitation services. Efforts to expand public health policies, subsidize assistive technologies, and strengthen community-based low vision programs are essential to ensure that individuals living with DR-related vision loss are not left behind [5, 27].

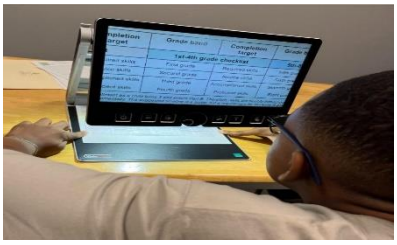

Figure 1: The Video magnifier or CCTV (*source: https://www.pathstoliteracy.org)*

Figure 2: The Handheld Magnifier (*source: https://www.ebay.com)*

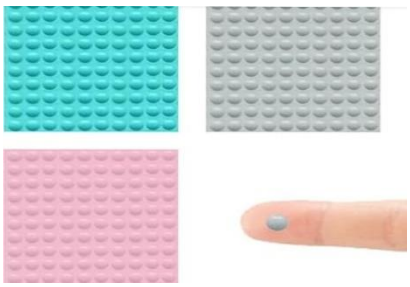

Figure 3: Tactile Markers (*source:/https://market.rivendalea.com/product-p-453398.html*

Figure 4: The Telescope *(https://www.lowvisiontn.com/low-vision-eye-diseases/macular-degeneration/low-vision-glasses/)*

Clinical protocol for rehabilitation of low vision in diabetic retinopathy

Step 1: Initial assessment: A comprehensive baseline assessment is critical to guide rehabilitation planning. This involves gathering case, medical, and ocular histories, as well as an evaluation of functional and psychosocial impact.

Case and medical history: Duration of DM: Longer duration of DM correlates with a higher risk of advanced DR [4]. Glycemic control: Review HbA1c, frequency of glucose monitoring, and adherence to therapy. Poor control predicts DR progression [28]. Systemic comorbidities: Hypertension, nephropathy, neuropathy, and cardiovascular disease accelerate DR progression [3, 29]. Medications and allergies: Documentation of systemic drugs (antihypertensives, insulin, oral hypoglycemics, anticoagulants) and adverse reactions is critical for safe management.

Ocular history: Prior DR treatments: Previous PRP, focal/grid laser, anti-VEGF injections, or vitrectomy influence visual prognosis [30, 31]. Past ocular surgeries: Cataract extraction and glaucoma procedures may affect current visual status. Family and refractive history: Family predisposition and refractive correction history provide context for rehabilitation planning.

Visual symptoms and functional complaints: Central vision: Metamorphopsia, reading difficulty, and facial recognition challenges [32]. Peripheral vision: Field constriction affecting mobility. Contrast sensitivity and glare: Reduced functional performance in daily life [33]. Color vision: Impairment may further limit quality of life [34].

Step 2: Impact on daily activities and quality of life: Occupational and ADLs: Vision impairment disrupts work, finances, and independence [35]. Psychosocial Concerns: Depression and anxiety are common in DR patients with low vision [36]. Support System: Family or caregiver support strongly predicts rehabilitation outcomes

Step 3: Perform a comprehensive eye examination: Best-corrected visual acuity (BCVA): Essential for quantifying residual vision [37]. Contrast sensitivity and Glare testing: Critical in DR for real-world performance deficits [38]. Visual field assessment: Perimetry identifies scotomas, guiding mobility training [39]. Retinal evaluation: Fundoscopy and OCT provide structural correlation with functional loss [40, 41]. Document functional vision goals. Patient-centered rehabilitation requires collaborative goal setting for reading, mobility, facial recognition, and independence in self-care [22].

Step 4: Stabilization of ocular condition: *Ophthalmology referral and management:* Laser Photocoagulation: PRP reduces severe vision loss in PDR [30]. Intravitreal Injections: Anti-VEGF therapy (ranibizumab, aflibercept, bevacizumab) is first-line for diabetic macular edema [42]. Vitrectomy: Effective in persistent vitreous hemorrhage and tractional detachment [43]. *Systemic optimization:* Glycemic control: Tight glucose regulation lowers DR risk [44]. Blood pressure control: < 130/80 mmHg reduces progression [29]. Lipid control: Statins and fibrates lower the risk of DME [45]. Lifestyle: Smoking cessation and exercise slow disease progression. *Multidisciplinary collaboration:* Coordination with endocrinology and primary care optimizes outcomes [3]. *Patient education:* Education fosters adherence and long-term visual stability [46].

Step 5: Low vision aid prescription: *Optical aids:* Handheld magnifiers: Portable and useful for spot reading of labels and price tags [47]. Stand magnifiers: Provide stability and hands-free use; helpful for patients with tremors [48]. High-addition near spectacles: Binocular magnifiers that allow free use of the hands for tasks such as writing or sewing [47]. Telescopic lenses: Enhance distance vision for recognizing faces or reading signs [50]. Filters and tints: Yellow, amber, or gray filters reduce glare and improve contrast [51]. *Non-optical aids:* High-contrast materials: Large-print books, bold-lined papers, and high-contrast keyboards [52]. Environmental modifications: Task lighting and glare reduction enhance functional vision [53]. Organizational strategies: Labeling and tactile markers for daily items improve independence [50]. *Electronic aids:* CCTV magnifiers and video magnifiers: Offer adjustable magnification and contrast [54]. Screen readers and text-to-speech software: Improve access to digital information [55]. Mobile accessibility apps: Smartphone tools assist with magnification, OCR, and navigation [56].

Step 6: Training and rehabilitation: *Device training:* Patients are taught correct use of magnifiers, telescopes, and electronic devices, with emphasis on working distance and scanning techniques [54]. *Orientation and Mobility:* Cane training and mobility instruction improve independence in navigating familiar and unfamiliar environments [51]. Spatial awareness exercises enhance auditory and tactile orientation cues [49]. *Occupational therapy:* Focuses on adaptive daily living skills such as cooking, grooming, and money management [52]. Workplace and educational modifications improve participation and productivity [49].

Step 7: Psychosocial support: Counseling: Addresses anxiety, depression, and frustration linked to vision loss [57]. Support groups: Provide peer interaction, emotional support, and community resources [52]. Vocational rehabilitation: Enables patients to adapt or retrain for alternative employment [53].

Step 8: Patient and caregiver education: Disease awareness: Patients and caregivers should understand DR progression and the importance of follow-up [47]. Lifestyle modifications: Emphasis on glycemic, blood pressure, and lipid control as vision-conservation strategies [12]. Home safety and ergonomics: Simple measures such as reducing clutter and enhancing lighting minimize falls and improve quality of life [58].

Step 9: Follow-up and monitoring: Regular reassessment: Every 3-6 months to evaluate functional vision, device effectiveness, and training outcomes [54]. Aid adjustments: Devices and rehabilitation strategies should be updated based on changing needs [55]. Systemic control reinforcement: Optimal control of diabetes and comorbidities supports ocular therapy outcomes [12]. Outcome documentation: Monitoring patient-reported quality of life and independence ensures holistic rehabilitation [21].

Recommendations

Early screening and intervention: Routine and timely screening for DR in all diabetic patients is crucial to detect early retinal changes before significant vision loss occurs. This can be achieved by integrating annual fundus examinations into standard DM management protocols. Community-based outreach programs and mobile eye clinics should also be encouraged to reach underserved populations, ensuring early intervention and reducing the risk of progression to irreversible low vision [4, 59].

Increased awareness: Public health education and awareness campaigns should be intensified to sensitize patients, caregivers, and the general population about the risks of DR and the need for strict glycemic control. Such campaigns should emphasize the role of lifestyle modification, adherence to prescribed medication, regular eye examinations, and the availability of low vision rehabilitation services. Involving community leaders, media platforms, and patient support groups can amplify the impact of these initiatives [5, 14].

Integration of low vision clinics: Low vision rehabilitation services should be mainstreamed into secondary and tertiary healthcare systems. Establishing dedicated low vision clinics within hospitals will allow for a multidisciplinary approach involving ophthalmologists, optometrists, occupational therapists, and rehabilitation specialists. This integration will ensure that patients with DR-related visual impairment have access to medical treatment and supportive rehabilitation tailored to their functional needs [60, 61].

Subsidization of low vision aids: The high cost of low vision aids (LVAs) such as magnifiers, telescopes, and electronic devices remains a barrier to their utilization, particularly in low- and middle-income countries. Governments, non-governmental organizations (NGOs), and international partners should collaborate to subsidize these aids or incorporate them into national health insurance schemes. This financial support will make rehabilitation services more equitable and accessible to patients across socioeconomic strata [58, 62].

Training of eye care professionals: Continuous professional development programs should be implemented to train ophthalmologists, optometrists, opticians, and vision rehabilitation specialists on modern strategies for managing low vision in DR patients. Training should include skills in low vision assessment, prescription of LVAs, counseling, and rehabilitation. Incorporating low vision care into medical and optometry curricula will also ensure that future eye care providers are well equipped to meet growing needs [63, 64].

Use of technology: Technological innovations, particularly smartphone-based applications, AI, and electronic visual aids, should be harnessed in low vision management. AI-driven retinal imaging can facilitate early DR detection, while accessible apps can enhance daily living for individuals with visual impairment. In resource-limited settings, affordable digital magnifiers and voice-enabled mobile technologies can provide cost-effective alternatives to conventional low vision devices. Partnerships with tech companies can further drive innovation and distribution of these solutions [45, 65].

Conclusion: Diabetic Retinopathy is not only a microvascular complication of diabetes but also a major driver of global low vision and blindness. The pathophysiological cascade-from hyperglycemia-induced vascular injury to ischemia, neovascularization, and macular edema-illustrates the intricate mechanisms leading to irreversible vision loss. With DR-related visual impairment on the rise, particularly in developing regions, proactive measures are urgently needed. WHO's classification of low vision underscores the severity of the problem, and epidemiological evidence confirms DR as a significant contributor to global visual disability. While curative treatments exist, they are often insufficient in restoring vision once extensive damage occurs. Hence, low vision rehabilitation and assistive aids are indispensable for enhancing independence and quality of life in affected individuals. A multi-pronged strategy-anchored on early screening, public health education, affordable access to low vision aids, and integration of rehabilitation services-remains the most effective approach to mitigate the burden of DR-related low vision. Ultimately, prioritizing preventive and rehabilitative interventions can reduce the global socio-economic impact of this vision-threatening condition.

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