

Original Research

Received 20 May 2026

Revised 05 July 2026

Accepted 20 July 2026

Natural Resources for Human Health 2026, Vol. 6 (13s): 179-209

KEYWORDS:

Diabetic retinopathy, lifestyle modification, Mediterranean diet, low-glycemic index, physical activity, sedentary behavior, sleep, depression, clinical pharmacy, progression.

Role of Lifestyle Modification in Preventing Diabetic Retinopathy – A Systematic Review DR and lifestyle

Muhammad Zahid Iqbal ¹, Amra Salahuddin ², Muhammad Umer Abdul Moiz ³, Mohd Faiyaz Khan ⁴, Sadaf Farooqui ⁴, Muhammad Shahid Iqbal ^{4*}, Shouket Ahmad Tilwani ⁵

¹ Department of Clinical Pharmacy, College of Pharmacy, King Khalid University, Abha 61421, Saudi Arabia

² Jinnah Postgraduate Medical Center (JPMC), Karachi, Pakistan

³ Jinnah Medical and Dental College, Karachi, Pakistan

⁴ Department of Clinical Pharmacy, College of Pharmacy, Prince Sattam bin Abdulaziz University, Al-Kharj 11942, Saudi Arabia.

⁵ Department of English, College of Science and Humanities, Prince Sattam bin Abdulaziz University, Al-Kharj 11942, Saudi Arabia.

*Corresponding author: Muhammad Shahid Iqbal ^{4*}, Department of Clinical Pharmacy, College of Pharmacy, Prince Sattam Bin Abdulaziz University, Al-Kharj 11942, Saudi Arabia

m.javed@psau.edu.sa

ABSTRACT: The vision-threatening stages of diabetic retinopathy (DR), which is still one of the main causes of vision loss, are mostly determined by progression rather than onset. The need for scalable adjuncts like lifestyle modification is highlighted by the fact that, despite their effectiveness, pharmaceutical and procedural therapy are expensive, time-consuming, and not always available. In order to discuss the implications for clinical pharmacy practice, it is necessary to systematically synthesize the evidence regarding the potential effects of lifestyle modification programs, dietary patterns, physical activity and sedentary time, alcohol and tobacco use, sleep/mental health, and multi-component programs on the progression of diabetes mellitus in adults with diabetes and pre-existing DR. In accordance with PRISMA 2020, we used MeSH and free-text phrases covering population, intervention, and progressive outcomes to search seven databases (Google Scholar, PubMed/MEDLINE, Web of Science, Scopus, ScienceDirect, ProQuest, and Cochrane Library). We searched in duplicate for eligible trials (adults with diabetes; retinal endpoints like development to proliferative DR/diabetic macular edema or therapy commencement; peer-reviewed designs). The MMAT 2018 was utilized to evaluate the methodological quality. The protocol was registered on PROSPERO. While culturally specific interventions improved glycemia and screening, increased physical activity and less sitting were associated with slower DR progression and fewer treatments across a variety of research designs. Omega-3-rich Mediterranean/low-GI meals were linked to a decreased incidence of DR that could cause blindness, but refined high-GI staples had the opposite effect. Depression and lack of sleep increased risk; modest alcohol consumption did not clearly improve development; and smoking results were mixed. Benefits most likely manifest as improved lipids, blood pressure, and HbA1c. A Mediterranean/low-GI diet, frequent exercise that breaks up sitting, and sleep/mental health assistance are all examples of lifestyle changes that regularly enhance conventional DR care and are achievable for pharmacist-led implementation, especially in areas with limited resources. To enhance causal inference, more studies using objective behavior measures and

standardized retinal endpoints are necessary, given the reliance on observational designs and potential exposure misclassification.

INTRODUCTION

One frequent and dangerous microvascular consequence of diabetes mellitus is diabetic retinopathy (DR), which affects over 589 million adult patients globally and continues to create a substantial demand on healthcare [1]. The most prevalent cause of reversible visual impairment and blindness in people of working age is DR, which has an impact on mental health, economic productivity, and quality of life [2]. The primary cause of this morbidity is not the acute development of diabetic retinopathy (DR), but the condition's progression from non-proliferative (NPDR) to proliferative stages, threatening vision: proliferative DR (PDR) with pathologic neovascularization in the retina, with fluid in the macula due to diabetic macular edema (DME) [3]. In clinical usage, the progression of diabetic retinopathy is typically acknowledged when patients progress from early to vision-threatening stages. Going from non-proliferative retinopathy to proliferative retinopathy and acquiring diabetic macular edema are two examples of progression, or the need for intervention with treatments like laser or intravitreal injections [4][5].

Sight-saving methods including laser photocoagulation and intravitreal anti-VEGF therapy are paired with strict glycemic blood pressure and cholesterol control as the current standard of care for managing the course of DR [6]. Although these treatments are advantageous, they have considerable limitations, including significant cost [7], restricted access, particularly in LMICs (low- and middle-income countries) [8] substantial reoccurrence requiring continuous treatment [9], excessive burden for the patient [10], and a partial response in a subset of individuals [11]. These restrictions show how urgently effective, scalable, and additional treatments are needed to lower the risk of the advancement of diabetic retinopathy [12].

For this review, “lifestyle modification” is described as a series of specific, intentional, evidence-based changes to behaviors that specifically target cardiometabolic risk factors that have been shown to affect DR progression [13]. These risk factors include: (i) improvement of overall dietary quality (i.e., in the context of the Mediterranean, DASH, or low-glycemic index diets), as well as caloric restriction to achieve and maintain weight loss; [14] (ii) participation in structured physical activity (aerobic and resistance) combined with decreased sedentary time; [15] (iii) smoking cessation and alcohol moderation; [16] (iv) sleep duration and quality optimization to lower glycemic variability and sympathetic activation; and [17] (v) dietary sodium (salt) restriction for blood pressure control [18]. Multi-component lifestyle programs which featured two or more of these domains will also be considered as long as adherence remains relevant as an important facet of exposure intensity [19]. This operationalization is in line with earlier research on lifestyle interventions and the American diabetic Association's (ADA) most recent diabetic recommendations [20].

Lifestyle adjustments offer a viable approach to impacting the underlying pathophysiology of diabetic retinopathy development [21]. The molecular variables include oxidative stress, systemic inflammation, and advanced glycation end-products (AGEs) brought on by persistent hyperglycemia, overexpression of VEGF, and hemodynamic dysregulation [22][23][24][25]. Of particular lifestyle areas specifically target these changeable mechanisms: dietary changes can improve hyperglycemia, dyslipidemia, and inflammation (e.g., a Mediterranean or low-glycemic index diet) [26]; ; Insulin sensitivity can be enhanced by exercise, increase endothelial function, and control blood flow to the retina [27]; smoking cessation can mitigate hypoxia and protect from oxidative stress [28]; sleep health can reduce glycemic variability and sympathetic tone [29]. This biological plausibility offers a compelling justification for examining lifestyle factors as influencers of diabetic retinopathy progression, rather than solely its occurrence [19].

Numerous previous studies have consolidated evidence regarding lifestyle and diabetes related complications; however, they frequently concentrate on isolated domains (e.g., nutrition or physical activity exclusively), the primary prevention of incident diabetic retinopathy, or surrogate metabolic outcomes such as HbA1c instead of definitive retinal endpoints [21][30]. As far as we know, There are no thorough systematic reviews that have combined data from all significant lifestyle categories and just investigated the course of DR in people who already have the condition, used the GRADE system to assess the evidence's level of certainty, and specifically considered implications for implementation in a variety of settings including LMICs and primary care interfaces. Such a gap warrants a systematic review that explicitly focuses on progression.

The main goal of this systematic review is to examine the data about how structured lifestyle modifications affect the course of diabetic retinopathy in adults with diabetes and pre-existing DR. Our secondary aims are to (i) compare the relative efficacy of

different lifestyle domains and intervention doses; (ii) identify any patient subgroups that may experience differential effects (e.g., stratified by baseline DR severity, type of diabetes, or metabolic status); (iii) highlight considerations for real-world application, and future research.

Ultimately, this review aims to provide a comprehensive, critically assessed summary of the data demonstrating how lifestyle modifications can help delay the onset of DR. With an emphasis on equity in global health, we will evaluate the degree of certainty in the data, explain who and under what circumstances these interventions work best, and discuss the consequences for research, public health policy, and clinical practice.

MATERIAL AND METHODS:

Search Strategy

A systematic review was conducted in compliance with the PRISMA 2020 guidelines to identify publications assessing how lifestyle changes affect the development of diabetic retinopathy (DR). Seven databases Google Scholar, PubMed/MEDLINE, Web of Science, Scopus, ScienceDirect, ProQuest, and the Cochrane Library were used to do a comprehensive literature search. The search strategy combined free-text terms and Medical Subject Headings (MeSH) with Boolean operators (AND, OR) to ensure inclusion. Among the primary search phrases included combinations of:

- **Population terms:** “Diabetic Retinopathy,” “Non-proliferative Diabetic Retinopathy,” “Proliferative Diabetic Retinopathy,” “Diabetes Mellitus Complications”
- **Intervention terms:** “Lifestyle Modification,” “Lifestyle Intervention,” “Diet Therapy,” “Nutritional Therapy,” “Physical Activity,” “Exercise,” “Smoking Cessation,” “Weight Reduction,” “Alcohol Moderation,” “Sleep Hygiene”
- **Outcome terms:** “Progression,” “Severity,” “Risk Reduction,” “Vision Loss,” “Retinopathy Grading”

INCLUSION AND EXCLUSION CRITERIA

Inclusion Criteria:

Studies that satisfied the following requirements were selected:

1. Examined the relationship between lifestyle modifications (such as dietary adjustments, exercise, stopping smoking, drinking alcohol in moderation, decreasing weight, or getting better sleep) and the onset of diabetic retinopathy (DR).
2. Quantitative outcomes of DR progression, include the emergence of proliferative DR, diabetic macular edema (DME), the need for treatment (anti-VEGF, vitrectomy, or PRP), or modifications in the severity of DR (e.g., ETDRS grading).
3. Participants were adults (18 years of age and older) with a diagnosis of Type 1 or Type 2 Diabetes Mellitus at any point during the course of the illness.
4. Were original investigations published as cross-sectional studies, case-control studies, cohort studies, randomized controlled trials, or systematic reviews in peer-reviewed journals
5. Published in English and accessible in full text.

Exclusion Criteria:

Excluded studies were those that:

1. Studies that did not particularly assess lifestyle therapies or offer information on their impact on the development of DR.
2. Studies that did not include lifestyle modification as an exposure or variable; instead, it concentrated only on pharmaceutical, surgical, or laser therapies.
3. Studies that were only simulation studies, in vitro tests, and animal models were covered.
4. Studies that were non-peer-reviewed publications such as literature, editorials, letters to the editor, conference abstracts, or commentary.
5. Studies that were not entirely accessible or published in languages other than English.

Study Selection

From the databases, a total of 1983 records were found. A total of 1372 records were screened using titles and abstracts after duplicates ($n = 583$) and renounced records ($n = 28$) were eliminated. 1128 of these were disqualified due to their failure to satisfy the requirements for inclusion.

Retrieval and Eligibility Assessment

We explored for the entire texts of 244 research, including 59 case studies and 97 conference proceedings, to retrieve, but 156 could not be retrieved. A further 88 studies underwent full-text assessment for eligibility, and 63 were excluded due to not aligning with inclusion criteria ($n = 38$) or the unavailability of full text ($n = 25$).

Quality Assessment

Following PRISMA guidelines, we used the Mixed Methods Appraisal Tool (MMAT, 2018 version) to assess the risk of bias and the strength of the evidence across the diverse studies. The tool's two-part structure; an initial screening checklist followed by methodological criteria for five study categories was used to rate each study ("Yes," "No," or "Can't tell"). A study was excluded from formal appraisal if it received a "No" on both screening questions or a "Can't tell" on either. A "Yes" denotes higher quality, while "Can't tell" indicates inadequate reporting. Two reviewers performed the appraisal independently, with conflicts settled by consensus or a third reviewer. Final results present item-level judgments, as recommended by the MMAT, rather than a summary score.

Final Selection

Twenty-one papers were included in the final review for in-depth analysis following the methodical screening and eligibility evaluation. To determine their applicability to lifestyle changes and the advancement of diabetic retinopathy, two independent reviewers went through the titles and abstracts of every record that was found. The same reviewers then independently evaluated full-text publications of potentially relevant research using the predetermined inclusion and exclusion criteria. Discussions were held to settle any disputes that arose during the screening or eligibility evaluation. When there was no consensus, a third reviewer was consulted to get a final verdict. Together, the included studies offered insightful information about how diet, exercise, quitting smoking, controlling weight, and other lifestyle choices affect the course and severity of diabetic retinopathy.

Registration and Protocol

Protocol Access: A full protocol was submitted to PROSPERO at the time of registration. The protocol may be made available after the completion of the review as per PROSPERO policy.

Amendments to Protocol: No amendments have been made to the registered protocol since its initial submission.

RESULTS:

The procedure for locating, screening, and adding studies to a systematic review is shown in the PRISMA diagram (Figure 1) that is supplied. A total of 1983 records were found in various databases. After removing duplicates (583) and renounced records (28), 1372 records were screened. Of these, 1128 were excluded. Among 244 studies sought for retrieval, 156 could not be retrieved (97 conference proceedings and 59 case studies). A further 63 studies were excluded after the eligibility assessment, leaving 25 studies included in the final review.

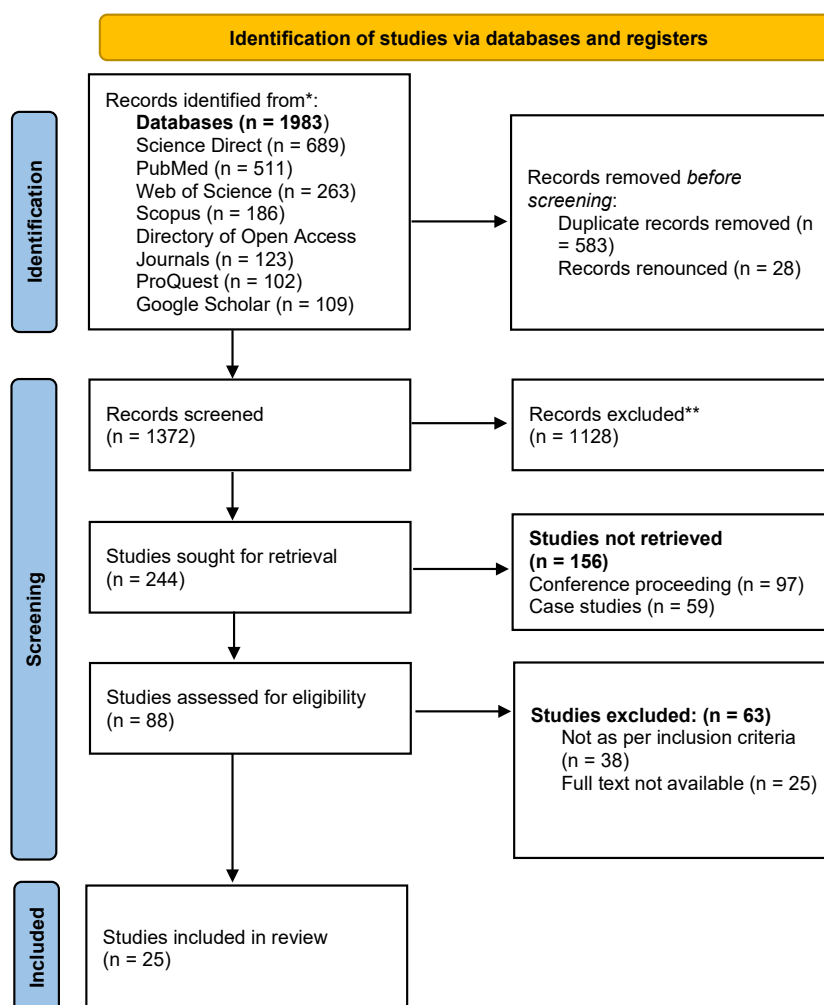


Figure 1: Diagram of the systematic review's PRISMA flow

Characteristics of the study:

Diabetic Retinopathy outcome ascertainment, principal findings, recommendations, and lifestyle exposure assessment (nutrition and food habits, exercise and inactivity, sleep and mental well-being, alcohol and tobacco use) are all included in the included studies, as summarized in Table 1. Randomized lifestyle interventions, large prospective cohorts with multiyear follow-up, cross-sectional analyses, case-control comparisons, and a Mendelian-randomization-augmented study that captures both incident DR and progression to vision-threatening disease are among the heterogeneous designs used in the evidence, which covers a number of regions (such as the United States, China, Nepal, Finland, Norway, Singapore, India, and Australia). Lifestyle exposures were usually assessed using validated questionnaires (e.g., MET-minutes for activity; HEI or food-frequency/recall instruments for diet; structured items for alcohol, smoking, and sleep; PHQ-9 for depression); whereas DR was determined using clinically meaningful proxies, such as the initiation of retinal photocoagulation documented in national registries, or standardized retinal imaging. A targeted analysis of modifiable behaviors in connection to DR was made possible by multivariable models that typically corrected for demographic and cardiometabolic variables (blood pressure, lipids, duration of diabetes, and glycemic control).

There were independent positive correlations between the incidence of DR and longer daily inactive time, while higher habitual physical activity was consistently associated with reduced DR risk and slower advancement, including fewer laser/retinal photocoagulation episodes across long-term follow-up. After correction, working-age persons who experienced short sleep duration and depressive symptoms had increased odds of developing DR, emphasizing the significance of sleep hygiene, mental health, and metabolic regulation. Eating at least 500 mg of long-chain omega-3 fatty acids daily (about two meals of fish per week) as part of a Mediterranean-style diet was associated with a nearly 50% decreased incidence of vision-threatening diabetic

retinopathy (DR) in older persons with type 2 diabetes. Additionally, community data support the recommendation of marine PUFA intake as a useful dietary lever. While there were no effects on advancement, infrequent or mild alcohol use was linked to a lower incidence of DR in other cohorts. These findings were not presented as advice to drink alcohol. Smoking-related evidence comprised an MR component that did not support smoking as a preventative measure and an analysis that revealed lower DR probabilities in specific subgroups without an impact on progression. These trends collectively identify Mediterranean-leaning diets with frequent oily fish, physical activity, decreased inactive time, and attention to sleep and mental health as recurrent protective factors in DR prevention and progression mitigation.

Standardized retinal grading or clinically relevant treatment proxies, large, population-based cohorts with registry linkages, and repeated dietary/activity measurements are among the methodological strengths; self-reported exposure measures, irregular reliance on self-reported DR diagnosis, possible residual confounding, and in certain analyses, attenuation of physical-activity effects after controlling for strong mediators like smoking and HbA1c are among the limitations. Notably, randomized data demonstrates a viable road from association to implementation, demonstrating that culturally specific, multi-component lifestyle programs can enhance glycaemia, lipids, and health behaviors while significantly increasing DR-screening uptake among newly diagnosed patients. The main idea of the review is generally supported by the body of research gathered in the given table 1: unhealthy routines (such as prolonged sedentary behavior) and unfavorable psychosocial factors are linked to higher risk, while modifiable lifestyle domains particularly regular physical activity combined with less sedentary time and cardioprotective dietary patterns are linked to lower DR risk or slower progression.

Table 1: The included study's characteristics

Sr .	Study Author & Year	Country	Study Design	Sample Size (N)	Study Objectives	Method	Result and Conclusion	Recommendations of Studies
1.	Li, Bo et al., 2024 [31]	United States	Population-based cross-sectional study	3482 adults with diabetes (18–64 years)	Investigate associations of lifestyle and mental health with diabetic retinopathy among working-age adults.	Data from NHANES 1999–2018; DR defined by self-reported physician diagnosis. Assessed smoking, alcohol, physical activity (MET-min/week), diet quality (HEI), sleep, and depression (PHQ-9≥10). Used univariable and multivariable logistic regression controlling for demographic, clinical, and metabolic factors.	DR affected 20.8% (weighted). DR cases showed greater heavy alcohol use, depression, sleep <5 h, insufficient activity, poor HbA1c, nephropathy and CVD. Adjusted studies showed that sadness (OR 1.35, p=0.025) and short sleep (<5 h; OR 3.18, p<0.001) increased odds, but mild-to-moderate	Target modifiable behaviors (moderate alcohol, more physical activity, depression management, adequate sleep) and embed these measures within diabetes care and public-health programs to lower DR risk and progression in working-age adults.

							drinking (OR 0.49, p=0.001) and increased physical activity (OR 0.64, p=0.044) decreased odds.	
2.	Wang, Bin, et al. 2024 [32]	China	Cross-sectional study	1300 participants	To look at the relationship between smoking and the onset and advancement of DR	This study employed two methods: Mendelian randomization utilizing genome-wide association data to investigate a possible causal relationship and a cross-sectional analysis of NHANES data to evaluate the correlation between smoking and diabetic retinopathy (DR).	According to the study, smoking was associated with a decreased risk of diabetic retinopathy, particularly in men, people with diabetes for more than ten years, and people with normal clinical profiles. Protective effects were seen in early and advanced DR stages, but smoking showed no effect on disease progression	Smoking should not be recommended as a preventive measure for diabetic retinopathy, despite observed associations suggesting a lower DR risk in certain subgroups
3	Shahina Pardhan, et al., 2023 [33]	Nepal	randomized controlled trial	110 total (Intervention n = 55; Control n = 55) newly diagnosed Type 2 diabetes patients.	To determine whether a culturally specific lifestyle program helps newly diagnosed individuals with their diabetes and	Patients were randomly assigned to usual care or a 12-week intervention comprising a Nepali educational video, individualized lifestyle targets, a	The intervention group showed noticeably larger gains in HbA1c at three months (6.1% vs. 6.6%), LDL cholesterol, diet, physical activity, and	The authors recommend wider implementation of this culturally tailored lifestyle intervention to improve patient outcomes. They suggest scaling the

					their health outcomes.	logbook, and weekly phone calls. Blinded assessors measured clinical and questionnaire-based outcomes at baseline and 3 months.	diabetic retinopathy screening attendance (100% vs. 0%) compared to controls. Knowledge gains were immediate and sustained.	program, integrating specialists into care teams, and conducting longer-term studies.
4.	Liu, Gang, et al. 2023 [34]	United States	Prospective cohort study	7,077 individuals with type 2 diabetes (4,982 NHS women and 2,095 HPFS males)	To investigate the relationship between the likelihood of developing microvascular problems in persons with diabetes and their commitment to a healthy lifestyle both before and after being diagnosed with the disease.	Patients with recently diagnosed type 2 diabetes from the Nurses' Health Study and Health Professionals Follow-Up Study in the United States were included in this prospective cohort study. Validated questionnaires were used to evaluate dietary and lifestyle factors before and after diagnosis, and individuals were monitored for health outcomes.	The study concluded that individuals with type 2 diabetes who followed a healthy lifestyle both before and after diagnosis had a significantly lower risk of developing microvascular complications, including a 35% reduced risk of diabetic retinopathy. Each additional healthy habit further decreased the overall risk of such complications.	To reduce the risk of microvascular problems like diabetic retinopathy, promote a healthy lifestyle that includes quitting smoking, maintaining a healthy weight, engaging in regular exercise, eating a balanced diet, and consuming alcohol in moderation both before and after being diagnosed with type 2 diabetes.
5.	Wu, Zhiyuan, et al. 2022 [35]	China	Prospective cohort study	8,948 adults with type 2 diabetes in China	To assess the relationship over time between Chinese	For a median of 4.82 years, 8,948 persons with type 2 diabetes from the Beijing	Although not for diabetic retinopathy, higher VAI and CVAI levels were	Despite the lack of a direct correlation with retinopathy, people with

					VAI (CVAI), the visceral adiposity index (VAI), and the risk of diabetic retinopathy and nephropathy in Chinese persons with type 2 diabetes.	Health Management Cohort (2013–2014) were monitored. Fundus photography and laboratory tests were used to evaluate retinopathy and nephropathy.	substantially associated with a higher risk of diabetic nephropathy.	type 2 diabetes should have their visceral fat levels monitored and managed to assist prevent the development of diabetic nephropathy.
6.	Alsibirk, Knud Erik et.al 2022 [36]	Norway	Cross-sectional observational study	510 diabetic patients (50 with type I and 460 with type II diabetes).	To evaluate the visual and retinal consequences in a diabetic population and look at how dietary consumption of marine polyunsaturated fatty acids (PUFAs) affects the onset of diabetic retinopathy.	In a community eye clinic serving 40,000 people, 510 diabetic patients were assessed for visual impairment and diabetic retinopathy. Data on diabetes type, HbA1c, medication use, dietary supplements, and fish consumption were collected through self-report	Diabetic retinopathy (DR) was present in 48% of patients with type 1 diabetes, including 16% with proliferative DR and 12% with diabetic macular edema, but all maintained good visual acuity in their best eye. Among those with type 2 diabetes, the majority (98%) also had good visual acuity, with a lower overall prevalence of vision-threatening complications.	To promote retinal health and lower the risk of diabetic retinopathy (DR) in diabetic patients, promote regular dietary intake of marine polyunsaturated fatty acids (PUFAs), such as those present in fatty fish.

7.	Rajani Kadri et al., 2021 [37]	India	One-year prospective institutional cohort study (prospective cohort).	261 (326 interviewed; 65 excluded; of 261, 106 had diabetic retinopathy).	Examine how particular dietary exposures contribute to the development of diabetic retinopathy in individuals with diabetes.	Dietary intake was measured by two nonconsecutive 24-hour recalls plus a weekly recall for infrequent items to compute daily calories and nutrients. Participants underwent full eye exams including fundus photography; age, sex, diabetes duration, smoking, alcohol, and treatment were recorded. Relationships with DR and severity were analyzed with uni- and multivariable logistic regression.	Univariate links with DR included sex, diabetes duration, fish (times/week), egg consumption, rice (meal/type), and total calories. In multivariable models, male sex (OR 3.20), longer diabetes duration (OR 1.05 per year), antioxidant use (OR 3.42) and rice consumption (OR 3.19) raised DR odds ($p < 0.05$). Eating fish $> 2 \times / \text{week}$ was protective against DR (OR 0.42) and severe DR (OR 0.06). Pharmacological diabetes treatment was protective (OR 0.16). Authors conclude frequent fish intake and drug therapy lower DR risk/progression, while rice, antioxidant	Dietary modification is feasible: promote oily fish and reduce overall calorie/carbohydrate portions (particularly rice/chapati). Given sample size and recall-bias limitations, the authors recommend larger, prospective studies to confirm associations and develop concrete diet recommendations for DR prevention.
----	--------------------------------	-------	---	---	--	--	--	---

							supplementation, male sex and longer diabetes duration increase odds.	
8.	Xixi yan et al., 2021 [15]	Australia	Prospective cohort — 10-year follow-up.	9,018 people with diabetes of working age were selected from the 45 and Up Study's baseline.	Analyse the relationship between the 10-year progression of DR and baseline physical activity.	In 2006, baseline self-reported physical activity was divided into three categories: low (less than five sessions per week), medium (5–14), and high (more than 14). Medicare records of retinal photocoagulation (RPC) from 2004 to 2016 were used as a stand-in for the advancement of DR. After controlling for covariates, the relationship between PA and RPC incidence was evaluated using Cox proportional hazards models.	During follow-up, higher baseline activity was linked to fewer RPC procedures; this effect persisted even after adjustment, with medium and high PA levels exhibiting noticeably lower risks than low PA.	Promote higher regular physical activity in routine diabetes care to reduce DR progression; integrate PA promotion into management and screening.
9.	Gupta, Preeti, et al 2021 [38]	Singapore	Prospective Cohort Study	656 Singaporean Indian participants with diabetes	To look into the relationship between baseline alcohol consumption and the	The study followed 656 diabetic participants from the Singapore Indian Eye Study with	While there was no correlation with the course of DR, infrequent alcohol use was	While findings suggest infrequent alcohol use may lower DR risk, alcohol should not be recommended

					likelihood of developing or exacerbating diabetic retinopathy (DR) among diabetic Singaporean Indians during a 6-year period.	baseline and follow-up retinal images over 6 years. Alcohol intake and DR status were assessed using questionnaires and retinal grading	associated with a much-decreased chance of acquiring DR. This implies that moderate alcohol use may have a preventive effect against the beginning of DR.	as a preventive strategy, and diabetes management should continue to focus on proven lifestyle and clinical interventions
10.	Heidi Tikkanen-Dolenc et al., 2020 [39]	Finland	Prospective observational cohort (longitudinal follow-up).	A total of 1,612 type 1 diabetic participants were followed for 10.7 ± 4.6 years on average, with 261 undergoing laser therapy.	Evaluate the relationship between baseline leisure-time physical activity (frequency, intensity, duration, total amount) and incidence of severe diabetic retinopathy, operationalized as initiation of laser treatment.	Baseline leisure-time physical activity (KIHD/Minnesota-derived) was expressed in METh/week and grouped (inactive <10; moderate 10–40; active >40); components included intensity, frequency (<1/1–2/>2 weekly) and duration (≤30/31–60/>60 min). Severe DR (laser) was obtained from the Care Register. Cox models with sequential adjustments for static and dynamic covariates plus smoking assessed	During follow-up 261 patients had laser treatment. Higher LTPA frequency was linked to lower severe-DR incidence (KM trend p=0.024); the effect remained after adjusting for static factors and SBP/TG/BMI but lost significance after adding HbA1c or smoking (both strong independent predictors). Total LTPA, intensity and duration showed no association. Authors cite possible mediation via HbA1c, lipids	Promote regular/frequent physical activity in diabetes care to reduce DR progression; pair PA promotion with smoking cessation and glycemic optimization. Interpret benefits cautiously (may be mediated by HbA1c and smoking) and call for studies using objective PA measures and detailed retinal imaging (fundus/OCT) to define mechanisms and safe exercise advice for advanced DR

						LTPA's relationship with severe DR.	and BP and note limits of self-reported PA and using laser as a surrogate	
1 1.	Aro, A., et al 2019 [40]	Finland	Randomized controlled trial (with post-intervention observational follow-up)	522 participants IG= 265 CG=257	To determine whether trial participants' incidence of retinopathy was impacted by their involvement in an earlier intervention.	522 people with impaired glucose tolerance participated in this trial and were randomly assigned to either the lifestyle intervention group or the control group lasting a median of four years. Fundus photographs were taken 5+ years later and assessed by masked ophthalmologists, with data from 211 participants included in the final analysis	The lifestyle intervention group had a significantly lower incidence of retinal microaneurysms (24%) than the control group (38%), according to the study. The probability of microaneurysms was 48% lower in the intervention group after controlling for covariates. Furthermore, a higher probability of microaneurysm development was associated with higher baseline blood triglyceride levels.	To lower the incidence of early diabetic retinal alterations, such as microaneurysms, overweight and obese people with impaired glucose tolerance should adopt and promote lifestyle modifications such as weight loss, a nutritious diet, and frequent exercise.
1 2.	Dharmastuti, D. P., et al. 2018 [41]	Indonesia	Cross-sectional	1116 participants	To look into how sedentary behavior and physical activity (PA) relate to	Fundus photos with the disc and macula centered were used to evaluate DR, and depending	The existence of DR was substantially correlated with a daily sedentary	According to this research, a public health campaign aimed at lowering the daily sedentary

					diabetic retinopathy (DR) in persons with type 2 diabetes.	on which eye was worse, DR was categorized as mild, moderate NPDR, or Vision-Threatening DR VTDR. The WHO GPAQ was used to measure physical activity (PA), and the mean physical activity level (PAL) was computed using exercise, walking distance, sleep, and sitting time. After then, PAL was divided into three lifestyle categories: sedentary, moderate, and vigorous.	lifestyle that lasted more than three hours. Walking distance, intense activity, and length of sleep did not significantly correlate with DR.	activities of people with type 2 diabetes may help lessen the burden of DR and VTDR.
1 3.	Praidou, Anna, et al. 2017 [42]	United Kingdom	Cross-sectional non-interventional	Diabetic patients = 240 Non-diabetic patients = 80	This research implies that a public health initiative to decrease the amount of time people with type 2 diabetes spend sitting down each day could help lessen the burden of	The International Physical Activity Questionnaire was used to measure the patients' physical activity (IPAQ, 2002). Measurements of BMI and HbA1C in diabetic individuals Group comparisons	Individuals with proliferative diabetic retinopathy (PDR) and severe to very severe non-proliferative diabetic retinopathy (NPDR) were less physically active overall than controls and those with mild to moderate	Frequent exercise may assist improve body weight and general glycemic management while also lessening the severity of diabetic retinopathy.

					DR and VTDR.	evaluated the degree of sedentary behavior and physical activity.	NPDR ($p < 0.05$). Severity of diabetic retinopathy was also negatively associated with physical activity, suggesting that as DR severity increased, physical activity decreased ($p < 0.05$).	
14.	Chew, Emily Y. 2017 [43]	United States	Randomized controlled trial (PREDIMED study)	PREDIMED trial included ~7,447 participants, with a diabetic subgroup	To find out if following the Mediterranean diet and consuming long-chain omega-3 fatty acids lowers the incidence of cardiovascular events and vision-threatening diabetic retinopathy in older persons with type 2 diabetes.	This study was a component of the PREDIMED randomized controlled trial, which randomized high-risk adults to one of three diets: a low-fat control diet, a Mediterranean diet with mixed nuts, or a Mediterranean diet with extra-virgin olive oil. Over a period of 4.8 years, the incidence of cardiovascular events and diabetic retinopathy was evaluated in relation to dietary omega-3 intake (≥ 500 mg/day).	Consuming at least 500 mg of long-chain omega-3 fatty acids daily, or two servings of fish per week, was linked to a roughly 50% lower incidence of vision-threatening diabetic retinopathy in older persons with type 2 diabetes.	To reach the necessary 500 mg/day of long-chain omega-3 fatty acids, people with type 2 diabetes should be encouraged to eat at least two meals of fatty fish per week. Encourage adherence to a Mediterranean diet that is enhanced with mixed nuts or extra-virgin olive oil to reduce the risk of cardiovascular problems and the potentially blinding condition known as diabetic retinopathy.

1 5.	Kuwata, Hirohito, et al 2017 [44]	Japan	Prospective cohort study	1,814 patients with type 2 diabetes without diabetic retinopathy (DR)	To elucidate the prospective relationship between baseline Physical Activity (PA) levels and the development of Diabetic Retinopathy (DR) over a 2-year follow-up period	Data from patients with type 2 diabetes without DR were obtained from a Japanese diabetes registry at Tenri Hospital, Nara, Japan. To assess the independent correlations between baseline PA levels and newly developed DR, the participants were divided into five categories based on their PA levels.	After 2 years of follow-up, 10.1% (184 patients) developed diabetic retinopathy (DR). An increased level of physical activity (PA) was linked to a decreased prevalence of DR.	In order to reduce the development of diabetic retinopathy (DR), Japanese individuals with type 2 diabetes should be encouraged to engage in more physical activity (PA).
1 6.	Horikawa, Chika, et al 2017 [45]	Japan	Multi-center prospective cohort study	1,516 Japanese individuals suffering from type 2 diabetes	To investigate, using data from a large, statewide, multicenter cohort in Japan, the association between the percentage of carbohydrates consumed and the incidence of diabetes-related complications—such as diabetic retinopathy, overt	Rates of cardiovascular disease (CVD), diabetic retinopathy, and overt nephropathy according to the quantities of dietary carbohydrates consumed as determined by the Food Frequency Questionnaire	There was no discernible correlation between the percentage of carbohydrates consumed and the risk of cardiovascular disease, diabetic retinopathy, or overt nephropathy in a follow-up analysis of 1,516 patients with type 2 diabetes over an 8-year period. After controlling for	It is not necessary to alter the percentage of carbohydrates consumed merely to shield individuals from diabetic consequences such as diabetic retinopathy, nephropathy, or cardiovascular disease.

					nephropathy, and cardiovascular disease in patients with type 2 diabetes.		confounding variables, a higher carbohydrate intake was linked to more consumption of grains, fruits, and sweets, but it had no discernible impact on diabetic complications.	
17.	Alcubierre, Nuria, et al. 2016 [46]	Spain	Case-control study	146 DR patients and 148 non-DR patients	To assess the amount of macronutrients consumed through diet, with a focus on fatty acids, and look into any possible links between these nutrients and the onset of diabetic retinopathy in people with type 2 diabetes.	A validated food frequency questionnaire was used to assess macronutrient intake.	Patients with diabetic retinopathy (DR) consumed less fiber, monounsaturated fats (MUFA), palmitic acid, and oleic acid. A decreased risk of developing DR was associated with higher intakes of oleic acid and MUFA. Those with moderate or high MUFA intake had about 50% lower odds of DR. Similarly, moderate or high oleic acid intake also reduced the risk of DR.	To assist lower the incidence of diabetic retinopathy (DR), patients with type 2 diabetes mellitus should be urged to increase their consumption of monounsaturated fatty acids (MUFA), particularly oleic acid, as part of their dietary pattern.

18.	Millen, Amy E., et al 2016 [47]	United States	Prospective cohort study	1,339 participants with diabetes 906 Caucasians, 433 African Americans	To evaluate the possible preventive effects of vitamin D through anti-inflammatory, anti-angiogenic, and metabolic regulatory mechanisms in relation to the existence of diabetic retinopathy in people with diabetes.	To evaluate the relationship between vitamin D levels and diabetic retinopathy, participants were monitored for three years. The relationship between serum 25-hydroxyvitamin D [25(OH)D] levels and the prevalence of diabetic retinopathy as determined by retinal imaging	Significantly lower risks of diabetic retinopathy were linked to higher serum 25(OH)D levels (≥ 75 nmol/L), which may have been caused by improved blood glucose regulation.	One possible tactic to lower the risk of diabetic retinopathy in patients with diabetes is to monitor and maintain appropriate serum vitamin D levels.
19.	Man, Ryan Eyn Kidd, et.al 2016 [48]	Singapore	Cross-sectional study	420 Asian individuals suffering from type 2 diabetes	In a clinical sample of Asian patients with type 2 diabetes mellitus, to examine the relationships between DR and generalized (as measured by body mass index, or BMI) and abdominal obesity.	In this cross-sectional study, retinal pictures of 420 type 2 diabetic patients at the Singapore National Eye Centre were rated for the severity of diabetic retinopathy (DR). Multinomial logistic regression was used to examine relationships between BMI, waist-to-hip ratio (WHR), and DR while controlling for	While a larger waist-to-hip ratio (WHR) was connected to a higher risk and severity of diabetic retinopathy (DR), particularly in women, a higher BMI was linked to a decreased risk of DR in Asian patients with type 2 diabetes. This implies that for DR, WHR might be a more pertinent risk	When assessing the risk of diabetic retinopathy (DR) in Asian patients with type 2 diabetes, especially in female patients, the waist-to-hip ratio (WHR) should be given more weight than the body mass index (BMI).

						clinical and demographic variables.	indicator than BMI.	
20.	Paul D. Loprinzi 2015 [49]	United States	Cohort study	282 participants	To assess the relationship, independent of physical activity (PA), between the prevalence of diabetic retinopathy (DR) in individuals in the United States and sedentary behavior (SB)	The National Health and Nutrition Examination Survey data from 2005–2006 were utilized.	Self-report, medication use, HbA1c $\geq 6.5\%$, or fasting glucose ≥ 126 mg/dL were used to define diabetes. DR was evaluated using ETDRS criteria in retinal imaging. An accelerometer was used to evaluate physical activity and sedentary behavior, and the results were expressed as average minutes per day.	The risks of mild or worsening diabetic retinopathy (DR) were considerably higher in those who engaged in more sedentary behavior (SB). Even after controlling for the length of diabetes, there was still a substantial 16% increase in the risks of DR for every 60 minutes per day that SB increased. But there was no correlation between DR and total physical activity (PA) ($p = 0.36$), and there was no interaction impact between SB and PA on DR.
21.	Qinghua Ma et.al 2015 [50]	China	Case–control study	100 diabetic controls without DR and 100 DR patients	To look at the relationship between people with diabetes who regularly drink Chinese green tea and their chance of	Using fundus photography, indirect ophthalmoscopy, and slit-lamp biomicroscope, skilled ophthalmologists conducted thorough retinal assessments to	According to the study, drinking Chinese green tea on a regular basis was associated with a roughly 50% lower chance of developing diabetic	Encourage patients with type 2 diabetes, particularly women, to regularly drink Chinese green tea at least once a week for a year or more as a possible preventive treatment

					developing diabetic retinopathy	evaluate diabetic retinopathy (DR). According to the Early Treatment Diabetic Retinopathy Study (ETDRS) criteria, DR was identified and categorized.	retinopathy (DR). All things considered, this protective effect was noteworthy, especially for women. Even after controlling for other variables, drinking green tea continued to be substantially connected to a lower chance of developing DR, whereas a family history of diabetes, higher systolic blood pressure, and longer duration of diabetes were associated with an increased risk.	against diabetic retinopathy (DR).
2 2.	Sasaki, Mariko, et al 2015 [51]	Australia	Cross-sectional study	379 individuals with diabetes	To assess the connection between the risk of developing diabetic retinopathy (DR) and dietary consumption of polyunsatur	A validated food frequency questionnaire was used to quantify dietary fatty acid intake. Fundus photos were used to grade diabetic retinopathy, and patients	More polyunsaturated fatty acid (PUFA) intake was associated with a lower risk and severity of diabetic retinopathy in patients with well-	The risk and severity of diabetic retinopathy (DR) may be decreased in people with well-controlled type 2 diabetes by increasing dietary intake of polyunsaturate

					ated fatty acids (PUFAs)	were divided into two groups according to their HbA1c levels: those with well-controlled (<7.0%) and poorly-controlled (≥7.0%) diabetes.	controlled diabetes, whereas more saturated fatty acid (SFA) intake was linked to an increased risk. There were no noteworthy correlations seen in those with poorly managed diabetes.	d fatty acids (PUFAs) and decreasing intake of saturated fatty acids (SFAs).
2 3.	Domanico, Daniela, et al 2015 [52]	Italy	Randomized controlled trial (RCT)	68 individuals with NPDR	To evaluate how antioxidant supplements affect central macular thickness (CMT) and circulation reactive oxygen species (ROS) levels in individuals with nonproliferative diabetic retinopathy (NPDR)	Patients with NPDR were split into two groups for this randomized study: Group A received an oral antioxidant supplement, while Group B served as a control. Reactive oxygen species (ROS) and central macular thickness (CMT) were assessed at baseline, three months, and six months for both groups.	The study found that individuals with NPDR who took antioxidant supplements had considerably lower levels of reactive oxygen species (ROS) and central macular thickness (CMT), whereas the control group had higher ROS and no discernible change in CMT.	Pycnogenol, vitamin E, and coenzyme Q10 are examples of antioxidant supplements that can be used as a supportive strategy to lower central macular thickness and oxidative stress in patients with nonproliferative diabetic retinopathy (NPDR).
2 4.	Mahoney, Sara E. et.al 2014 [53]	United States	Cross-sectional study	381 participants with diabetes	To ascertain if consumption of fruits and vegetables high in flavonoids is linked to	Information gathered between 2003 and 2006. Diabetic retinopathy (assessed via retinal imaging),	Lower CRP, HgbA1C, and glucose levels were linked to higher consumption of flavonoid-rich fruits and vegetables	To help improve glycemic control and reduce inflammation, people with diabetes should be encouraged

					diabetes-related indicators, such as HbA1c levels, and whether diabetic retinopathy occurs in diabetics.	HgbA1C, fasting glucose, insulin, and CRP levels	(HFVC). A 30% lower risk of diabetic retinopathy was associated with higher HFVC.	to eat more fruits and vegetables high in flavonoids. This could reduce their chance of developing diabetic retinopathy by as much as 30%.
25.	Janevic, Mary R. et.al 2013 [54]	United States	Cross-sectional	1811; age >50 years)	To examine the associations of the diabetic complications with physical activity	Logistic regression was used to examine the relationship between diabetes complications and adherence to physical activity recommendations in data from the 2003 US Health and Retirement Study.	Just 43% of diabetics were receiving enough exercise, according to the study. Individuals with heart disease, diabetic retinopathy, nephropathy, or neuropathy were less likely to adhere to physical exercise recommendations.	It is recommended to promote and support physical activity among individuals with diabetes, especially those with complications. Tailored interventions and accessible exercise programs may help improve their activity levels and overall health

Quality Assessment

According to the MMAT (2018) appraisal, the majority of the evidence in our study is derived from quantitative observational designs, primarily descriptive cross-sectional and non-randomized cohort/case-control studies, with a small number of randomized trials. This is because lifestyle exposures are typically studied in non-experimental, real-world settings. All screening criteria (clear research questions and sufficient data to answer them) were fulfilled. Core safeguards such as adequate randomization, baseline comparability, assessor blinding, and adherence were often graded as "Yes" in the randomized studies; however, a few entries for outcome completeness or blinding were marked as "Can't tell," indicating sporadic reporting gaps. Participants in non-randomized studies were frequently representative, and measurements were appropriate; nevertheless, confounder control varied (some respondents said "yes," while others said "can't tell"), and the completeness of the results was not always guaranteed, which are common drawbacks for observational research. While the most common area of doubt for quantitative descriptive research was the risk of nonresponse bias, sampling procedures and measurement appropriateness were generally considered good, and statistical analyses were generally regarded as appropriate. Table 2 displays the quality assessment's findings.

Table 2. Mixed Methods Appraisal Tool (MMAT), version 2018

Category of study designs	Methodological quality criteria	Li, B o et al., 2024	Wang, Bin, et al. 2024	Shahina Pardhan, et al., 2023	Li u, Ga ng, et al. 2023	Wu, Zhiyuan, et al. 2022	Als birk, Knud Erik et.a l 2022	Rajani Ka dri et al., 2021	Xi xi ya n et al., 2021	Gu pta, Pre ti, et al 2021	Heidi Tikkane n - Dolenc et al., 2020	Ar o, A., et al	Dhar mastuti, D. P., et al. 2018	Prai dou, Ann a, et al. 2017	Ch ew, E mil y Y. 2017	Kuwa ta, Hiro hito, et al 2017	Hori kawa, Chik a, et al 2017	Alcu bierr e, Nuri a, et al. 2016	Mil len, Am y E., et al 2016	Man, Ry an Ey n Kidd, et. al 2016	Paul D. Lop rinz i 2015	Qin ghu a Ma et.al 2015	Sasaki, Mar iko, et al 2015	Dom anico, Dani ela, et al 2015	Mah oney, Sara E. et.al 2014	Jan evic, Mar y R. et.a l 2013
												2019														
Screening questions	S1. Are there clear research questions?	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
	S2. Do the collected data allow to address the research questions?	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Quantitative Randomized Controlled trials	2.1. Is randomization appropriately performed?	NA	NA	Yes	NA	NA	NA	NA	NA	NA	NA	Yes	NA	NA	Yes	NA	NA	NA	NA	NA	NA	NA	Yes	NA	NA	NA
	2.2. Are the groups comparable at baseline?	NA	NA	Yes	NA	NA	NA	NA	NA	NA	NA	Yes	NA	NA	Yes	NA	NA	NA	NA	NA	NA	NA	Yes	NA	NA	NA
	2.3. Are there complete outcome data?	NA	NA	Yes	NA	NA	NA	NA	NA	NA	NA	Can't tell	NA	NA	Yes	NA	NA	NA	NA	NA	NA	NA	Yes	NA	NA	NA

	2.4. Are outcome assessors blinded to the intervention provided?	NA	NA	Yes	NA	NA	NA	NA	NA	NA	NA	Yes	NA	NA	Yes	NA	NA	NA	NA	NA	NA	NA	NA	Can't tell	NA	NA
	2.5 Did the participants adhere to the assigned intervention?	NA	NA	Yes	NA	NA	NA	NA	NA	NA	NA	Yes	NA	NA	Yes	NA	NA	NA	NA	NA	NA	NA	NA	Yes	NA	NA
Quantitative non-randomized	3.1. Are the participants representative of the target population?	NA	Yes		Yes	Yes	Yes	Can't tell	Yes	Yes	Yes	NA	NA	NA	NA	Yes	Yes	Can't tell	Yes	NA	NA	No	Can't tell	NA	NA	NA
	3.2. Are measurements appropriate regarding both the outcome and intervention (or exposure)?	NA	Yes		Yes	Yes	Yes	Can't tell	Yes	Yes	Yes	NA	NA	NA	NA	Yes	Yes	Yes	Yes	NA	NA	Can't tell	Yes	NA	NA	NA
	3.3. Are there complete outcome data?	NA	Yes		Yes	Yes	Yes	Can't tell	Yes	Can't tell	Yes	NA	NA	NA	NA	Can't tell	Can't tell	Yes	Can't tell	NA	NA	Yes	Yes	NA	NA	NA
	3.4. Are the confounders accounted for in the design and analysis?	NA	Can't tell	NA	Yes	Yes	Can't tell	Can't tell	Yes	Yes	Yes	NA	NA	NA	NA	Yes	Yes	Yes	Yes	NA	NA	Yes	Yes	NA	NA	NA

	3.5. During the study period, is the intervention administered (or exposure occurred) as intended?	NA	Yes		Yes	Yes	Yes	Yes	Yes	Yes	Yes	NA	NA	NA	NA	Yes	Yes	Yes	Yes	NA	NA	Yes	Yes	NA	NA	NA
Quantitative descriptive	4.1. Is the sampling strategy relevant to address the research question?	Yes	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	Yes	Can't tell	NA	NA	NA	NA	NA	Yes	Yes	NA	NA	NA	Yes	Yes
	4.2. Is the sample representative of the target population?	Yes	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	Yes	Can't tell	NA	NA	NA	NA	NA	Can't tell	Yes	NA	NA	NA	Yes	Yes
	4.3. Are the measurements appropriate?	Yes	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	Yes	Yes	NA	NA	NA	NA	NA	Yes	Yes	NA	NA	NA	Yes	Yes
	4.4. Is the risk of nonresponse bias low?	Can't tell	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	Yes	Can't tell	NA	NA	NA	NA	NA	Yes	Can't tell	NA	NA	NA	Can't tell	Can't tell
	4.5. Is the statistical analysis appropriate to answer the research question?	Yes	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	Yes	Yes	NA	NA	NA	NA	NA	Yes	Yes	NA	NA	NA	Yes	Yes

While emphasizing the need for additional rigorously reported longitudinal and interventional studies to lessen residual confounding and strengthen causal inference, the quality profile generally supports cautious confidence in the relationships seen between lifestyle factors and DR outcomes.

DISCUSSION

A rising global health concern, diabetes mellitus necessitates preventative actions on multiple fronts, such as controlling blood pressure, lipid profiles, and glycemia; encouraging healthy lifestyles; changing one's diet; and increasing physical activity [55]. Building on this idea, our systematic review investigated the effects of lifestyle modifications, such as dietary changes and exercise regimens, on how individuals with diabetes get diabetic retinopathy (DR). Lifestyle changes were usually linked to improved metabolic risk variables, stabilization of DR severity, and, in some cohorts, a delay in progression to proliferative or treatment-requiring phases across the included trials. Simultaneously, a number of initiatives improved screening compliance and illness awareness, highlighting the significance of patient involvement and behavior modification for vision preservation [56].

Glycemic control, blood pressure, and lipids as cross-cutting targets

Numerous studies have shown a continuous correlation between improved glycemic control and a decreased risk of both developing and worsening diabetes mellitus. Many studies found that altering the way people lived significantly decreased HbA1c, and in certain groups, these metabolic improvements were accompanied by slower microvascular decline [57][21]. Lower total and LDL cholesterol were linked to slower DR progression, and one study in 2019 found baseline triglyceride concentration to be a powerful predictor of microaneurysm development, highlighting the importance of early lipid management in individuals with impaired glucose tolerance. Lipid optimization emerged as a complementary target [40]. Controlling blood pressure was still a key factor in microvascular risk and probably worked in conjunction with lifestyle improvements to lessen the burden of retinal ischemia. When combined, these findings support the idea that physical exercise and nutrition serve as both independent levers and enhancers of conventional cardiometabolic treatment.

Dietary patterns and specific nutritional exposures

Dietary interventions that prioritized plant-forward eating, Mediterranean-style eating, and low-glycemic index options had positive impacts on inflammation and glycemic management and were linked to either stabilization or a delayed deterioration in the severity of DR [43][51]. Particular exposures were important within these more general patterns. While a higher reliance on refined carbohydrates, such as frequent consumption of white rice, was associated with negative retinal outcomes in some cohorts, regular consumption of oily fish and a higher intake of monounsaturated fats (such as nuts and olive oil) were linked to better metabolic profiles and fewer progression markers. Sugary drinks were linked to greater HbA1c and an increased incidence of DR, according to Mirghani et al. (2021), indicating a clear and practical dietary target for risk reduction [58]. These results support realistic dietary recommendations that emphasize healthy fats, fiber-rich, minimally processed carbs, and avoiding sugar-sweetened beverages.

Physical activity: dose, modality, and independent effects of sitting time

The duration and intensity of physical activity interventions varied. However, they all demonstrated beneficial benefits on glycemic control and systemic inflammation, including reductions in interleukin-6 and C-reactive protein, which had implications for the advancement of DR [42][44]. According to WHO and ADA guidelines, engaging in moderate-intensity aerobic exercise for at least 150 minutes per week was often linked to improved vascular health markers and a decreased HbA1c [15]. In specific samples, structured walking and mixed aerobic-resistance programs were associated with improved visual outcomes and delayed microvascular degradation [39]. Crucially, inactivity is detrimental even when overall exercise objectives are fulfilled, lack of exercise and sleep had higher correlations with DR risk than sedentary behavior or diet alone, and alcohol did not show up as a significant risk factor in those models [31]. These findings support a thorough mobility plan that reduces prolonged sitting throughout the day and boosts weekly exercise.

Sleep, mental health, and health behaviors

Sleep duration and quality add independent information to DR risk stratification. Sleeping less than six hours a night and being physically inactive, especially among men, were both linked to a higher chance of developing DR, according to Pereira-Payo et al. 2024. In their models, the benefits of sleep and activity surpassed those of food and sedentary behavior [59]. Given the functions of sleep in autonomic tone, inflammatory signaling, and glycemic variability, this pattern makes physiologic sense.

Therefore, by enhancing adherence and lowering physiological stressors that hasten microvascular damage, behavioral therapies that incorporate sleep hygiene and mental health support may enhance the retinal advantages of diet and exercise.

Adjunctive therapies from traditional medicine

Abelmoschus manihot (Jiahua tablets) was used as an adjuvant in non-proliferative DR, Zhao et al. 2020 observed decreases in blood VEGF and improvements in visual function, retinal structure, and disease severity [60]. These results point to a plausible anti-inflammatory and anti-angiogenic mechanism. This evidence is encouraging, but it should be considered preliminary. Given the diversity in herbal formulations and the need to comprehend interactions with current medications, larger, longer trials with standardized retinal endpoints are necessary before pharmacobotanical medicines are recommended in regular DR care.

Digital health interventions and quality of life

Beyond clinical markers, digital platforms can improve patient-centered outcomes. Quality of life was improved with a comprehensive digital intervention, according to Yao et al. in terms of mobility, social interaction, emotional health, and visual function. It also strengthened adherence to illness knowledge and good habits [61]. The scalability of digital tools to provide education, reinforce behavior modification, and promote screening adherence is supported by these findings. This can help with early diagnosis and prompt treatment of vision-threatening diseases.

Long-term lifestyle programs and microvascular endpoints

Evidence from intensive, multi-year lifestyle programs suggests durable retinal benefits. The susceptibility of early retinal lesions to cardiometabolic improvement and lipid control was highlighted by Aro et al.'s 2019 study, which found that patients with impaired glucose tolerance who underwent an intensive lifestyle intervention experienced a 52% reduction in microaneurysm incidence [40]. However, Kaarniranta et al. 2024 observed that changing one's lifestyle did not result in a long-term decrease in the incidence of clinically diagnosed DR, and that cumulative HbA1c continued to be a strong indicator of DR risk, highlighting the importance of maintaining glycemic management [62]. Broadening the scope, Gong et al. found that a six-year lifestyle modification was followed by a significantly decreased incidence of severe DR over a two-decade period, indicating that significant, long-term protection can result from early and consistent adjustments [63]. Together, these contradictory findings highlight that the common approach to retinal benefit is permanent metabolic improvement, even though they differ in endpoints (lesion-level vs. clinical diagnosis vs. severe illness), follow-up duration, and adherence.

Microbiome signals and emerging biomarkers

Qin et al. connected the risk of DR to the gut microbiota by demonstrating that individuals with DR had reduced levels of plasma acetate and butyrate and that bacteria that produce short-chain fatty acids were diminished [64]. Despite their promise, these findings nevertheless raise questions because of the small sample sizes and cross-sectional design of the majority of microbiome research. To elucidate causality and determine if microbiome manipulation might alter retinal outcomes, longitudinal cohorts and interventional trials will be required.

Comparative synthesis across domains

When taken as a whole, food and exercise yield complimentary advantages that are greater than when taken separately. Loprinzi found that a comprehensive strategy that improved nutrition and activity at the same time provided better protection against moderate-to-severe DR than either behavior alone, suggesting a synergistic effect on inflammation, lipids, and blood sugar [65]. However, in many multivariable models, alcohol did not show up as a major risk factor, and isolated supplement studies enhanced surrogate markers without verifying protection against retinal outcomes [31][38]. Compared to self-reported diet, sleep and activity frequently had higher relationships with DR risk. This could be due to the powerful physiological effects of movement and rest on glycemic variability and vascular stress, as well as measurement accuracy (accelerometry and sleep duration are easier to quantify) [18][41]. The overwhelming body of research in these areas supports behavior-based, integrated care programs that are strengthened by frequent screening, teaching, and digital reinforcement.

Clinical implications, implementation and limitations

In addition to medicine, the practical advice for clinicians is to recommend systematic, customized lifestyle modifications. At least 150 minutes a week of moderate-intensity aerobic exercise should be recommended for patients, employing strategies to break up long spans of time of sitting throughout the day. In addition to avoiding sugar-sweetened beverages, dietary counselling

should promote low-GI staples, increased consumption of fruits, vegetables, and legumes, regular oily fish, and the replacement of refined carbohydrates with whole-grain alternatives. Regular diabetic evaluations can include sleep screening and brief counselling, and by encouraging DR screening attendance and reinforcing practices, digital platforms can provide help in between visits. Pharmacist-led, culturally-specific programs provide a scalable delivery paradigm that has already demonstrated improvements in metabolic control and adherence in health systems with limited resources.

Although the patterns are generally consistent, care should be taken due to a number of methodological constraints. Some studies had short follow-up times, different designs, and a lot of self-reported exposures, which can lead to measurement error and recollection bias. Sample sizes were occasionally limited, and it is unable to completely rule out confounding, especially by glycemic control, disease duration, socioeconomic status, and co-medications. Trials with retinal endpoints are necessary for causal inference, even in cases where relationships are substantial. Pragmatic, longer-duration randomized studies that evaluate sleep, sedentary-time interruption, and combined diet-and-activity programs utilizing standardized retinal grading and objective exposure metrics should be given priority in future research. Emerging fields like adjuvant botanicals and microbiota modification should be thoroughly assessed in multicenter trials before being incorporated into guidelines.

CONCLUSION

In order to slow the progression of diabetic retinopathy, a healthy, low-GI/Mediterranean-leaning diet, regular exercise with less sitting, enough sleep, and mental health management consistently supplement standard care. This is primarily due to long-lasting improvements in HbA1c, blood pressure, and lipids, as well as improved screening adherence. Particularly in environments with limited resources, pharmacist-led, culturally specific initiatives are useful and scalable. The balance favors including organized lifestyle counselling into routine DR care, despite inconsistent findings and varying evidence quality. To reinforce causation, future trials should use objective behavior measures and standardized retinal endpoints.

ACKNOWLEDGMENT: “The authors extend their appreciation to Prince Sattam bin Abdulaziz University for funding this research work through the project number (PSAU/2025/03/38196).”

Funding: “The authors extend their appreciation to Prince Sattam bin Abdulaziz University for funding this research work through the project number (PSAU/2025/03/38196).”

REFERENCES

- [1] International Diabetes Federation, “Diabetes Atlas 11th Edition,” 2025. <https://diabetesatlas.org/> (accessed Mar. 18, 2025).
- [2] R. Bourne, S. Flaxman, ... T. B.-T. L. G., and undefined 2017, “Magnitude, temporal trends, and projections of the global prevalence of blindness and distance and near vision impairment: a systematic review and meta,” *thelancet.comRR4 Bourne, SR Flaxman, T Braithwaite, MV Cicinelli, A Das, JB Jonas, J KeffeThe Lancet Glob. Heal.* 2017•*thelancet.com*, Accessed: Sep. 09, 2025. [Online]. Available: [https://www.thelancet.com/journals/langlo/article/PIIS2214-109X\(17\)30293-0/fulltext?uuiid=eZRypWhIesimRf2q0082](https://www.thelancet.com/journals/langlo/article/PIIS2214-109X(17)30293-0/fulltext?uuiid=eZRypWhIesimRf2q0082).
- [3] J. H. Gonzalez-Cortes *et al.*, “Current Treatments and Innovations in Diabetic Retinopathy and Diabetic Macular Edema,” *Pharm.* 2023, *Vol. 15, Page 122*, vol. 15, no. 1, p. 122, Dec. 2022, doi: 10.3390/PHARMACEUTICS15010122.
- [4] C. Flaxel, R. Adelman, S. Bailey, A. Fawzi, ... J. L.-, and undefined 2020, “Diabetic retinopathy preferred practice pattern®,” *aaajournal.org*, Accessed: Sep. 09, 2025. [Online]. Available: [https://www.aaajournal.org/article/S0161-6420\(19\)32092-5/abstract](https://www.aaajournal.org/article/S0161-6420(19)32092-5/abstract).
- [5] C. Wilkinson, F. F. III, R. Klein, P. L.- Ophthalmology, and undefined 2003, “Proposed international clinical diabetic retinopathy and diabetic macular edema disease severity scales,” *ElsevierCP Wilkinson, FL Ferris III, RE Klein, PP Lee, CD Agardh, M Davis, D Dills, A KampikOphthalmology*, 2003•*Elsevier*, Accessed: Sep. 09, 2025. [Online]. Available: <https://www.sciencedirect.com/science/article/pii/S0161642003004755>.
- [6] J. G. Gross *et al.*, “Five-Year Outcomes of Panretinal Photocoagulation vs Intravitreal Ranibizumab for Proliferative Diabetic Retinopathy: A Randomized Clinical Trial,” *JAMA Ophthalmol.*, vol. 136, no. 10, pp. 1138–1148, Oct. 2018, doi: 10.1001/JAMAOPHTHALMOL.2018.3255.
- [7] D. W. Hutton, J. D. Stein, N. M. Bressler, L. M. Jampol, D. Browning, and A. R. Glassman, “Cost-effectiveness of Intravitreal Ranibizumab Compared With Panretinal Photocoagulation for Proliferative Diabetic Retinopathy: Secondary Analysis From a Diabetic Retinopathy Clinical Research Network Randomized Clinical Trial,” *JAMA Ophthalmol.*, vol. 135, no. 6, pp. 576–584, Jun. 2017, doi: 10.1001/JAMAOPHTHALMOL.2017.0837.

- [8] R. R. A. Bourne *et al.*, “Effective refractive error coverage in adults aged 50 years and older: estimates from population-based surveys in 61 countries,” *Lancet Glob. Heal.*, vol. 10, no. 12, pp. e1754–e1763, Dec. 2022, doi: 10.1016/S2214-109X(22)00433-8.
- [9] H. Patel *et al.*, “Diabetic Retinopathy Disease Burden in Patients With Lower Household Incomes vs Higher Household Incomes,” *J. Vitreoretin. Dis.*, vol. 9, no. 3, pp. 297–302, 2025, doi: 10.1177/24741264241309683.
- [10] R. Wittenberg *et al.*, “Costs and cost-effectiveness of the Kerala pilot screening programme for diabetic retinopathy in the public health system,” *Eye*, vol. 38, no. 17, pp. 3352–3356, Dec. 2024, doi: 10.1038/S41433-024-03304-W;SUBJMETA=3161,3934,692,699,700;KWRD=EYE+DISEASES,HEALTH+CARE+ECONOMICS.
- [11] S. Somani *et al.*, “Characteristics and Treatment Patterns of Patients with Diabetic Macular Edema Non-Responsive to Anti-Vascular Endothelial Growth Factor Treatment in Ontario, Canada,” *Clin. Ophthalmol.*, vol. 17, p. 2013, 2023, doi: 10.2147/OPHTH.S399981.
- [12] R. S. Beaser, W. A. Turell, and A. Howson, “Strategies to improve prevention and management in diabetic retinopathy: Qualitative insights from a mixed-methods study,” *Diabetes Spectr.*, vol. 31, no. 1, pp. 65–74, Feb. 2018, doi: 10.2337/DS16-0043.
- [13] U. Mudaliar *et al.*, “Cardiometabolic Risk Factor Changes Observed in Diabetes Prevention Programs in US Settings: A Systematic Review and Meta-analysis,” *PLoS Med.*, vol. 13, no. 7, Jul. 2016, doi: 10.1371/JOURNAL.PMED.1002095.
- [14] J. Shah, Z. Y. Cheong, B. Tan, D. Wong, X. Liu, and J. Chua, “Dietary Intake and Diabetic Retinopathy: A Systematic Review of the Literature,” *Nutrients*, vol. 14, no. 23, p. 5021, Dec. 2022, doi: 10.3390/NU14235021/S1.
- [15] X. Yan, X. Han, C. Wu, X. Shang, L. Zhang, and M. He, “Effect of physical activity on reducing the risk of diabetic retinopathy progression: 10-year prospective findings from the 45 and Up Study,” *PLoS One*, vol. 16, no. 1, p. e0239214, Jan. 2021, doi: 10.1371/JOURNAL.PONE.0239214.
- [16] W. Zhu, Y. F. Meng, Y. Wu, M. Xu, and J. Lu, “Association of alcohol intake with risk of diabetic retinopathy: A metaanalysis of observational studies,” *Sci. Rep.*, vol. 7, no. 1, pp. 1–9, Jan. 2017, doi: 10.1038/S41598-017-00034-W;SUBJMETA.
- [17] Y. Yang *et al.*, “Association of sleep quality with glycemic variability assessed by flash glucose monitoring in patients with type 2 diabetes,” *Diabetol. Metab. Syndr.*, vol. 13, no. 1, pp. 1–10, Dec. 2021, doi: 10.1186/S13098-021-00720-W/TABLES/2.
- [18] C. Horikawa and H. Sone, “Dietary salt intake and diabetes complications in patients with diabetes: An overview,” *J. Gen. Fam. Med.*, vol. 18, no. 1, p. 16, Mar. 2017, doi: 10.1002/JGF2.10.
- [19] A. Z. A. M. AlShammari, F. F. Alhamad, Z. E. E. Abdelgadir, H. M. AlShammari, M. Alahmadi, and K. F. Alharbi, “Impact of Lifestyle Interventions on the Progression of Diabetic Retinopathy in Patients Diagnosed With Diabetes Mellitus: A Systematic Review,” *Cureus*, vol. 17, no. 4, p. e82411, Apr. 2025, doi: 10.7759/CUREUS.82411.
- [20] A. D. A. P. P. Committee *et al.*, “3. Prevention or Delay of Diabetes and Associated Comorbidities: Standards of Care in Diabetes—2025,” *Diabetes Care*, vol. 48, no. Supplement_1, pp. S50–S58, Jan. 2025, doi: 10.2337/DC25-S003.
- [21] A. Bryl, M. Mrugacz, M. Falkowski, and K. Zorena, “The Effect of Diet and Lifestyle on the Course of Diabetic Retinopathy—A Review of the Literature,” *Nutr. 2022, Vol. 14, Page 1252*, vol. 14, no. 6, p. 1252, Mar. 2022, doi: 10.3390/NU14061252.
- [22] Y. Li *et al.*, “Diabetic vascular diseases: molecular mechanisms and therapeutic strategies,” *Signal Transduct. Target. Ther.*, vol. 8, no. 1, pp. 1–29, Dec. 2023, doi: 10.1038/S41392-023-01400-Z;SUBJMETA.
- [23] M. Błaskiewicz, A. Walulik, K. Florek, I. Górecki, O. Ślawatyniec, and K. Gomulka, “Advances and Perspectives in Relation to the Molecular Basis of Diabetic Retinopathy—A Review,” *Biomedicines*, vol. 11, no. 11, 2023, doi: 10.3390/biomedicines11112951.
- [24] Y. An *et al.*, “The role of oxidative stress in diabetes mellitus-induced vascular endothelial dysfunction,” *Cardiovasc. Diabetol.*, vol. 22, no. 1, pp. 1–17, Dec. 2023, doi: 10.1186/S12933-023-01965-7/FIGURES/4.
- [25] T. Yue, Y. Shi, S. Luo, J. Weng, Y. Wu, and X. Zheng, “The role of inflammation in immune system of diabetic retinopathy: Molecular mechanisms, pathogenetic role and therapeutic implications,” *Front. Immunol.*, vol. 13, p. 1055087, Dec. 2022, doi: 10.3389/FIMMU.2022.1055087/FULL.
- [26] D. Zooravar, P. Soltani, and S. Khezri, “Mediterranean diet and diabetic microvascular complications: a systematic review and meta-analysis,” *BMC Nutr.*, vol. 11, no. 1, pp. 1–13, Dec. 2025, doi: 10.1186/S40795-025-01038-W/FIGURES/5.
- [27] C. Shen *et al.*, “Association of wearable device-measured physical activity with full-course diabetic retinopathy and retinal

- traits: insights from the middle-aged and older adult cohort,” *Diabetol. Metab. Syndr.*, vol. 17, no. 1, pp. 1–11, Dec. 2025, doi: 10.1186/S13098-025-01745-1/TABLES/3.
- [28] A. Boretsky *et al.*, “Nicotine Accelerates Diabetes-Induced Retinal Changes,” *Curr. Eye Res.*, vol. 40, no. 4, p. 368, Apr. 2014, doi: 10.3109/02713683.2014.924147.
 - [29] R. Brandt, M. Park, K. Wroblewski, L. Quinn, E. Tasali, and A. Cinar, “Sleep quality and glycaemic variability in a real-life setting in adults with type 1 diabetes,” *Diabetologia*, vol. 64, no. 10, pp. 2159–2169, Oct. 2021, doi: 10.1007/S00125-021-05500-9/FIGURES/2.
 - [30] Y. AlQabandi *et al.*, “Physical Activity Status and Diabetic Retinopathy: A Review,” *Cureus*, vol. 14, no. 8, p. e28238, Aug. 2022, doi: 10.7759/CUREUS.28238.
 - [31] B. Li *et al.*, “Modifiable lifestyle, mental health status and diabetic retinopathy in U.S. adults aged 18–64 years with diabetes: a population-based cross-sectional study from NHANES 1999–2018,” *BMC Public Health*, vol. 24, no. 1, pp. 1–10, 2024, doi: 10.1186/s12889-023-17512-8.
 - [32] B. Wang, H. Li, H. Ma, and Z. H. Chen, “The association of cigarette smoking with the development and progression of diabetic retinopathy: based on cross-sectional survey and mendelian randomization,” *J. Transl. Med.*, vol. 22, no. 1, 2024, doi: 10.1186/s12967-024-06002-z.
 - [33] S. Pardhan *et al.*, “Individual patient-centered target-driven intervention to improve clinical outcomes of diabetes, health literacy, and self-care practices in Nepal: A randomized controlled trial,” *Front. Endocrinol. (Lausanne)*, vol. 14, no. January, pp. 1–14, 2023, doi: 10.3389/fendo.2023.1076253.
 - [34] G. Liu *et al.*, “Adherence to a Healthy Lifestyle in Association With Microvascular Complications Among Adults With Type 2 Diabetes,” *JAMA Netw. Open*, vol. 6, no. 1, pp. e2252239–e2252239, Jan. 2023, doi: 10.1001/JAMANETWORKOPEN.2022.52239.
 - [35] Z. Wu *et al.*, “Association of visceral adiposity index with incident nephropathy and retinopathy: a cohort study in the diabetic population,” *Cardiovasc. Diabetol.*, vol. 21, no. 1, pp. 1–9, 2022, doi: 10.1186/s12933-022-01464-1.
 - [36] K. E. Alsirk, J. H. Seland, and J. Assmus, “Diabetic retinopathy and visual impairment in a Norwegian diabetic coast population with a high dietary intake of fish oils. An observational study,” *Acta Ophthalmol.*, vol. 100, no. 2, pp. e532–e538, Mar. 2022, doi: 10.1111/AOS.14977.
 - [37] R. Kadri, P. Vishwanath, D. Parameshwar, S. Hegde, and A. A. Kudva, “Dietary associations with diabetic retinopathy—A cohort study,” *Indian J. Ophthalmol.*, vol. 69, no. 3, pp. 661–665, Mar. 2021, doi: 10.4103/IJO.IJO_253_20.
 - [38] P. Gupta *et al.*, “Association of alcohol intake with incidence and progression of diabetic retinopathy,” *Br. J. Ophthalmol.*, vol. 105, no. 4, pp. 538–542, Apr. 2021, doi: 10.1136/BJOPHTHALMOL-2020-316360.
 - [39] H. Tikkanen-Dolenc *et al.*, “Frequent physical activity is associated with reduced risk of severe diabetic retinopathy in type 1 diabetes,” *Acta Diabetol.*, vol. 57, no. 5, pp. 527–534, 2020, doi: 10.1007/s00592-019-01454-y.
 - [40] A. Aro *et al.*, “Life Style Intervention Improves Retinopathy Status—The Finnish Diabetes Prevention Study,” *Nutrients*, vol. 11, no. 7, Jul. 2019, doi: 10.3390/NU11071691.
 - [41] D. P. Dharmastuti *et al.*, “Associations of Physical Activity and Sedentary Behaviour with Vision-Threatening Diabetic Retinopathy in Indonesian Population with Type 2 Diabetes Mellitus: Jogjakarta Eye Diabetic Study in the Community (JOGED.COM),” *Ophthalmic Epidemiol.*, vol. 25, no. 2, pp. 113–119, Mar. 2018, doi: 10.1080/09286586.2017.1367410.
 - [42] A. Praidou, M. Harris, D. Niakas, and G. Labiris, “Physical activity and its correlation to diabetic retinopathy,” *J. Diabetes Complications*, vol. 31, no. 2, pp. 456–461, 2017, doi: 10.1016/j.jdiacomp.2016.06.027.
 - [43] E. Y. Chew, “Dietary Intake of Omega-3 Fatty Acids From Fish and Risk of Diabetic Retinopathy,” *JAMA*, vol. 317, no. 21, p. 2226, Jun. 2017, doi: 10.1001/JAMA.2017.1926.
 - [44] H. Kuwata, S. Okamura, Y. Hayashino, S. Tsujii, and H. Ishii, “Higher levels of physical activity are independently associated with a lower incidence of diabetic retinopathy in Japanese patients with type 2 diabetes: A prospective cohort study, Diabetes Distress and Care Registry at Tenri (DDCRT15),” *PLoS One*, vol. 12, no. 3, p. e0172890, Mar. 2017, doi: 10.1371/JOURNAL.PONE.0172890.
 - [45] C. Horikawa *et al.*, “Is the proportion of carbohydrate intake associated with the incidence of diabetes complications?—an analysis of the Japan diabetes complications study,” *Nutrients*, vol. 9, no. 2, pp. 1–10, 2017, doi: 10.3390/nu9020113.
 - [46] N. Alcubierre *et al.*, “Association of low oleic acid intake with diabetic retinopathy in type 2 diabetic patients: a case-control study,” *Nutr. Metab. (Lond)*, vol. 13, no. 1, Jun. 2016, doi: 10.1186/S12986-016-0099-5.
 - [47] A. E. Millen *et al.*, “Adequate vitamin D status is associated with the reduced odds of prevalent diabetic retinopathy in African Americans and Caucasians,” *Cardiovasc. Diabetol.*, vol. 15, no. 1, p. 128, Sep. 2016, doi: 10.1186/S12933-016-

- 0434-1.
- [48] R. E. K. Man *et al.*, “Differential Association of Generalized and Abdominal Obesity With Diabetic Retinopathy in Asian Patients With Type 2 Diabetes,” *JAMA Ophthalmol.*, vol. 134, no. 3, pp. 251–257, Mar. 2016, doi: 10.1001/JAMAOPHTHALMOL.2015.5103.
- [49] P. D. Loprinzi, “Concurrent healthy behavior adoption and diabetic retinopathy in the United States,” *Prev. Med. Reports*, vol. 2, pp. 591–594, Dec. 2015, doi: 10.1016/j.pmedr.2015.07.002.
- [50] Q. Ma, D. Chen, H. P. Sun, N. Yan, Y. Xu, and C. W. Pan, “Regular Chinese Green Tea Consumption Is Protective for Diabetic Retinopathy: A Clinic-Based Case-Control Study,” *J. Diabetes Res.*, vol. 2015, p. 231570, 2015, doi: 10.1155/2015/231570.
- [51] M. Sasaki *et al.*, “The Associations of Dietary Intake of Polyunsaturated Fatty Acids With Diabetic Retinopathy in Well-Controlled Diabetes,” *Invest. Ophthalmol. Vis. Sci.*, vol. 56, no. 12, pp. 7473–7479, 2015, doi: 10.1167/IOVS.15-17485.
- [52] D. Domanico, S. Fragiotta, A. Cutini, C. Carnevale, L. Zompatori, and E. Vingolo, “Circulating levels of reactive oxygen species in patients with nonproliferative diabetic retinopathy and the influence of antioxidant supplementation: 6-month follow-up,” *Indian J. Ophthalmol.*, vol. 63, no. 1, pp. 9–14, Mar. 2015, doi: 10.4103/0301-4738.151455.
- [53] S. E. Mahoney and P. D. Loprinzi, “Influence of flavonoid-rich fruit and vegetable intake on diabetic retinopathy and diabetes-related biomarkers,” *J. Diabetes Complications*, vol. 28, no. 6, pp. 767–771, Nov. 2014, doi: 10.1016/j.jdiacomp.2014.06.011.
- [54] M. R. Janevic, S. J. McLaughlin, and C. M. Connell, “The association of diabetes complications with physical activity in a representative sample of older adults in the United States,” *Chronic Illn.*, vol. 9, no. 4, pp. 251–257, Dec. 2013, doi: 10.1177/1742395313475461.
- [55] D. Care and S. S. Suppl, “10. Cardiovascular disease and risk management: Standards of care in diabetes—2025,” *Diabetes Care*, vol. 48, no. January, pp. S207–S238, 2025, doi: 10.2337/dc25-S010.
- [56] Z. Khair *et al.*, “Health education improves referral compliance of persons with probable Diabetic Retinopathy: A randomized controlled trial,” *PLoS One*, vol. 15, no. 11 November, pp. 1–16, 2020, doi: 10.1371/journal.pone.0242047.
- [57] J. P. Bantle *et al.*, “Effect of a Long-Term Behavioral Weight Loss Intervention on Nephropathy in Overweight or Obese Adults with Type 2 Diabetes: the Look AHEAD Randomized Clinical Trial,” vol. 2, no. 10, pp. 801–809, 2015, doi: 10.1016/S2213-8587(14)70156-1.Effect.
- [58] H. Mirghani, N. Alali, H. Albalawi, and R. Alselaimey, “Diet sugar-free carbonated soda beverage, non-caloric flavors consumption, and diabetic retinopathy: Any linkage,” *Diabetes, Metab. Syndr. Obes.*, vol. 14, pp. 2309–2315, 2021, doi: 10.2147/DMSO.S309029.
- [59] D. Pereira-Payo, Á. Denche-Zamorano, M. Mendoza-Muñoz, and R. Pastor-Cisneros, “Diabetes Eye Disease Sufferers and Non-Sufferers Are Differentiated by Sleep Hours, Physical Activity, Diet, and Demographic Variables: A CRT Analysis,” *Healthc.*, vol. 12, no. 23, pp. 1–16, 2024, doi: 10.3390/healthcare12232345.
- [60] Y. Zhao *et al.*, “Therapeutic Effect of Abelmoschus manihot on Type 2 Diabetic Nonproliferative Retinopathy and the Involvement of VEGF,” *Evidence-based Complement. Altern. Med.*, vol. 2020, 2020, doi: 10.1155/2020/5204917.
- [61] X. Yao, X. Cao, Z. Yan, X. Qian, D. Qian, and Z. Lin, “Effectiveness of Internet + E-Coach chronic disease management on blood glucose, lipid levels, liver function, and quality of life in patients with chronic diabetic retinopathy: a comparative study,” *BMC Ophthalmol.*, vol. 24, no. 1, 2024, doi: 10.1186/s12886-024-03737-7.
- [62] K. Kaarniranta, M. Valtanen, S. Keinänen-Kiukaanniemi, J. Tuomilehto, J. Lindström, and M. Uusitupa, “Long-term Cumulative Incidence of Clinically Diagnosed Retinopathy in the Finnish Diabetes Prevention Study,” *J. Clin. Endocrinol. Metab.*, vol. 110, no. 3, p. e615, Mar. 2024, doi: 10.1210/CLINEM/DGAE287.
- [63] Q. Gong *et al.*, “Long-term effects of a randomised trial of a 6-year lifestyle intervention in impaired glucose tolerance on diabetes-related microvascular complications: The China da Qing Diabetes Prevention Outcome Study,” *Diabetologia*, vol. 54, no. 2, pp. 300–307, 2011, doi: 10.1007/s00125-010-1948-9.
- [64] X. Qin *et al.*, “Gut microbiota predict retinopathy in patients with diabetes: A longitudinal cohort study,” *Appl. Microbiol. Biotechnol.*, vol. 108, no. 1, 2024, doi: 10.1007/s00253-024-13316-x.
- [65] P. D. Loprinzi, “Concurrent healthy behavior adoption and diabetic retinopathy in the United States,” *Prev. Med. Reports*, vol. 2, pp. 591–594, 2015, doi: 10.1016/j.pmedr.2015.07.002.