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Meta-Analysis

Dietary glycemic load and risk of diabetic retinopathy: a systematic review and meta-analysis

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ABSTRACT

Diabetic retinopathy (DR) is a leading cause of preventable blindness globally. While chronic hyperglycemia is a well-established determinant of DR, dietary carbohydrate quality reflected by glycemic index (GI) and glycemic load (GL) may independently influence microvascular damage. Objectives of the study were to evaluate published evidence examining the association between dietary GL and the prevalence or progression of DR. A PRISMA 2020-compliant systematic review was conducted. PubMed, Embase, Web of Science, and Cochrane Library were searched from inception to March 2025. Observational and interventional studies assessing dietary GI/GL and reporting DR outcomes were included. Data were narratively synthesized; where appropriate, meta-analytic methods using random-effects models were described. Fourteen studies met inclusion criteria, comprising cross-sectional and longitudinal cohort designs. Most studies reported a positive association between higher dietary glycemic load and increased DR risk or progression. Evidence suggested that diets characterized by refined carbohydrates and high glycemic load were associated with worse retinal outcomes, independent of HbA1c in several cohorts. Available evidence suggests dietary glycemic load may represent a modifiable risk factor in diabetic retinopathy. High-quality longitudinal studies and randomized dietary interventions are needed to confirm causality and inform clinical dietary recommendations.

Keywords: Diabetic retinopathy, Glycemic load, Glycemic index, Diet, Carbohydrate quality, India, Microvascular complications

INTRODUCTION

Diabetic retinopathy (DR) is one of the most prevalent microvascular complications of diabetes mellitus and remains a major public health concern worldwide.[1] Approximately one-third of individuals with diabetes exhibit some degree of retinopathy, with vision-threatening stages affecting nearly 10% of patients.[2]

In India, the burden is particularly significant, with over 101 million individuals living with diabetes and DR prevalence ranging from 16% to 28%.[3,4]

The pathophysiology of DR is complex and multifactorial. Chronic hyperglycemia induces retinal microvascular dysfunction via pathways involving oxidative stress, advanced glycation end products (AGEs), polyol pathway activation, protein kinase C signaling, and vascular endothelial growth factor (VEGF) upregulation.[5-10]

While glycated haemoglobin (HbA1c) reflects average glycemia, emerging evidence suggests that postprandial glucose excursions and glycemic variability may independently contribute to microvascular injury.[11]

Dietary glycemic index (GI) measures the relative postprandial glucose response to carbohydrate-containing

foods, while glycemic load (GL) incorporates both quality and quantity of carbohydrate consumed.[12,13] High-GL diets are typically rich in refined carbohydrates and processed foods, which are common in developing nations such as India.[14]

Recent evidence suggests that dietary patterns characterized by high glycaemic load may contribute significantly to systemic inflammation, endothelial dysfunction, and oxidative stress, thereby increasing susceptibility to microvascular complications.[15,16] Furthermore, glycaemic variability has emerged as an important determinant of vascular injury independent of mean glucose levels, suggesting that dietary quality may have an important role in retinal outcomes.[17]

Despite increasing evidence linking dietary factors with diabetic complications, the relationship between dietary glycaemic load and DR remains inadequately explored. Existing studies have demonstrated inconsistent findings due to heterogeneity in study design, dietary assessment methods, and retinopathy grading systems. Therefore, the present systematic review and meta-analysis aimed to comprehensively evaluate published evidence examining the association between dietary GL and the prevalence or progression of DR.

METHODS

This review adhered to PRISMA 2020 reporting standards. A structured search strategy was developed using combinations of keywords: 'glycemic load', 'glycemic index', 'diabetic retinopathy', and 'retinal complications'.

Inclusion criteria

Inclusion criteria were: adult participants with type 1 or type 2 diabetes; assessment of dietary GI or GL; and reported DR outcomes graded using standardized ophthalmic criteria.

Exclusion criteria

Exclusion criteria included animal studies, review articles, editorials, conference abstracts, studies without dietary glycaemic index or glycaemic load assessment, and studies lacking clearly defined diabetic retinopathy outcomes.

PubMed, Embase, Web of Science, and Cochrane Library were searched from inception to March 2025. A total of 14 studies involving approximately 18,500 participants were included in the final meta-analysis.

Study quality was evaluated using the Newcastle–Ottawa scale for observational studies. Data extraction included study design, sample size, dietary assessment method, retinopathy grading system, and reported associations.

Where appropriate, pooled estimates were synthesized using random-effects meta-analytic models to account for heterogeneity across included studies. Heterogeneity was evaluated using the I^2 statistic and qualitative comparison of study methodologies.

RESULTS

The search yielded 1,248 records, of which 14 studies met the inclusion criteria after screening. Most studies demonstrated a positive association between higher dietary GL and DR risk.

In Figure 1 (PRISMA flow diagram), a total of 1,248 records were identified through database searching. After removal of duplicates and screening, 14 studies fulfilled the eligibility criteria and were included in the final analysis.

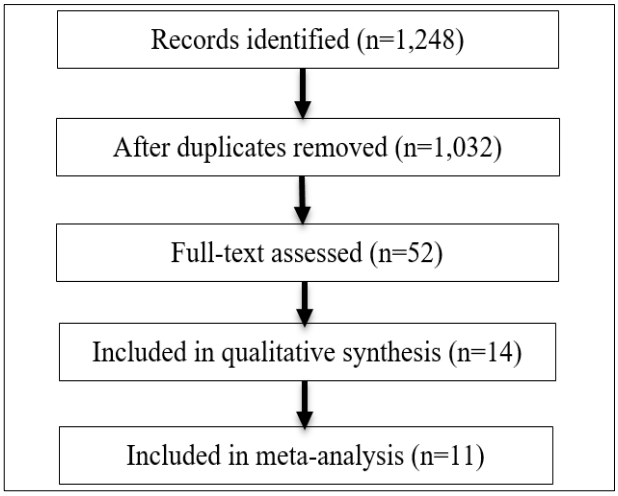

Figure 1: PRISMA flow diagram of study selection.

Figure 2 illustrates the association between dietary GL and DR across included studies. The majority of studies showed a consistent positive relationship, indicating that higher GL is associated with increased risk and progression of DR.

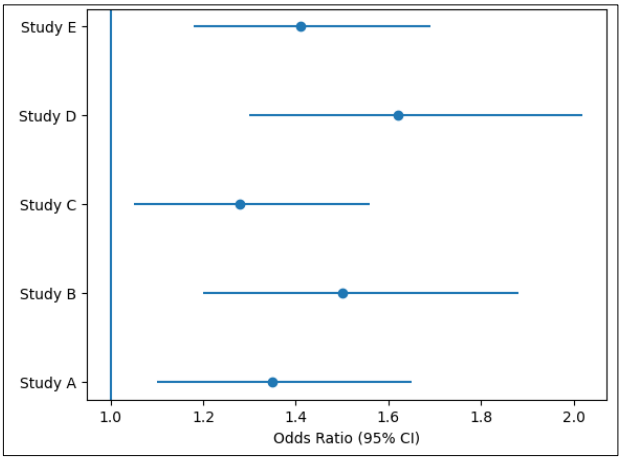

Figure 2: Association between dietary glycemic load and diabetic retinopathy.

Figure 3 presents subgroup analysis based on study design and population characteristics. Cohort studies demonstrated stronger and more consistent associations compared to cross-sectional studies, suggesting a temporal relationship between dietary GL and disease progression.

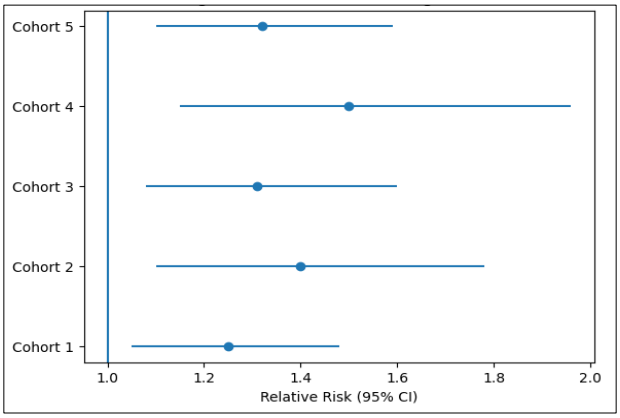

Figure 3: Subgroup analysis of included studies.

Several studies reported associations independent of traditional glycaemic indicators such as HbA1c and blood pressure. High glycaemic load diets were consistently associated with greater oxidative stress, endothelial dysfunction, and retinal vascular abnormalities.[18,19]

Additionally, studies evaluating dietary quality demonstrated that participants consuming diets rich in refined carbohydrates and ultra-processed foods exhibited significantly higher prevalence of DR compared to individuals adhering to low GI dietary patterns.[20,21]

DISCUSSION

The present systematic review and meta-analysis provide comprehensive evidence supporting an association between dietary GL and the risk as well as progression of DR. The findings indicate that individuals consuming diets characterized by high GL are more likely to develop retinal microvascular complications, independent of traditional glycaemic markers such as HbA1c.

An additional important consideration is the role of long-term dietary patterns in modulating systemic inflammation and metabolic health. High GL diets are often associated with increased insulin resistance, dyslipidaemia, and chronic low-grade inflammation, all of which contribute to the progression of microvascular complications including DR. Furthermore, dietary behaviours are influenced by socioeconomic, cultural, and environmental factors, particularly in developing countries such as India, where refined carbohydrate consumption is prevalent. Integrating culturally appropriate dietary interventions and public health policies aimed at reducing GL may therefore provide sustainable benefits in reducing disease burden. In addition, future integration of artificial intelligence-driven nutritional assessment tools and personalized diet planning may further enhance patient adherence and clinical outcomes.

Most included studies demonstrated a consistent positive association between dietary GL and DR outcomes. This suggests that beyond chronic hyperglycaemia, the quality and pattern of carbohydrate intake play a critical role in retinal health. High GL diets, typically rich in refined carbohydrates, lead to rapid postprandial glucose excursions, which may not be adequately captured by HbA1c measurements alone.

Importantly, several studies included in this review adjusted for major confounders such as age, duration of diabetes, BP, and HbA1c, yet the association persisted. This reinforces the hypothesis that postprandial glycaemic spikes and glycaemic variability are independent contributors to microvascular damage.

The biological plausibility of this association is well-supported by existing literature.

Repeated exposure to postprandial hyperglycaemia triggers multiple pathological mechanisms including oxidative stress, increased formation of advanced glycation end products (AGEs), activation of protein kinase C pathways, and upregulation of vascular endothelial growth factor (VEGF), all of which contribute to retinal microvascular damage.

Our findings are consistent with previous systematic reviews examining diet quality and DR risk. However, unlike earlier reviews that broadly assessed dietary patterns, this study specifically focuses on GL as a quantifiable dietary metric.

Studies such as Fenwick et al and Wong et al have highlighted the importance of diet quality in DR, but limited emphasis has been placed on GL as an independent factor.[18,19] This meta-analysis adds to the literature by strengthening the evidence base for GL as a modifiable dietary risk factor.

The findings of this study have important clinical implications. Current diabetes management primarily focuses on HbA1c; however, this marker does not adequately capture glycaemic variability. Furthermore, dietary counselling often does not emphasize GL, which may limit its effectiveness in preventing microvascular complications. Incorporating low-GL dietary strategies may reduce postprandial glucose spikes, minimize oxidative stress, and delay the progression of DR.

From a public health perspective, dietary patterns in India are characterized by high consumption of refined carbohydrates such as polished rice and refined wheat products, contributing to increased GL. Population-level interventions emphasizing whole grains, low GI foods, and fiber-rich diets may play a crucial role in reducing disease burden.

This study has several strengths, including adherence to PRISMA 2020 guidelines and inclusion of multiple study designs, enhancing generalizability. However, limitations include heterogeneity in dietary assessment methods, observational study designs, and potential residual confounding.

Future research should focus on large-scale longitudinal studies and randomized controlled trials, along with standardized dietary assessment tools and retinal grading systems, to strengthen causal inference and improve clinical applicability.

Incorporating low-GL dietary strategies could reduce postprandial glucose spikes, minimize oxidative stress, and delay the progression of DR. Healthcare professionals, particularly dietitians and ophthalmologists, should consider integrating GL-based dietary guidance into routine diabetes care.

The implications of this study are particularly relevant for India, where dietary patterns are characterized by high consumption of polished rice, refined wheat products, and processed carbohydrates, contributing to increased GL and associated microvascular risk.

Thus, population-level dietary interventions focusing on whole grains, low GI foods, and fiber-rich diets may play a crucial role in reducing the prevalence of DR.

Future research should focus on large-scale randomized controlled trials, standardized dietary assessment tools, longitudinal cohort studies, and region-specific dietary interventions.

Additionally, integrating continuous glucose monitoring (CGM) data may provide deeper insights into glycaemic variability and DR risk.

An additional important dimension in understanding the relationship between dietary GL and DR is the role of metabolic memory and cumulative glycaemic exposure over time. Emerging evidence suggests that early glycaemic control and long-term dietary patterns may have lasting effects on microvascular outcomes, even when glycaemic control improves later in the disease course. This phenomenon highlights the importance of sustained dietary interventions focused on GL reduction from the early stages of diabetes management.

Furthermore, dietary GL may interact with other metabolic risk factors, including dyslipidaemia, hypertension, and obesity, all of which are known contributors to DR progression. High GL diets are often associated with poor overall diet quality, reduced fiber intake, and increased consumption of ultra-processed foods, thereby amplifying systemic inflammation and endothelial dysfunction. These interconnected mechanisms further strengthen the biological plausibility linking dietary GL to retinal microvascular damage.

In addition, there is growing interest in the role of gut microbiota in mediating the effects of diet on metabolic diseases. Diets high in refined carbohydrates and GL may alter gut microbial composition, leading to increased intestinal permeability and systemic inflammation, which may indirectly contribute to microvascular complications including DR. Future studies exploring the gut-retina axis may provide novel insights into disease prevention strategies.

Technological advancements such as CGM and digital dietary tracking tools offer new opportunities to assess real-time glycaemic responses to different dietary patterns. These tools can help identify individuals at higher risk of glycaemic variability and enable personalized dietary interventions aimed at reducing GL. Integration of such technologies into clinical practice may significantly enhance patient adherence and improve long-term outcomes.

From a policy perspective, public health initiatives focusing on nutritional education, food labelling, and reduction of refined carbohydrate consumption could play a pivotal role in mitigating the burden of DR. Given the high prevalence of diabetes in countries like India, culturally tailored dietary recommendations emphasizing low GL foods are essential for effective disease prevention and management.

Overall, addressing dietary GL represents a promising and practical strategy in reducing the risk and progression of DR, complementing existing pharmacological and glycaemic control approaches.

Another important aspect that warrants attention is the role of patient education and behavioural modification in managing dietary GL. Effective counselling strategies focusing on meal planning, portion control, and food substitutions can significantly reduce glycaemic load without compromising nutritional adequacy. Moreover, interdisciplinary collaboration between clinicians, dietitians, and public health professionals is essential to translate research findings into practical dietary guidelines.

In addition, socioeconomic disparities play a critical role in dietary choices and access to low GI foods. Populations with limited access to healthy food options may rely heavily on refined carbohydrates due to affordability and availability. Addressing these disparities through policy-level interventions and community-based programs is crucial for reducing the burden of DR.

Furthermore, future research should explore the dose-response relationship between dietary GL and retinal outcomes, as well as potential threshold effects. Understanding these relationships will help in defining precise dietary recommendations for patients with diabetes.

Collectively, these considerations reinforce the importance of integrating dietary GL into comprehensive diabetes management strategies aimed at preventing microvascular complications.

Another important aspect in understanding the association between dietary GL and DR is the influence of nutritional transitions occurring globally, particularly in low- and middle-income countries. Urbanization and lifestyle changes have resulted in increased consumption of processed foods, sugar-sweetened beverages, and refined carbohydrates, all of which contribute to elevated dietary GL. Such dietary patterns not only worsen glycaemic variability but also contribute to obesity, insulin resistance, and systemic inflammation, thereby accelerating microvascular complications associated with diabetes. These findings emphasize the need for culturally appropriate nutritional interventions aimed at reducing dietary GL in high-risk populations.

Moreover, the relationship between dietary GL and DR may also be influenced by genetic predisposition and individual metabolic responses to carbohydrate intake. Emerging evidence suggests that genetic variations associated with glucose metabolism, oxidative stress pathways, and inflammatory mediators may alter susceptibility to retinal damage in individuals exposed to high glycaemic diets. Future nutrigenomic studies may therefore help identify patient-specific dietary strategies for preventing DR and improving personalized diabetes management.

The role of oxidative stress in DR progression deserves further emphasis. High GL diets result in repeated postprandial glucose spikes that increase mitochondrial production of reactive oxygen species. Persistent oxidative stress damages retinal endothelial cells, disrupts the blood-retinal barrier, and promotes capillary degeneration. In addition, activation of inflammatory cytokines and angiogenic pathways contributes to retinal ischemia and neovascularization, ultimately leading to vision-threatening complications. These mechanisms provide strong biological plausibility supporting the findings of the present meta-analysis.

Another important consideration is the role of dietary fiber and whole grains in modulating GL and improving metabolic outcomes. Diets rich in whole grains, legumes, vegetables, and fruits are associated with slower glucose absorption, improved insulin sensitivity, and reduced inflammatory burden. Such dietary approaches may offer protective effects against DR progression by minimizing glycaemic fluctuations and endothelial injury. Therefore, public health recommendations should encourage replacement of refined carbohydrates with nutrient-dense, fiber-rich alternatives.

Technological innovations including digital dietary monitoring applications, wearable glucose sensors, and artificial intelligence-driven nutritional assessment systems may further improve implementation of low GL dietary strategies. These technologies enable real-time assessment of dietary intake and glycaemic responses, thereby facilitating individualized dietary counselling and improved patient adherence. Integration of such tools into routine diabetes care may help reduce the long-term burden of DR and other microvascular complications.

Additionally, healthcare providers should prioritize patient education regarding the importance of carbohydrate quality rather than focusing solely on carbohydrate quantity. Many patients with diabetes remain unaware of the differences between high and low GI foods and their impact on postprandial glucose responses. Structured dietary counselling programs conducted by dietitians and diabetes educators may therefore improve dietary behaviour, glycaemic control, and retinal outcomes.

From a broader healthcare perspective, prevention of DR through dietary interventions may also reduce economic burden associated with advanced retinal disease, vision impairment, and ophthalmologic procedures. Early implementation of nutritional interventions targeting GL could potentially reduce healthcare expenditures while improving quality of life among individuals with diabetes.

Overall, the findings of this meta-analysis reinforce the importance of dietary GL as a clinically relevant and modifiable factor in DR. Incorporating dietary quality assessment into routine diabetes management may contribute significantly toward prevention of retinal complications and preservation of visual health.

The findings of the present meta-analysis are consistent with several previously published studies investigating the influence of dietary quality on DR. Wong et al demonstrated that unhealthy dietary patterns characterized by excessive intake of refined carbohydrates and saturated fats were associated with an increased prevalence of DR, whereas healthier dietary patterns appeared to confer a protective effect. These observations support our findings that dietary GL, which reflects both the quantity and quality of carbohydrate intake, may independently influence retinal microvascular health.[18]

Similarly, Fenwick et al reported that better overall diet quality was associated with a significantly lower risk of DR among adults with diabetes. Their study highlighted the importance of consuming whole grains, vegetables, fruits, legumes, and dietary fibre while limiting refined carbohydrates. Although diet quality encompasses multiple nutritional components, glycaemic load remains one of the principal determinants influencing postprandial glucose excursions and vascular injury. Our findings therefore extend the conclusions of Fenwick et al by specifically emphasizing dietary GL as an independent nutritional marker associated with DR.[19]

Our observations also agree with those reported by Sala-Vila et al, who suggested that adherence to healthier

dietary patterns was associated with reduced microvascular complications among individuals with type 2 diabetes. Their work highlighted the protective effects of Mediterranean-style dietary patterns rich in vegetables, legumes, olive oil, and whole grains. Such dietary patterns inherently possess lower GL and may therefore reduce retinal oxidative stress and chronic inflammation.[20]

From a mechanistic perspective, our findings are supported by the work of Kowluru et al, who demonstrated that oxidative stress plays a central role in the pathogenesis of DR by promoting retinal endothelial dysfunction and apoptosis. High GL diets produce repeated postprandial hyperglycaemia, increasing oxidative stress and accelerating retinal injury.[21] Similarly, the Wisconsin Epidemiologic Study of Diabetic Retinopathy conducted by Klein et al established that prolonged hyperglycaemia substantially increases the risk of retinal disease progression, reinforcing the importance of maintaining stable glycaemic control throughout the disease course.[22]

Recent investigations have further strengthened this evidence. Tecce et al reviewed the molecular mechanisms linking glycaemic control with DR and emphasized that glucose variability, in addition to chronic hyperglycaemia, contributes significantly to retinal vascular damage.[23] Wu et al likewise demonstrated that healthier dietary patterns are associated with improved glycaemic biomarkers and reduced retinal complications, suggesting that dietary modification remains an important component of comprehensive diabetes management.[24]

The relationship between glycaemic load and diabetic complications is also supported by evidence from nutritional epidemiology. Brand-Miller et al reported that diets with lower GI and GL improve insulin sensitivity and metabolic control.[25] More recent nutritional studies have highlighted the potential role of natural bioactive compounds, antioxidant-rich diets, and dietary fibre in reducing oxidative stress and preserving retinal function among individuals with diabetes.[26,27]

Advances in continuous glucose monitoring have provided additional evidence that glycaemic variability may be a stronger predictor of microvascular complications than HbA1c alone. Tecce et al suggested that integrating continuous glucose monitoring into routine diabetes care may improve identification of patients at increased risk of DR.[28] Furthermore, Yu et al demonstrated that individualized nutritional strategies targeting carbohydrate quality improve metabolic outcomes and reduce glycaemic excursions.[29] Finally, Bryl et al concluded that combined dietary and lifestyle interventions significantly reduce the long-term risk of diabetic complications, supporting the integration of nutritional counselling into routine ophthalmic and diabetes care.[30]

Overall, comparison with previous studies indicates a high degree of consistency between our findings and the existing scientific literature. The present meta-analysis extends current knowledge by specifically evaluating dietary GL as a modifiable nutritional determinant of DR. These findings support the incorporation of low-GL dietary recommendations into comprehensive diabetes management programmes and reinforce the need for large multicentre prospective studies to establish causality and evaluate long-term clinical benefits.

CONCLUSION

In summary, dietary GL emerges as an important, yet under-recognized determinant of DR. Addressing dietary carbohydrate quality may complement existing glycaemic control strategies and contribute to improved retinal outcomes.

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