The role of diet and nutrition in glaucoma

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Purpose of review
This review aims to explore the connection between diet and nutritional intake with optic nerve health for patients with glaucoma.

Recent findings
Using the AAO Grading Criteria to determine level of evidence, Level 1 and Level 2 studies reviewed here examine associations between nutritional intake and glaucoma. Increasing consumption of dietary nitrates and retinols, incorporating the Mediterranean diet, and reducing intake of ultra-processed foods to lower glaucoma risk are supported by Level 1 evidence. Level 2 evidence suggests that dietary niacin, antioxidants, fruits, and vegetables have potential to improve optic nerve health and are associated with reduced glaucoma risk. Evidence from both Level 1 and Level 2 studies suggest that combining multiple beneficial dietary components may produce more meaningful effects to reduce glaucoma risk than single dietary factors alone.

Summary
Although some studies highlight the protective role of single dietary components against glaucoma, adopting a combination of beneficial dietary habits appears to be more effective as an adjunctive treatment to enhance optic nerve health and lower glaucoma risk.

Keywords
diet, glaucoma, intraocular pressure, nutrition

INTRODUCTION

In 2022, an estimated 4.22 million people had glaucoma in the United States, with 1.5 million people having resultant blindness or significant vision loss [1]. Globally, figures were expected to reach 111.8 million by 2024 [2]. Despite glaucoma's global burden, little is known about the effects of nutrition on glaucoma risk and optic nerve health. Current treatment is centered on IOP-lowering medical and surgical interventions [3].

This review explores literature linking dietary components and glaucoma. Studies included were categorized as Level 1 or 2 per AAO Grading Criteria adapted from 2011 Oxford Centre for Evidence-Based Medicine (see Table 1). Level 1 evidence was assigned to randomized trials or observational studies with dramatic effects. Level 2 evidence is comprised of nonrandomized controlled cohort studies or follow-up studies. We evaluate how specific dietary nutrients impact glaucoma risk and how optimizing nutrition can be used as a prevention strategy in those at risk of glaucoma and is likely beneficial as an adjunctive treatment to existing interventions for patients with glaucoma.

LEVEL 1 EVIDENCE

Dietary nitrates

A large Level 1 prospective cohort study with a 25-year follow-up by Kang *et al.* [4] found that dietary nitrates, which increase nitric oxide, reduced primary open angle glaucoma (POAG) risk. Participants in the highest quintile (median 240 mg/day) had a 33% lower risk of POAG [95% confidence interval (95% CI) = 0.52–0.85] compared to those in the lowest quintile (median 80 mg/day) when adjusting for confounders and intake of dietary folate, antioxidants, vitamin A, calories, caffeine, and alcohol. The effect was greater among those with early paracentral

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Curr Opin Ophthalmol 2026, 37:99–107

DOI:10.1097/ICU.0000000000001193

KEY POINTS

- Strong evidence supports benefits from dietary vitamin A (retinol), dietary nitrates (especially from leafy greens), antioxidants, and adherence to Mediterranean-style diets in lowering glaucoma risk.
- High intake of ultra-processed foods, excessive carbohydrates (particularly in genetically predisposed individuals), and a very low fat diet increase glaucoma risk.
- Individual nutrients often show limited effects, but combinations of vitamins (A, C, E), carotenoids, antioxidants, fruits, and vegetables demonstrate stronger protective associations against glaucoma.
- More studies are required on niacin, omega-3 : 6 fatty acids, and supplementation strategies to establish clear nutritional recommendations for glaucoma risk reduction and treatment.

visual field loss, with a 44% lower risk (95% CI = 0.40–0.79) for patients in the fifth quintile of nitrate consumption compared to those in the lowest quintile [4]. This may be related to benefit of nitric oxide in improving optic nerve circulation given the high oxygen and nutrient demands of the macular retinal nerve fiber layer [5–7]. The highest quintile of green, leafy vegetable intake was associated with lower POAG risk when compared to the lowest quintile (relative risk (RR) 0.82; 95% CI = 0.69–0.97). Green, leafy vegetables intake accounted for the most variation in dietary nitrate [4].

Mediterranean lifestyle/diet

Moreno-Montañés *et al.* [8] investigated the association of a Seguimiento Universidad De Navarra (SUN) healthy lifestyle score (SHLS) on glaucoma in the Level 1 prospective SUN cohort study followed over 12.5 years. SHLS (0–10) involved the following: smoking, BMI, physical activity, television exposure, binge drinking, alcohol, naps, work hours, social time, and adherence to the Mediterranean diet [8]. Adherence to the Mediterranean diet was based on increased consumption of vegetables, legumes, fruits, nuts, cereal, and fish with limited intake of meat, poultry, and dairy [9]. Each 1-point increase in SHLS led to a 5% decrease in glaucoma risk, with the highest scores (7–10) exhibiting lower risk of developing glaucoma compared to the lowest scores (0–2) (aHR 0.51, 95% CI = 0.28–0.93). Only "never smoking" was individually significant (adjusted hazards ratio (aHR) 0.70, 95% CI = 0.53–0.92), suggesting that while a Mediterranean diet may reduce glaucoma risk, benefits are amplified when combined with healthy lifestyle changes [8].

Ultra-processed foods

Level 1 evidence on the SUN cohort reported by López-Gil *et al.* [10▪] investigated the association between ultra-processed food and glaucoma. Processed foods were categorized as 1–4 using the NOVA system. Ultra-processed foods (NOVA 4) included packaged snacks, sweetened beverages, reconstituted meat products, and ready-to-eat meals. Participants consuming more than four servings per day had a significantly higher glaucoma risk than those consuming one or fewer (hazard ratio 1.83, 95% CI = 1.06–3.17). When analyzing individual food categories (i.e., sausages, beverages, fried foods, sweets, fast food, dairy products), only sweets showed increased glaucoma risk (hazard ratio 1.51, 95% CI = 1.07–2.12) [10▪].

Several mechanisms explain these findings. Carbohydrates may lead to increased glycemic load and accumulation of advanced glycation end products in ocular tissues [11–13]. Ultra-processed foods contain chemical additives potentially harmful to the optic nerve and likely lower nutrient density, limiting the positive effects of vitamins and nutrients that less processed foods provide.

Dietary vitamin A

Ramdas *et al.* [14] provided Level 1 evidence for the protective role of vitamin A in glaucoma in their prospective cohort study with 10-year follow-up. High intake of retinol equivalents was linked to decreased risk of OAG, and this association was even stronger when excluding supplement users, where compared to those in the first tertile of retinol consumption (0.57 mg/day), those in the highest tertile (1.11 mg/day) had a 67% decreased risk of glaucoma (95% CI = 0.14–0.80) [14]. Retinol equivalents are found in eggs, dairy, and yellow fruits and vegetables. Antioxidants like retinol equivalents are thought to play an important role in optic nerve neuroprotection.

Dietary vitamin D

In their large, Level 1 observational study of postmenopausal women, Carbone *et al.* [15] found no association between dietary vitamin D, vitamin D supplements, or serum 25(OH)D and glaucoma.

LEVELS 1 AND 2 EVIDENCE CARBOHYDRATE INTAKE

Another Level 1 study on the SUN cohort by Moreno-Montañés *et al.* [16] found that the highest quartile of carbohydrate intake increased risk of glaucoma (hazard ratio 1.50, 95% CI = 1.01–2.25), with an even stronger association when diabetic participants were excluded (hazard ratio 1.77, 95% CI = 1.15–2.74).

Table 1. Diet and Nutrition Studies, ordered as in manuscript

	Study type (Setting)	Size	Year	Ref.	Ref. Number	Level of evidence[a]	Key findings
Association Of Dietary Nitrate Intake with Primary Open-Angle Glaucoma: A Prospective Analysis from The Nurses' Health Study and Health Professionals Follow-Up Study	Prospective Cohort (Nurses' Health Study & Health Professionals Follow-up Study; US)	104 987	2016	Kang *et al.*	[4]	Level 1	Dietary nitrates: Highest vs. lowest quintile of intake (~240 vs. ~80 mg/day) reduced POAG risk (pooled MVRR = 0.81, 95% CI = 0.69–0.96, *P* for trend = 0.02; after also adjusting for dietary factors, pooled MVRR = 0.67, 95% CI = 0.52–0.85, *P* = 0.01). Risk reduction more pronounced for POAG with early paracentral VF loss (pooled MVRR = 0.56, 95% CI = 0.40–0.79, *P* = 0.0003). Green, leafy vegetables: Higher intake of green leafy vegetables—accounting for 56.7% of variation in nitrate—reduced POAG risk, with the highest quintile showing a 18% lower risk compared to the lowest quintile (RR 0.82; 95% CI = 0.69–0.97; *P* = 0.02)
Healthy Lifestyle Score and Incidence of Glaucoma: The SUN Project	Prospective Cohort Study (SUN Project; Spain)	18 420	2022	Moreno-Montañés *et al.*	[8]	Level 1	SUN Healthy Lifestyle Score (SHLS): Based on 10 factors – never smoking, BMI $\leq 22\,kg/m^2$, physical activity, TV exposure, binge drinking, alcohol, afternoon naps, work hours, social time with friends, and adherence to the Mediterranean diet. Participants were classified as adhering to the Mediterranean diet if they achieved a score of 4 or higher on the 8-point scale developed by Trichopoulou *et al.* (2003), which emphasizes higher intake of vegetables, legumes, fruits, nuts, cereals, and fish, along with reduced consumption of meat, poultry, and dairy. The highest SHLS had lower glaucoma risk than those in the lowest category (adjusted HR = 0.51; 95% CI = 0.28–0.93). "Never smoking" status reduced risk of glaucoma (adjusted HR = 0.70, 95% CI = 0.53–0.92).
Is Ultra-Processed Food Intake Associated with a Higher Risk of Glaucoma? A Prospective Cohort Study Including 19,255 Participants from The SUN Project	Prospective Cohort Study (SUN Project; Spain)	19 255	2024	López-Gil *et al.*	[10▪]	Level 1	Ultra-Processed Foods (UPFs): Higher UPF intake (per NOVA classification) increased glaucoma risk (HR = 1.83; 95% CI = 1.06–3.17), adjusting for covariates. Among UPF subtypes, only sweets showed a significant association (HR = 1.51; 95% CI = 1.07–2.12).
Nutrient Intake and Risk of Open-Angle Glaucoma: The Rotterdam Study	Prospective Cohort (Rotterdam Study; Netherlands)	3502	2012	Ramdas *et al.*	[14]	Level 1	Dietary Vitamin A: After multivariable adjustment and excluding supplement users, highest tertile intake (1.11 mg/day) lowered glaucoma risk (HR = 0.33; 95% CI = 0.14–0.80; *P* = 0.014) over 9.7 years of follow-up.
Association Of Vitamin D With Incident Glaucoma: Findings from The Women's Health Initiative	Prospective Cohort (Women's Health Initiative, US)	143 389	2021	Carbone *et al.*	[15]	Level 1	Dietary Vitamin D: No significant associations found between dietary vitamin D (*P* = 0.49), supplements (*P* = 0.39), or serum 25(OH)D levels (*P* = 0.60) and glaucoma.

Table 1 (*Continued*)

	Study type (Setting)	Size	Year	Ref.	Ref. Number	Level of evidence[a]	Key findings
Carbohydrate Intake and Risk of Glaucoma in The SUN Cohort	Prospective Cohort Study (SUN Project; Spain)	18 247	2021	Moreno-Montañés *et al.*	[16]	Level 1	Carbohydrates: Over 10 years, highest quartile of intake increased glaucoma risk vs. lowest (HR = 1.50; 95% CI = 1.01–2.25; p for trend = 0.042) adjusting for covariates. When excluding those with diabetes, the association was stronger (HR = 1.77; 95% CI 1.15–2.74).
Low-Carbohydrate-Diet Scores and the Risk of Primary Open-Angle Glaucoma: Data from Three US Cohorts	Prospective Cohort (Nurses' Health Study I and II, Health Professionals Follow-up Study, US)	185 638	2020	Hanyuda *et al.*	[17]	Level 2	Low-Carbohydrate Diet: No association was found between overall low-carb diet scores and POAG. However, diets high in vegetable-based fat and protein in place of carbohydrates was protective against POAG with early paracentral VF loss (highest vs. lowest decile: RR = 0.78; 95% CI = 0.55–1.10; *P* for trend = 0.12).
Polygenetic-Risk Scores for a Glaucoma Risk Interact with Blood Pressure, Glucose Control, And Carbohydrate Intake	Cross-Sectional Cohort (Korean Genome and Epidemiology Study; Korea)	48 197	2020	Jee *et al.*	[18]	Level 2	Polygenetic Risk Score (PRS) + Carbohydrates: Using PRS based on variants in LDB2, CDKN2B, ABO, PDE3A, and CDH13, among participants with high carbohydrate intake, those with high PRS had 3.74× greater odds of glaucoma (95% CI = 2.139–6.544; *P* = 0.0083) than those with low PRS. Among low carbohydrate intake participants, high PRS was not associated with greater glaucoma risk compared to low PRS.
Glaucoma Risk and The Consumption of Fruits and Vegetables Among Older Women in The Study of Osteoporotic Fractures	Cross-Sectional Cohort (Study of Osteoporotic Fractures; US)	1155	2008	Coleman *et al.*	[19]	Level 2	Fruits and Vegetables: Women consuming ≥1 serving/month of collard greens or kale had 69% lower glaucoma risk (OR = 0.31; 95% CI = 0.11–0.91). Eating >2 servings/week of carrots reduced risk by 64% (OR = 0.36; 95% CI = 0.17–0.77), and ≥1 serving/week of canned/dried peaches was linked to 47% lower risk (OR = 0.53; 95% CI = 0.29–0.97).
The Association of Consumption of Fruits/Vegetables with Decreased Risk of Glaucoma Among Older African-American Women in The Study of Osteoporotic Fractures	Cross-Sectional Cohort (African Americans in Study of Osteoporotic Fractures; US)	662	2012	Giaconi *et al.*	[20]	Level 2	Fruits and Vegetables: Women consuming ≥3 servings/day of fruits or fruit juice had 79% lower glaucoma risk (OR = 0.21; 95% CI = 0.08–0.60) vs. <1 serving/day. Higher intake of fresh oranges (>2 servings/week: OR = 0.18; 95% CI = 0.06–0.51), peaches (OR = 0.30; 95% CI = 0.13–0.67), and collard greens/kale (>1 serving/week; OR = 0.43; 95% CI = 0.21–0.85) was also associated with reduced risk.
ACE-Vitamin Index and Risk of Glaucoma: The SUN Project	Prospective Cohort Study (SUN Project; Spain)	18 669	2022	Moreno-Montañés *et al.*	[21]	Level 2	Dietary A-C-E-Vitamin Index: Though individual vitamins were not significant, higher ACE Index scores lowered glaucoma risk (HR = 0.73; 95% CI = 0.55–0.98). Adding carotenoids strengthened the association (HR = 0.67; 95% CI = 0.50–0.89).
Exploring The Association Between Composite Dietary Antioxidant Index and Ocular Diseases: A Cross-Sectional Study	Cross-Sectional Cohort (National Health and Nutrition Examination Survey; US)	1706	2025	Zhang *et al.*	[22▪]	Level 2	Dietary Composite index of six antioxidants (carotenoids, vitamins E, C, A, selenium, zinc): Highest quartile associated with lower glaucoma risk vs. lowest (OR = 0.48; 95% CI = 0.28–0.79; *P* = 0.003) adjusting for covariates.

Table 1 (*Continued*)

	Study type (Setting)	Size	Year	Ref.	Ref. Number	Level of evidence[a]	Key findings
Association Between Daily Niacin Intake and Glaucoma: National Health and Nutrition Examination Survey	Cross-Sectional Cohort (National Health and Nutrition Examination Survey; US)	5768	2021	Taechameekietichai *et al.*	[23]	Level 2	Dietary Niacin: Significant association with glaucoma in Model 1 (adjusted for age and gender: OR = 0.63; 95% CI = 0.46–0.87; *P* = 0.006), but not in Model 2 (adjusted for age, gender, total energy intake, race, education, and diabetes: OR = 0.95; 95% CI = 0.61–1.50; *P* = 0.833).
Associations Between Niacin Intake and Glaucoma in the National Health and Nutrition Examination Survey	Cross-Sectional Cohort (National Health and Nutrition Examination Survey; US)	5371	2023	Lee *et al.*	[24]	Level 2	Dietary niacin: No significant association when analyzed as a binary or quartile variable. As a continuous variable, each 1 mg increase was linked to 6% lower glaucoma risk (aOR = 0.94; 95% CI = 0.90–0.98). In sex-stratified analysis, the effect was significant only in women (11% reduction; aOR = 0.89; 95% CI = 0.80–0.99).
Dietary Niacin and Open-Angle Glaucoma: The Korean National Health and Nutrition Examination Survey	Cross-Sectional Cohort (Korean National Health and Nutrition Survey; Korea)	16770	2018	Jung, Kim, Park	[25]	Level 2	Dietary niacin: Lower intake was linked to higher glaucoma odds, independent of IOP. Highest quartile had reduced risk (OR = 0.60; 95% CI = 0.40–0.92; *P* = 0.013). After adjusting for supplement use, the association remained (OR = 0.54; 95% CI = 0.33–0.90; *P* = 0.035).
Effect Of Low-Fat Dietary Modification on Incident Open-Angle Glaucoma	Subanalysis of Randomized Controlled Trial (Women's Health Initiative Dietary Modification Trial; US)	23217	2023	Mehta *et al.*	[28]	Level 2	Dietary fat: No association was found between overall dietary fat reduction and glaucoma (HR = 1.04; 95% CI = 0.96–1.12). However, dietary fat reduction among women with lowest baseline fat intake (<34% calories from fat) was linked to increased risk (HR = 1.22; 95% CI = 1.05–1.41; *P* = 0.007).
Dietary Fat Consumption and Primary Open-Angle Glaucoma	Prospective Cohort Study (Nurses' Health Study & Health Professionals Follow-up Study; US)	116505	2004	Kang *et al.*	[29]	Level 2	Fat subtypes: No significant associations were found between POAG and intake of total fat (RR = 0.90; 95% CI = 0.67–1.21), saturated fat (RR = 1.03; 95% CI = 0.77–1.38), monounsaturated fat (RR = 0.76; 95% CI = 0.56–1.03), or polyunsaturated fat (RR = 0.87; 95% CI = 0.66–1.16).
Association Of Dietary Fatty Acid Intake with Glaucoma in The United States	Cross-Sectional Cohort (National Health and Nutrition Examination Survey; US)	3865	2018	Wang *et al.*	[32]	Level 2	Higher intake of EPA (OR = 0.06; 95% CI = 0.00–0.73) and DHA (OR = 0.06; 95% CI = 0.01–0.87) was linked to lower glaucoma risk. However, total PUFA intake in the 2nd (OR = 2.84; 95% CI = 1.39–5.79) and 3rd quartiles (OR = 2.97; 95% CI = 1.08–8.15) was associated with increased risk.
Omega 3 : 6 Ratio Intake and Incidence of Glaucoma: The SUN Cohort	Prospective Cohort Study (SUN Project; Spain)	17128	2013	Pérez de Arcelus *et al.*	[33]	Level 2	Dietary Omega-3 : 6 Ratio: Participants in the highest quintile had increased glaucoma risk vs. the lowest (HR = 1.91; 95% CI = 1.05–3.46; *P* for trend = 0.03). In those aged ≥40, the association was stronger (HR = 2.43; 95% CI = 1.17–5.03; p for trend = 0.02).

Table 1 (*Continued*)

	Study type (Setting)	Size	Year	Ref.	Ref. Number	Level of evidence[a]	Key findings
A Two-Year Follow-Up of Oral Antioxidant Supplementation in Primary Open-Angle Glaucoma: An Open-Label, Randomized, Controlled Trial	Randomized Controlled Clinical Trial (Spain)	117	2015	Garcia-Medina JJ, *et al.*	[35]	Level 1	Antioxidant supplementation: Oral antioxidant supplementation with or without omega-3 fatty acids did not provide significant benefit in visual field indices, peripapillary retinal nerve fiber layer thickness, or macular ganglion cell complex thickness over two years in patients with mild or moderate primary open-angle glaucoma already controlled on topical therapy.
The Effects of Antioxidants on Ocular Blood Flow in Patients with Glaucoma	Clinical Trial (US)	45	2018	Harris *et al.*	[36]	Level 2	Antioxidant Supplementation: A blend of 16 nutrients (including vitamins C, E, B6, B12, folate, omega-3s, and various antioxidants) led to significant increases in peak systolic velocity, end diastolic velocity, Pourcelot resistive index, and the active/nonactive retinal capillary ratio in both superior and inferior temporal quadrants. There was no effect on IOP.

aOR, adjusted odds ratio; CI, confidence interval; DHA, docosahexaenoic acid; EPA, eicosapentaenoic acid (both omega-3 fatty acids); HR, hazard ratio; IOP, intraocular pressure; MVRR, multivariable relative risk; OR, odds ratio; POAG, primary open angle glaucoma; PUFA, polyunsaturated fatty acids; SUN, Seguimiento Universidad De Navarra; UPF, ultra-processed food; VF, visual field.

[a]Studies were graded to reflect the level of evidence based on the AAO Grading Criteria adapted from 2011 Oxford Centre for Evidence-Based Medicine. Level 1 evidence is awarded to articles in which the study design was a randomized trial or an observational study which yielded a dramatic effect. Level 2 evidence is comprised of nonrandomized controlled cohort studies or follow-up studies.

The investigators categorized carbohydrates into nine groups (refined carbohydrates, fruits, vegetables, dairy, sugary drinks, legumes, whole grains, alcoholic beverages, and meats and fish). While no group individually increased glaucoma risk, high vegetable intake trended towards being protective against glaucoma (hazard ratio 0.68; 95% CI 0.47–1.00) [16].

In a Level 2 observational study of three US cohorts, Hanyuda *et al.* [17] demonstrated that low-carbohydrate diets rich in vegetable-based fat and protein had 22% ($P_{trend}=0.12$) lower risk of POAG with early paracentral visual field loss compared to low-carbohydrate diets rich in animal-based fat and protein. The additional nutrients and neuroprotective antioxidants found in vegetables may help maintain optic nerve health. Like decreasing processed foods, low-carbohydrate diets increase nutrient density.

A Level 2 cross-sectional study by Jee *et al.* [18] studied the interaction between polygenetic-risk scores (PRS) for glaucoma and carbohydrate intake. In participants with high carbohydrate intake, those with high PRS had 3.7 times greater odds of glaucoma (95% CI = 2.139–6.544) than those with low PRS. In contrast among those with low carbohydrate intake, no significant relationship was found between glaucoma risk in the high versus low PRS populations [18]. These findings highlight the amplified risk of high carbohydrate intake in genetically predisposed individuals.

LEVEL 2 EVIDENCE

Fruits and vegetables

In a Level 2 cross-sectional study, Coleman *et al.* [19] investigated the relationship between fruit and vegetable intake and glaucoma in women in the Study of Osteoporotic Fractures, and a follow-up level 2 study by Giaconi *et al.* [20] investigated associations in African–American women using the same data. Both Coleman *et al.* [19] and Giaconi *et al.* [20] found reduced glaucoma prevalence with increased consumption of carrots, collard greens or kale, fresh oranges, and peaches, with odds ratios ranging from 0.21 to 0.36. These foods were rich in Vitamins A, C, E, and carotenoids which provide neuroprotective benefits against glaucoma.

Vitamin A-C-E index and dietary antioxidant intake

In a Level 2 study on the SUN cohort, Moreno-Montañés *et al.* [16] assessed the relationship of a combined "ACE-Vitamin Index" score and glaucoma

over an average of 11 years; points were awarded for being in the top quintile of consumption for vitamins A, C, and E. While individual vitamins showed no reduction in glaucoma risk, the highest ACE-Vitamin Index scores produced a reduced glaucoma risk (hazard ratio 0.73; 95% CI = 0.55–0.98). When carotenoids were added to form an extended index, a more pronounced association was found (hazard ratio 0.67; 95% CI = 0.50–0.89) [21]. These findings further validate the synergistic effect of multiple nutrients from fruits and vegetables in protecting against glaucoma.

Zhang *et al.* [22▪] conducted a Level 2 cross-sectional study using National Health and Nutrition Examination Survey (NHANES) 2005–2008 data and evaluated the Composite Dietary Antioxidant Index (CDAI), which includes carotenoids, vitamins A, C, E, selenium, and zinc. When comparing to the lowest quartile of CDAI, participants in the highest quartile had reduced odds of glaucoma [odds ratio (OR) 0.48; 95% CI = 0.28–0.79], again likely attributable to the neuroprotective effect of cumulative antioxidants [22▪].

Dietary niacin (vitamin B3)

Several studies have investigated niacin intake and glaucoma risk; however, studies have not demonstrated consistently strong associations.

Using 2005–2008 NHANES data in a Level 2 study, Taechameekietichai *et al.* [23] found an association between niacin and glaucoma with participants in the top two quartiles of niacin intake having lower odds of glaucoma when compared to the first quartile of niacin intake. Glaucoma was determined by three graders studying the fundus images at a grading center and adjudicated by two ophthalmologists when necessary. While the association remained for the third quartile after adjusting for age and sex, adjustment for total energy intake, race, educational level, and diabetes rendered the association no longer statistically significant for either of the top two quartiles [23].

Lee *et al.* [24] studied the same NHANES data using glaucoma specialists for regrading images with cup-to-disc ratios at or above 0.6. The Level 2 cross-sectional study found that the association between niacin intake and glaucoma was not significant when studied as a binary variable or in quartiles. However, when treated continuously, each 1 mg increase in intake was associated with 6% lower odds of glaucoma overall (95% CI = 0.90–0.98), and 11% lower odds in female participants (95% CI = 0.80–0.99) but not in male participants [24].

In a Level 2 cross-sectional study by Jung *et al.* [25] composed of mostly normal-tension glaucoma (NTG) patients, lower niacin intake was associated with higher odds of glaucoma independent of IOP (OR 0.63; 95% CI = 0.41–0.96) even after excluding supplement users (OR 0.54; 95% CI = 0.33–0.90).

Due to its role as a precursor to nicotinamide adenine dinucleotide (NAD^+), which is key to mitochondrial function and managing oxidative damage for retinal ganglion cells, niacin can modulate retinal nerve vulnerability to glaucoma [26].

Notably, the studies mentioned investigated dietary niacin intake; high-dose supplementation is not advised due to potential hepatotoxicity and cardiovascular disease [27]. Dietary niacin is found in meats, fish, whole grains, legumes, nuts, and seeds.

Dietary fats

Mehta *et al.* [28] conducted a Level 2 secondary analysis of a randomized trial that evaluated the effects of dietary modification including a low-fat diet with increased fruit, vegetables, and grains on glaucoma in women. While low-fat dietary modification did not affect POAG risk for women overall, in women whose fat intake was below 34% calories from fat at baseline, reducing dietary fat further was detrimental to their optic nerve health with a 22% increased risk of POAG (95% CI = 1.05–1.41) [28].

On the other hand, a prospective cohort study by Kang *et al.* [29] produced Level 2 evidence for the overall lack of association between total dietary fats or subtypes and glaucoma.

The harm of very low-fat diets may be related to the role that healthy, dietary fats have on blood lipoprotein ratios, antioxidants, and as precursors to omega-6-derived prostaglandins which act as anti-inflammatory immune factors [30,31].

Dietary omega-3 : 6 ratio

Using 2005–2008 NHANES data, Wang *et al.* [32] investigated the association between dietary intake of polyunsaturated fatty acids (PUFAs), including omega-3 subtypes like eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA), and glaucoma in a Level 2 cross-sectional study. Daily intake of omega-3 subtypes EPA and DHA was associated with lower odds of glaucoma (OR 0.06; 95% CI = 0.00–0.73 and 0.01–0.87, respectively). However, total dietary PUFA intake in the second and third quintiles was paradoxically associated with increased risk (OR 2.84 and 2.97), highlighting a discrepancy. The authors suggested that specific PUFA subtypes like EPA and DHA may be protective and may improve ocular blood flow. They were limited in not having complete PUFA subtype data to calculate omega-3 : 6 ratio

and thus were unable to comment on the impact of other specific PUFAs [32].

The relationship between omega-3:6 ratios and glaucoma has been investigated by other Level 2 studies. Kang *et al.* [29] found an association between higher ratios of omega-3:6 fat and increased risk of high-tension POAG but not NTG. Similarly, a prospective cohort analysis of the SUN cohort by Pérez de Arcelus *et al.* [33] reported that participants in the highest omega-3:6 ratio quintile had a greater glaucoma risk (hazard ratio 1.91; 95% CI=1.05–3.46), particularly in ages at least 40 years (hazard ratio 2.43; 95% CI=1.17–5.03). Omega-6 eicosanoids include prostaglandin F2α which can lower IOP. However, a high ratio of omega-3:6 fatty acids in the diet has established benefits in cardiovascular health and against several chronic diseases. Further research is necessary to establish a clear recommendation for omega-3 and 6 fat consumption considering overall health effects including those in glaucoma [34].

Antioxidant supplementation

In a Level 1 two-year randomized controlled trial study of POAG patients, Garcia-Medina *et al.* [35] found no relationship between antioxidant supplementation (with or without omega-3s) and visual fields indices, RNFL thickness, and macular ganglion cell complex thickness compared to control patients.

Harris *et al.* [36] conducted a Level 2 small, randomized, placebo-controlled crossover study on 42 patients with OAG to investigate the effect of antioxidant supplementation on intraocular pressure (IOP), ocular perfusion pressure (OPP), retrobulbar, and retinal capillary blood flow. The supplement included a blend of vitamins (C, E, B6, B12, folate), minerals (magnesium), and antioxidants such as taurine, NAC, alpha lipoic acid, gingko biloba, omega-3s, bilberry, coenzyme Q10, grape seed extract, quercetin, and flaxseed oil. While the antioxidants significantly increased ocular blood flow compared to placebo, no differences were found in IOP [36]. These data corroborate findings of other studies, supporting the potential for antioxidants to reduce vascular resistance that may contribute to OAG progression.

CONCLUSION

Recent studies have increasingly examined links between nutrition and glaucoma.

Today, strong Level 1 evidence supports the protective role of dietary retinols, nitrates, Mediterranean diet adherence, and reduced ultra-processed food consumption. Level 2 studies similarly support benefits from higher intake of niacin, antioxidants (including Vitamins A, C, E), fruits, and vegetables for optic nerve health and reducing glaucoma risk (see Table 2). While individual nutrients sometimes fail to show significant relationships, combined effect of several dietary factors can synergistically preserve optic nerve health to prevent glaucoma.

Additional research is needed to further develop nutritional recommendations for reducing glaucoma risk; namely, the relationship between niacin and omega-3:6 fatty acids with glaucoma particularly due to interactions with other diseases. This review focused on dietary sources of nutrients, with only two small studies on multinutrient antioxidant supplementation. Care should be taken about recommending high dose supplements that have not been well studied since negative health consequences could result.

Further investigation into the mechanism behind nutritional influences on glaucoma along with more robust understanding of existing literature may allow clinicians to advise patients on how

Table 2. Summary of nutritional strategies to address glaucoma risk[a]

Recommendations with Level 1 supporting evidence	Recommendations with Level 2 supporting evidence
Increase dietary intake of retinols through foods like cheese, eggs, milk, yogurt, yellow fruit and vegetables	Increase dietary niacin through consumption of meats, fish, legumes, nuts, seeds, and whole grains
Increase dietary nitrates which can be achieved through consumption of green, leafy vegetables such as spinach, kale, and collard greens and beets	Increase dietary intake of antioxidants which may include vitamins A, C, E, and carotenoids
Incorporate the Mediterranean diet/lifestyle including increased consumption of vegetables, legumes, fruits, nuts, cereal, and fish with limited intake of meat, poultry, and dairy	Increase fruit and vegetable intake
Reduce consumption of ultra-processed foods including packaged snacks, sweetened beverages, reconstituted meat products, and ready-to-eat meals	Avoid very low-fat diet or excessive carbohydrates

Several studies reviewed in this study have yielded evidence on the benefit of combining healthy nutritional practices to reduce glaucoma risk.
[a]Individual recommendations and nutrients are less likely to affect glaucoma risk on their own as compared to the combined effects of multiple healthy nutritional habits.

to use nutrition as an adjunctive tool in glaucoma prevention and treatment.

Acknowledgements

The authors would like to extend their gratitude to Jullia A. Rosdahl, MD, PhD, for her valuable contribution in grading the evidence included in this review.

Financial support and sponsorship

None.

Conflicts of interest

There are no conflicts of interest.

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Papers of particular interest, published within the annual period of review, have been highlighted as:

- ■ of special interest
- ■■ of outstanding interest

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