Special Article

Vegetarian and vegan diets in type 2 diabetes management

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Vegetarian and vegan diets offer significant benefits for diabetes management. In observational studies, individuals following vegetarian diets are about half as likely to develop diabetes, compared with non-vegetarians. In clinical trials in individuals with type 2 diabetes, low-fat vegan diets improve glycemic control to a greater extent than conventional diabetes diets. Although this effect is primarily attributable to greater weight loss, evidence also suggests that reduced intake of saturated fats and high-glycemic-index foods, increased intake of dietary fiber and vegetable protein, reduced intramyocellular lipid concentrations, and decreased iron stores mediate the influence of plant-based diets on glycemia. Vegetarian and vegan diets also improve plasma lipid concentrations and have been shown to reverse atherosclerosis progression. In clinical studies, the reported acceptability of vegetarian and vegan diets is comparable to other therapeutic regimens. The presently available literature indicates that vegetarian and vegan diets present potential advantages for the management of type 2 diabetes.

INTRODUCTION

Diabetes has reached epidemic proportions, with an estimated 180 million cases worldwide.[1] Dietary factors and obesity play major roles in the risk of developing type 2 diabetes, and nutritional changes are a key aspect of disease management.[2]

Current dietary approaches for managing type 2 diabetes typically call for limiting carbohydrate intake, limiting intake of saturated and trans fats and cholesterol, and reducing energy intake in overweight individuals.[2] These guidelines are individualized based on medical condition, lifestyle, and food preferences.[3] However, evidence from observational and clinical studies suggests that plant-based diets offer specific advantages. In randomized trials, vegetarian and low-fat vegan diets have been shown to improve glycemic control, blood lipid concentrations, and body weight, in some instances to a greater extent than is achieved with more conventional dietary guidelines.[4]

This review summarizes observational and intervention studies on the effect of vegetarian diets on type 2 diabetes.

LITERATURE SEARCH METHOD

A Medline (National Library of Medicine, Bethesda, MD) search was conducted for scientific articles containing information on vegetarian diets and diabetes using the key words "vegetarian" or "vegan" and "diabetes", with the search limited to studies of adult humans published in the English language since 1966. Additional reports were identified from the references listed in these articles and from personal communications.

Two reviewers (NDB and HIK) judged the eligibility of the studies independently. These searches yielded 116 potentially relevant articles, of which 10 were directly related to glycemic control and diabetes management. Additional articles reported findings on other clinically

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relevant endpoints (e.g., weight loss, cardiovascular risk) and are discussed in subsequent sections.

Observational studies

Several studies have reported that diabetes prevalence is lower among vegetarians compared with omnivores.[5–10] Seventh-day Adventists are a population of interest because nearly all avoid tobacco, alcohol, and caffeine, while roughly half are omnivores and half are vegetarians. Overall, Adventists have only 45% of the diabetes prevalence of the general population.[8] In three large Adventist cohort studies, the prevalence of diagnosed diabetes was 1.6 to 2 times higher among non-vegetarians compared with vegetarians or vegans.[8,9,10] Further adjustment for body weight reduced this difference only slightly.

Regular consumption of even small amounts of meat was associated with an increased risk of diabetes in this population. In a 17-year study of 8401 Seventh-day Adventists, those who ate meat at least once per week were 29% more likely to develop diabetes compared with those eating no meat.[7] Those who consumed any processed meats (specifically salted fish and frankfurters) were 38% more likely to develop diabetes. Long-term adherence (over 17 years) to a vegetarian diet was associated with a 74% reduced risk of developing diabetes relative to long-term adherence to a diet that included at least weekly meat intake. There was no association between an index of animal product consumption (meats, dairy, and eggs), with diabetes incidence. Other large cohort studies have also reported that meat consumption is associated with an increased risk of type 2 diabetes.[11,12]

Intervention trials in diabetes management

Because vegetarian and vegan diets are associated with a lower body weight,[13] increased insulin sensitivity,[14,15] and reduced risk of diabetes, intervention trials have tested their effectiveness for diabetes management. Early studies reported a dramatic decrease in medication use when following a plant-based diet. Subsequent studies demonstrated a greater improvement in insulin sensitivity and glycemic control with a vegetarian diet compared with a traditional diabetes diet.

Anderson and Ward[16] tested the effect of a low-fat, high-carbohydrate (9% of energy from fat, 70% from carbohydrate) near-vegetarian diet containing 65 g of fiber and 65 g of cholesterol per day in 20 normal-weight men with insulin-treated type 2 diabetes in a 16-day trial. Energy intake was individualized to prevent changes in body weight. By the end of the study period, insulin use was discontinued in nine participants and, in the remainder, was reduced from a mean of 26 to 11 units per day ($P < 0.001$) (Figure 1). Despite this reduction in medication use, mean fasting plasma glucose concentration fell non-significantly from 164 mg/dL to 152 mg/dL.

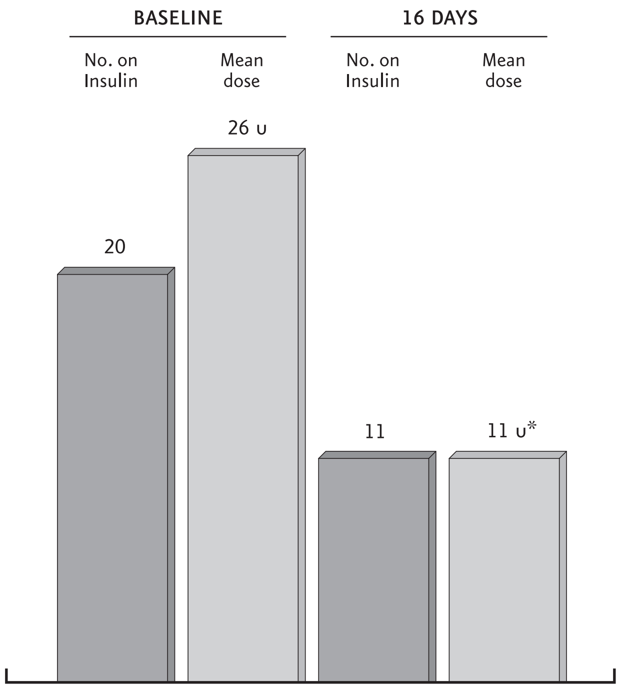

Figure 1 **Effect of a 16-day near-vegetarian diet on insulin use and mean insulin dose in men with type 2 diabetes.**[16]

Barnard et al. tested the effect of a 26-day residential program using a near-vegetarian diet (containing <100 g of fish or fowl/week) deriving less than 10% of energy from fat, with 35–40 g fiber per 1000 kcal in 652 individuals with type 2 diabetes.[17] The program also included intensive exercise, precluding the possibility of isolating the effect of diet. Of 212 participants treated with insulin at baseline, 83 (39%) discontinued its use. Nonetheless, their mean fasting glucose concentration dropped 6% ($P < 0.001$). Of 197 participants treated with oral agents, 140 discontinued their use. Mean fasting glucose concentration in this subgroup decreased 17% ($P < 0.001$). Of those on no medications at baseline, fasting glucose fell 24% ($P < 0.001$).

The effect of a low-fat vegan diet on type 2 diabetes was first tested in a small 12-week pilot study in 1999 ($n = 13$).[18] Fasting plasma glucose decreased 28%, compared with 12% for a more conventional portion-controlled, energy-restricted diabetes diet, and weight loss was also significantly greater in the vegan group (7.2 kg, compared to 3.8 kg). Of six participants in the vegan group on oral hypoglycemic agents, medication use was discontinued in one and reduced in three.

Insulin was reduced in both vegan-group participants using insulin. In contrast, none of the control-group participants on oral hypoglycemic agents reduced medication use.

A similar dietary intervention was subsequently tested in 64 healthy (non-diabetic), postmenopausal, overweight women with no energy intake limit. After 14 weeks, weight decreased 5.8 kg in the low-fat vegan group, compared with a 3.8 kg weight reduction in a control group asked to follow the diet guidelines of the National Cholesterol Education Program ($P = 0.012$).[19] Insulin sensitivity increased 24% in the intervention group, but remained unchanged in the control group. After an additional 2 years of observation, net weight reduction continued to be greater for participants in the low-fat vegan group compared with the control group (−3.1 kg versus −0.8 kg, $P = 0.02$).[20]

In a 22-week randomized trial, 99 individuals with type 2 diabetes were randomly assigned to either a low-fat, low-glycemic-index, vegan diet with no limits on energy or carbohydrate intake and no restrictions on portion sizes, or to a control group, in which each member received individualized diet instruction according to 2003 American Diabetes Association (ADA) guidelines.[4] Participants in both groups attended weekly, 1-h meetings conducted by a physician and a registered dietitian and/or a cooking instructor.

Overall, hemoglobin A1c (HbA_{1c}) decreased 0.96 percentage points in the vegan group and 0.56 points in the control group ($P = 0.09$) (Figure 2). Excluding those who changed medications during the study period, HbA_{1c} decreased 1.2 points in the vegan group, compared to 0.4 points in the ADA group ($P = 0.01$); body weight decreased 6.5 kg in the vegan group and 3.1 kg in the control group ($P < 0.001$).

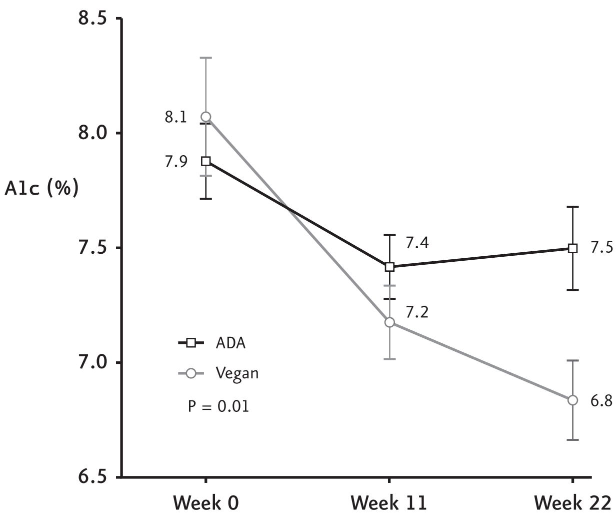

Figure 2 **Hemoglobin A1c levels at baseline and at 11 and 22 weeks in individuals with type 2 diabetes following a low-fat, vegan diet or an individualized diet based on the 2003 ADA guidelines.** Figure includes only individuals with no medication changes.[4]

Following the same patients for an additional year showed that clinical improvements were partially preserved. HbA_{1c} changes from baseline to last available value or last value before medication adjustment were −0.40 in the vegan group and +0.01 in the ADA group ($P = 0.03$). Body weight changes, compared to baseline values, were largely maintained in both the vegan group (−4.4 kg) and the ADA group (−3.0 kg), without a significant between-group difference ($P = 0.25$).

Putting these findings in context, the hypoglycemic effect observed in the control group following a diet based on the 2003 ADA guidelines in the latter study[4] was somewhat less than that reported in prior trials using similar diets for type 2 diabetes (1–2 percentage points).[21–25] The differences in reported outcomes may relate to differences in study design. Each of these prior studies lasted 6 months or less, and none accounted for medication alterations or drop-outs in reports of HbA_{1c} changes.

Mechanisms for improving glycemic control

Several possible mechanisms may explain the effect of low-fat, plant-based diets on glycemic control:

Weight loss. Weight loss accounts for much, although not all, of the effect of plant-based diets on glycemic control.[4] Even in the absence of specific limits on energy intake or portion sizes, low-fat vegan diets reduce body weight,[13] an effect that is attributable to their low fat and high fiber content, which tend to reduce energy density and energy intake.[26,27] Weight loss is typically accompanied by improvements in glycemic control and insulin sensitivity. In the randomized trial of a vegan diet in individuals with type 2 diabetes described above,[4] body weight change correlated strongly with change in HbA_{1c} at both 22 weeks ($r = 0.51$, $P < 0.0001$) and 74 weeks ($r = 0.50$, $P = 0.001$.) However, weight loss is clearly not the sole factor accounting for the hypoglycemic effect of plant-based diets, as evidenced by Anderson and Ward's[16] study of a low-fat, high-carbohydrate diet, which achieved improvements in glycemic control in the absence of weight loss.

Changes in intramyocellular lipid. Intramyocellular lipid accumulation is strongly associated with insulin resistance.[28] High-fat diets appear to downregulate the genes required for mitochondrial oxidative phosphorylation in skeletal muscle, fostering an increase in intramyocellular lipid,[29] while fat malabsorption induced by biliopancreatic diversion has the opposite effect on accumulated lipid.[30] Vegan diets are often low in fat, especially saturated fat, and would be expected to reduce intramyocellular lipid concentrations. In a case-control study, soleus muscle intramyocellular lipid concentrations were 31% lower in a group of 21 vegans, compared with 25 omnivores matched for age and body weight ($P = 0.01$).[31] These studies suggest that reductions in fat intake, as typically occur with low-fat vegan diets, reduce intracellular fat accumulation, leading to improved insulin sensitivity.

Reductions in saturated fat intake. A few studies have reported that dietary saturated fat can adversely affect insulin sensitivity.[32,33] In a study of 162 healthy men and women, insulin sensitivity was significantly impaired (−10%, $P = 0.03$) after administration of a diet high in saturated fatty acids (17% of energy) for 3 months.[32] Likewise, Xiao et al.[33] reported a decrease in insulin sensitivity following oral ingestion of emulsions containing predominantly saturated fatty acids (45% of energy) over 24 h in overweight men and women. Reductions in saturated fat intake have been reported to increase insulin sensitivity, an effect that is independent of changes in body weight.[34,35]

Reduced glycemic index. In a recent meta-analysis of prospective cohort studies, there was a 40% increase in risk of type 2 diabetes in participants whose diets were in the highest quintile of glycemic index versus the lowest.[36] A meta-analysis by Brand-Miller et al.[37] of 14 randomized clinical trials reported that low glycemic index diets reduced HbA_{1c} by 0.43 percentage points (95% CI 0.13–0.73) more than high-glycemic index diets in individuals with diabetes.

Increased intake of dietary fiber. In a randomized, crossover study in patients with type 2 diabetes, consuming a diet containing 50 g/day of dietary fiber for 6 weeks decreased 24-h glucose and insulin concentrations by 10% and 12%, respectively, compared to a diet containing a more moderate amount of fiber (24 g/day).[38] In observational studies, dietary fiber intake is inversely associated with diabetes incidence[39] and insulin resistance.[40] Dietary fiber, in particular viscous fibers,[41] may improve glycemic control by 1) delaying gastric emptying, which reduces the rate of glucose absorption, 2) decreasing the rate of glucose uptake by increasing the thickness of the unstirred water layer, 3) being fermented into propionate in the colon, which inhibits glucose production in hepatocytes, and 4) increasing satiety, which promotes weight loss and improved insulin sensitivity.[41–43]

Reductions in iron stores. Serum ferritin, the storage form of iron, was positively correlated with insulin resistance[44,45] and predicted the development of hyperglycemia[46] and type 2 diabetes[47] in observational studies. Hua et al.[48] reported greater insulin sensitivity and lower serum ferritin levels in lacto-ovo vegetarians compared with omnivores matched for age and body mass index. In this study, serum ferritin and insulin resistance were strongly and positively correlated ($r = 0.80$, $P = 0.0001$). Lowering body iron by phlebotomy in six male omnivores to levels similar to those seen in vegetarians resulted in a 40% enhancement of insulin-mediated glucose disposal.[48] Heme-iron intake has been reported to be positively related to diabetes incidence, whereas non-heme iron, the primary iron source in vegetarians, was negatively correlated.[49] Because a vegan diet provides non-heme iron, which is less bioavailable than heme iron, it may tend to reduce iron stores.[50]

Prevention of complications

Cardiovascular disease. Because of the risk of cardiovascular disease in diabetes, control of blood lipid concentrations and blood pressure is essential. In free-living, hyperlipidemic women and men, nutritional interventions similar to the Therapeutic Lifestyle Changes diet of the National Cholesterol Education Program typically reduce low-density lipoprotein cholesterol (LDLC) concentrations by about 5–10%,[51,52] although better effects have been obtained in studies using prepared foods and intensive monitoring.[53]

Low-fat, vegetarian diets are more effective than other diets in reducing LDLC concentrations[4,54–57] and result in significant reductions in cardiovascular disease risk and cardiovascular events. In a study by Ornish et al.[55] of hyperlipidemic, free-living individuals (mean age, 57 years) with cardiovascular disease, treatment for 1 year with a low-fat, vegetarian diet in combination with mild exercise, stress management, and smoking cessation decreased total and LDL cholesterol concentrations by 24% and 37%, respectively, and angiographic evidence of reversal of atherosclerotic lesions was found in 82% of participants. Over the following 5 years, the average percent diameter stenosis continued to decrease (−4.5% at year 1 and −7.9% at year 5), weight loss was partially maintained (−10.6 kg at year 1 and −5.8 kg at year 5), and the risk of cardiac events was 60% lower than that of the usual-care control group.[56]

Similarly, Esselstyn et al.[58] reported cardiovascular disease arrest in all ($n = 11$) and regression in eight (73%) patients with severe coronary artery disease who underwent angiographic analysis after following a plant-based diet containing <10% fat for 5 years. Cholesterol-lowering medication was used if necessary to achieve and maintain a total serum cholesterol concentration of <150 mg/dL. Esselstyn[59] subsequently reported that after 12 years, adherent patients ($n = 16$) experienced no extension of clinical disease and no coronary events, and required no interventions.

Predicated on the initial findings by Ornish et al.,[55,56] 22 clinical sites enrolled volunteers in the Multisite Cardiac Lifestyle Intervention Program using a low-fat, vegetarian diet as part of a comprehensive program of lifestyle changes.[60,61] Among the 1152 participants, marked reductions in cardiovascular risk factors were observed.[61] Of patients with angina at baseline, 74% were angina-free within 12 weeks, and an additional 9% moved from limiting to mild angina.[61]

Vegetarian and vegan diets appear to alter cholesterol concentrations and other cardiovascular risk factors in individuals with diabetes as effectively as in individuals who do not have diabetes.[62] In the Multicenter Lifestyle Demonstration Project, which used a low-fat vegetarian diet along with other lifestyle changes, individuals with diabetes had reductions in body weight and total and LDL cholesterol concentrations that were similar to those of individuals without diabetes.[62] Among individuals with type 2 diabetes beginning a vegan diet, the 22-week study described above found a 21% reduction in LDLC, compared with an 11% decrease in the group following ADA guidelines ($P = 0.02$).[4]

The cholesterol-lowering effect of a plant-based diet occurs quickly. A dietary portfolio including a vegetarian diet emphasizing nuts, soy protein, foods rich in soluble fiber, and plant sterols led to a 28% reduction in LDLC in 4 weeks, compared to a 30.9% reduction with lovastatin (20 mg/day) in participants following a low-saturated-fat, low-cholesterol diet (<7% saturated fat, <200 mg cholesterol).[54]

Vegetarian diets tend to be low in fat and high in carbohydrate. If they include substantial amounts of sugars or refined carbohydrates and are low in fiber, they may lead to transient elevations in triglyceride and VLDL concentrations in some individuals.[63,64] However, high-fiber and low-glycemic-index foods appear to have the opposite effect, reducing triglycerides.[4,65] Intervention studies show that coronary atherosclerosis and the risk of cardiovascular events are significantly reduced by treatment regimens that include a low-fat vegetarian diet.[55,56,58,59]

The lipid-lowering effect of low-fat vegetarian and vegan diets contrasts with that of low-carbohydrate diets. Although low-carbohydrate diets often reduce triglyceride concentrations and increase HDLC, approximately one-third of low-carbohydrate dieters have increased LDLC concentrations, some of which are quite severe.[66,67] This adverse effect is not reported in articles that describe only group mean values. Low-fat vegetarian and vegan diets have a much more beneficial effect on LDLC.[4,54–57]

Hypertension is a major risk factor for cardiovascular disease that also improves with a vegetarian diet. A meta-analysis of data from one million adults in 61 prospective studies reported that in adults aged 40–69 years, each 20 mm Hg increase in usual systolic blood pressure and 10 mm Hg increase in usual diastolic blood pressure is associated with at least a twofold increased risk of death from ischemic heart disease and stroke.[68] Vegetarian diets are associated with lower blood pressure in epidemiologic studies and randomized clinical trials,[69,70] an observation that served as the inspiration for the Dietary Approaches to Stop Hypertension (DASH) trial.[71]

Individuals following a low-fat vegetarian diet may have greater blood vessel elasticity. Vogel et al.[72] reported that flow-mediated vasoactivity decreased approximately 50% at 2, 3, and 4 h after a high-fat (900 kcal, 50 g fat) non-vegetarian meal in healthy, physically active men and women, whereas no change in vasoactivity was observed after an isocaloric low-fat (0 g fat) vegetarian meal ($P <$ 0.05 between groups).

Dietary patterns emphasizing antioxidant-rich foods (e.g., fruits and vegetables) are consistently associated with reduced cardiovascular risk in observational studies,[73] an effect that may be at least partly attributable to reduced lipoprotein oxidation.[74] A similar effect may be observed with vegetable proteins, including both soy protein[75] and wheat gluten.[76] These foods are abundant in vegetarian and vegan diets and may provide an additional explanation for their cardiovascular benefits.

Renal function. The amount and type of protein provided by plant-based diets may slow the loss of renal function compared with a diet high in animal protein. Among 1624 women participating in the Nurses' Health Study, animal protein intake was associated with continued loss of renal function among those with some degree of renal impairment at baseline.[77] Mild renal impairment is found in approximately 40% of individuals with diabetes.[78]

Several studies have reported reductions in urinary protein losses in patients with nephropathy when following a low-protein, vegetarian diet.[79–81] Jibani et al.[81] reported a 54% decrease in fractional albumin clearance in eight patients with type 1 diabetes after substituting vegetable protein for animal protein, although protein intake also decreased 28%. In the 22-week study described above, urinary albumin decreased −15.9 mg/24 h in the vegan group versus −10.9 mg/24 h in the ADA group ($P = 0.013$).[4]

Diabetic neuropathy. A 1994 study investigated the effect of a low-fat vegan diet on painful diabetic neuropathy.[82] In a 25-day residential study of 21 patients with type 2 diabetes and peripheral neuropathy, a program that included a low-fat vegan diet and daily exercise (a 30-min walk) permitted five patients to discontinue oral hypoglycemic agents, and reduced insulin dosages by approximately half in the remaining participants. In 17 of the 21 participants, neuropathic leg pains remitted completely in 2 weeks, and the four remaining participants had partial relief.

Nutrient adequacy

The American Dietetic Association holds that well-planned vegetarian diets, including vegan diets, are nutritionally adequate.[83] Omnivores who adopt vegan diets typically reduce their intake of fat, saturated fat, and cholesterol, and increase their intake of fiber, carotenoids, vitamins C and K, folate, magnesium, and potassium.[84,85] A low-fat vegan diet has been associated with improvements in the Alternate Healthy Eating Index (a quantitative measure of diet-related disease risk), compared with a more conventional diabetes diet.[86] However, individuals beginning vegan diets may reduce their intake of vitamins D and B_{12}, and calcium.[84,85] Iron intake in vegan and vegetarian diets tends to be higher than iron intake in non-vegetarian diets.[83] In clinical trials, iron intake increased slightly, though not significantly, after changing from an omnivorous diet to a vegan diet.[84,86] Planning for adequate intakes of these nutrients, along with exposure to sunlight, is important with all diets to ensure adequacy.

Acceptability

Low-fat vegetarian and vegan diets do not require individuals to limit energy or carbohydrate intake and, because they are based on qualitative, rather than quantitative guidelines, they are reasonably easy to understand. However, they often require patients to learn new tastes and new food preparation techniques. In a 1995 survey of 510 women living in the United States conducted by Opinion Research Corporation International, 4–11% reported that they considered themselves to be vegetarian (i.e., a person who does not eat meat, fish, or poultry), with the highest frequency reported in those aged 18–24 years (unpublished data).

Studies have assessed the acceptability of vegetarian and vegan diets in individuals with cardiovascular disease,[87] women with dysmenorrhea,[88] overweight but otherwise healthy postmenopausal women,[89] and individuals with diabetes.[85] These studies indicate that vegan diets may require some initial effort, but otherwise appear to be no different from other therapeutic diets in quantitative measures of acceptability or enjoyment. A vegan diet led to no increases in dietary restraint, disinhibition, or hunger,[89] as rated using the Eating Inventory,[90] that would indicate that participants were perturbed by the prescribed diet.

The sustainability of vegetarian and vegan diets has been assessed directly and indirectly. In a study testing the effect of a vegan diet on body weight in overweight, postmenopausal women, participants' diets were assessed.[20] Two years after completion of the original 14-week study period, 61% (19/31) of participants reported consuming ≤3 ounces of meat per week, ≤1 dairy serving per week, ≤1 egg per week, and ≤2 servings of high-fat items (e.g., nuts, salad dressings) per day. In the 22-week study of a low-fat vegan diet described above,[4] nutrient intake changes were largely maintained at follow-up 1 year later (Barnard et al.[22]).

Another study using a vegetarian diet as part of a lifestyle program for coronary disease showed partial maintenance of weight loss and lipid changes at 5 years,[56] suggesting that dietary modifications had been maintained to a substantial degree. Similarly, a University of Pittsburgh survey of young women who had tried either a vegetarian or a calorie-restricted diet showed that the mean duration of adherence to vegetarian diets was at least 2 years, compared to only 4 months for calorie-restricted diets.[91]

In research studies, dietary adherence is facilitated by family involvement and use of support groups,[92] although the latter may be less available in other settings. Nonetheless, these studies suggest that the acceptability of low-fat, vegetarian and vegan diets is comparable to that of other therapeutic diets.

CONCLUSION

Observational and clinical trials indicate a benefit of vegetarian and vegan diets for diabetes management. Observational studies show a significantly reduced risk of developing type 2 diabetes in individuals following a vegetarian or vegan diet. Because observational studies can be confounded by other healthful behaviors, clinical trials have been conducted to determine the effects of vegetarian and vegan diets in management of type 2 diabetes. Evidence from these studies indicates low-fat vegan diets are at least as effective as more conventional diabetes diets for weight reduction and glycemic control, and are significantly more effective for lipid management. Individuals adopting such diets typically have favorable changes in macronutrient and micronutrient intake, although planning for nutrient adequacy is important with any therapeutic diet. Larger clinical trials are needed to confirm the effectiveness of vegetarian and vegan diets in diabetes management. However, the consistency of observed beneficial outcomes from studies employing vegetarian and vegan diets warrant additional research and future expansion of dietary guidelines to endorse vegan and vegetarian diets as a viable alternative to conventional dietary interventions.

Acknowledgments

Dr. Barnard writes books and gives lectures regarding low-fat plant-based diets. He is president of the Physicians Committee for Responsible Medicine and The Cancer Project, which are organizations that promote plant-based diets.

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