# The Impact of Low-carbohydrate Diets on Glycemic Control and Weight Management in Patients With Type 2 Diabetes

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## ABSTRACT

Low-carbohydrate diets are popular amongs individuals with type 2 diabetes to achieve weight loss. These diets recommend lower carbohydrate intakes (<45% of energy) than current nutritional recommendations. This evidence-based review aims to determine the potential benefits and risks associated with their use for weight management and glycemic control. Emerging evidence suggests that in the short term (within 6 months), when substituted for a conventional low-fat diet, low-carbohydrate diets can result in greater weight loss and better glycemic control, without a negative effect on blood lipids. There is, however, insufficient research to evaluate long-term risks or benefits. Individuals with type 2 diabetes who significantly restrict food groups or specific foods should have their diets assessed for fibre, antioxidant, nutrient and folate content.

## RÉSUMÉ

Beaucoup de personnes atteintes de diabète de type 2 suivent un régime à faible teneur en glucides pour perdre du poids. Ces régimes recommandent un apport en glucides plus faible (< 45 % de l'énergie) que celui recommandé actuellement. Le présent examen factuel a pour objet de déterminer les avantages et les risques possibles associés à ces régimes pour la gestion du poids et le contrôle de la glycémie. Des données récentes semblent indiquer qu'à court terme (dans les 6 mois), si on les substitue à un régime hypolipidique classique, les régimes à faible teneur en glucides peuvent aboutir à une perte de poids plus importante et à un meilleur contrôle de la glycémie, sans avoir d'effet négatif sur les lipides sanguins. La recherche est cependant insuffisante pour évaluer les risques et les avantages à long terme. Les personnes atteintes de diabète de type 2 qui limitent considérablement la consommation de certains groupes d'aliments ou d'aliments particuliers doivent faire évaluer leur alimentation du point de vue de l'apport de fibres, d'antioxydants, d'éléments nutritifs et d'acide folique.

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**Keywords:** high-protein diet, low-carbohydrate diet, obesity, satiety, weight loss

## INTRODUCTION

Low-carbohydrate diets that provide <45% of energy from carbohydrates have been a popular method for individuals with type 2 diabetes mellitus to achieve weight loss (1). Type 2 diabetes is a major health challenge in Canada, affecting >4.1 % of adults or 1 063 698 persons in 2001 (2). However, its true prevalence is estimated to be >7% (2.2 million people) based on population studies that indicate it to be >30% higher than that derived from physicians' diagnoses (3). Furthermore, 80 to 90% of these patients are overweight or obese (3). The prevalence of obesity is also a health concern affecting 23% of Canadian adults (2). Obesity is an independent risk factor for type 2 diabetes and the reason weight loss through change in lifestyle is highly recommended in both prevention and treatment of the disease (3,4). However, the challenges of losing and maintaining weight loss are well documented for obese individuals with diabetes (5). Because therapeutic attempts are often unsuccessful (6), the appeal of popular diet strategies for rapid weight loss has increased. In the United States (US), >20% of dieters report having used fad and popular diets (7).

Diets that recommend reducing dietary carbohydrates (e.g. Atkins diet, South Beach diet and Zone diet) have gained widespread popularity (6) and have cut into the profits of potato farmers, bakeries and pasta-makers. According to Statistics Canada, the yield of potatoes has been voluntarily reduced for the first time since 1988 (8). This craze, however, may not be a trend, but rather a fad, as indicated by the company Atkins Nutritionals Inc. filing for bankruptcy court protection in 2005. Nevertheless, the food industry has responded by marketing >930 low-carbohydrate food products in the last 5 years (9), making the low-carbohydrate diet less boring, but possibly less effective if some of the weight loss induced by these diets is due to their monotony and lower caloric content (10,11). According to the National Purchase Diary (NPD) Group survey, 75% of people reporting that they were following a low-carbohydrate diet ate a mean of 128 g of carbohydrate per day — 6 times what most very low-carbohydrate diets would recommend. Furthermore, according to this survey, many did not know which foods contained carbohydrates (12).

The popularity of low-carbohydrate diets has generated concern within the healthcare profession about their efficacy, tolerance, adverse effects and safety (13-16); the media has asked for the "return of the carbs," while personal testimonials from members of the public have questioned why some people are successful in losing weight when adopting such diets (16). Proponents of low-carbohydrate diets believe that hyperinsulinemia and insulin resistance contribute to the development of obesity (6,15,16) and assume that by limiting carbohydrates insulin levels will be lowered and fat storage decreased, thereby enabling fat to be mobilized for energy. In *Atkins Diabetes Revolution*, carbohydrates are restricted to <20 g/day until glycemic control is attained. Carbohydrates are reintroduced only if glycemic control (based on a glycemic ranking that combines glycemic index, glycemic load and net carbohydrate) is maintained.

Carbohydrate content in these diets may vary from very low (<20 g/day in the induction phase of the Atkins diet) to low (<40% of energy as in the Zone diet), both of which are inconsistent with *Canada's Guidelines for Healthy Eating*, the Dietary Reference Intake for carbohydrate (≥130 g/day and ≥45% contribution to energy) and the Canadian Diabetes Association 2003 Clinical Practice Guidelines for the Prevention and Management of Diabetes in Canada (3). Because of this inconsistency, the National Nutrition Committee (NNC) of the Canadian Diabetes Association reviewed the scientific evidence regarding potential benefits and risks associated with the use of low-carbohydrate diets by adults with or without type 2 diabetes for weight management and with type 2 diabetes for glycemic control. This report by the NNC focuses on popular low-carbohydrate diets, for which long-term use has been studied in a controlled manner, and provides practical advice on how a health professional can evaluate the safety of such diets.

## METHODS

Relevant peer-reviewed papers published between 1979 and 2005 were searched using PubMed and the keywords "low-carbohydrate," "high-protein," "weight-reducing diet" and "satiety." Reference to relevant published reviews, comments and editorials was also made. Twenty-three relevant papers were retrieved and reviewed.

## RESULTS

### Effect on diet quality

Low-carbohydrate diets, by definition, emphasize the consumption of protein, and limit fruit, vegetable, cereal and bread intake, primary sources of essential micronutrients, antioxidants, carotenoids, polyphenols, phytochemicals and fibre—all recognized for their health benefits (17) and their potential to reduce the risk of diabetes, some forms of cancer (18) and coronary heart disease (CHD) (19). Furthermore, in the event that meat is frequently chosen, epidemiological evidence suggests a dose-response relationship between meat intake and risk of cancer (20). Epidemiological studies have associated high meat consumption with an increased risk of prostate cancer (21). Low-carbohydrate diets that result in higher intakes in saturated fat may aggravate levels of total cholesterol (TC) and low-density lipoprotein cholesterol (LDL-C), major risk factors for CHD (22). Low-carbohydrate diets that significantly restrict food groups or foods normally found in the diet of those with type 2 diabetes should be assessed for their content of fibre (18), antioxidants (17) and nutrients, particularly folate (19).

### Effect on body weight

There is evidence that substituting a very low-carbohydrate, energy-deficient diet for a conventional low-fat, low-energy diet produces significantly greater short-term weight loss (within 6 months) in individuals with type 2 diabetes. Most of the weight loss seen with low-carbohydrate diets has been shown to occur within the first weeks of introducing the diet. It has been attributed to loss of intracellular water due to the mobilization of hepatic and muscle glycogen stores to meet the body's needs for glucose through gluconeogenesis before induction of metabolic ketosis (23). Ketosis that reflects fatty acid utilization has been proposed to decrease appetite and total food intake (23), but weight loss was not associated with urinary ketone excretion in the trial by Foster and colleagues (24). The energy loss due to urinary ketones is small and cannot account for reported weight loss by individuals on these diets.

Results of selected studies are summarized in Table 1. Samaha and colleagues (25) included obese subjects with type 2 diabetes and found that very low-carbohydrate intake produced significantly more weight loss at 6 months than a low-fat diet (–5.7±8.6 kg vs. 1.8±3.9 kg, $p=0.002$), even after adjustment for confounders such as age, ethnicity, sex, baseline energy intake and the presence or absence of diabetes. No follow-up on weight loss maintenance was done.

Westman and colleagues (26) reported that overweight and obese individuals without diabetes (body mass index [BMI] 26 to 33 kg/m$^2$), consuming <25 g/day carbohydrate for 6 months, with no limit on protein and fat, decreased energy intake to 1447±350 kcal/day, weight by 9 kg ($p<0.001$) and body fat from 42.3 to 39.4% ($p<0.001$). Adherence to diet was determined by presence of ketonuria. Of the 51 subjects, 41 attended all visits and 15 reported adhering to diet every day. Weight loss correlated with dietary adherence and ketonuria. Five percent of participants lost no weight. The diet was associated with an increase in urinary calcium ($p<0.001$) and uric acid excretion ($p=0.02$), bad breath and constipation.

Foster and colleagues (24) conducted a 12-month controlled trial in obese nondiabetic subjects assigned to either a very low-carbohydrate or a conventional low-fat, 1500-kcal diet.

**Table 1. Summary of studies reviewed**

| Study | Population (N) | kcal | Carbohydrate (g) | Protein (g) | Duration (mo) | Weight loss (kg, mean ±SD) | Effects on lipids | Adherence (%) |
|---|---|---|---|---|---|---|---|---|
| Samaha et al (25) | Mixed (132 severe obese, 51 type 2 diabetes) | ad lib | <30 | ad lib | 6 | 5.7±8.6 | ↓TG | 60 |
| Westman et al (26) | Overweight/obese, non-diabetes (51) | ad lib | <25 | ad lib | 6 | 9.0 | ↓TC, TG, LDL-C ↑HDL-C | 80 |
| Foster et al (24) | Obese, non-diabetes (63) | ad lib | 20 | ad lib | 6/12 | 7.0±6.5 4.4±6.7 | ↓TG ↑HDL-C (6 and 12 mo) | 67 (6 mo) 59 (12 mo) |
| Voleck et al (27) | Obese, non-diabetes (28) | –500 | <30 | — | 1–1.5 | 7.0 (men) 3.0 (women) | NA | 100 |
| Brinkworth et al (34) | Obese, non-diabetes (58) | 1500 | 161 | 108 | 3 | 8.5±0.6 | ↓TG | 74 |
| Layman et al (35) | Obese, non-diabetes (24) | 1600 | 171 | 125 | 2.5 | 7.0 | ↓TG | 100 |
| Parker et al (36) | Type 2 diabetes (66) | 1600 | 160 | 120 | 2 | 4.5 | ↓TC, TG, LDL-C | 82 |
| Boden et al (39) | Type 2 diabetes (10) | ad lib | 21 | ad lib | 15 days | 1.7 | ↓10% TC ↓35% TG | 100 |
| Meckling et al (45) | Obese (20) | ad lib | 50 | 87 | 2 | 5.0 | ↓TC, TG, LDL-C ↔HDL-C | 80 |

HDL-C = high-density lipoprotein cholesterol
LDL-C = low-density lipoprotein cholesterol
SD = standard deviation
TC = total cholesterol
TG = triglyceride

Although weight loss was significantly greater with the low-carbohydrate diet at 3 months (–6.8±5.0% vs. –2.7±3.7% of initial weight, p=0.001) and at 6 months (–7.0±6.5% vs. –3.2±5.6%, p=0.002), it was low relative to excess weight, and at 12 months did not differ between groups (–4.4±6.7% vs. –2.5±6.3%, p=0.26). This study was also characterized by a high dropout rate, and intention-to-treat analysis was not performed. Adherence to the diets was equally poor in both groups, a finding attributed in part to the self-help nature of the treatment.

In a randomized, crossover study, Voleck and colleagues (27) compared a very low-carbohydrate, ketogenic diet to a low-fat diet with the same calculated deficit of 500 kcal/day. Each diet was given for 50 days to 15 obese men and 30 days to 13 obese women. Participants reported greater reduction in weight, total fat mass and trunk fat with the low-carbohydrate than the low-fat diet. These findings were more pronounced in men than women, especially during the first period of study; but there was weight regain in some subjects when the low-fat high-carbohydrate diet was given during the second period. Although weight reduction was greater, men reported eating more calories during the low-carbohydrate diet phase. This observation was interpreted as indicating that there may be overestimation in reporting intakes from food sources of protein and underestimation in reporting those from carbohydrate (27). Greater fat loss in the trunk region led the authors to conclude that low-carbohydrate diets may provide a metabolic advantage (28), mediated by changes in insulin, leptin, cortisol or other factors that influence nutrient partitioning.

A greater weight loss with the low-carbohydrate diet has been attributed to the greater thermic effect of protein compared with carbohydrate and fat (25 vs. 7 vs. 2% of energy content, respectively [29-32]). Replacing 60 g of carbohydrates with protein represents, at most, 36 kcal/day, 6048 kcal over 24 weeks or approximately 0.8 kg (16). If compensation for the energy derived from carbohydrate were from protein and fat, the increase in thermic effect of the meal would be minimal, and even less so in people with poorly controlled type 2 diabetes in whom the thermic effect of protein has been shown to be blunted (33).

Brinkworth and colleagues (34) reported that replacing carbohydrate with protein during 12 weeks of a low-calorie diet induced comparable weight loss to a conventional diet (34). At week 68, weight was still lower than baseline with both diets, but percentage loss of initial weight was greater in the low-carbohydrate high-protein group (–4.1±5.8% vs. –2.9±3.6%, p<0.01).

In a study by Layman and colleagues (35), weight loss did not differ between diets restricted to 1600 kcal per day, regardless of the protein-to-carbohydrate ratio (3.5 vs. 1.4 [125 vs. 68 g protein/day]). However, the higher-protein diet was associated with a proportionally greater loss of body fat compared with lean tissue than the lower-protein diet (35).

Parker and colleagues also observed greater fat loss (5.3 vs. 2.8 kg, p<0.05) but similar weight loss (4.5 kg) in subjects with type 2 diabetes after 8 weeks of a 1600-kcal per day diet with a carbohydrate-to-protein ratio of 1.5 vs. 3.4 (36). Increasing proportional dietary protein during energy restriction achieves nitrogen equilibrium (37), but less so in poorly controlled obese subjects with type 2 diabetes, in whom an inability to adapt to the protein-sparing challenge of energy restriction has been shown (38). In a controlled inpatient study, Boden and colleagues (39) found that short-term reduction of dietary carbohydrate from 300 to 21 g/day was associated with a decrease in energy intake of ~1000 kcal/day, which was sufficiently great to explain the observed weight loss. The energy deficit resulted from restricting carbohydrate without increasing protein and fat intakes.

An earlier review of low-carbohydrate diets concluded that weight loss was associated with magnitude of caloric restriction, diet duration and initial weight, and was not due to reduced carbohydrate content (40). Popular diets that reduce energy intake will lead to weight loss (41).

Dietitians of Canada (42) has warned Canadians that low-carbohydrate diets are unlikely to achieve sustained long-term weight loss. It has also questioned the safety of such diets, and does not recommend them for people with diabetes. Those with diabetes should be made aware of terms as "net carbs" and "impact carbs" on US labels. These terms are not regulated and usually mean that fibre, sugar alcohols and glycerol have been subtracted from total carbohydrates. Such an approach may underestimate carbohydrates that affect blood glucose (BG) and mislead people with diabetes who rely on carbohydrate counting to determine their insulin dosage.

## Effect on glycemic control

In the short term, consumption of low-carbohydrate diets by those with type 2 diabetes is associated with reductions in postprandial BG (43) and glycosylated hemoglobin (A1C) (39,43) and increases in insulin sensitivity (25,39). These effects may or may not be independent of concomitant reduction in energy intake. The reductions in fasting BG occur only when dietary carbohydrate is severely restricted (25,38,39). Indeed, in type 2 diabetes, fasting glucose concentrations have been shown to decrease with very low-carbohydrate, ketogenic diets, whether energy is severely restricted (38,44) or not (25,39). Replacing 15% of energy from carbohydrate with protein during 5 weeks of a weight-maintaining diet resulted in a decrease in postprandial BG concentration and in A1C, but not in fasting BG concentration (43). Insulin sensitivity improved after a 6-month carbohydrate-restricted diet compared with a low-fat diet (6±9 vs. –3±8%, p=0.01) (25), independent of weight loss. In contrast, in free-living women without diabetes, no change in fasting BG, insulin concentrations or response to an oral glucose tolerance test was observed with a low-carbohydrate diet (70 g/day) over 8 weeks, despite concurrent decreases in caloric intake and weight (45).

### Effect on lipid profile

As indicated in Table 1, with low-carbohydrate diets, TC (26,39), LDL-C (26) and triglyceride (TG) decreased (25,26,39), and HDL-C increased (26) in some, but not all, studies (45). Foster and colleagues (24) found a reduction in TC and LDL-C after 3 months of a low-fat, conventional diet. However, both of these lipid concentrations increased after 6 and 12 months, and did not differ between subjects following the conventional or low-carbohydrate diets. It was concluded that the adverse effect of a greater saturated fat intake associated with the low-carbohydrate diet may have been offset by the greater weight loss in that group. At 12 months, reductions in serum TG and increases in HDL-C were seen only with the low-carbohydrate diet. Notwithstanding the positive findings, high saturated fat intakes, which are often characteristic of low-carbohydrate diets and come mainly from animal protein, have been demonstrated throughout the literature to raise TC and LDL-C (22). In type 2 diabetes, consuming a low-carbohydrate diet for 2 weeks resulted in a 10% reduction in plasma TC and a 35% decrease in TG (39).

### Effect on C-reactive protein

Limited data exist on low-carbohydrate diets and C-reactive protein, an inflammatory risk factor for coronary artery disease (46). One study examining the effect of a low-carbohydrate, high-protein diet on coronary blood flow reported an increase in C-reactive protein and a decrease in blood flow (47). The mechanism and long-term implications for individuals with diabetes are unclear, but this result suggests that a high-protein diet may negatively influence this risk factor.

### Effect on kidneys

Low-carbohydrate diets are hypothesized to negatively affect kidney function (48), primarily because of the higher protein intake. However, Skov and colleagues failed to detect any detrimental effect on kidney size and glomerular function in obese, non-diabetic persons after 6 months on a high-protein, low-fat diet (49). Westman and colleagues (26) reported similar findings in patients consuming a very low-carbohydrate diet. There is currently insufficient research in individuals with type 2 diabetes to evaluate the safety of consuming low-carbohydrate, high-protein diets in the presence of renal complications. Although there are no studies on the risks or benefits of low-carbohydrate diets in those with reduced renal function, meta-analysis suggests that high-protein diets resulting from reducing carbohydrates may be contraindicated (50).

### Effect on bone health

There are no published studies on the impact of low-carbohydrate diets on bone health in individuals with type 2 diabetes. In people without diabetes, very low-carbohydrate ketogenic diets are associated with a mild metabolic acidosis as indicated by decreases in serum bicarbonate concentrations (26), accompanied by an increase in urinary excretion of calcium (26). Furthermore, the greater urinary losses of calcium associated with high-protein intake (51) may be coming from bone, as N-telopeptide (a marker of bone resorption) was elevated in subjects consuming a high-protein compared with a low-protein diet (52). However, Skov and colleagues reported no effect on bone mineral density in obese subjects with adequate calcium intake after 6 months of following a high-protein, low-fat diet (49).

### Increased complications of diabetes

Low-carbohydrate diets may potentially exacerbate BG control or increase the risk of complications in type 2 diabetes. Risk of cardiovascular disease, which is the primary cause of death in persons with diabetes, may increase, particularly in the absence of weight loss, because these diets favour the selection of saturated-fat-containing foods known to be associated with high LDL-C levels (1,22). People with diabetes are already at increased risk of nephropathy and kidney failure, and the additional burden of high dietary protein loads may further impair renal function or speed the progression of renal dysfunction (40,53). Ketosis and its complications are also generally feared in uncontrolled diabetes, but mainly in type 1 diabetes. Given that induction of ketosis occurs in very low-carbohydrate diets, it may not be safe for persons with diabetes to adhere to this form of treatment for obesity. Effects of long-term ketosis and mild metabolic acidosis in diabetes remain to be determined. The same applies to risks of hypoglycemia with low-carbohydrate diets for individuals on oral antihyperglycemic agents and/or insulin treatment. To our knowledge, no study has assessed the risks, benefits and effects of very low-carbohydrate diets on BG control in type 1 diabetes.

The evidence available on the metabolic consequences of high-dietary protein intake in adults was addressed by Metges and Barth (54). They concluded that when energy balance was maintained, there was no benefit to increasing protein intake beyond recommendations, even to improve physical performance. In contrast, exercise increased nitrogen utilization and protein retention at low-protein intake. Evidence suggests that there may be a benefit in partially replacing refined carbohydrates with food sources of protein that are low in saturated fat (1,25).

### Effect on fatigue

There are no studies on whether low-carbohydrate diets influence fatigue in individuals with type 2 diabetes. In people without diabetes, low-carbohydrate diets may contribute to fatigue if there is an associated decrease in BG and depletion of muscle glycogen (55,56). It is hypothesized that changes in plasma amino acids and their uptake into the brain occur during the consumption of low-carbohydrate diets and this alters serotonin and other neurotransmitters in the brain. Deficiencies in serotonin have been related to sleep latency, mood change, depression and aggressiveness (57). However, there is no evidence at present to support the view that serotonin levels are disrupted in people consuming the popular low-carbohydrate, high-protein diets.

**Effect on satiety**

It has been reported that when protein content is similar, consumption of low-carbohydrate diets by those with type 2 diabetes is equally satiating as higher-carbohydrate diets (39). When carbohydrate content is similar, consumption of high-protein diets (30% of energy) in nondiabetic persons is more satiating than lower-protein diets (15% of energy) (58). There is evidence that shows that protein is more satiating than carbohydrate and fat (58). Consequently, if by adhering to a low-carbohydrate diet, protein intake increases, total food intake may decrease due to the increase in satiety. Hill and Blundell (reviewed in reference 59) found that high dietary protein content, contributing 31% of a 500-kcal meal, was associated with greater sensation of fullness and lesser desire to eat than a meal with 52% of energy derived from carbohydrate. Subsequent food intake was reduced by 19% after a high-protein (54% of energy) compared with a high-carbohydrate (63%) meal. Others have observed that consumption of protein induces a feeling of fullness (32,33) and is associated with greater ability to suppress hunger compared with consumption of carbohydrates or fat for similar energy density (49,58,60). However, Boden and colleagues (39) reported that in type 2 diabetes, a low-carbohydrate diet was equally satiating as a conventional diet. The authors could not attribute the spontaneous decrease of nearly 30% in energy intake to lack of diet variety and palatability, or to the small increase in blood ketone levels, also considered to be anorectic (23). Mechanisms proposed to explain the anorectic effect of high-protein diets include release of gut peptides, changes in liver metabolism, neurological effect of changes in amino acids (61) or increased central nervous system leptin sensitivity (58).

**Effect on adherence to diet**

There are no published studies on the effect of low-carbohydrate diets on diet adherence in individuals with type 2 diabetes. As shown in Table 1, adherence to low-carbohydrate diets in clinical trials is poor. In the study by Foster and colleagues attrition was 41%. Brinkworth and colleagues (34) reported a 26% dropout at 68 weeks when studying obese nondiabetic subjects, and poor long-term adherence was seen with both low- and high-carbohydrate diets. These findings are supported by those of Dansinger and colleagues (62), who found after a 1-year randomized clinical trial in 160 obese subjects, a discontinuation rate of 48% with the Atkins diet, 50% with the Ornish diet, and 35% with the Zone diet and Weight Watchers®. The subjects found the diets too hard to follow or not yielding sufficient weight loss.

**Lifestyle interventions**

There is evidence to suggest that weight loss is independent of the macronutrient composition of the diet and the key to weight loss is energy deficit through dietary energy restriction, as well as increased physical activity/exercise (41,63,64). Long-term lifestyle intervention trials (~3 to 6 years) for the treatment and/or prevention of type 2 diabetes have lead to weight loss and improvements in lipid profile and glycemic control with diets high in carbohydrate, but low in fat and composed of unrefined foods (65).

**Recommended approach for health professionals**

When patients admit to following a popular diet, one should capitalize on their motivation to lose weight and sudden interest in changing eating behaviour. The safety of these diets for people with type 2 diabetes is not supported by research. Thus, these individuals should be followed more closely with regular assessments of glycemic control and adjustments of medications as appropriate (insulin, oral antihyperglycemic agents, particularly sulfonylureas, and diuretics). Lipid profile should be monitored, particularly if weight loss has ceased and the individual continues to adhere to a diet high in saturated fat. Ideally, strategies should be adopted to work around popular diets and retain the beneficial outcomes that may be present. For example, people who have consumed a diet high in simple carbohydrates and high glycemic index foods will inevitably decrease consumption of particularly rapidly absorbable sugar-sweetened beverages when they restrict carbohydrates. Restricting carbohydrates may also result in decreased dietary fat and total energy (e.g. no dessert means no sugar and no fat; no pasta means no oil-based sauce; no bagel means no cream cheese), but may not induce the satiety that results from choosing high-volume energy-diluted foods. There is considerable evidence that satiety is regulated more by volume of food than calorie content (66).

If carbohydrate restriction is severe and insulin levels low, refeeding with carbohydrates can significantly increase insulin, and result in hypokalemia (67). Carbohydrates should, therefore, be reintroduced slowly. When carbohydrates are restricted, the small allowances of carbohydrate should be devoted to those fruits and vegetables with a high-vitamin (particularly folic acid), mineral, calcium, phytochemical and fibre content in order to maximize micronutrient intake.

Strategies that succeed in inducing a caloric deficit long enough to achieve weight loss may vary from individual to individual. Furthermore, strategies for maintaining weight loss may be quite different from those that achieve the initial weight loss. Restricting carbohydrates during weight maintenance, however, may aggravate cardiovascular and renal complications in the long term, limit food sources of

**Table 2. Benefits and risks of low-carbohydrate diets in the management of type 2 diabetes**

Current Canadian Diabetes Association and Health Canada guidelines recommend a contribution of ≥45% of energy from carbohydrates. Many low-carbohydrate diets recommend lower carbohydrate intake than this figure. Currently, however, there is insufficient research on the use of low-carbohydrate, high-protein diets in type 2 diabetes to evaluate:

- maintenance of weight loss beyond 1 year
- ability to adhere to diet
- effect on fatigue
- effect on glycemic management beyond 1 year
- effect on progression of renal complications in those with normal renal function
- effect on blood lipids beyond 2 weeks
- effect on other cardiovascular risk factors
- effect on bone health

Low-carbohydrate diets that significantly restrict food groups or foods normally included in the diet of those with type 2 diabetes should be assessed for their content of fibre, antioxidant nutrients and folate (18,19). Low-carbohydrate, high-protein diets may be contraindicated in those with renal insufficiencies (50) or diabetic renal disease.

Evidence indicates that in the short term (within 6 months):

- Substituting a very low-carbohydrate diet for a conventional low-fat, low-energy diet (25) results in significantly greater weight loss in type 2 diabetes
- Consumption of low-carbohydrate diets in type 2 diabetes is associated with reductions in postprandial BG (43) and A1C (39,43) and increases in insulin sensitivity (39). Reductions in fasting BG in type 2 diabetes occur only when carbohydrate is severely restricted (25,38,44)
- Consuming a low-carbohydrate diet for 2 weeks results in a reduction in plasma total cholesterol and triglycerides (39)
- Low-carbohydrate diets are as satiating as higher-carbohydrate diets (39)

A1C = glycosylated hemoglobin
BG = blood glucose

essential micronutrients, particularly folic acid and calcium, and affect bone health. Individually planned approaches that address and correct the reasons for weight gain may be conducive to healthy weight control over time. Dietary advice that incorporates low-energy-dense foods such as fruits, vegetables and broth-based soups, and limits fat in food preparation has been shown to be associated with greater weight loss in obese women than that which suggests reducing portion size of all foods (68).

## CONCLUSIONS

Few studies have explored the long-term effects of low-carbohydrate diets in persons with type 2 diabetes and none has been conducted in those with type 1 diabetes. Whether obese persons with type 2 diabetes can better adhere to energy-restricted diets when these diets are low in carbohydrate rather than low in fat, and whether insulin sensitivity and glycemic control can be improved independently of weight loss, remain to be demonstrated. Recent data indicate that the macronutrient composition of a weight-reducing diet may vary in its effectiveness depending upon a person's insulin sensitivity. Indeed, low-carbohydrate, high-fat diets were shown to induce greater weight loss in insulin-resistant obese women, while high-carbohydrate, low-fat diets induced greater weight loss in insulin-sensitive obese women (69).

The conclusions regarding the safety and benefit of low-carbohydrate diets for people with type 2 diabetes are summarized in Table 2. Emerging evidence suggests that in the short term (within 6 months), low-carbohydrate diets, when substituted for a conventional low-fat diet, can result in greater weight loss and better glycemic control, without a negative effect on blood lipids. There is, however, insufficient research to evaluate long-term risks or benefits. Individuals with type 2 diabetes who significantly restrict food groups or specific foods should have their diets assessed for adequacy of fibre, antioxidant and micronutrient (particularly folate) content.

## ACKNOWLEDGEMENTS

The authors acknowledge Josie Plescia for her secretarial expertise.

## AUTHOR DISCLOSURES

No dualities of interest declared.

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