Low-Carbohydrate Diets: An Update on Current Research

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The diabetes and obesity epidemics have stimulated research to assess the benefits and potential risks of low-carbohydrate diets. Carbohydrate comprises less than 45% of calories in carbohydrate-restricted diets, but very low carbohydrate ketogenic diets may restrict carbohydrate to 20 g initially with variability in the carbohydrate level subsequently. Some research suggests that low-carbohydrate diets may achieve better early weight loss than comparison diets higher in carbohydrate. Studies of up to 1 year suggest that weight loss on low-carbohydrate diet is comparable with fat-restricted diets with higher carbohydrate content. Limited research has been conducted to evaluate low-carbohydrate diets in managing type 2 diabetes. Although science continues to advance in this field, current research suggests that low-carbohydrate diets can be a viable option for achieving weight loss and may have beneficial effects on glycemic control, triglyceride levels, and high-density lipoprotein cholesterol levels in some patients.

Introduction

The diabetes and obesity epidemics have stimulated research to assess the benefits and potential risks of low-carbohydrate diets. Providing advice to patients regarding the use of low-carbohydrate diets in diabetes and obesity involves clinical decision making regarding medication adjustments and consideration of the research evidence. Until recently, the evidence base was largely limited to case series or clinical trials that were of short duration or included a relatively small sample of patients with diabetes [1,2•,3]. This article examines variability in the definition of low-carbohydrate diets, the evolution of carbohydrate restriction to manage obesity and diabetes, the growing evidence base regarding weight, glycemia and lipids, and the clinical management of patients on low-carbohydrate diets.

Low-Carbohydrate and Restricted-Carbohydrate Definitions

There are variable interpretations of what is meant when a patient or health provider refers to a low-carbohydrate diet. A recent meta-analysis of restricted-carbohydrate diets in diabetes management used less than 45% of calories as criteria for inclusion [2•].

The American Academy of Family Physicians has defined low-carbohydrate diets in the following manner:

> Low-carbohydrate diets restrict caloric intake by reducing the consumption of carbohydrates to 20 to 60 g/d (typically less than 20% of the daily caloric intake). The consumption of protein and fat is increased to compensate for part of the calories that formerly came from carbohydrates [4].

Restricting carbohydrate intake to 20 g/d would generally be considered a very low carbohydrate diet that is likely to produce ketosis. Very low carbohydrate, higher fat diets are considered ketogenic because the diet, which mimics aspects of starvation, forces the body to burn fat rather than carbohydrate. Normally, the carbohydrates in food are converted into glucose, which is then transported around the body for energy. However, if there is very little carbohydrate in the diet, the liver converts fat into fatty acids and ketone bodies, which are used for energy. When the diet contains more carbohydrate, usually 40 to 60 g/d of carbohydrate, the diet would not induce ketosis, and thus it would be considered low rather than very low carbohydrate.

An analysis from the 1994 to 1996 Continuing Survey Food Intake by Individuals by the United States Department of Agriculture considered a very low carbohydrate intake to be less than 30% of daily calories and a low-carbohydrate intake to be 30% to 45% of daily calories [5]. A recent meta-analysis of carbohydrate restriction in diabetes management compared lower carbohydrate diets, which varied in carbohydrate content from 4% to 45%

of daily calories, to control diets higher in carbohydrates [2•]. Thus, when a patient mentions a low-carbohydrate diet, we need to query further. We need to elicit information about what foods a patient considers excluded and included even when a specific diet is mentioned.

Evolution of Low-Carbohydrate Diets in Diabetes and Obesity Management

The diet of early hunter-gatherers and some isolated societies contained little carbohydrate because most foods rich in carbohydrates are from cultivated crops [5,6]. Agricultural development brought about the rise of civilization and the gradual rise of carbohydrate levels in human diets. The rise in agribusiness resulted in a particularly sharp rise in refined carbohydrate intake. The term *diabetes mellitus*, which means siphon or pass though with honey sweetness, was chosen by the ancient Greeks to describe diabetic symptoms [7]. Restricting sweet foods was commonly used to control glycosuria early in the treatment of diabetes, although arguments were also made for eating food that would replace the urinary losses.

In an overview of the history of low-carbohydrate–weight diets, Taubes [8] suggested that carbohydrate restriction for weight control was popularized by William Banting almost a century and half ago. Banting was an obese English undertaker under the care of Dr. William Harvey, Fellow of the Royal College of Surgeons and an ear, nose, and throat specialist [8]. The Banting dietary recommendations included giving up bread, butter, milk, sugar, beer, and potatoes. Dr. Harvey developed the recommendation for Banting based on the theories of Dr. Claude Bernard regarding the role that the liver played in diabetes. Bernard suggested that the liver, in addition to secreting bile, also secreted a sugar-like substance that it made from elements of the blood passing through it. Harvey then considered the roles of the various food elements in diabetes with questions about how sugars and starches affected the body. The Banting booklet was widely distributed and the word *Banting* was often used as verb much in the same way "dieting" is used to describe weight-loss actions. At the beginning of the 20th century, Dr. Fredrick Allen published case reports detailing the effects of severe carbohydrate restriction, which was often 20 or 30 g/d, on diabetes symptoms [8]. Before the advent of insulin therapy in the 1920s, dietary intervention usually with carbohydrate restriction was the only treatment available. Severe carbohydrate restriction was considered essential to short-term survival for youth who developed diabetes in the pre-insulin era, although the very low carbohydrate diet was also used for overweight individuals who developed diabetes (type 2) later in life.

After insulin treatment became available, the level of carbohydrate restriction was liberalized. For several decades, limiting carbohydrate intake to 40% of daily energy intake was recommended by the American Diabetes Association, with emphasis on carbohydrate's role in controlling blood glucose without focusing on carbohydrate in relation to the role of obesity in diabetes management [9]. However, studies in the late 1950s reported that ketosis and weight loss were not accompanied by feelings of illness or undue symptoms, and the authors described this observation as resistance to adverse effects of ketosis in obese subjects [10,11].

The 1967 publication of the "Stillman diet" popularized a low-calorie high-protein diet that was also low carbohydrate and low fat [12]. Five years later, *Dr. Atkin's Diet Revolution*, which advocated a low-carbohydrate ketogenic diet based on clinic practice experience, dramatically increased interest in carbohydrate restriction in weight management [13].

Overview of Popular Low-Carbohydrate Diets

A low-carbohydrate Internet forum has examined the features of eight popular low-carbohydrate weight-loss diets [14].

Atkins diet

The original *Dr. Atkin's Diet Revolution* book provided weight-loss recommendations based on his consideration of the scientific literature [13]. The program begins with considerable restriction (≤ 20 g of carbohydrate per day) in the Induction phase. After that, the amount of restriction is tailored to the individual, depending upon his or her response to the diet. The phases include detailed instructions on adding small amounts of carbohydrate. The program focuses on helping people find their individual carbohydrate tolerance levels. The Atkins diet has four phases: Induction, Ongoing Weight Loss, Pre-maintenance, and Maintenance. During Induction, dieters are instructed to restrict carbohydrate intake to 20 g/d to induce ketosis and "jumpstart" weight loss. If weight loss is on target, phase 1 lasts for about 2 weeks. During Ongoing Weight Loss, dieters begin to add variety into the food plan controlling the amount of carbohydrate added (usually 5 g/d each week) if weight loss is occurring. Dieters are to stay in phase 2 until they are within 10 lb of their weight goal. During Pre-Maintenance, more independence is permitted. Dieters are encouraged to add carbohydrate-containing foods from an acceptable food list until weight is considered to be at equilibrium. The amount of carbohydrate permitted is individualized at the level of carbohydrate consumed when weight equilibrium is achieved. During Maintenance, the carbohydrate goal is based on the amount of carbohydrate associated with weight equilibrium in phase 3. Dieters are encouraged to focus on that level of carbohydrate and to monitor their weight to stay within 5 lb of their goal weight. A re-initiation of the ketogenic phase 1 is recommended for treating relapse.

Bernstein Diabetes diet

The original *Dr. Bernstein's Diabetes Solution* book provided diabetes control advice based on his personal experience in controlling his type 1 diabetes with consideration of the scientific literature [15]. Intensive blood glucose monitoring is an integral component of diabetes management, with weight playing a secondary role. The goal is to achieve normal, nondiabetic blood glucose (~ 85 mg/dL), with emphasis on the pathophysiologic changes that can occur with fasting glucose that exceeds the prediabetes threshold of 100 mg/dL and the diabetes threshold of 126 mg/dL. The diet contains very little carbohydrate (< 30 g/d), with one relatively simple plan that does not change over time based on weight changes due to the high emphasis on glycemia. Although low-carbohydrate vegetables are included, grains, starchy vegetables, and fruits are prohibited, which limits intake of vitamins, minerals, and phytochemicals needed for optimal health. Therefore, supplements are recommended to achieve adequate micronutrient intake.

Neanderthin or Caveman diet

The *Neanderthin: Eat Like a Caveman to Achieve a Lean, Strong, Healthy Body* book popularized consideration of diet eaten by early man, which he began to follow to control his own weight and diabetes [16]. The dietary focus is on avoiding processed and other foods not considered to be consistent with the Paleolithic base, which was the original diet for humans with no carbohydrate counting or measuring. Instructions focus on eating from the "acceptable" food list with emphasis on physical activity, which was an integral component of the Paleolithic lifestyle. Some advocates suggest that the food list can be simplified by choosing less processed foods by "shopping the perimeter of the grocery store." The debate about what constitutes a "proper paleo" diet includes consideration of genetic adaptation to eating milk and other dairy products via lactose tolerance variability.

Protein Power diet

The original *Protein Power* book provided weight-loss advice based on the dietary approach used in the doctors' practice [17]. The Protein Power diet is a very low carbohydrate diet (30–40 g/d) with relatively simple instructions for eating based on awareness and counting carbohydrate intake. The Eades emphasize nutrition, focusing on what nutrients are in various foods and the roles of antioxidants and phytochemicals in health. However, supplementation is likely to be required to achieve desired intake of micronutrients.

Sonoma diet

The *Sonoma Diet* book, written by a nutritionist, provides weight-loss advice based on the Mediterranean diet and a California twist [18]. Wave 1 of the Sonoma diet, which is 10 days, excludes fruit, some vegetables, and dairy products, and most sources of saturated fat. Grains are limited to two servings per day of whole grains. Wave 2, which is to be used until the dieter has completed weight loss, adds some fruit, dairy, grains, and the restricted vegetables in specific amounts. Wave 3 is maintenance. The diet eliminates all refined sugar, white flour and its products (white bread, cake, bagels, crackers, etc.), potatoes, and other foods that are high on the glycemic index. The carbohydrate content varies from about 40% of to as high as 50% to 55% of daily energy intake if low glycemic index foods are chosen.

South Beach diet

The original *South Beach Diet: The Delicious, Doctor-Designed, Foolproof Plan for Fast and Healthy Weight Loss* book provided weight-loss advice based on the approach the doctor used in his practice [19]. The South Beach diet uses a qualitative approach by eliminating some carbohydrate sources that have higher glycemic index values when starting the diet. The proportion size for permitted foods is not specified, and the dieter is encouraged to eat until no longer feeling hungry. The phases used in the South Beach Diet are threefold: In phase 1, dieters are instructed to eat normal meals of chicken, beef, turkey, fish, and shellfish, lots of vegetables, eggs, cheese, nuts, and garden salads using olive oil for your salad dressing. Fruits, starchy vegetables, and grains are not permitted during this 2-week period, and dieters are encouraged to return to this phase if weight loss slows or stops. In phase 2, dieters are instructed to liberalize their food list to include a wider variety of fruits and vegetables and with more emphasis on selecting low glycemic index foods (eg, apples, berries, grapefruit, high-fiber cereal, and whole grain breads). The expected weight loss is reported as 1 to 2 lb weekly. In phase 3, dieters move to a more liberal maintenance phase, which allows more foods that are labeled as medium glycemic index foods (usually starches) and an occasional treat (eg, chocolate cake) when they reach their target weight.

Sugar Busters diet

The *Sugar Busters! Cut Sugar to Trim Fat* book is based on a dietary approach developed by a group of physicians in clinical practice [20]. The dietary advice is to avoid foods that are off-limits and choose foods that are not forbidden. There are no phases, no counting, no measuring, and very little special knowledge needed. The emphasis is on avoiding highly refined carbohydrate sources (eg, sugar and white flour) and eliminating foods that contain forbidden ingredients. The issue of eating less saturated fat is mentioned, but menu examples are inconsistent with that recommendation and include butter, cream, and cheese.

Zone diet

The first *Zone: A Dietary Roadmap* book provided weight-loss advice based on proportions of carbohydrate, protein, and fat, as well as "favorable" and "unfavorable" types of each [21]. Recommendations focus on

Table 1. Summary of Kirk et al. [2•] meta-analysis of studies of CHO-restricted diets in diabetes management*

Studies, *n*	Study design	Low CHO arm (% CHO)	Comparison diet (% CHO)	Intervention duration, *wk*	Sample size	Analysis results
13	9 RCT [1] (6 crossover and 3 parallel), 3 pre-post†, 1 nonrandomized two-arm trial	Range, 4% to 45%; mean 29% (14% SD)	Range, 40% to 70%; mean 55% (8% SD)	Range, 1–26	Range, 8–52	Lower HbA_{1c}, fasting glucose, and triglyceride levels were observed on lower CHO diets. No differences were observed for weight and cholesterol or its subfractions
5	1 RCT (crossover, isocaloric), 1 nonrandomized two-arm trial, 3 pre-post†	Very low [2•]; range, 4% to 25%	Range, 40% to 70%	Range, 1–16	Range, 8–28	No analyses were done for the very low or low-CHO subcategories
8	8 RCT (5 crossover and 3 parallel) [3]	Low [2•]; range, 33% to 40%	Range, 51% to 65%	Range, 4–26	Range, 8–52	

*Of the RCTs, five of six crossover and two of the parallel design studies used isocaloric diets. The Samaha et al. [1] study, which tested the Atkins diet, was classified as low CHO rather than very low CHO, as the CHO-restricted (Atkins diet) arm reported 37% of calories from CHO when dietary intake was first assessed at 26 weeks.
†The studies used a single group and the effects were based on pre-intervention and post-intervention comparisons. There was no other diet (higher in carbohydrate or usual diet) that could serve as the control group.
CHO—carbohydrate; HbA_{1c}—hemoglobin A_{1c}; RCT—randomized controlled trial.

protein and carbohydrate food options, which have a low glycemic impact and contain fats that are primarily monounsaturated and rich in omega-3 fatty acids. Conversely, the diet is low in fatty meats, other sources of saturated fat such as butter, most vegetable oils (except for olive oil and similar oils), grains, added sugars, starchy vegetables, and egg yolks. There is a lot of structure. The diet consists of five meals and two snacks per day, each with a "good" carbohydrate, protein, and fat selection. Dieters are instructed to choose from food group lists and to eat within an hour of getting up, do not go too long without eating, and do not eat more than 500 calories at a time. The goal is to tailor the diet based on protein requirement, with the goal of 40% carbohydrate, 30% protein, and 30% fat of daily energy intake. A variety of Zone products are sold that conform to the recommended dietary composition, which are often offered as modular menus.

Studies of Carbohydrate Restriction in Diabetes Management

Most studies to assess the effects of low carbohydrate in diabetes management are of short duration with a relative sample size. A 2008 meta-analysis of low-carbohydrate diet in diabetes management by Kirk et al. [2•] included 13 papers published between 1980 and 2006. The literature search for this meta-analysis yielded only three studies that were longer than 3 months and no studies that were longer than 6 months in duration. Table 1 provides an overview of analysis findings. Carbohydrate comprised 30% and 55% of the daily energy intake for the low- and high-carbohydrate diets, respectively. However, there was a slight overlap between the low- and high-carbohydrate diet; the percent of energy from carbohydrate for the low-carbohydrate diets ranged from 4% to 45% of daily energy intake, whereas the high-carbohydrate diets ranged from 40% to 70% of daily energy intake.

Two more recent clinical trials by Westman et al. [22•] and Davis et al. [23•] expanded the evidence base for evaluating the role of low-carbohydrate diets in diabetes management. Tables 2 and 3 highlights the characteristics of the 2008 Westman et al. [22•] trial (n = 97, with a 24-week intervention) and the 2009 Davis et al. [23•] trial (n = 105, with a 1-year intervention). Participants in both trials were predominately women (~ 80%), obese (body mass index mean, 35–37 kg/m^2), and approximately half were black. The two studies based their low-carbohydrate diet on the Atkins diet, but the trials differed in the implementation approach. Davis et al. [23•] used isocaloric diets, which used a 500-calorie deficit for the low-carbohydrate and the low-fat comparison diet, with individual counseling; Westman et al. [22•] used lay books for the Atkins and low glycemic index diets [24,25], offered no specific calorie recommendation, and provided support in group counseling. Davis et al. [23•] reported results using an intention-to-treat analysis, which included dropouts based on worst-case scenario (participants who did not follow the diets were included in the analyses). Westman et al. [22•] reported results based on completers, with the dropouts excluded, which provides insights for the best-case scenario (Tables 2 and 3). Focusing on the active participants provides insights into what might happen in a practice setting among the patients remaining after attrition.

Table 2. Randomized clinical trials in 2008 to 2009 designed to assess the effects of very low CHO diet in diabetes management

Study	Davis et al. [23•]	Westman et al. [22•]
Low CHO arm	Very low CHO initial diet (20–22 g) with caloric deficit to achieve 1 lb of weight loss per wk, if at interim weight goal then 5 g of CHO added per wk	The low CHO (≤ 20 g) diet included allowed food in unlimited amounts (meat, chicken, fish) and limited amounts of allowed cheeses (4 oz of hard cheese, 2 oz of ricotta or cottage), salad vegetables (2 cups), and nonstarchy vegetables with no calorie restriction
Comparison diet	Low-fat diet (25% of calories) with caloric deficit to achieve 1-lb weight loss per wk	The low GI diet was designed with a 500-calorie deficit from estimated weight maintenance diet and 55% of calories from CHO with emphasis on low GI CHO sources
Physical activity recommendations (given at randomization)	30 min 5 times/wk	30 min 3 times/wk
Study sample	Randomized (*n* = 105); completed the study (*n* = 85)	Randomized (*n* = 97); completed the study (*n* = 50)
Educational method	Isocaloric menus provided to both treatment arms (varying in macronutrient composition). Both treatment arms received a 45-min initial individual RD consult and 6 additional 30-min RD consults over the 12 mo. Each treatment arm monitored intake	Lay press books, handouts, and RD consult were provided to both treatment arms. Group visits were weekly for 3 mo and then every other wk for the remaining 3 mo
Medication adjustments	Algorithm for medication reduction	Algorithm for medication reduction
Analysis	Intention-to-treat	Limited to completers
Duration	1 y	24 wk

CHO—carbohydrate; GI—glycemic index; RD—registered dietitian.

Table 3. Results of the randomized clinical trials from Table 2

Results	Davis et al. [23•]		Westman et al. [22•]	
	Low CHO	Low fat	Low CHO	Low GI
Weight (changes), *kg**	-3.1 (*P* = 0.005)	-3.1 (*P* = 0.005)	-11.1 (*P* = 0.05)	-6.9 (*P* = 0.05)
HbA_{1c} (changes), %	-0.02	0.24	-1.5 (*P* = 0.05)	-0.5
Blood pressure (changes)				
Systolic, *mm Hg*	2.0	-1.8	-16.6 (*P* = 0.05)	-10.7 (*P* = 0.05)
Diastolic, *mm Hg*	-2.9	-2.2	-8.1 (*P* = 0.05)	-5.6 (*P* = 0.05)
Triglycerides (changes), *mg/dL*	-13.4	-0.9	-67.5 (*P* = 0.05)	-19.3
Total cholesterol (changes), *mg/dL*	+3.9	-5.0	-4.4	-5.8
LDL cholesterol (changes), *mg/dL*	-1.5	-6.9	+1.3	-2.8
HDL cholesterol (changes), *mg/dL*	+6.9	+2.3	+5.6 (*P* = 0.05)	0
Dietary intake (end-of-study period)	(*n* = 68 total)		(*n* = 8)	(*n* = 7)
Kcal/d	1642 (600 SD)	1810 (590 SD)	1550 (440 SD)	1335 (372 SD)
CHO, %	33.4	50.1	13 (49 g)	44 (149 g)
Fat, %	43.9	30.8	59	36
Protein, %	22.7	18.9	28	20

**P* values represent within-group differences.
CHO—carbohydrate; GI—glycemic index; HbA_{1c}—hemoglobin A_{1c}; HDL—high-density lipoprotein; LDL—low-density lipoprotein.

Physiologic Effects of Low-Carbohydrate Diets in Diabetes Management

The effects of low-carbohydrate diets on weight, glycemia, blood pressure, and lipids are important considerations. However, the American Diabetes Association Standards of Medical Care suggests intensifying medical management, which is likely to greatly affect achieving the ABC goals of diabetes treatment (ie, A for hemoglobin A_{1c} [HbA_{1c}] with a goal of < 7%, B for blood pressure with a goal of < 130/80 mm Hg, and C for cholesterol with a low-density lipoprotein [LDL] cholesterol goal of < 100 mg/dL) [26]. This section focuses on studies conducted in individuals who have diabetes.

Weight

The Kirk et al. [2•] meta-analysis reported no difference between the lower and higher carbohydrate diets with respect to weight change. Other studies, which were not conducted in individuals who had diabetes, reported inconsistent weight-loss findings with better early (6-month) weight loss found with low-carbohydrate diet [27–32]. A 2006 meta-analysis by Nordmann et al. [33] of six clinical trials compared very low carbohydrate diets without energy restriction to low-fat diets; weight loss was greater at 6 months on the low-carbohydrate diet but not at 12 months. The Samaha et al. [1] study, which was the only study to be included in both the Kirk et al. [2•] and Nordmann et al. [33] meta-analyses, reported better weight loss with the low-carbohydrate diet at 6 months; however, the 12-month follow-up paper by Stern et al. [34] reported no significant difference in weight between the diet arms. The reported weight-loss analyses were not restricted to the subsample of patients with diabetes. The results in the more recent diabetes-specific trials also have shown a better weight loss with low-carbohydrate diets that appear to be sustainable up to 6 months. Westman et al. [22•] reported greater weight loss at 24 weeks on the low-carbohydrate diet than on the low glycemic index diet. Davis et al. [23•] reported a more rapid weight loss on the low-carbohydrate diet; however, the 12-month weight loss did not differ between the low-carbohydrate and the low-fat diets.

Glycemic control

The meta-analysis by Kirk et al. [2•] found that the lower carbohydrate diets resulted in better glycemic control than the higher carbohydrate diet based on HbA_{1c} and fasting glucose values. In contrast, a recent type 2 diabetes study found that carbohydrate counting did not achieve better glycemic control than using a simple insulin algorithm with more general medical nutrition therapy that focused on healthy eating without including carbohydrate counting, but the level of carbohydrate was not compared [35,36].

Gumbiner et al. [32] reported that a highly ketogenic, very low calorie diet controlled hepatic glucose output and hyperglycemia more effectively then a very low calorie diet that was less ketogenic in their intervention with obese subjects who had type 2 diabetes. Ironically, the premise of the Banting diet was to reduce the effects of the liver on diabetes. Westman et al. [22•] reported that after adjusting for baseline values neither the low-carbohydrate nor the low glycemic index diet significantly improved HbA_{1c}. However, both diets significantly improved fasting glucose levels with no significant differences between the arms. Davis et al. [23•] found significant improvement in HbA_{1c} levels during the first 3 months, which was not sustained over the duration of the trial.

Blood pressure

Relatively little research has been published with regard to the effects of low-carbohydrate diets on blood pressure in diabetes management. The Kirk et al. [2•] meta-analysis did not include any blood pressure evaluation. Westman et al. [22•] reported significant improvements in blood pressure as well as weight loss on the low-carbohydrate and glycemic index diets at 24 weeks. Davis et al. [23•] did not find significant improvement in blood pressure over the course of the 1-year intervention, but the weight loss was less than reported by Westman et al. [22•].

Cholesterol

The Kirk et al. [2•] meta-analysis reported no difference between the lower and higher carbohydrate diets with respect to total cholesterol or the LDL and high-density lipoprotein (HDL) cholesterol subfractions. The Nordmann et al. [33] meta-analysis found greater improvement in HDL cholesterol concentrations but significantly higher LDL cholesterol on the low-carbohydrate diets than the low-fat diets. Westman et al. [22•] found no significant changes in the total and LDL cholesterol levels on the low-carbohydrate or glycemic index diets, which did not include specific calorie instructions. With respect to HDL cholesterol, the low-carbohydrate diet resulted in a significant improvement, whereas no change was observed for the low glycemic index diet. Davis et al. [23•] also found a significant improvement in HDL cholesterol with the low-carbohydrate diet.

Triglycerides

The Kirk et al. [2•] and the Nordmann et al. [33] meta-analyses found greater improvement in triglyceride levels with the lower carbohydrate than with the higher carbohydrate diets. Westman et al. [22•] also reported a significant improvement in triglyceride levels with the low-carbohydrate but not the low glycemic index diet at 24 weeks. Davis et al. [23•] reported no significant changes in triglyceride levels with the low-carbohydrate or low-fat diets at 12 months.

Addressing Potential Adverse Effects

Concerns have been raised regarding potential adverse effects of a very low carbohydrate diet, which include constipation, a rise in LDL cholesterol secondary to an increase in saturated fatty acids, elevation of uric acid lev-

els associated with an increase in protein intake, risk of gallstone formation secondary to a rapid weight loss, and electrolyte imbalance. For patients with diabetes, hypoglycemia is also a potential adverse effect.

Achieving recommendations for fiber intake poses a challenge for the general population [37–39], which in general is no greater for patients with diabetes [35–39]. For patients who start very low carbohydrate diets, fiber supplementation should be recommended. However, fiber is being incorporated into a growing number of low-carbohydrate projects to achieve a low "net carbohydrate content": fiber is subtracted from the total carbohydrate listed on the nutrient label (grams of total carbohydrate minus grams of fiber = net carbohydrate) [39].

A case report of fatality associated with being on a restricted carbohydrate diet associated with potential electrolyte depletion has prompted examinations of electrolytes in ketogenic low-carbohydrate diet studies [40]. An examination of acid-base balance from two studies of ketogenic diets by Yancy et al. [41] found mild compensated metabolic acidosis but no cases of significant metabolic derangement. Davis et al. [42] reported that serum potassium decreased within 3 days of initiating a low-carbohydrate ketogenic diet with a similar fall within 1 week on a low-fat isocaloric comparison diet in a randomized controlled clinical trial. The proportion needing potassium supplementation did not differ between the low-carbohydrate and low-fat treatment arms.

One of the primary concerns with initiating low-carbohydrate diets in patients with type 2 diabetes is the risk of hypoglycemia [43,44]. This risk is enhanced in patients using insulin or an insulin secretagogue. A medication adjustment algorithm can minimize the potential risk [25]. Patients may require significant dose reduction of insulin and/or insulin secretagogues, accompanied by more frequent glucose monitoring during the initiation phases.

Conclusions

The American Diabetes Association in its 2008 nutrition recommendation stated that "optimal macronutrient distribution of weight-loss diets has not been established" [38]. The recommendations emphasize that further research is needed to determine the long-term efficacy and safety of low-carbohydrate diets. Although no recommendation is made for the amount of carbohydrate related to diabetes management, the recommended dietary allowance (RDA) for digestible carbohydrate is 130 g/d [45]. The RDA is based on providing adequate glucose as the required fuel for the central nervous system without reliance on glucose production from ingested protein or fat. Although brain fuel needs can be met on lower-carbohydrate diets, more research is needed to determine long-term metabolic effects of very low carbohydrate diets. The American Diabetes Association recommends a dietary pattern that incorporates carbohydrates from fruits, vegetables, whole grains, legumes, and low-fat milk. Questions about the glycemic index and glycemic load emerge with respect to glycemic control and body weight [46].

The glycemic index of a food is determined by comparative feeding tests; study subjects are typically given a test food that provides 50 g of carbohydrate and a control food (white bread or pure glucose) that provides the same amount of carbohydrate on different days. The glycemic index for a food item is calculated by dividing the area under the blood glucose response curve for the food by the area under the response curve for reference carbohydrate (glucose or white bread). The reference food is given a value of 100%. Foods with a glycemic index of less than 55 are usually considered low glycemic index foods; medium glycemic index foods are usually 55 to 70; and foods with a glycemic index of greater than 70 are considered high glycemic index foods. The glycemic load of a food is calculated by multiplying the glycemic index by the amount of carbohydrate in grams provided by a food and dividing the total by 100. Dietary glycemic load is the sum of the glycemic loads for all foods consumed in the diet.

A 2008 Cochrane meta-analysis of 11 studies that were 4 weeks or longer concluded that choosing low glycemic food could help improve glycemic control, but it made no conclusions with regard to the effects of a low glycemic diet on weight [47].

Depending on patient preference, a low-carbohydrate diet may be an important alternative to low-fat diets in diabetes management. Patients with diabetes are exposed to many carbohydrate-reducing diets in the lay press that vary widely in the carbohydrate amount. The amount of carbohydrate often varies considerably across the phases of a diet, and personal interpretation or choices for implementation also can vary. Therefore, dietary assessment is critical to make needed adjustments in medications that raise circulating insulin levels to prevent hypoglycemia. Although science continues to advance in this field, current research suggests that low-carbohydrate diets can be a viable option for achieving weight loss and may have beneficial effects on glycemic control, triglyceride levels, and HDL cholesterol levels in some patients.

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References and Recommended Reading

Papers of particular interest, published recently, have been highlighted as:

- • Of importance
- •• Of major importance

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