Review

Carbohydrate and Fiber Recommendations for Individuals with Diabetes: A Quantitative Assessment and Meta-Analysis of the Evidence

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To review international nutrition recommendations with a special emphasis on carbohydrate and fiber, analyze clinical trial information, and provide an evidence-based recommendation for medical nutrition therapy for individuals with diabetes. Relevant articles were identified by a thorough review of the literature and the data tabulated. Fixed-effects meta-analyses techniques were used to obtain mean estimates of changes in outcome measures in response to diet interventions. Most international organizations recommend that diabetic individuals achieve and maintain a desirable body weight with a body mass index of $\leq$25 kg/m^2. For diabetic subjects moderate carbohydrate, high fiber diets compared to moderate carbohydrate, low fiber diets are associated with significantly lower values for: postprandial plasma glucose, total and low-density lipoprotein cholesterol, high-density lipoprotein cholesterol, and triglycerides. High carbohydrate, high fiber diets compared to moderate carbohydrate, low fiber diets are associated with lower values for: fasting, postprandial and average plasma glucose; hemoglobin A_{1c}; total, LDL-cholesterol, HDL-cholesterol and triglycerides. Low glycemic index diets compared to high glycemic index diets are associated with lower fasting plasma glucose values and lower glycated protein values. Based on these analyses we recommend that the diabetic individual should be encouraged to achieve and maintain a desirable body weight and that the diet should provide these percentages of nutrients: carbohydrate, $\geq$55%; protein, 12–16%; fat, $<$30%; and monounsaturated fat, 12–15%. The diet should provide 25–50 g/day of dietary fiber (15–25 g/1000 kcal). Glycemic index information should be incorporated into exchanges and teaching material.

Key teaching points:

- Medical nutrition therapy is the cornerstone to diabetes management.
- For obese type 2 diabetic persons, weight management is the most important task with a goal of achieving a body mass index of $\leq$25 kg/m2.
- The most effective diabetes diet, based on a detailed review and meta-analysis of the literature, is a higher carbohydrate, higher fiber diet.

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- Because of the high risk for atherosclerotic disease, optimal management of lipoproteins, blood pressure and oxidative stress is important.
- Health-promoting diabetes diets emphasize whole grains, vegetables, fruits, and low glycemic index foods, and soy protein.

Introduction

Diabetes is emerging in epidemic proportion throughout the world [1,2]. Nutritional recommendations for individuals with diabetes mellitus need revision as new information about effects of nutrients on insulin sensitivity, glycemic excursion, serum lipoproteins, and pathophysiology of diabetes mellitus emerge. The medical literature was reviewed and research data were assembled in order to reexamine and prioritize the goals of medical nutrition therapy of diabetes mellitus. We also reviewed recommendations from international diabetes associations and cardiovascular nutrition expert panels. We assessed randomized-clinical trials using quantitative (meta-analysis) techniques to apply this evidence-based knowledge to recommendations about intake of macronutrients and dietary fiber for persons with diabetes. These recommendations also have implications for persons at high risk for developing diabetes. In this review we will focus on these areas: nutrition recommendations from various national diabetes associations and cardiovascular nutrition expert panels, percentage of energy recommended from carbohydrate considering its impact on glycemic control and serum lipoproteins, reevaluation of amount of dietary fiber to be recommended and updated assessment of the glycemic index and its potential role in nutrition management.

International Nutrition Recommendations for Persons with Diabetes

Nutrition recommendations for persons with diabetes are available from the American Diabetes Association [3], British Diabetes Association [4], Canadian Diabetes Association [5], European Association for the Study of Diabetes [6], as well as from India [7], Japan [8] and South Africa [9]. Because of the concern about CHD for persons with diabetes the recent recommendations of the American Heart Association [10] and the National Cholesterol Education Panel (Adult Treatment Panel 3) [11] were also considered. All of these recommendations are summarized in Table 1.

Recommendations from the international community are similar except for those regarding overweight and obesity. Six of the nine groups recommend weight loss to a desirable weight with recommendations to achieve and maintain a body mass index (BMI) of $\leq$25 kg/m^2. Most diabetes authorities recommend a carbohydrate intake of 50–60% of energy. They emphasize whole grains, vegetables, fruits, and dry beans. While most diabetes associations have specific restrictions on sugar intake, the American Diabetes Association does not emphasize restriction of sugars [3]. Most authorities recommend an increase in dietary fiber intake while there is not a consensus on use of the glycemic index. The British and Canadian Associations recommend moderation in protein intake while others have recommended ranges that are similar to those for the general population. Total fat intake is usually limited to $<$30% of energy with an emphasis on restriction of saturated and trans-fatty acids. Moderation in polyunsaturated fat intake is recommended and monounsaturates are the fatty acids of choice. These considerations provide the foundation for this evidence-based review and recommendations.

Macronutrient Considerations

To assess the effects of carbohydrate and fiber intake on glycemic control and serum lipids we have reviewed clinical studies performed over the last 25 years. Studies were identified by a search of MEDLINE and by review of references in relevant research reports and reviews. After tabulating data we calculated effect size expressed as percentage change for each variable and then, using the fixed-effects model for meta-analysis, we calculated variance-adjusted percentage changes as previously described [12,13].

We evaluated all clinical trials that provided glycemic outcome data. Study designs were classified as observational, controlled, randomized, or randomized and controlled trials (RCT). Observational studies presented data before and after dietary intervention. Controlled studies compared the intervention with a control diet. Randomized studies used some form of randomization. RCTs used randomization and control-diet observations. Data from all trials were tabulated and assessed. Where adequate data from RCTs were available, these data were analyzed using variance-weighted (meta-analysis) methods as previously described [12–14]. In some instances, variance-weighted values are presented for all studies. We will use the term "variance-weighted" values to represent mean estimates obtained by the fixed-effects meta-analysis model.

The levels of carbohydrate intake were classified as follows: high carbohydrate, $\geq$60% of energy; moderate carbohydrate, 30% to 59.9% of energy; low carbohydrate, $<$30% of energy. The levels of fiber were classified as follows: high fiber, $\geq$20g/1000 kcal; moderate fiber, 10 to 19.9 g/1000 kcal; and low fiber, $<$10 g/1000 kcal.

To estimate recommended ranges for nutrients we averaged lower and higher values recommended for each nutrient. When a specific recommendation (e.g., 60% of energy from carbohydrate) was given and a range was not provided we calculated the mean range from available data and added and subtracted half the range for the recommended value. For example, the mean range for carbohydrate from lowest to highest recommended values from seven associations was 9.3%. Half the range was 4.65%, which was rounded to 5%. Thus, we added

Table 1. International Recommendations for Medical Nutrition Therapy for Persons with Diabetes

Parameter	ADA [3]	BDA [4]	CDA [5]	EASD [6]	Japan [8]	S Africa [9]	India [7]	AHA [10]	NCEP [11]
Weight Reduction	Modest weight loss (5–7%)	BMI to approach desirable weight	Maintain healthy weight (7–10%)	BMI 18.5–25 desirable weight	Attain & maintain desirable weight	Achieve & maintain reasonable weight	19–23 BMI desirable weight	Achieve & maintain desirable weight	Maintain desirable weight
Carbohydrate	50–60%	50–55%	50–60%	45–60% (55–60% with low GI foods)	60%	55–60%	>65%	45–55%	50–60%
Polysaccharides	Whole grains, fruits, vegetables	Most of CHO, rich in fiber or resistant starch	Whole grain cereals & legumes	Low GI foods	Vegetables-300 g	Whole grain cereals & legumes	Vegetables, fruits, legumes—40 g/d; cereal—40 g		Grains, whole grains, fruits, vegetables
Mono- & Disaccharides	No restriction	<25 g/d	≤10% added	<10% calories	1 serving fruit	<10% added sugar	From foods	No comment	No comment
Glycemic index	Does not recommend for general use	Discusses	Includes low GI foods	With meals, low GI foods recommended	Recommended	Quotes supportive references			No comment
Fiber, total	As for general population	>30 g/d	25–35 g/d	Increase with low GI foods	1 fruit, 400 g vegetables	40 g/d	From fruits, vegetables, legumes	≥25 g/d	20–30 g/d
Protein	15–20%	10–15%	11%, 0.86 g/kg/d	10–20%	15–20%	12–20%		~15%	~15%
Total fat	25–35%	30–35%	≤30%	≤35%	20–25%	<30%	<21%	<30%	25–35%
Saturated/Trans Fatty Acids	<10%	<10%	<10%	<10%		<10%	<7%	<10%	<7%
Monounsaturated Fatty Acids	10–20%	10–15%	10–15% favored	10–20% favored		<13%	<7%	<11%	up to 20%
Polyunsaturated Fatty Acids	~10%	<10%	≤10%	≤10%		6–8%	<7%	<10%	up to 10%
Cholesterol	<300 mg/d	<300 mg/d		≤300 mg				<200 mg	<200 mg

and subtracted 5% to the specific recommendation to obtain values for range. When a specific recommendation of 60% of energy from carbohydrate was recommended, we expanded this to a range of 55–65%.

Carbohydrate and Dietary Fiber

Twenty-four studies met the inclusion criteria and summary characteristics are presented in Table 2. Eleven studies compared moderate carbohydrate, high fiber (MCHF) to moderate carbohydrate, low fiber diets [15–25]. These studies examined the independent effects of dietary fiber on glucose and lipid metabolism; they included an average of 16 subjects and were an average duration of 43 days. Nine of the 11 MCHF studies were RCTs.

Thirteen studies (Table 2) examined high carbohydrate, high fiber diets (HCHF) with lower carbohydrate, lower fiber diets [26–38]. These studies examined the effects of increasing both carbohydrate and fiber in the diet; they enrolled an average of 13 subjects for an average of 29 days. Four of the 13 HCHF studies were RCTs.

Because body weight change has an important impact on serum glucose and lipoprotein values [39], we assessed weight change for these studies. Investigators provided weight change information for 18 of the 24 studies; the average subject lost a variance-adjusted 0.58% of initial body weight (95% confidence intervals, −3.7 to +1.6%). Variance-adjusted weight losses were not statistically significant for MCHF diets or HCHF diets and there was not a significant correlation between weight change and fasting plasma glucose changes.

In Table 3, the variance-weighted (meta-analysis) MCHF diet effects on serum glucose and lipid values are presented. Only RCTs are included in this table. A meta-analysis using all available studies yielded results consistent with those presented in this table. Compared to control diets, MCHF diets decreased fasting plasma glucose values in 5 of 5 studies reporting this variable but these changes were not statistically significant.

Table 2. Descriptive Characteristics of Moderate Carbohydrate, High Fiber and High Carbohydrate, High Fiber Studies

Study	Number of Subjects	Study Design	Type of Diet	Treatment Period (d)
Rivellese [15]	4 IDDM/4 NIDDM	randomized, controlled	MCHF	10
Rivellese [16]	6 IDDM/8 NIDDM	randomized, controlled	MCHF	10
Dodson [17]	50 NIDDM	randomized, controlled	MCHF	90
Karlstrom [18]	14 NIDDM	randomized, controlled	MCHF	21
Riccardi [19]	6 IDDM/8 NIDDM	randomized, controlled	MCHF	10
Pacy [20]	3 IDDM/14 NIDDM	observational	MCHF	90
Pacy [21]	11 NIDDM	observational	MCHF	90
Hagander [22]	14 NIDDM	randomized, controlled	MCHF	56
Venhaus [23]	10 IDDM	observational	MCHF	42
Lafrance [24]	9 IDDM	randomized, controlled	MCHF	12
Chandalia [25]	13 NIDDM	randomized, controlled	MCHF	42
Anderson [26]	7 IDDM/3 NIDDM	controlled	HCHF	18
Anderson [27]	20 IDDM	controlled	HCHF	16
Anderson [30]	10 IDDM/4 NIDDM	controlled	HCHF	14–35
Simpson [28]	9 IDDM	randomized, controlled	HCHF	42
Simpson [29]	18 NIDDM	randomized, controlled	HCHF	42
Hoffman [31]	7 NIDDM	controlled	HCHF	7
Ward [32]	7 NIDDM	randomized, controlled	HCHF	42
Taskinen [33]	10 IDDM	controlled	HCHF	14
Pacy [34]	5 IDDM/20 NIDDM	controlled	HCHF	90
Story [35]	14 IDDM	controlled	HCHF	14–28
Simpson [36]	13 NIDDM	observational	HCHF	18
O'Dea [37]	10 NIDDM	randomized	HCHF	14
Anderson [38]	10 IDDM	randomized, controlled	HCHF	28

Table 3. Results of a Meta-Analysis on Moderate Carbohydrate, High Fiber versus Moderate Carbohydrate, Low Fiber Diets-Analysis of Randomized Controlled Trials

Parameter	Number of Studies	Number of Subjects	Weighted Average Percent Change	LCI	UCI
Fasting Plasma Glucose	5	59	−6.0	−13.8	1.8
Postprandial Plasma Glucose	4	45	−20.9	−32.6	−9.2
Average Daily Plasma Glucose	5	59	−5.0	−11.3	1.2
HbA1c	4	62	2.5	−3.2	8.1
Total Cholesterol	8	112	−6.5	−9.4	−3.7
LDL Cholesterol	6	77	−7.9	−12.0	−3.9
HDL Cholesterol	8	112	−3.9	−9.0	1.3
Triglycerides	7	98	−8.3	−14.1	−2.4

Similarly, MCHF diets were associated with lower average daily plasma glucose values in 4 of 5 studies but these changes were not significant. However, MCHF diets were accompanied by lower postprandial plasma glucose values in 5 of 5 studies reporting this variable and these reductions averaging 21% were statistically significant.

MCHF diets also significantly decreased total and LDL cholesterol (7% and 8% respectively). These diet insignificantly decreased HDL-cholesterol values by ~4%. Values for LDL:HDL-cholesterol ratios were not provided for some studies but the changes can be estimated for the changes in LDL- and HDL-cholesterol values and indicate that values decreased ~4.5%. MCHF diets significantly decreased fasting serum triglyceride values an average of 8%. In Table 4, a meta-analysis of HCHF diet effects on glucose and lipid values are presented. Because of the limited number of randomized, controlled trials in this area, all applicable studies were included in this analysis. The analysis of average, unweighted changes for all studies and a meta-analysis using only randomized, controlled trials yielded data that were consistent with those data presented in this table. Compared to baseline measurements, HCHF diets decreased fasting plasma glucose values in all 12 studies and HbA_{1c} in all 6 studies reporting these variables. Thus, HCHF diets were shown to significantly decrease all indicators of glycemia, particularly fasting plasma glucose (14%), postprandial plasma glucose (14%), and average daily plasma glucose (13%). The decrease in HbA_{1c} was also significant.

HCHF diets decreased serum cholesterol values in all 12 studies with 10 of the studies reporting significant reductions. HCHF diets reduced all serum lipid measures. Total cholesterol

Table 4. Results of a Meta-Analysis on High Carbohydrate, High Fiber versus Moderate Carbohydrate, Low Fiber Diets—All Studies

Parameter	Number of Studies	Number of Subjects	Weighted Average Percent Change	LCI	UCI
Fasting Plasma Glucose	12	141	−14.3	−19.2	−9.4
Postprandial Plasma Glucose	3	47	−13.6	−24.6	−2.6
Average Daily Plasma Glucose	3	37	−12.5	−22.0	−3.0
HbA1c	6	79	−6.0	−11.6	−0.3
Total Cholesterol	11	146	−19.3	−22.6	−15.9
LDL Cholesterol	5	71	−16.4	−25.2	−7.7
HDL Cholesterol	7	91	−6.3	−10.9	−1.7
Triglycerides	9	119	−12.8	−21.2	−4.3

decreased significantly by 19% and LDL-cholesterol decreased significantly by 16%. HDL-cholesterol decreased nonsignificantly by 6%. Importantly, decreases in LDL:HDL-cholesterol values were ~10.9%. HCHF diets significantly decreased fasting serum triglyceride levels by 13%.

Comments

These clinical trials indicate that high-fiber, moderate-carbohydrate (MCHF) diets significantly improve glycemic control of diabetic subjects compared to moderate carbohydrate, low-fiber diets. These analyses provide the best estimate of the effects of increasing dietary fiber independent of carbohydrate in the diet of persons with diabetes. Increasing the dietary fiber has the greatest impact on postprandial serum glucose values. The MCHF diets also significantly decrease fasting serum cholesterol, LDL-cholesterol, and triglyceride values. The MCHF diets were accompanied by insignificant decreases of HDL-cholesterol values of ~4%. It seems likely that favorable changes in the LDL:HDL cholesterol values and decreases in serum triglycerides would outweigh the unfavorable changes in serum HDL-cholesterol values. Based on previous estimates [39], the reduced serum cholesterol values would decrease CHD risk by ~16.4% while the decreased HDL-cholesterol values would increase risk by ~11.9%. Of course, the decreased fasting serum triglycerides would further reduce risk for CHD. These low-fiber vs. high-fiber diet comparisons indicate that increasing dietary fiber in the diet of diabetic individuals is likely to improve glycemic control and lower risk for CHD. The high-fiber diets in these studies provided ≥20 grams of dietary fiber/1000 kcal.

High-carbohydrate, high-fiber (HCHF) diets provide even greater benefits on glucose and lipid values for diabetic individuals when compared to low or moderate carbohydrate, low or moderate fiber diets. HCHF diets are accompanied by significant decreases in all aspects of glycemic control including HbA_{1c}. Of course, these benefits result from increases in both carbohydrate and fiber intakes. Earlier studies have documented the glycemic and lipidemic benefits of increases in carbohydrate and decreases in fat intake [38,40,41]. HCHF diets produce even greater reductions in all lipid parameters including HDL-cholesterol values. However, these diets were lower in saturated fat and cholesterol content than the control diets; decreased saturated fat intake would be expected to lower serum HDL-cholesterol values [42]. Again, the reductions in cholesterol and triglycerides appear to outweigh the decreases in HDL-cholesterol values since the cholesterol reduction would reduce risk by an estimated 48.1% while the HDL-reduction would increase risk by 20.1% [39]. Also, the LDL:HDL-cholesterol values were ~10.9% lower on the HCHF than control diets. These studies support the argument that increasing carbohydrate content of the diet to ≥60% of energy and including ≥20 grams of dietary fiber/1000 kcal. provide distinct benefits on glycemic control and serum lipoprotein values for diabetic individuals.

Dietary fiber has many health benefits and addresses the specific health problems of diabetic individuals. In addition to non-specific CHD protective effects [14,43–45], dietary fiber has favorable effects on serum LDL-cholesterol [45–47], triglycerides [48], blood pressure [43], weight management [49] and postprandial glycemia (both first and second meal effects) [50]. Thus, there appear to be many reasons to recommend that diabetic individuals consume more fiber than recommended for the general population.

Based on the available data, we recommend that diabetic patients consume a high-carbohydrate, high-fiber, low-fat diet. Overweight individuals, of course, should reduce energy intake and increase physical activity to achieve and maintain a desirable body weight. The available data, as summarized above, suggest that the greatest benefits on glycemic control and serum lipoproteins are achieved with a carbohydrate intake of ≥60% of energy. The longest studies were 90 days in duration and, therefore, long-term clinical research data on HCHF diets are not available. However, since clinical evidence suggest that long-term benefits can be achieved for diabetic individuals with 55% of energy from carbohydrate [51], we recommend that carbohydrate goals should be ≥55% with a desirable range of 55–65% of energy to increase the practical application of this dietary change. The potential advantages and disadvantages of substituting monounsaturated fats for carbohydrates is discussed elsewhere [3].

The available data indicate that high intakes of dietary fiber (≥20 grams/1000 kcal) in the setting of moderate or of high-carbohydrate intakes clearly have benefits for glycemic control and serum lipoproteins. In a one-year RCT for dyslipidemic non-diabetic subjects we demonstrated the serum lipid benefits of a diet providing 55% of energy as carbohydrate and 25 grams/day of dietary fiber (~13 grams/1000 kcal) [26]. The US National Academy of Sciences Institute of Medicine recently recommended that adult men 50 years and younger consume 38 grams of total dietary fiber daily and women 50 years and younger consume 25 grams of fiber daily. For persons over 50 years the recommendation is for 30 and 21 grams daily for men and women, respectively [52]. Based on the evidence and recommendations from the international diabetes community (Table 1) we recommend a dietary fiber intake of 25–50 grams/day or 15–25 grams/1000 kcal. for diabetic individuals. The carbohydrate and fiber guidelines can readily by achieved by following consensus nutrition guidelines. A healthy diet including, for example, 1500 kcal/day from these choices: three servings of whole grains; five other servings of bread, cereal, rice and pasta; one or more serving of beans; four servings of vegetables; three servings of fruit; two servings of low-fat dairy products, two servings of protein; and three servings of fat. With inclusion of other foods not rich in fiber to reach an energy intake of 2000 kcal/day, this intake would provide approximately these amounts of nutrients: carbohydrate, 285 grams (57% of energy), 70 grams of protein (14% of energy), 65 grams of fat (29% of energy) and 42 grams of fiber (21 grams/1000 kcal). Care should be taken not to increase fiber intake predominantly from insoluble sources such as wheat bran since the evidence is not strong that the non-viscous fiber sources benefit glycemic control [53,54]

Because of the potential HDL-cholesterol-lowering effect of these diets, these levels should be monitored regularly and diabetic individuals should be encouraged to increase physical activity and, of course, avoid cigarette smoking [10,11]. Choosing lower glycemic index foods may also favorably affect serum HDL-cholesterol values [55,56]. For some individuals, substituting monounsaturated fat for carbohydrate may increase serum HDL-cholesterol values [57]. Foods including nuts, avocado, and olive oil with green vegetables may be particularly useful for inclusion [58].

Glycemic Index

The glycemic index of a food is defined as the ratio of the glycemic response to that food and the glycemic response to a standard food, typically white bread. Consumption of low glycemic index foods results in lower postprandial plasma glucose and a lower insulin response as compared to consumption of high GI foods. The preferential response to low GI foods is seen in both diabetics and nondiabetic individuals. The potential benefits of low GI foods are summarized elsewhere [59,60].

We compiled the results of ten studies comparing the effects of low GI diets and high GI diets in diabetic patients [61–70]. The characteristics of these studies are presented in Table 5. Nine of the 10 studies were RCTs. These studies included an average of 14 subjects for a mean duration of 33 days. Recently Brand-Miller has completed a meta-analysis of 14 clinical studies comparing low vs. high glycemic index diets in diabetic individuals [71]. Inclusion criteria for our current analysis and that of Brand-Miller differed so the included studies differed. Her analyses also included data from these studies [24,72–76].

We completed a meta-analysis on the data from the nine randomized controlled trials, the results of which are presented in Table 6. Fasting plasma glucose values were significantly lower on low GI diets than high GI diets. Fructosamine and HbA_{1c} were lower with the low GI than the higher GI diets but the differences were not statistically significant. When Brand-Miller aggregated the glycated proteins (HbA_{1c} and fructosamine) she noted a significant 7.4% reduction in glycated proteins (95% CI, −8.8 to −6.0) [71]. In our analysis, total cholesterol and LDL-cholesterol values were lower with lower GI than higher GI diets but these changes were not significant. HDL-cholesterol was increased slightly by an average of 3%. The decrease in the LDL:HDL-cholesterol ratio was ~8.5%. Our analysis indicates that low GI diets compared to high GI diets are associated with a decrease in serum triglycerides of

Table 5. Descriptive Characteristics of Low GI Diet Versus High GI Diet Studies

Study	Number of Subjects	Study Design	Treatment Period (d)
Jenkins [61]	8 NIDDM	randomized, controlled	14
Calle-Pascual [69]	12 IDDM/12 NIDDM	nonrandomized, controlled	28
Collier [62]	7 IDDM children	randomized, controlled	42
Fontvieille [70]	8 IDDM	randomized, controlled	21
Brand [68]	16 NIDDM	randomized, controlled	84
Wolever [65]	6 NIDDM	randomized, controlled	42
Fontvieille [67]	12 IDDM/6 NIDDM	randomized, controlled	35
Wolever [66]	15 NIDDM	randomized, controlled	14
Jarvi [64]	20 NIDDM	randomized, controlled	24
Luscombe [63]	21 NIDDM	randomized, controlled	28

Table 6. Meta-Analysis of Responses to Low GI Diets Versus High GI Diets

Parameter	Number of Studies	Number of Subjects	Weighted Average Percent Change	LCI	UCI
Fasting Plasma Glucose	8	104	−7.5	−14.5	−0.5
Fructosamine	7	81	−2.5	−6.4	1.5
HbA1c	4	62	−3.3	−8.5	1.8
Total Cholesterol	7	97	−1.4	−5.2	2.3
LDL Cholesterol	5	71	−5.4	−12.6	1.8
HDL Cholesterol	8	104	3.4	−2.1	9.0
Triglycerides	8	104	−6.3	−17.4	4.9

~6%. Brand-Miller, in an analysis of 8 studies, reported an average triglyceride reduction of 12% [71]. The non-significance of the decreases in the levels of glycosylated proteins that we observed could have been due to the fact that all but one of the studies involved treatment periods of less than two months.

Comments

Low glycemic index foods represent healthy choices for persons with diabetes or dyslipidemia. Lower GI foods, compared to higher GI foods, decrease fasting and postprandial blood glucose values [60]. These foods decrease serum LDL-cholesterol and triglyceride values. Lower GI foods are associated with significantly higher HDL-cholesterol values than higher GI foods [55,56,77]. The health implications of the GI were recently critically reviewed. [78,79]. Liu and colleagues have examined the relationship between high glycemic load and fasting serum HDL-cholesterol, serum triglycerides, risk for CHD, and risk for diabetes [80]. The glycemic load, representing the grams of carbohydrate multiplied by the glycemic index ratio (a food with a GI of 100 has a ratio of 1.0 while a food with a GI of 60 has a ratio of 0.6), is proportional to the GI. Thus, with the same carbohydrate intake, persons with a low glycemic load have a lower GI diet [80]. Persons with a low glycemic load compared to persons with a high glycemic load have significantly higher HDL-cholesterol and significantly lower fasting serum triglyceride values [56]. Persons with the low glycemic load have lower risk for developing diabetes [81,82], but not all studies support this conclusion [83]. A lower glycemic load appears to reduce risk for CHD [84] and lower non-lipid risk factors for CHD [80].

A number of diabetes associations endorse the use of GI information and recommend that low GI foods be incorporated into the diet. For example, Diabetes Australia defines the GI and recommends that the diet include three low GI foods throughout the day, ideally one at each meal; low GI foods are listed in bold in food exchange lists [85]. Other diabetes associations are developing easy-to-use strategies for encouraging use of low GI foods. Brand-Miller lists the following organizations that endorse the use of the GI: FAO/WHO [86], European Association for the Study of Diabetes [87], Diabetes Australia [88], Canadian Diabetes Association [5], German Dietetic Association, South African Diabetes Association and New Zealand Dietetic Association [71]. Gilbertson and colleagues document that low GI diets are "easy to teach, easy to learn" for Australian children with type 1 diabetes [75,90].

The many clinical studies we have reviewed and the observational studies almost invariably suggest that lower GI diets provide health benefits, improve glycemic control and favorably alter CHD risk factors. These studies do not suggest harmful or detrimental effects. While we agree that more research is required [89], we conclude that the benefits outweigh the disadvantages for use of low GI food information in counseling. We endorse the recommendations emanating from many national and international diabetes and nutrition organizations and advocate that diabetic individuals be encouraged to show preference to low GI foods and include three low GI foods into their diet daily.

Whole Grains, Vegetables and Fruits

Whole grains, vegetables and fruits are an integral part of the recommended high carbohydrate, high fiber diet. Most whole grain foods are rich sources of insoluble fiber, minerals, antioxidants and other bioactive compounds [91]. Higher intakes of whole grains are associated with protection from CHD [14,92], diabetes [83] and, perhaps, obesity [93]. Diabetes associations and national advisory bodies recommend intake of three servings of whole grain foods per day [94]. The importance of whole grains with its many facets, including the germ and the potential low glycemic index value, may have to be stressed since wheat bran alone may have little effect on blood lipids or glycemic control [54]. Many vegetables and fruits are rich sources of soluble and insoluble fiber, vitamins and minerals. Soluble fiber-rich foods, such as dry beans and whole grain oat and barley products, have important hypocholesterolemic effects [47]. Diabetes associations and national advisory boards recommend intake of a minimum of three servings of vegetables and two servings of fruit per day.

Recommendations

Recommended Ranges from International Organizations. International and US recommendations are tabulated in Table 7 (middle column). These weighted values were determined as described in the Methods section. The international

Table 7. Evidence-Based Nutrition Recommendations for Persons with Diabetes.

	Weighted Values from International Bodies	Evidence-Based Recommendations
Weight Reduction	Attain & maintain desirable weight (BMI≤25)	Attain & maintain desirable weight (BMI≤25)
Carbohydrate	50–60%	55–65%
Polysaccharides	Whole grains, legumes, vegetables	Whole grains, legumes, vegetables
Mono- & Disaccharides	<40 g/d, fruits and vegetables	Moderation
Glycemic Index	Low GI foods favored	Incorporate GI into exchanges and teaching material
Fiber, Total	25–35 g/d	25–50 g/d (15–25 g/1000 kcal)
Protein	11–18%	12–16%
Total fat	25–30%	<30%
SFA/Trans	<10%	<10%
MUS	9–14%	12–15%
PUFA	<9%	<10%
Cholesterol	<200 mg	<200 mg/d
Glycemic Index	Low GI foods favored	Incorporate GI into exchanges and teaching material

diabetes community, the AHA and NCEP recommendations are fairly concordant except for weight recommendations. Six of the nine recommendations indicate that achieving and maintaining a desirable weight (BMI < 25 kg/m^2) is a strong health recommendation. Mann and Lewis-Barned [95], summarizing recommendations for Europe and North America recommend a BMI goal of <25 kg/m^2. Because 58% of newly diagnosed Chinese persons with type 2 diabetes are overweight, Pan [96] recommends reducing weight to desirable (BMI <25 kg/m^2). The importance of weight management for obese diabetic individuals is reviewed in detail elsewhere [97].

The recommended mean range for total carbohydrate intake is 50–60% of energy with an emphasis on whole grains, dry beans and lentils, vegetables and fruits. The general diabetes community recommends that monosaccharides and disaccharides intake be in the moderate range. Three diabetes associations and Diabetes Australia [85] recommend use of the glycemic index and only the American Diabetes Association does not recommend the glycemic index for general use. The recommended mean fiber intake of 25–35 grams per day is higher than most populations consume and, thus, represent a recommended increase in fiber intake for persons with diabetes. The US National Academy of Sciences Institute of Medicine [52] recently recommended that men under 50 years of age consume 38 grams of dietary fiber/day and that women under 50 consume 25 grams/day.

The recommended mean protein intake represents 11–18% of energy. The recommended mean intakes for fats are as follows: total fat, 25–30% of energy; saturated plus trans fatty acids, <10%; monounsaturated fatty acids, 9–14%; and polyunsaturated fatty acids, <9%. The recommended intake for dietary cholesterol is <200 mg/day for diabetic individuals [10,11]. These recommended mean intakes are recommendations from these groups but may not represent values developed from an evidence-based analytical review of the literature. Nevertheless, there is a fairly remarkable similarity across these recommendations.

Evidence-Based Recommendations. In this review we have carefully assessed the clinical studies examining issues regarding macronutrient and fiber intake and applied quantitative analysis using meta-analysis techniques to assess the strength of the evidence for various recommendations. Our recommendations (Table 7, right hand column), where data are available, are based on this process. The major areas of disagreement relate to recommendations regarding weight loss and maintenance, dietary fiber intake, use of the glycemic index, and protein recommendations.

Weight gain and obesity are the major contributing factors to development of diabetes [98–100]. Weight gain and obesity are major risk factors for development of CHD [39]. Diabetic individuals have a three- to five-fold higher risk for CHD [101] and ~80% of diabetic individuals die from atherosclerotic cardiovascular disease [102]. Excessive energy intake and obesity are major contributors to insulin resistance and poor glycemic control [97]. Based on these considerations we recommend that a major nutrition goal is attaining and maintaining a desirable body weight (BMI ≤ 25 kg/m^2) [97].

Our evidence-based analysis supports recommendations that the total carbohydrate intake be ≥55% or in the range of 55–65% of energy intake. The high-carbohydrate, high-fiber diet extensively and effectively used by Viswanathan and colleagues [103] in Madras, India, for diabetes management has included 67% carbohydrate, 19% protein (predominantly from vegetable sources), and 14% fat with >25 g/1000 kcal of dietary fiber for >40 years. Our clinical impression and long-term clinical observations suggest that the glycemic benefits of higher carbohydrate intakes can be achieved with intakes of ~55% of energy [35]. The health benefits of whole grain foods are emerging strongly [14], and the US FDA recently approved a health claim indicating that "intake of whole grains as part of a diet lower in saturated fat and cholesterol may reduce risk for CHD" [104]. Vegetables are universally endorsed as promoting health and four servings per day are recommended [105]. Only one diabetes association recommends a limitation of fruit intake; we concur with most diabetes associations that fruit intake should not be restricted. We concur with the broad recommendations that added monosaccharides and disaccharides, not from fruit or vegetables, should be used in moderation.

The extensive data regarding the glycemic and lipidemic benefits of high fiber intakes (as summarized in tables 3 and 4) lead to the conclusion that higher fiber intakes should be recommended for persons with diabetes. Higher fiber intakes improve glycemic control, lower serum cholesterol and LDL-cholesterol levels and slightly reduce serum triglyceride values. Fiber intake also reduces risk for CHD [14] and assists in weight management [106]. Based on these observations, we recommend a fiber intake of 25–50 grams/day or 15–25 grams/1000 kcal. These levels can be readily achieved by following general nutrition guidelines for intake of these foods: whole grains, especially oats and barley; whole grain breads, cereals, and pastas; brown rice, dry beans, peas and lentils; nuts; fruits; and vegetables.

The glycemic index has been controversial since first introduced [107]. Extensive research indicates that the glycemic index of a meal is a major determinant of postprandial hyperglycemia in nondiabetic and diabetic individuals [59]. The glycemic indices of many foods have been measured and tabulated [108]. Many diabetes associations recommend that the glycemic index be incorporated into nutrition counseling for diabetic individuals (Table 1). The evidence indicates that short-term increases in the intake of low glycemic foods significantly lowers fasting plasma glucose values and produces favorable trends in other glycemic and lipidemic parameters. Long-term intake of larger amounts of low glycemic index foods is related to higher HDL-cholesterol values [109] and a lower risk for developing CHD [84]. Based on these observations we recommend that the glycemic index be incorporated into diabetes exchange lists and nutrition teaching material to be an integral part of medical nutrition therapy.

The recommended means for protein intake are fairly consistent across the international community. Our recommendations that protein provide 12–16% of energy relate to the likelihood that excessive animal protein intake acts to sustain abnormal renal hyperfiltration that may contribute to development of diabetic nephropathy. Our clinical research indicates that substituting soy protein for animal protein significantly reduces hyperfiltration in type 1 diabetes [110]. Teixiera and colleagues [111] document that soy protein intake decreases albuminuria in type 2 diabetes. We suggest that reducing animal protein and increasing soy protein may have renoprotective effects at all stages of renal function. This hypothesis is still under examination. Soy protein intake has other health benefits, especially for diabetic individuals. Soy food intake improves serum lipid values [12,112], lowers CHD risk factors such as homocysteine and oxidation of LDL [113] and decreases risk for CHD in a variety of other ways [114].

There is not strong clinical evidence to make definitive recommendations about dietary fat. Intake of saturated and trans-fatty acids and cholesterol has adverse effects on serum lipoproteins and should be restricted [10]. To de-emphasize animal protein intake in favor of vegetable proteins such as soy we recommend that dietary cholesterol be restricted to <200 mg/day.

Conclusions

Medical nutrition therapy is the foundation upon which other diabetes management approaches are built. Fundamental nutrition goals are: blood glucose management, achieving and maintaining a desirable body weight, managing serum lipoproteins, reducing other risks for atherosclerotic cardiovascular disease and reducing risks for microvascular disease. Focusing on weight management is a very important nutrition task for obese diabetic individuals. A strong majority of the international diabetes community but not a consensus has these nutrition recommendations for diabetic individuals: attain and maintain a desirable body weight (BMI $\leq$ 25 kg/m^2), have carbohydrate intakes of 50–60% of energy, limit monosaccharide and disaccharide intake from sources other than fruits and vegetables, use low glycemic index foods, have total dietary fiber intakes of 25–35 g/day, have protein intakes of 11–18% of energy, limit total dietary fat to 25–30% of energy, have saturated plus trans fatty acid intakes of $<10\%$ of energy, polyunsaturated fat intakes of $<9\%$ of energy, and monounsaturated fat intakes of 9–14% of energy and have cholesterol intakes of <200 mg/d. These recommendations encourage use of whole grains, legumes, vegetables and fruits.

Our evidence-based review using meta-analyses techniques largely support the strong majority recommendations of the international diabetes community. Strong RCTs support these recommendations: intake of carbohydrate of $\geq 55\%$ or 55–65% of energy, dietary fiber intakes of 25–50 g/d (15–25 g/1000 kcal), total fat intakes of $<30\%$ of energy and incorporation of the glycemic index into diabetes counseling. There is very strong support for the recommendation that diabetic individuals achieve and maintain a desirable body weight with a BMI ≤ 25 kg/m^2.

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