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Effects of Dietary Fiber and Carbohydrate on Glucose and Lipoprotein Metabolism in Diabetic Patients

Dietary recommendations for the treatment of diabetic patients issued by national and international diabetes associations consistently emphasize the need to increase carbohydrate consumption. However, these recommendations have been questioned on the basis of growing evidence that, in both insulin-dependent and non-insulin-dependent diabetic patients, a high-carbohydrate diet does not offer any advantage in terms of blood glucose and plasma lipid concentrations compared with a high-fat (mainly unsaturated) diet. It has been shown repeatedly that a high-carbohydrate diet increases plasma insulin and triglyceride levels and can deteriorate blood glucose control in the postprandial period. However, much of the controversy between advocates and detractors of dietary carbohydrate can be settled by taking into account dietary fiber. Several studies have shown that the adverse metabolic effects of high-carbohydrate diets are neutralized when fiber and carbohydrate are increased simultaneously in the diet for diabetic patients. In particular, these studies demonstrated that a high-carbohydrate/high-fiber diet significantly improves blood glucose control and reduces plasma cholesterol levels in diabetic patients compared with a low-carbohydrate/low-fiber diet. In addition, a high-carbohydrate/high-fiber diet does not increase plasma insulin and triglyceride concentrations, despite the higher consumption of carbohydrates. Unfortunately, dietary fiber represents a heterogenous category, and there is still much to understand as to which foods should be preferred to maximize the metabolic effects of fiber. There are indications that only water-soluble fiber is active on plasma glucose and lipoprotein metabolism in humans. Therefore, in practice, the consumption of legumes, vegetables, and fruits—rich in water-soluble fiber—should be particularly encouraged. The mechanisms by which dietary fiber exerts its hypoglycemic and hypolipidemic activities are unknown. However, the ability of dietary fiber to retard food digestion and nutrient absorption certainly has an important influence on lipid and carbohydrate metabolism. The beneficial effects of high-fiber foods are also exerted by some foods not particularly rich in fiber. The fiber content and physical form of the food can influence the accessibility of nutrients by digestive enzymes, thus delaying digestion and absorption. The identification of these foods with a low-glycemic response would help enlarge the list of foods particularly suitable for diabetic patients. In conclusion, a diet low in cholesterol and saturated fat should be recommended to all diabetic patients to prevent cardiovascular disease. A balanced increase in consumption of fiber-rich foods and unsaturated fat is the most rational way to replace foods rich in saturated fat and cholesterol in the diabetic diet.
***Diabetes Care* 14:1115–25, 1991**

The approach to the dietary treatment of patients with diabetes mellitus has drastically changed in the last decade. Diabetologists are becoming increasingly more aware that the diabetic diet should not only help improve blood glucose control but also help prevent cardiovascular disease. There is much evidence that diabetic patients are at high risk of cardiovascular disease and that this risk

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increases in the presence of one or more of the other risk factors (1–3). In particular, there are data supporting a direct linear relationship between plasma cholesterol concentrations and cardiovascular mortality in diabetic and nondiabetic individuals (4). This indicates that there is no clear threshold separating individuals with high or normal plasma cholesterol values; thus, the lower the plasma cholesterol levels, the better the prognosis for the patient.

The most effective dietary measure to decrease plasma cholesterol levels in humans is to reduce the intake of saturated fat and cholesterol (5). Therefore, a diet low in cholesterol and saturated fat is recommended to all diabetic patients (regardless of their plasma cholesterol levels) to prevent or delay the occurrence of cardiovascular disease (6–7).

TOWARD A DIETARY STRATEGY FOR TREATMENT OF DIABETIC PATIENTS

Many diabetic patients, particularly those with non-insulin-dependent diabetes (NIDDM), are overweight and would benefit from a reduction in caloric intake due to a lower consumption of foods rich in saturated fat or cholesterol. However, in patients of normal weight, foods rich in saturated fat and cholesterol should be partially replaced by alternative sources of calories. Because it does not seem prudent to increase protein intake, which is already high in western diets, there are two possible alternatives to replace saturated fat in the diabetic diet: *1*) carbohydrates and *2*) unsaturated fats. The first approach is usually referred to as the "low-fat/high-carbohydrate diet" (total and saturated fats are reduced and replaced by carbohydrate), whereas the alternative represents the so-called "fat-modified diet" (total fat is not reduced because saturated fat is replaced by unsaturated fat) (Fig. 1). Both approaches include a reduction of dietary cholesterol. All current dietary recommendations for diabetic patients are based on the low-fat/high-carbohydrate diet (Table 1). However, the statement of the American Diabetes Association is more stringent because it limits in every case the intake of total fat to <30% of total energy intake (6). Conversely, the European document, although advising a similar amount of total fat, allows a higher intake of total fat, provided that monounsaturated and not saturated fatty acids are increased (7).

The various documents do not state clearly the reasons for preferring the low-fat/high-carbohydrate diet for the treatment of diabetic patients. However, this choice has been strongly influenced by the adoption of similar policies by other scientific societies aiming at cardiovascular disease prevention in the general public (8,9). The underlying reason is probably the assumption that, not only does the intake of saturated fat and cholesterol but the intake of total fat also needs to be reduced to lower plasma cholesterol concentrations.

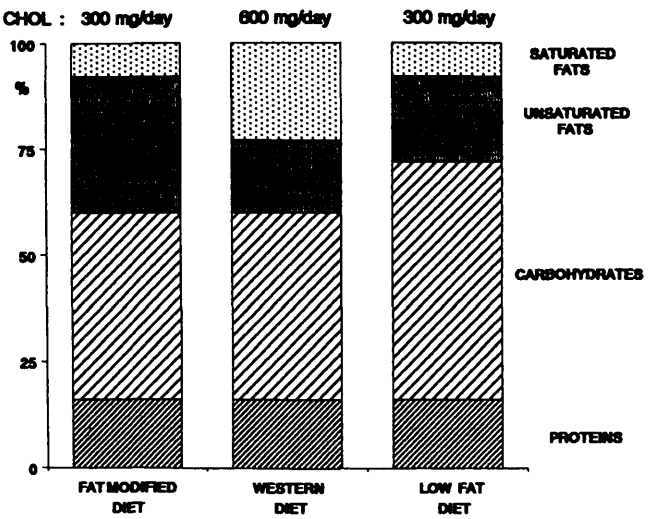

FIG. 1. Schematic representation of nutrient distribution in diet habitually consumed in western countries and 2 alternative dietary approaches that can be used to reduce plasma cholesterol (chol) levels in diabetic and nondiabetic individuals.

This is not necessarily true because epidemiological intercultural comparisons and dietary experiments have clearly shown that among the various types of dietary fat, only saturated fat can increase plasma cholesterol levels (10–12). Conversely, the intake of unsaturated fat (monounsaturated and polyunsaturated) has no significant hypercholesterolemic effect in humans (13).

Therefore, there is a rationale for proposing the fat-modified diet as a suitable alternative to the low-fat diet to achieve a substantial reduction of plasma and low-density lipoprotein cholesterol (LDL-chol) concen-

TABLE 1
Recommended composition of weight-maintaining diet for diabetic patients

	American Diabetes Association (1986)	European Association for the Study of Diabetes (1988)
Protein	10–15%	Decreased
Fat		
Total	<30%	<30%*
Saturated	<10%	<10%
Monounsaturated	<13%	<10%
Polyunsaturated	<7%	<10%
Cholesterol	<300 mg/day	<300 mg/day
Carbohydrate	55–60%	50–60%
Sucrose (added)	modest	<30 g/day
Fiber	40 g/day	40 g/day
Alcohol	<10 g/day	<25–30 g/day†
Sodium	<3 g/day	<6 g/day

*Intake of total fat may be higher, provided that only monounsaturated fat is increased.
†Same intake recommended to general population (ref. 8)

trations in diabetic and in nondiabetic individuals. Furthermore, this alternative approach is justified because the treatment of diabetic patients with low-fat/high-carbohydrate diets has been questioned because of possible adverse metabolic effects (14). In particular, it has been claimed that low-fat/high-carbohydrate diets would deteriorate blood glucose control, adversely affect plasma lipoproteins (increasing triglycerides and decreasing high-density lipoproteins [HDL]), and elevate the concentration of plasma insulin (considered as a possible cardiovascular risk factor) (15–17). Based on these considerations, an official document of the National Institutes of Health (Bethesda, MD) suggested that low-fat/high-carbohydrate diets may be suitable for some but not all NIDDM patients, and, therefore, in some cases a fat-modified diet would be more appropriate (18).

The comparison between high-carbohydrate/low-fat diets and fat-modified diets in diabetic patients has been attempted in many studies that gave conflicting results. However, to interpret correctly the existing evidence, attention should be paid to the exact composition of the two diets being compared.

High-carbohydrate/low-fat diets may contain different proportions of monodisaccarides, starch, or fiber, whereas in fat-modified diets, the proportion of monounsaturated/C20:5ω3 polyunsaturated/C20:5ω6 polyunsaturated fatty acids may vary. Each of these dietary constituents has different effects on glucose and lipid metabolism, therefore, the comparison between high-carbohydrate/low-fat and fat-modified diets may favor one or the other dietary approach according to the types of carbohydrates and fats used.

This might explain many of the discrepancies between the results of different studies. In most trials showing a superiority of the low-fat/high-carbohydrate diet, the diet also had lower saturated fat and a higher fiber content (19,20). Conversely, when the results were not in favor of the low-fat/high-carbohydrate diet, a substantial proportion of the carbohydrate quota in this diet was monodisaccarides (21). Furthermore, some of these dietary experiments were not relevant to the clinical experience because the diets used were not physiological in terms of both the use of unnatural foods (liquid-formula diets) and in the choice of a very unbalanced diet composition (>70% carbohydrate with little or no fat) (22,23).

Therefore, despite many published studies comparing fat-modified with high-carbohydrate/low-fat diets, only a few are clinically relevant and also give an unequivocal answer as to which of these two dietary approaches yields a more pronounced cholesterol-lowering activity, induces a greater improvement of blood glucose control, and has a more beneficial influence on the overall cardiovascular risk-factor profile in diabetic patients.

For a clinically relevant comparison, the diets to be tested should have some specific prerequisites. The major fat component in the fat-modified diet has necessarily to be monounsaturated fat because consumption of polyunsaturated fat >10% of the daily energy intake is not recommended (8,9,24). This is motivated by the lack of available evidence on the long-term safety of very-high-polyunsaturated-fat diets. On the other hand, diets rich in monounsaturated fat are certainly safe because they have been consumed for centuries in Mediterranean countries where cardiovascular and total mortalities are particularly low (25). In addition, in contrast with previous beliefs, experimental data in hyperlipidemic individuals have shown that diets rich in either mono-unsaturated or polyunsaturated fat exert similar effects on plasma lipoproteins (5,26,27).

In relation to the low-fat/high-carbohydrate diet, there are only two possible alternatives that are clinically relevant: *1*) a diet in which starchy foods represent the major source of dietary carbohydrate; *2*) a low-fat/high-carbohydrate diet in which the carbohydrate quota derives mostly from unprocessed vegetables rich in fiber. These two possibilities should be considered separately because there is much evidence that dietary fiber influences blood glucose and lipid metabolism in both diabetic and nondiabetic individuals (28,30). It can be anticipated that much of the controversy about low-fat/high-carbohydrate diets could be settled if the metabolic effects of dietary fiber in diabetic patients were taken into account. Also, the range of variations in the proportion of carbohydrate to fat in the diets tested has to be necessarily limited. From a practical point of view, it is irrelevant to compare an almost fat-free diet with a diet with >50% fat. The really meaningful question in terms of clinical implementation is whether carbohydrate and fat should represent 60 and 20 or 40 and 40%, respectively, of total energy intake (14).

HIGH STARCH OR HIGH MONOUNSATURATED FAT?

The comparison between a high-starch and a high–monounsaturated fat diet has been attempted by our group, in both insulin-dependent diabetic (IDDM; 31) and NIDDM patients (16). In one diet, the contribution of carbohydrate and fat to the daily calorie intake was 60 and 20%, respectively (low-fat/high-carbohydrate diet), whereas in the other diet, carbohydrate was reduced to 40%, and fat was increased to 40% (fat-modified diet). This dietary variation was obtained by substituting olive oil (rich in monounsaturated fat) with an isoenergetic amount of starchy foods (bread, potatoes, rice). Both diets were low in saturated fat (~10% calories) and cholesterol (~350 mg/day) and had similar contents of calories, monodisaccarides, fiber, and protein. The only difference between the diets was in the amounts of monounsaturated fat and complex digestible carbohydrate, respectively. Both diets consisted only of natural foods distributed in various daily

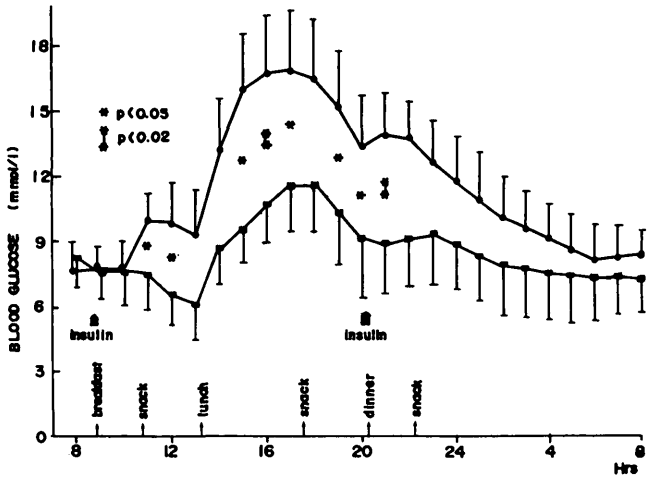

FIG. 2. Mean ± SE daily blood glucose profiles recorded 15 days after either a high-starch (●) or high–monounsaturated fat (■) diet in insulin-dependent diabetic patients (*n* = 8) (ref. 31).

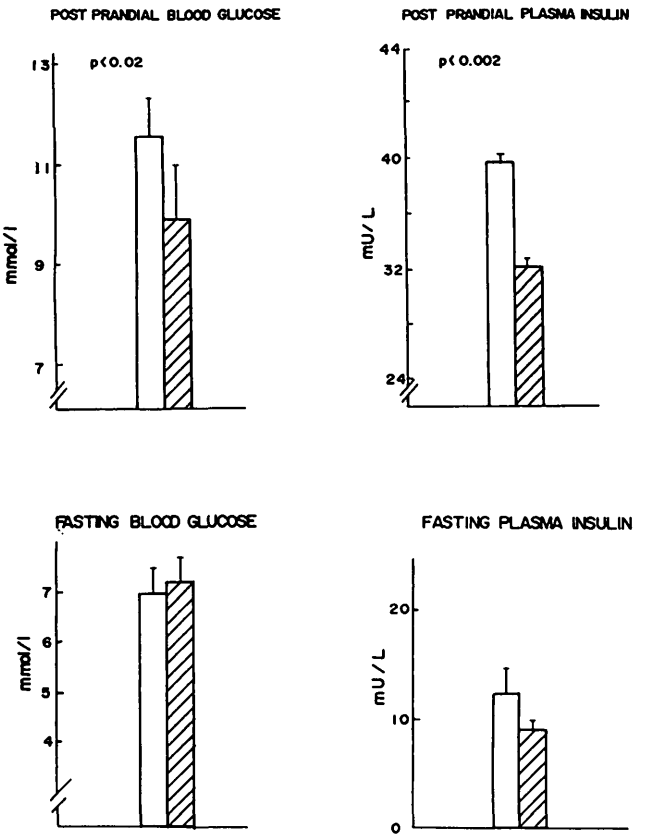

FIG. 3. Mean ± SE fasting and postprandial blood glucose and plasma insulin concentrations measured after 15 days on either a high-starch (*open bars*) or high–monounsaturated fat (*hatched bars*) diet in non-insulin-dependent diabetic patients (*n* = 18).

menus. Patients were randomly assigned to one of the diets, which was followed for 15 days, then crossed over to the other diet, which was also followed for 15 days.

In IDDM patients, the insulin dosage was not modified throughout the study and at the end of each dietary period, blood glucose was continuously monitored for 24 h. Moreover, a fasting blood sample was taken for lipoprotein analysis. Blood glucose concentrations throughout the 24 h were consistently higher after the high-starch diet; however, the greatest difference was reached after meals, particularly after lunch (the main meal in Italy); at this time, blood glucose concentration was on average ~5.6 mM higher than after the monounsaturated fat–rich diet. In addition, plasma glucose excursions during the day were much higher after the starch-rich diet (Fig. 2). In contrast, plasma lipoproteins were not significantly modified by diet; however, patients had reasonably good blood glucose control and were normolipidemic.

The same diets were also evaluated in NIDDM patients treated with diet alone or diet plus hypoglycemic drugs, with a similar experimental design. In this case, at the end of the two dietary periods, the glycemic control was evaluated by measuring blood glucose concentrations in the fasting state and 2 h after lunch. At both times, plasma insulin was also measured, whereas plasma lipoproteins were analyzed in a fasting patient.

Even in these patients, blood glucose control was worse after the high-starch diet; in particular, postprandial blood glucose concentrations were significantly higher after the high-starch diet, whereas, fasting blood glucose levels did not vary with the two diets (Fig. 3). In addition, the starch-rich diet compared with the diet rich in monounsaturated fat induced significantly higher plasma insulin levels—particularly in the postprandial phase (Fig. 3)—and significantly higher plasma triglyceride levels (Fig. 4). Conversely, total and HDL-chol concentrations were similar at the end of the two dietary periods (Fig. 4).

Similar experiments by other groups have yielded substantially similar results (15). Moreover, it has been clearly demonstrated in IDDM patients that the amount of carbohydrate in the meal influences postprandial blood glucose concentrations, even if the amount of insulin injected is modified according to the carbohydrate content of the meal (32,33).

The results we obtained in NIDDM patients treated with diet and/or hypoglycemic drugs are in close agreement with those of Garg et al. (15), who evaluated the metabolic effects of partial substitution of monounsaturated fat for starch in the diet of NIDDM patients treated with insulin. This dietary maneuver resulted in better blood glucose control, reduced insulin requirements, lower concentrations of plasma triglycerides, lower levels of very-low-density lipoprotein (VLDL), and higher levels of HDL. Conversely, plasma levels of total and LDL-chol did not vary. These results agree also with those of Coulston et al. (34).

There are some indications in NIDDM patients with

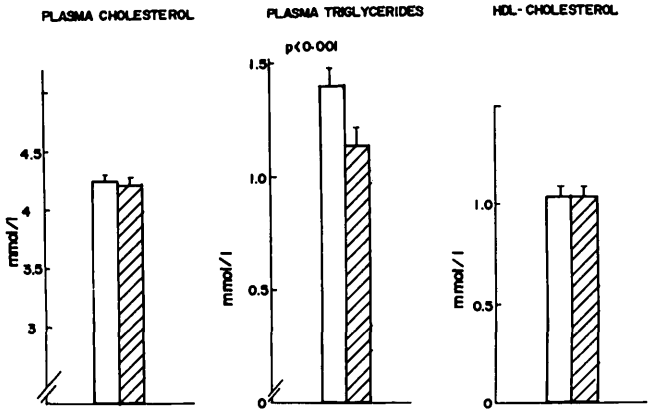

FIG. 4. Mean ± SE fasting plasma lipid levels measured after 15 days on either high-starch (*open bars*) or high–mononsaturated fat (*hatched bars*) diet in non-insulin-dependent diabetic patients (n = 18). HDL, high-density lipoprotein.

a mild form of the disease that the effects of a high-carbohydrate diet on blood glucose control will not be as deleterious as in the more severe cases (35). However, this hypothesis still deserves adequate testing.

Another important parameter that needs to be evaluated in NIDDM patients treated with a low-fat/high-carbohydrate diet or a fat-modified diet is insulin sensitivity. It has been claimed that a higher carbohydrate consumption leads to a general increase in the ability of insulin to stimulate glucose disposal. Impaired insulin sensitivity represents a key metabolic derangement in diabetes and seems to also be involved in the etiology of its cardiovascular complications (36,37). Therefore, the possibility of improving insulin sensitivity by means of a low-fat/high-carbohydrate diet has always been a strong argument in favor of the adoption of this type of diet by NIDDM patients. However, evidence supporting this concept suffers from major flaws due to poor diet comparability (differences in the polyunsaturated-saturated fat ratio, fiber content), extreme dietary variations (>75% carbohydrate), use of liquid-formula diets, and inadequate methods to assess insulin sensitivity (oral glucose tolerance tests, insulin infusion test) (19–23,38,39).

In our dietary experiment on the metabolic effects of a high-starch diet compared with a high–monounsaturated fat diet, we evaluated insulin sensitivity by the euglycemic-hyperinsulinemic clamp technique in a subgroup of nine NIDDM patients. Contrary to our expectations, insulin sensitivity did not improve after the high-starch diet; the opposite was true because insulin-stimulated glucose disposal (M value) was significantly increased after the high–monounsaturated fat diet compared with the high-carbohydrate diet (mean ± SE 6.2 ± 0.6 vs. 4.8 ± 0.6 mg · kg^{-1} · min^{-1}, $P < 0.05$; 40). This finding is consistent with all other metabolic effects of the high–monounsaturated fat diet (lower plasma glucose, insulin, and triglyceride levels) that might have contributed to the improvement of insulin sensitivity.

Available evidence clearly indicates that an increase in the intake of complex digestible carbohydrate is not always the best way to replace saturated fat and cholesterol in the diabetic diet. In IDDM patients, high consumption of starchy foods significantly deteriorates blood glucose control and increases the glycemic excursions throughout the day. This can only be partially prevented by increasing the dosage of insulin.

In NIDDM patients, a high-starch diet deteriorates blood glucose control (although to a lesser extent and only in the postprandial phase) but increases plasma insulin concentrations, elevates plasma triglycerides, lowers plasma levels of HDL (in some patients), and worsens peripheral insulin sensitivity. Such untoward effects of the high-starch diet can be more pronounced in particular groups of patients (i.e., hypertriglyceridemic, severely hyperglycemic).

ROLE OF DIETARY FIBER IN TREATMENT OF DIABETIC PATIENTS

Results of studies comparing a fat-modified diet with a low-fat/high-carbohydrate diet have been clearly in favor of the former. However, this does not imply that the outcome has to be the same if the fat-modified diet is compared with a low-fat/high-carbohydrate diet in which unprocessed vegetable foods (fiber rich), instead of starch, represent the major carbohydrate source. Studies show that dietary fiber has important beneficial effects on blood glucose and lipoprotein metabolism (30).

There are many definitions of dietary fiber; however, the one that seems more appropriate from a physiological and clinical point of view was proposed in the 1970s by Trowell (41), who first suggested that dietary fiber may play a role in diabetes. According to this definition, dietary fiber is represented by plant polysaccharides that are resistant to hydrolysis by the digestive enzymes of humans.

The important role of dietary fiber in the treatment of diabetic patients was indicated by the pioneer studies of Kiehm et al. (42), who showed a drastic reduction of the insulin dosage and a dramatic improvement of blood glucose control in insulin-treated diabetic patients by prescribing a high-carbohydrate/high-fiber diet. However, from that study, it was not clear to what extent the effects of the high-carbohydrate/high-fiber diet should be ascribed to the high-fiber content or to other dietary modifications, including changes in the type and amount of carbohydrate and fat. Therefore, we decided to undertake a dietary experiment to evaluate the separate influence of dietary fiber and carbohydrate on blood glucose and lipoprotein metabolism (28,43). In six IDDM and eight NIDDM patients, we compared a fat-modified diet in which olive oil

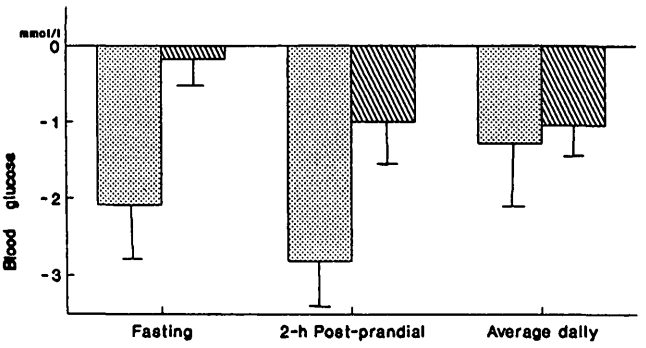

FIG. 5. Mean ± SE variations in blood glucose levels obtained by changing from low-carbohydrate/low-fiber to high-carbohydrate/high-fiber diet in insulin-dependent (*stippled bars*) and non-insulin-dependent (*hatched bars*) diabetic patients. This dietary maneuver had a significant effect on 2-h postprandial ($P < 0.01$) and daily average ($P < 0.005$) blood glucose concentrations but not on fasting glucose levels (NS); the effect was not significantly different for insulin-dependent non-insulin-dependent diabetic patients (ref. 43).

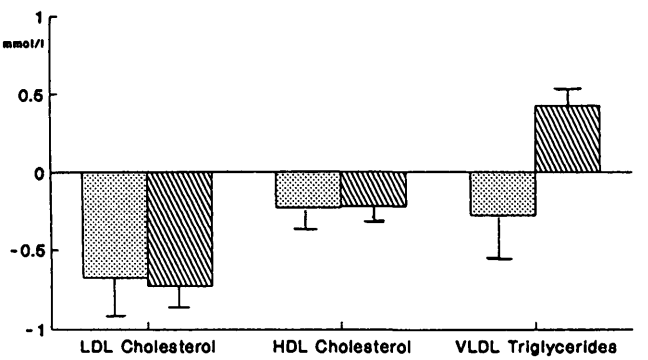

FIG. 6. Mean ± SE variations in serum lipoprotein composition obtained by changing from low-carbohydrate/low-fiber to high-carbohydrate/high-fiber diet in insulin-dependent (*stippled bars*) and non-insulin-dependent (*hatched bars*) diabetic patients. This dietary maneuver had a significant effect on low-density lipoprotein (LDL) ($P < 0.001$) and high-density lipoprotein (HDL) ($P < 0.001$) cholesterol concentrations but not on very-low-density lipoprotein (VLDL) triglyceride levels (NS); the effect was not significantly different for insulin-dependent non-insulin-dependent diabetic patients (ref. 43).

was the major source of fat, with a low-fat/high-carbohydrate diet in which the high-carbohydrate quota was obtained by increasing the consumption of fiber-rich foods (legumes, fruit, vegetables). In the first diet, carbohydrate and fat represented 42 and 37% of the total energy intake, whereas the other diet had proportions of these dietary constituents equal to 53 and 30%, respectively. Both diets were low in saturated fat and cholesterol and had a similar content of calories, monodisaccarides, and protein. To evaluate separately the effects of dietary fiber and carbohydrate on glucose and lipoprotein metabolism, a third diet was included in the experiment. This was also a low-fat/high-carbohydrate diet (53% carbohydrate, 30% fat), but in this case, the carbohydrate quota was mainly fiber-depleted starchy foods (bread, potatoes). Thus, fiber content was 20 g/day in the fat-modified diet, 54 g/day in the fiber-enriched low-fat/high-carbohydrate diet, and 16 g/day in the fiber-depleted low-fat/high-carbohydrate diet. The three diets, which consisted exclusively of natural foods, were consumed in random order for consecutive periods of 10 days while the patients were hospitalized in a metabolic ward.

The comparison between the fat-modified diet and the fiber-rich low-fat/high-carbohydrate diet was clearly in favor of the latter. In both IDDM and NIDDM patients, the fiber-rich low-fat/high-carbohydrate diet produced a significant decrease in postprandial and daily average blood glucose concentrations; fasting glucose levels were also reduced but the difference did not reach statistical significance (Fig. 5). Also LDL-chol concentrations were significantly reduced after the fiber-rich low-fat/high-carbohydrate diet compared with the fat-modified diet in both types of diabetic patients; conversely, VLDL triglyceride levels were not significantly modified. There was a significant reduction in HDL-chol concentrations in both IDDM and NIDDM patients with the fiber-rich high-carbohydrate diet (Fig. 6).

The beneficial effects of fiber-rich low-fat/high-carbohydrate diets have been often ascribed to their high-carbohydrate content rather than to fiber. Therefore, this experiment evaluated the effects of fiber, per se, on glucose and lipoprotein metabolism. This was done by comparing the results of the two diets with an identical carbohydrate quota (53% of calories in both diets) and differing only for the amount of fiber (16 vs. 54 g/day). This comparison clearly shows that an increased amount of dietary fiber in the diet is able, per se, and independent of any change in the other dietary components, to reduce significantly postprandial and daily average blood glucose concentrations by 25 and 15%, respectively, and to reduce LDL-chol and VLDL triglyceride levels by 25 and 10%, respectively, in both IDDM and NIDDM patients. Conversely, there is no significant effect of dietary fiber, per se, on fasting blood glucose and HDL-chol concentrations.

The results of this study have been confirmed by other groups. In particular, in a randomized crossover study performed in IDDM and NIDDM outpatients, Simpson et al. (20) demonstrated that a high-carbohydrate/high-fiber diet can be followed by diabetic patients in their usual home setting without major feasibility problems and with the same beneficial metabolic effects that we observed in hospitalized patients. Other concordant results have been obtained in diabetic children, pregnant diabetic women, patients with secondary failure to oral hypoglycemic drugs, and diabetic patients with chronic renal failure (44–47).

TABLE 2
Metabolic effects (increase, decrease, no effect) of low-fat high-carbohydrate diet in which either starch or fiber-rich foods are mainly represented

	Blood glucose	Plasma insulin	Insulin sensitivity	Plasma lipoproteins		
				VLDL	LDL	HDL
High starch	Increased	Increased	Decreased	Increased	No effect	No effect/decreased
High fiber	Decreased	No effect	Increased	No effect	Decreased	No effect/decreased

VLDL, very-low-density lipoprotein; LDL, low-density lipoprotein; HDL, high-density lipoprotein.

However, there have been other studies in which the improvement of blood glucose control in diabetic patients by means of a high-carbohydrate/high-fiber diet could not be reproduced (48,49). This apparent discrepancy can be explained by examining the list of the foods used for the high-fiber diets in the various experiments. In our study and most other studies with results concordant with ours, the high dietary fiber intake was mainly obtained by increasing the consumption of legumes, fruits, and vegetables. Conversely, no significant effects of the high-fiber diet were recorded in studies in which whole-meal cereals represented the major source of dietary fiber (48). This difference can be at least partly explained by the different properties of fiber present in cereals, on the one hand, and legumes, fruits, and some vegetables on the other. The latter foods contain mostly water-soluble, gel-forming fiber able to retard the mixing of food with the intestinal juice, thus delaying the digestion and absorption of nutrients; conversely, cereal fiber is largely non–water-soluble and unable to significantly influence the rate of food digestion in the small intestine (30,50). In addition, in some studies claiming that dietary fiber has no effect on blood glucose control, the measurements of blood glucose concentrations were only performed in the fasting state, whereas, the most pronounced influence of dietary fiber on blood glucose metabolism is exerted in the postprandial period (49).

In the evaluation of the metabolic properties of the high-carbohydrate/high-fiber diet, another aspect that deserves attention is the effect of this diet on insulin sensitivity. This has been attempted only in nondiabetic individuals, and the results seem to indicate that high-carbohydrate/high-fiber diets can induce improvement of insulin sensitivity (51).

The results of the comparison between a fat-modified diet and a low-fat/high-carbohydrate diet go in opposite directions according to whether fiber-depleted starchy foods or unprocessed vegetable foods (fiber rich) are present in the high-carbohydrate diet (Table 2). In the latter case (contrary to what has been shown in the previous section for the starch-rich diet), the low-fat/high-carbohydrate diet has clear metabolic advantages over the fat-modified diet in both IDDM and NIDDM patients. It improves blood glucose control (mainly in the postprandial period), decreases plasma and LDL-chol concentrations, and prevents the elevation of the plasma triglyceride levels, usually observed when dietary carbohydrates are increased. Also, it may improve peripheral insulin sensitivity.

In relation to the effects of fiber-rich foods on plasma lipoprotein metabolism, note that their ability to reduce plasma cholesterol and LDL concentrations is independent of other dietary modifications. In particular, reduction in dietary cholesterol and saturated fat and increased consumption of fiber-rich foods have an additive effect in lowering plasma cholesterol and LDL levels. The overall effect of this combined dietary maneuver is a reduction of plasma cholesterol by as much as 30% in NIDDM patients (28,29,43).

GLYCEMIC RESPONSE TO CARBOHYDRATE-RICH FOODS

The beneficial effects of low-fat/high-carbohydrate diets with high contents of unprocessed vegetable foods on blood glucose and lipoprotein metabolism are usually interpreted as a consequence of the high-fiber content of these diets. This is only partially true because other characteristics of these foods, besides fiber content, are able to influence their glycemic response and they might contribute to the beneficial metabolic effects of diets rich in legumes, vegetables, and fruits (52,53). Among these characteristics, the physical form of the food certainly plays a major role (54). This has been clearly shown in a study performed in NIDDM patients that evaluated the glycemic response to identical portions of beans processed by different methods into two physical forms (55). In one form, the integrity of the cells was maintained, whereas in the other, the cells were ruptured. Obviously, the composition of the two portions of beans, including the type and amount of dietary fiber, was identical, but, nevertheless, the glycemic response was 50% lower in beans with unruptured cells. These results emphasize the complex nature of the factors controlling plasma glucose response to carbohydrate-rich foods and suggest that the glycemic and insulinemic response to a food is not necessarily predictable on the basis of its biochemical composition.

This concept is now supported by many studies, including Wolever et al. (56), who tested numerous

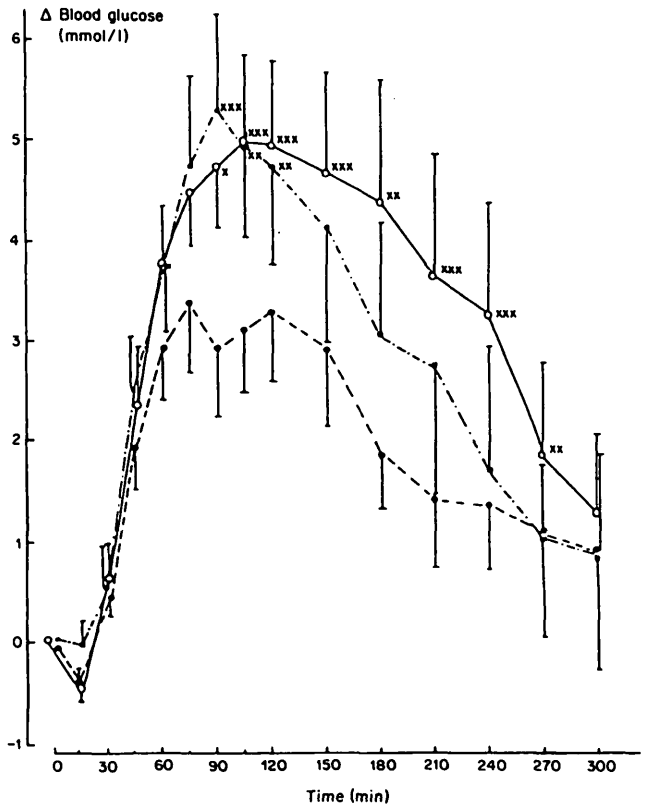

FIG. 7. Mean ± SE blood glucose rise above baseline after 3 standard test meals containing a 50-g carbohydrate portion of either bread (○), spaghetti (●), or potatoes (■) in non-insulin-dependent diabetic patients (n = 7; ref. 57). *$P < 0.05$, **$P < 0.025$, ***$P < 0.01$ vs. spaghetti.

foods for their blood glucose response in diabetic and nondiabetic individuals (56).

In the search for carbohydrate-rich foods that, although fiber-depleted, would behave as fiber-rich foods in relation to their beneficial effects on blood glucose, we evaluated spaghetti, breads, and potatoes in NIDDM patients (57). They were given, in random order and on alternate days, three test meals of identical composition. Each meal consisted of a standard serving to which a portion containing 50 g carbohydrate of either bread (90 g), spaghetti (65 g), or potatoes (285 g) was added. The glycemic response to the meal containing bread or potatoes was higher by 68 and 48%, respectively, compared with the meal containing spaghetti, thus indicating that, although fiber-depleted, the latter has the same beneficial effects on blood glucose metabolism as fiber-rich foods (Fig. 7).

This enlarges the list of the carbohydrate-rich foods to be preferentially used in the diet for diabetic patients. It should include not only those foods rich in gel-forming, water-soluble dietary fiber but other foods with slow rates of digestion and absorption of their carbohydrate content because of the physical form. Among them are foods prepared with whole- or partly milled grains and seeds (i.e., whole-grain bread), in which starch is present within undisrupted plant structures. Therefore, accessibility to hydrolysis by pancreatic amylase in the small bowel is limited or, at least, delayed (58). The list should also include spaghetti and parboiled rice in which starch accessibility is limited because the technological process used to prepare them has modified the physical form of starch (incomplete gelatinization delays starch digestion). Influencing starch digestibility by means of appropriate utilization of food technology opens new perspectives on the preparation of starchy foods that would be particularly suitable for diabetic patients.

However, long-term studies are needed to verify whether foods with a low glycemic response in acute test meal experiments will improve blood glucose control in the long term. So far, only a few of these studies are available, and although their results are promising, further confirmations are required before the evaluation of the glycemic response in acute test meal experiments becomes a routine method for the selection of the most suitable carbohydrate-containing foods for diabetic patients (59).

Finally, because the beneficial metabolic effects of unprocessed vegetable foods are only partially due to dietary fiber, we cannot expect that purified vegetable fiber used as a pharmacological agent to treat diabetic patients could be as effective (and as safe) as a high-fiber diet. The data available are not particularly impressive (30).

CONCLUSIONS

Going back to the dietary recommendations for diabetic patients—after having reviewed the available evidence on the metabolic effects of clinically significant dietary manipulations in diabetic patients—we conclude that they are wise in proposing a fiber-rich low-fat/high-carbohydrate diet for the treatment of both IDDM and NIDDM patients. However, it should be better clarified that when, for whatever reason, the patient cannot increase the consumption of unrefined vegetable foods, he should not be allowed to substitute these with fiber-depleted starchy foods but rather should be advised to increase the intake of unsaturated fat. It is also interesting to contemplate the possibility that the reduction of saturated fat in the diabetic diet could be compensated by a balanced increase in both unprocessed vegetable foods and unsaturated fat to improve the compliance to the dietary prescription (60). A diet based almost exclusively on vegetable products does not look feasible to most people in western countries. Conversely, a moderate increase in the consumption of fiber-rich foods, especially legumes, vegetables, and fruits (increasing the daily fiber intake up to 40 g) combined with a preferential use of unsaturated fat would be more easily accepted. A

diet low in saturated fat and cholesterol and rich in vegetables and olive oil resembles the type of diet used in the Mediterranean region that is becoming increasingly popular in many western countries.

The possibility of offering diabetic patients a nutritional model that is not artificially created in a metabolic kitchen but is a life experience—with strong historical, cultural, and gastronomical background—would certainly facilitate compliance for millions of people. Moreover, this dietary model is not exclusively for diabetic patients, but is a proposal offered to the general population, because it represents the best available diet for the prevention of cardiovascular disease, cancer, and many other degenerative diseases that are becoming epidemic in the western world (61). Therefore, the diabetic patient will not be separated from the rest of his family in his dietary prescription but will share with others a diet useful to preserve and improve health.

ACKNOWLEDGMENTS

This work was supported in part by Italian National Research Council Grant 91.00226.PF41—target project "Prevention and Control of Disease Factors," subproject "Nutrition;" by the Ministry of Education and by the University of Naples.

We gratefully acknowledge Anna Pafundi for secretarial assistance and Rosanna Scala for linguistic consultation.

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