Long-Term Dietary Treatment With Increased Amounts of Fiber-Rich Low–Glycemic Index Natural Foods Improves Blood Glucose Control and Reduces the Number of Hypoglycemic Events in Type 1 Diabetic Patients

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OBJECTIVE — To evaluate in type 1 diabetic patients *1*) the long-term feasibility of a high-fiber (HF) diet composed exclusively of natural foodstuffs and *2*) the efficacy of this diet in relation to blood glucose control and incidence of hypoglycemic episodes.

RESEARCH DESIGN AND METHODS — The study was randomized with parallel groups. Participants were part of a larger multicenter study on the effects of acarbose on glucose control in diabetes. A total of 63 type 1 diabetic patients, age 28 ± 9 years, BMI 24 ± 0.6 kg/m^2, after a 4-week run-in period on their habitual diet, were randomized to either an HF (n = 32) or a low-fiber (LF) diet (n = 31) for 24 weeks. The two diets, composed exclusively of natural foodstuffs, were weight-maintaining and, aside from their fiber content, were similar for all nutrients. At the end of the run-in period and the dietary treatment, fasting blood samples for the measurement of plasma cholesterol, HDL cholesterol, triglyceride, and HbA_{1c} were collected. A daily glycemic profile was performed on a day in which the participants had consumed a standard menu representative of their treatment diet (HF or LF).

RESULTS — Of the 63 study subjects, 29 in the HF group (91%) and 25 in the LF group (81%) completed the study. Compared with the LF diet, the HF diet after 24 weeks decreased both mean daily blood glucose concentrations ($P < 0.05$) and number of hypoglycemic events ($P < 0.01$). When compliance to diet was taken into account, 83% of the subjects on the HF diet and 88% on the LF diet were compliant. In this subgroup, compared with the LF diet, the HF diet significantly reduced mean daily blood glucose concentrations ($P < 0.001$), HbA_{1c} ($P < 0.05$), and number of hypoglycemic events ($P < 0.01$).

CONCLUSIONS — In type 1 diabetic patients, an HF diet is feasible in the long term and, compared with an LF diet, improves glycemic control and reduces the number of hypoglycemic events.

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Dietary treatment is an essential component of successful diabetes management not only in patients with type 2 diabetes but also in those with type 1 diabetes. In fact, diet counseling represents an essential component of an intensive approach to diabetes treatment in these patients because premeal insulin dosage and meal composition need to be well matched to avoid excessive blood glucose excursions as a result of high after-meal blood glucose values and/or hypoglycemic episodes between meals (1,2).

A controversial issue is whether specific carbohydrate-rich foods should be preferred in the diabetes diet in view of their favorable impact on blood glucose control (3,4).

High-fiber (HF) foods, particularly if rich in soluble fiber (i.e., fruits, vegetables, and legumes), are recommended as a preferential source of carbohydrate by the Nutrition Study Group of the European Association for the Study of Diabetes (EASD) because of their ability (tested in acute or short-term studies) to reduce postprandial blood glucose levels (5). The American Diabetes Association considers the evidence on the effects of dietary fiber on blood glucose control inconclusive; however, the consumption of fiber-rich foods is still recommended because of their beneficial effects on plasma lipids and colonic function (6,7). Both fiber supporters and detractors claim that long-term studies are needed to clarify whether dietary fiber has any relevant metabolic effect in diabetic patients. In fact, it is generally agreed that fiber-rich foods can indeed delay glucose absorption from the small intestine and thus reduce postprandial blood glucose concentrations (8,9). However, the effect of dietary fiber on blood glucose control could be too small to be clinically relevant when only natural foods are consumed in amounts compatible with the eating habits of Western populations.

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Abbreviations: EASD, European Association for the Study of Diabetes; HF, high-fiber; LF, low-fiber.

A table elsewhere in this issue shows conventional and Système International (SI) units and conversion factors for many substances

Table 1—*Baseline features of type 1 diabetic patients*

	Intention to treat		Compliant to diet	
	LF	HF	LF	HF
n	25	29	22	24
Sex (M/F)	9/16	12/17	7/15	10/14
Age (years)	26.2 ± 7.9	29.5 ± 11.0	26.3 ± 8.1	30.3 ± 11.6
BMI (kg/m^2)	24.2 ± 3.3	23.6 ± 1.8	24.0 ± 3.4	23.9 ± 1.5
HbA_{1c} (%)	8.8 ± 1.4	8.8 ± 1.4	8.6 ± 1.4	8.8 ± 1.3
Fasting blood glucose (mmol/l)	12.9 ± 5.7	12.1 ± 5.7	13.0 ± 5.5	12.4 ± 5.6
Insulin dose (U/day)	42.7 ± 13.1	47.9 ± 16.2	44.1 ± 12.7	47.6 ± 16.5

Data are *n* or means ± SD.

Against this background, we have undertaken a study in a group of unselected type 1 diabetic patients to evaluate *1*) the feasibility in the long term (6 months) of an HF diet composed exclusively of natural foodstuffs easily available in ordinary supermarkets and *2*) the efficacy of such a diet in relation to blood glucose control and rate of hypoglycemic events.

RESEARCH DESIGN AND METHODS

Patients

A total of 63 type 1 diabetic patients from each sex (C-peptide negative, mean age 28.2 ± 9.5 years, BMI 23.9 ± 0.6 kg/m^2, duration of diabetes 10.3 ± 6.3 years, treated with insulin [two or more injections per day], and with HbA_{1c} levels >7 and $<10\%$) participated in the study. Participants represented the Neapolitan cohort of a larger multicenter study on the effects of acarbose on glycemic control in type 1 diabetic patients (10). They were recruited consecutively from all new patients referred to our unit who fulfilled the inclusion criteria. Diabetic patients with renal failure, liver disease, or symptomatic cardiovascular disease were excluded from the study. Patients gave their written informed consent to the protocol, which had been approved by the ethics committee of Federico II University Medical School.

Diets

The experimental dietary treatments were an HF or a low-fiber (LF) diet; the two diets were weight-maintaining and similar in terms of carbohydrate, protein, and fat content (20% protein, 30% fat, and 50% carbohydrate); in particular, the amount of saturated, monounsaturated, and polyunsaturated fatty acids (8, 20, and 2% of total daily energy intake, respectively), cholesterol (226 mg/day), and monodisaccharides (20%) were the same in both diets. The only difference was represented by fiber content, which was 15 g/day in the LF diet and 50 in the HF diet, with emphasis on water-soluble fiber. This difference was obtained by advising patients on the HF diet to consume one serving of legumes, three servings of HF fruit (such as apples, oranges, pears, and tangerines), and two servings of HF vegetables (such as artichokes, eggplants, mushrooms, and broccoli) every day, whereas patients on the LF diet were advised to limit legume consumption to less than once a week and to consume preferentially LF fruit (bananas and fruit juice) and LF vegetables (such as tomatoes, lettuce, red cabbage, and pepper). The average glycemic index of the two diets was also different: 70% in the HF diet and 90% in the LF diet. A standard menu (breakfast and lunch) of the HF and LF diets was prepared in the outpatient clinic and consumed on the day the blood glucose profile was measured on the metabolic ward. The standard HF menu was made up of apples (250 g) and partially skimmed milk (150 g) at breakfast and boiled beans (280 g), meat (80 g), artichokes (250 g), white bread (100 g), apple (250 g), tomato (100 g), and olive oil (20 g) at lunch (18% protein, 25% fat, 57% carbohydrates, 58 mg cholesterol, 53 g fiber, and 1,026 kcal). The standard LF menu was made up of orange juice (150 g) and partially skimmed milk (150 g) at breakfast, and of rice (80 g), tomato (100 g), meat (100 g), lettuce (100 g), white bread (100 g), orange juice (150 g), and olive oil (20 g) at lunch (17% protein, 23% fat, 60% carbohydrates, 62 mg cholesterol, 8.2 g fiber, and 1,059 kcal).

All patients followed an intensive dietary education program that included diet history, the formulation of a personalized diet, two 1-h educational sessions with a dietitian who provided recipes, written suggestions for eating out, and food choices. The test diet prescribed to each individual patient was formulated taking into account the caloric intake and food choices outlined in the dietary record filled in during the run-in period. Subsequent individual meetings with the dietitian were scheduled at each monthly visit during the 24 weeks of dietary treatment; on that occasion, the filled-out 7-day food records were reviewed with each patient, and deviations from the prescribed diet were underlined to reinforce the dietary prescription.

Study design

The study was randomized with two parallel groups. After a 4-week run-in period in which they consumed their habitual weight-maintaining diet, the 63 diabetic patients were randomized to receive either an HF diet ($n = 32$) or an LF diet ($n = 31$) for 24 weeks. During the run-in period, patients were instructed to fill in their food diary, to perform their home blood glucose monitoring with a reflectometer (glucometer; Bayer, Milan, Italy) and to record any hypoglycemic episodes. All efforts were made to avoid changing the dose of insulin after the run-in period; the dose was varied only if plasma glucose concentrations were $\geq$11 mmol/l at fasting and 14 mmol/l at 2 h postprandial, on repeated occasions, or in case of hypoglycemic episodes (more than one per week at the same time of the day—morning, afternoon, or night).

At the end of the run-in period and after 24 weeks of each experimental diet, the patients were admitted to the outpatient clinic, where fasting blood samples for the measurement of total plasma cholesterol, HDL cholesterol, plasma triglyceride, and HbA_{1c} concentrations were collected; thereafter, a glycemic profile was performed on a day in which they consumed a standard menu representative of their treatment diet (HF or LF). Blood glucose measurements were performed at fasting, 2 h after breakfast, and before and 2 and 4 h after lunch. Body weight measurements and physical examinations were performed every month at the control visit; on this occasion, possible variations of the daily insulin dose were decided on the basis of the patients' home blood glucose profiles and hypoglycemic events recorded in their diaries. Hypoglycemia was defined on the basis of specific symptoms and a low blood glucose value ($<$3.0 mmol/l) measured by the reflectometer.

Compliance to the diet was evaluated on the basis of a diary in which the patients recorded their daily food/drink intake for 7 days every month (7-day food record). A specific computer program was used to calculate each patient's diet composition, as recorded in the food diary, on the basis of Italian food composition tables (11). Compliance to diet was considered to be unsatisfactory when the average consumption of carbohydrate during the treatment period was <45% of total energy for both diets and/or the consumption of fiber was >20 g/day for the LF diet or <30 g/day for the HF diet.

Plasma glucose, cholesterol, HDL cholesterol, and triglyceride concentrations were measured by standard enzymatic colorimetric methods (Boehringer Mannheim, Mannheim, Germany), and HbA_{1c} was analyzed by a high-performance liquid chromatography method (12).

Efficacy evaluation

This study cohort was also part of a randomized placebo-controlled multicenter study on the effects of acarbose on blood glucose control in type 1 diabetic patients (10).

One patient was excluded from all analyses because he lost contact with the study physicians before diet prescription (HF diet). During the study, there were eight drop-outs: three in the HF diet and five in the LF diet. Therefore, altogether 54 diabetic patients completed the study: 29 patients in the HF (91%) and 25 patients in the LF diet (81%). A statistical analysis on this sample was performed according to the intention to treat. The two groups were comparable for all baseline variables (Table 1); the proportion of patients treated with acarbose was similar in the two groups (45% in the HF group and 48% in the LF group). When compliance to diet was taken into account, eight patients were excluded from the analysis because their fiber intake was either too high (*n* = 3 in the LF group) or too low (*n* = 5 in the HF group); carbohydrate intake was satisfactory in all subjects. After this exclusion, a further analysis was performed on the remaining 46 patients (24 in the HF and 22 in the LF group) who represented those compliant to diet. Their clinical characteristics are reported in Table 1. Again in this case, subgroup analysis showed the two groups to be comparable for all baseline variables, including the proportion of patients treated with acarbose.

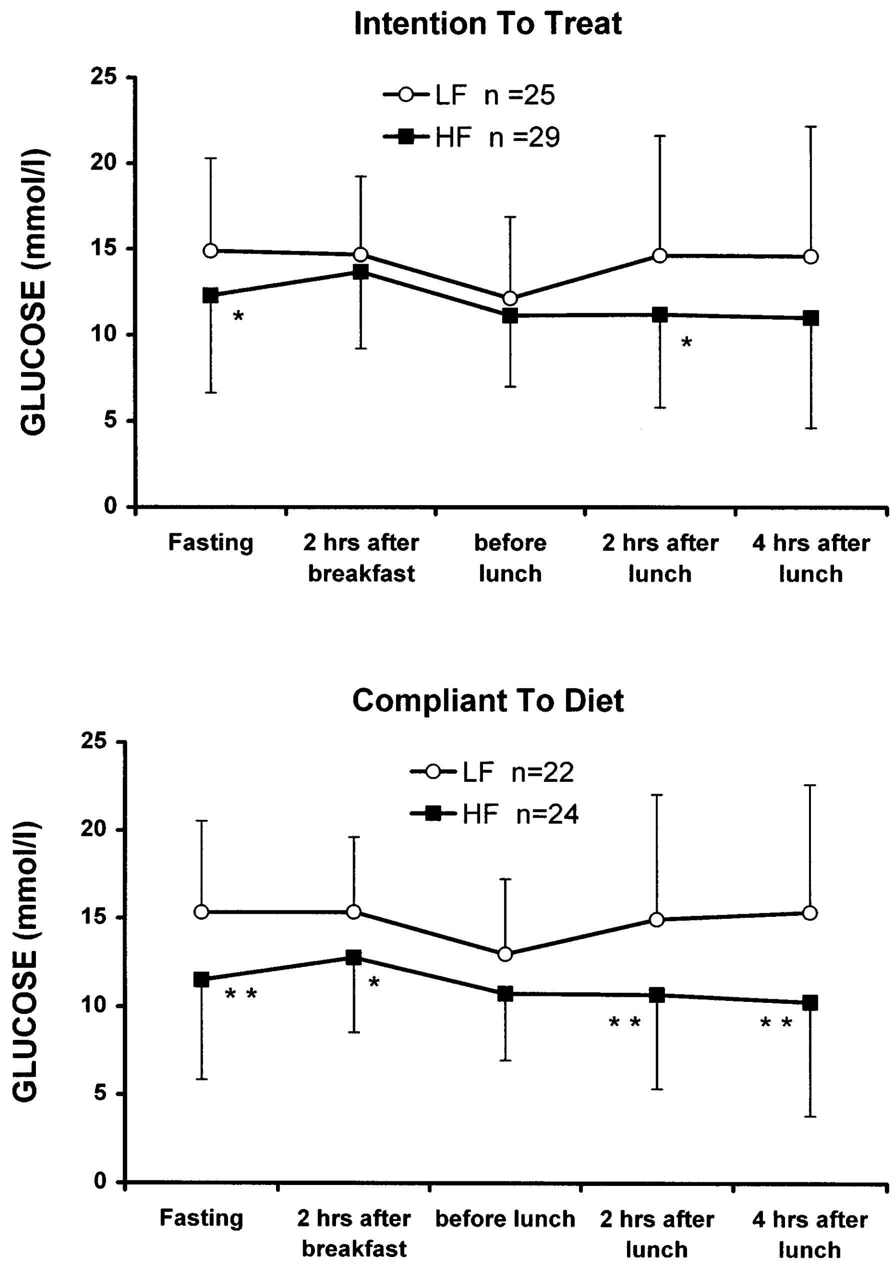

Figure 1—*Blood glucose daily profile (means ± SD) in type 1 diabetic patients after 6-month treatment with either an LF (○) or HF (■) diet. The analysis included intention to treat and diet-compliant patients.* *P ≤ *0.05,* **P < *0.01.*

Statistical analysis

All data are expressed as means ± SD. The mean daily blood glucose concentration was calculated as the average of all five blood glucose measurements performed at the outpatient clinic on the last day of the treatment period with the HF and LF diet, respectively. The differences between the two dietary treatments were analyzed by covariance analysis according to a standard computerized statistical procedure (SPSS). Because acarbose treatment was not associated with any significant effect on the parameters evaluated in our study cohort and because it did not show any interaction with dietary treatment (two-way analysis of variance), patients treated with acarbose or placebo were combined in the analysis; however, acarbose treatment and baseline measurements were included in the model as covariates. For checking differences in side effects between the groups, Pearson's χ^2 test was performed. For all analyses, the level of statistical significance was set at P = 0.05 (two-tailed). The sample size of the study was calculated on the basis of the

Table 2—*Metabolic parameters at the end of the study in type 1 diabetic patients by intention-to-treat analysis or after the exclusion of noncompliant individuals*

	Intention to treat				Compliant to diet			
	L F	Δ (%)	H F	Δ (%)	L F	Δ (%)	H F	Δ (%)
n	25	—	29	—	22	—	24	—
HbA_{1c} (%)	9.1 ± 1.3	3.4	8.8 ± 1.0	0	9.1 ± 1.4	5.8	8.6 ± 0.9*	−2.0
Mean daily plasma glucose (mmol/l)	14.5 ± 4.5	−6.5	11.8 ± 3.3*	−9.0	14.7 ± 4.1	0	11.2 ± 2.9†	−15.0
Triglyceride (mmol/l)	0.87 ± 0.28	0.8	0.86 ± 0.44	−0.4	0.86 ± 0.30	3.5	0.90 ± 0.48	0
Cholesterol (mmol/l)	5.1 ± 1.2	4.0	4.7 ± 0.9	0	5.0 ± 1.3	3.0	4.7 ± 0.8	−0.6
HDL cholesterol (mmol/l)	1.4 ± 0.4	2.8	1.5 ± 0.3	0.8	1.4 ± 0.4	2.0	1.5 ± 0.4	0
Hypoglycemic events ($n \cdot \text{patient}^{-1} \cdot \text{month}^{-1}$)	1.5 ± 1.2	—	0.7 ± 0.7†	—	1.7 ± 1.2	—	0.8 ± 0.7†	—
Body weight (kg)	65.5 ± 10.9	0.9	66.7 ± 10.2	0.9	64 ± 11	0.5	67 ± 11	1.1
Insulin dose (U/day)	42.1 ± 12.7	−1.4	47.6 ± 16.5	−0.6	43.7 ± 12.3	−8.0	48.4 ± 16.6	1.7

Data are means ± SD, unless otherwise indicated. †$P < 0.05$; **$P < 0.01$. Δ (%), change from baseline.

assumption that a clinically relevant difference in HbA_{1c} was >0.5%; other assumptions were an SD of 0.8%, a type 1 error equal to 0.5%, and a power of the study equal to 80%.

RESULTS

Analysis according to the intention to treat

Compared with the LF diet, the HF diet improved the blood glucose daily profile (Fig. 1) and significantly reduced the mean daily blood glucose concentration (11.8 ± 3.3 vs. 14.5 ± 4.5 mmol/l; $F = 3.9$; $P < 0.05$). Even HbA_{1c} levels were lower after the HF diet than after the LF diet but did not reach the conventional level of statistical significance (8.8 ± 1.0 vs. 9.1 ± 1.3%; $F = 2.6$, $P = 0.11$). In addition, the number of hypoglycemic events was significantly lower on the HF diet than on the LF diet (0.73 ± 0.7 vs. 1.5 ± 1.2 events per patient per month; $P < 0.01$) (Table 2).

No effect of diet on plasma triglyceride, cholesterol, and HDL cholesterol levels was observed (Table 2). Insulin dose and body weight at the end of the study were not significantly modified with either the HF or LF diet compared with baseline values (Table 2).

Analysis on patients compliant to diet

At the end of the study, the percentage of patients compliant to diet was 83% in the HF diet group and 88% in the LF diet group. Taking into account the original cohort, they represented 75 and 71% of the patients initially recruited for the HF and LF diets, respectively. In these patients, the composition of the diet followed during the treatment period was similar for all components except fiber, which was significantly different between the two groups as expected from study design ($P < 0.01$) (Table 3). Compared with the LF diet, the HF diet significantly reduced mean daily blood glucose concentrations by 24% (11.2 ± 2.9 vs. 14.7 ± 4.1 mmol/l; $F = 13.0$; $P < 0.001$) (Table 2 and Fig. 1); the difference was most pronounced after lunch (−30%; $P < 0.01$). Accordingly, HbA_{1c} was also significantly lower after the HF diet than after the LF diet (8.6 ± 0.9 vs. 9.1 ± 1.4%; $F = 4.1$; $P < 0.05$) (Table 2). In addition, the number of hypoglycemic events was significantly lower in the HF group than in the LF group (0.8 ± 0.7 vs. 1.7 ± 1.2 events per patient per month; $P < 0.01$) (Table 2).

These results cannot by any means be influenced by the concomitant treatment with acarbose given to ~50% of the study participants. In fact, the proportion of patients using acarbose was similar in both diet groups (45 vs. 48%); moreover, in our study population, this drug did not exert any significant effect on HbA_{1c} levels (9.1 ± 1.1 vs. 8.7 ± 1.2%; $P = 0.18$ acarbose versus placebo), nor did it show any interaction with diet on this parameter ($P = 0.49$). Similarly, acarbose did not have any influence on hypoglycemic events ($P = 0.35$) and had no interaction with diet ($P = 0.18$) on this parameter.

No effect of diet on fasting plasma triglyceride, cholesterol, and HDL cholesterol levels was observed (Table 2).

Insulin dose and bodyweight at the end of the study did not vary significantly compared with baseline values with either the HF or LF diet (Table 2).

Of the patients treated with the HF diet, 56% recorded some minor gastrointestinal side effects (flatulence, meteorism, and diarrhea) in comparison with 40% of the patients treated with the LF diet (NS). The proportion of patients with gastrointestinal side effects was even higher in the groups treated with HF diet and acarbose (87%; $P < 0.05$). However, none of these episodes induced patients to discontinue

Table 3—*Diet composition during dietary treatment in type 1 diabetic patients by intention-to-treat analysis or after exclusion of noncompliant individuals*

	Intention to treat		Compliant to diet*	
	LF	HF	LF	HF
n	25	29	22	24
Energy (kcal/day)	1,846 ± 435	1,756 ± 306	1,829 ± 396	1,813 ± 254
Protein (%)	17.1 ± 1.8	20.0 ± 1.8	17.3 ± 1.3	19.3 ± 1.3
Fat (%)	28.3 ± 4.7	27.9 ± 3.7	28.5 ± 3.5	27.8 ± 3.4
Saturated fat (%)	8.2 ± 2.2	8.3 ± 2.1	8.1 ± 1.9	8.0 ± 2.0
Cholesterol (mg/day)	227 ± 53	230 ± 56	213 ± 49	238 ± 58
Carbohydrate (%)	54.6 ± 4.4	52.2 ± 4.3	54.3 ± 3.1	52.9 ± 3.9
Fiber (g/day)	15.4 ± 3.6	36.7 ± 9.4†	15.0 ± 2.8	39.1 ± 8.8†

Data are *n* or means ± SD. *Fiber >30 g/day (HF); fiber <20 g/day (LF). †$P < 0.001$.

the diet or to drop out of the study or seek medical advice.

CONCLUSIONS

— This study shows that, in type 1 diabetic patients, an increased consumption of natural foods rich in dietary fiber and with a low glycemic index is both feasible and effective on blood glucose control in the long term. So far, only short- or medium-term studies are available, and, therefore, the clinical usefulness of this type of dietary approach within the context of the usual setting of diabetes care is questioned (13–15). In this respect, we believe that our results can be reasonably generalized to the general population of adult type 1 diabetic patients treated in specialized outpatient clinics by experienced and qualified personnel. In fact, all attempts were made to choose a study conduct reproducible in the usual clinical setting of diabetes care. In particular, the cohort enrolled in this study was represented by unselected adult type 1 diabetic patients routinely attending our diabetic clinic. The diet prescribed was based exclusively on natural foodstuffs easily available in ordinary supermarkets, and the consumption of any food artificially enriched with fiber was not allowed. The amount of dietary fiber used in the study was not much higher than that recommended to the general population (30 g/day) or that usually consumed by type 1 diabetic patients in southern Italy (~25 g/day); nevertheless, it is appreciably higher than that consumed in North America or Northern European countries (16,17). The average fiber consumption among our diabetic outpatient population is 28.8 g/day. The increased fiber intake was obtained by encouraging the consumption of fruit, legumes, and vegetables, which represent, together with olive oil, the cornerstones of the traditional Mediterranean diet (18,19). Patients were prescribed the diet by experienced dietitians as part of an intensive dietary education program. Dietary adherence was checked every month with food records, and deviations from the prescribed regimen were used by the dietitian to reinforce the nutritional message.

The beneficial metabolic effects of the HF diet included both an improvement in the daily blood glucose profile and a marked reduction in number of hypoglycemic events. In the subgroup of patients compliant to diet, this result was even stronger, with a significant difference in glycated hemoglobin. Conversely, in contrast with studies in type 2 diabetic patients, the HF diet did not yield any significant effect on plasma lipids, which, however, were very low, as is often the case for type 1 diabetic patients (20). The possibility that an HF intake may reduce glycated hemoglobin in type 1 diabetic patients was strongly suggested by a recent large multinational epidemiological study in which an independent negative significant association was shown between fiber intake and levels of HbA_{1c} (21). Moreover, in these patients, an HF intake was associated with a lower prevalence of cardiovascular disease (22). The health benefits of an increased intake of HF foods in relation to glucose metabolism are further underlined by the evidence that, in the general population, an HF consumption predicts a lower incidence of type 2 diabetes (23).

In the Diabetes Control and Complications Trial, a negative relationship was demonstrated between the degree of metabolic control and the rate of hypoglycemic events in the whole cohort (24). In that study, the general theorem proposed was that in type 1 diabetic patients, any attempt to intensify the hypoglycemic treatment to improve blood glucose control would result in an increased risk of hypoglycemia. In contrast, this study shows that by increasing the consumption of fiber-rich foods, it is possible to improve blood glucose control and at the same time reduce the incidence of hypoglycemic events. So far, this is the only treatment approach for type 1 diabetic patients capable of combining these two important achievements for patient care.

Body weight and insulin dosage did not vary during the study; therefore, they cannot contribute to account for the different outcomes of the two diets. Moreover, because the two diets were similar for all nutrients, the results obtained can be ascribed only to the different consumption of HF foods.

Of course, the nature of this study does not allow us to verify whether dietary fiber represents the marker or the cause of the metabolic benefits obtained consuming specific types of carbohydrate-rich foods, particularly those with a low glycemic index (9). As a matter of fact, we are well aware that long-term studies using pharmacological preparations based on purified fiber have given conflicting results in diabetic patients (25–27). However, this can be well understood if we consider that increased ingesta viscosity represents only one of the possible mechanisms of the hypoglycemic activity of dietary fiber (28–30). An even more important mechanism is represented by reduced carbohydrate accessibility because of the particular fiber/carbohydrate relationship present in natural foods. In fact, these foods have a fiber matrix that encompasses carbohydrate granules that limits the access to digestive enzymes and the diffusion of solutes, thus reducing the postprandial blood glucose rise (31,32). The use of fiber extracts can reproduce only the viscosity effects of fiber but certainly cannot reproduce the typical structure of natural foods.

As for the side effects, local gastrointestinal discomfort was more common among patients treated with the HF diet, particularly when acarbose treatment was also used; however, symptoms were mild and did not influence to a major extent the compliance to the prescribed diet.

As a matter of fact, a similar proportion of patients in both the HF and LF groups were able to successfully complete the study (91 vs. 81%, respectively) and showed a satisfactory compliance to the dietary treatment prescribed (75 and 71%, respectively). Moreover, none of safety laboratory evaluations showed any significant clinical problems associated with diet treatment. This is in line with a large body of evidence showing that consumption of naturally fiber-rich foods is not associated with malabsorption of vitamins or minerals (33–35).

In conclusion, adult type 1 diabetic patients are able to comply with a long-term dietary treatment based on an HF/low–glycemic index diet in >70% of cases, with a significant and long-lasting improvement in plasma glucose control without major drawbacks. Our data support the dietary recommendations issued by the EASD Nutrition Study Group; they also provide the evidence, so far lacking, that diabetic patients should be encouraged to increase the consumption of fiber-rich natural foods on the basis of the beneficial effects of the latter on blood glucose control.

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