The Effects of Variations in Percent of Naturally Occurring Complex and Simple Carbohydrates on Plasma Glucose and Insulin Response in Individuals with Non-insulin-dependent Diabetes Mellitus

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SUMMARY

In the present study, 12 patients with non-insulin-dependent diabetes mellitus (NIDDM) consumed eucaloric, mixed food diets on three consecutive days. Diets provided 50% of the calories as carbohydrate, 35% as fat, and 15% as protein. The percent of carbohydrate fed as complex (starches) and simple (mono- and disaccharides) varied among the 3 days. On day 1, the diet contained 80% of the carbohydrate as complex and 20% as simple (80/20); another contained 50% complex and 50% simple (50/50); and the final diet contained 20% of the carbohydrate as complex and 80% as simple (20/80). All simple carbohydrates represent naturally occurring sugars in fruits, vegetables, and dairy products. No refined sugars were added to any of the diets. The three experimental diets were randomly assigned using a 3 × 3 Latin square design.

Blood was obtained hourly from 0800 to 1700 h for day-long glucose and insulin concentrations, and 24-h urine collections were made for the measurement of urine glucose. Mean (± SEM) day-long glucose concentrations were significantly greater for the 80/20 diet (2245 ± 199 mg/dl · h, $P < 0.05$) than for either the 50/50 (2030 ± 157 mg/dl · h) or the 20/80 diets (2008 ± 160 mg/dl · h). No significant differences were noted between the 50/50 and the 20/80 diets. In contrast, day-long insulin concentrations were not significantly different with 401 ± 62, 370 ± 50, and 369 ± 60 μU/ml · h on the 80/20, 50/50, and 20/80 diets, respectively. Twenty-four-hour urinary glucose excretion paralleled plasma glucose concentrations. Significant differences were noted when the 80/20 diet (25.1 ± 4.5 g/24 h, $P < 0.05$) was compared with the 20/80 diet (9.7 ± 3.3 g/24 h). Substantial quantitative differences also existed between the 80/20 and 50/50 (12.2 ± 4.5 g/24 h), but these differences did not reach statistical significance.

The results of the present study support the hypothesis that variations in relative proportions of naturally occurring, complex and simple dietary carbohydrate will have no deleterious effect on glycemia in patients with NIDDM. Thus, there seems to be no apparent reason why patients with NIDDM should avoid foods that are high in naturally occurring, simple carbohydrate.
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Recommendations that individuals with diabetes restrict their intake of simple carbohydrates and increase the proportion of carbohydrate consumed as complex carbohydrates is a concept that has been included in most reports on the dietary management of diabetes.[1-3] However, we are unaware of any studies in the literature addressing this specific question in a quantitative manner. Indeed, we are not sure what patient behavior is expected from the advice to consume more complex and less simple carbohydrates. For example, both applesauce and apple pie contain sucrose, a simple carbohydrate. Are both of these sucrose-containing foods to be avoided? Alternatively, the dictum that patients with diabetes should not eat simple carbohydrates may not apply when naturally occurring, carbohydrate-containing foods are ingested. Consequently, it appeared to us that there was a need to develop the data base required to provide rational dietary advice to patients with diabetes. To initiate this process, we designed the present study, which was based on the hypothesis that plasma glucose and insulin responses would not change in response to variations in the proportion of complex to simple carbohydrate occurring naturally in foods.

To test this formulation, we devised three test diets, varying only in the relative proportion of complex to simple carbohydrate. Specifically, plasma glucose and insulin concentrations were measured in response to diets that contained (as percent of total carbohydrate) 80% complex/20% simple, 50% complex/50% simple, and 20% complex/80%

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TABLE 1
Clinical characteristics

Subject	Age (yr)	Sex (M/F)	BMI (kg/m²)	Fasting plasma glucose (mg/dl)	Treatment
1	64	F	28.3	282	Sulfonylurea
2	58	F	29.1	185	Sulfonylurea
3	56	M	24.5	222	Sulfonylurea
4	60	M	25.1	146	Diet
5	61	F	27.8	167	Diet
6	69	F	24.4	129	Diet
7	61	M	29.5	193	Sulfonylurea
8	71	M	19.6	178	Sulfonylurea
9	69	F	29.2	201	Diet
10	59	M	25.9	274	Diet
11	67	M	25.6	131	Diet
12	48	M	27.3	133	Diet
Mean	62	7M/5F	26.3	187	
SEM	2		0.8	15	

simple carbohydrate. The results presented in this paper demonstrate remarkable similarities in plasma glucose and insulin response to diets varying tremendously in the percentage of simple and complex carbohydrates, and suggest that patients with NIDDM may consume naturally occurring, simple carbohydrate without any worsening of diabetic control.

MATERIALS AND METHODS

Subjects. Twelve volunteers, who satisfied the criteria for NIDDM,[4] were recruited for these studies. With the exception of diabetes, all subjects were in good general health and not taking any medication, other than sulfonylureas, known to affect glucose, insulin, or lipid metabolism. Five subjects were treated with sulfonylureas and seven by diet therapy alone. None of the subjects were or had been on insulin therapy. The clinical characteristics of these individuals are presented in Table 1. Subjects ranged in age from 48 to 71 yr with a mean of 62 yr. The ages of females ranged from 58 to 69 yr, and none of them were menstruating. Mean (± SEM) body mass index (BMI) was 26.3 kg/m², with a range of 19.6–29.5 kg/m². After signing consent forms approved by the Human Subjects Committee, subjects were admitted to Stanford University General Clinical Research Center for 3 days of testing.

Test diets. Subjects consumed eucaloric mixed food diets on each of three consecutive days. The total daily caloric intake was divided into 3 meals containing 1/5, 2/5, and 2/5 of total calories, consumed at 0800 h, 1200 h, and 1700 h, respectively. Test meals provided 50% of the calories as carbohydrate, 35% as fat, and 15% as protein (Table 2). Carbohydrate, fat, and protein food sources were held constant. However, the percentage of the carbohydrate fed as complex (starches) and simple (mono- and disaccharides) differed, and this was achieved by varying the amount of complex and simple carbohydrate-containing foods. Using this protocol, we developed three daily diets (Table 3) containing 80% of the carbohydrate as complex and 20% as simple carbohydrate (80/20), 50% of the carbohydrate as complex and 50% as simple (50/50), and 20% of the carbohydrate as complex and 80% as simple carbohydrate (20/80). The test meals were consumed over a 20–25-min period.

It is important to understand that no refined simple carbohydrate was included in the diets. The only source of simple carbohydrate was naturally occurring sugars in the fruits, vegetables, and dairy products. The three experimental diets were randomly assigned using a 3 × 3 Latin square design, using four squares to accommodate the 12 volunteers. The use of this experimental design allowed us to account for two sources of variation: first, the variation normally found between patients, and second, the potential confounding influence that one diet might have on the subsequent diet. No sequential effect of diet order was noted.

TABLE 2
Composition of test meals per 1000 kcal*

	80% Complex (g)	50% Complex (g)	20% Complex (g)
Protein	37.9 (15%)	36.5 (15%)	37.3 (15%)
Fat	38.9 (35%)	37.8 (34%)	38.7 (35%)
Carbohydrate	124.5 (50%)	128.4 (51%)	125.7 (50%)
Complex†	98.8 (79%)	56.4 (49%)	24.4 (21%)
Simple†	25.5 (21%)	57.7 (51%)	91.3 (79%)
Dietary fiber	8.3	12.8	14.9

*Calculations based on: USDA Agriculture Handbook no. 456, 8-1, 8-8, and 8-9, Washington, DC: Agricultural Research Services, U.S. Government Printing Office; and Paul, A. A., Southgate, D. A. T.: McCance and Widdowson's The Composition of Foods. 4th edit., no. 297. *London, Her Majesty's Stationery Office, 1978.*

†*Percentage of accountable complex and simple carbohydrate.*

TABLE 3
Itemized composition of test meals per 1000 kcal

Food items	80% Complex (g)	50% Complex (g)	20% Complex (g)
Breakfast			
Corn flakes	19.3	7.9	
Low-fat milk	53.0	51.5	
Whole wheat bread	11.4	11.1	11.3
Margarine	4.6	4.5	3.6
Egg	23.5	22.1	39.0
Orange slices		74.6	166.3
Lunch			
Whole wheat bread	22.4	21.7	22.2
Turkey	25.5	18.4	22.5
Lettuce	7.5	7.3	7.5
Mayonnaise	7.0	6.8	7.0
Rice	33.6	12.8	
Margarine	8.5	6.7	7.2
Banana, sliced	37.5	98.0	36.6
Low-fat milk	61.7	121.7	
Whole milk			72.7
Grape juice			180.8
Dinner			
Spaghetti	159.2	89.0	26.9
Parmesan cheese	5.0	4.9	5.0
Lean beef	20.1	24.8	28.9
Carrots	34.2	37.8	44.8
Margarine	14.5	14.0	13.8
Orange juice	93.1	147.2	148.1
Applesauce		119.0	121.6
Banana, sliced			95.4

Biochemical analyses. Blood samples were drawn fasting at 0800 h and hourly until 1700 h for the sequential measurement of glucose[5] and insulin.[6] In addition, total 24-h urines were collected each day for the measurement of urinary glucose.

Statistics. Data are presented as mean ± SEM. Multiple comparisons between treatment means were made using analysis of variance for Latin square design.[7] Since there were no significant differences between the four 3 × 3 squares, the data were pooled into a common analysis of variance table. The level of statistical significance was assessed by the Studentized multiple range test for comparison of three means.[8] The level of statistical significance was set at 5%.

RESULTS

There were no significant differences noted in glucose or insulin response between those subjects treated with sulfonylureas and those on diet alone. Thus, the patients were considered to comprise one group. Mean (± SEM) plasma glucose and insulin responses to the 3 test diets are presented in Figure 1. It is clear from this figure that both fasting and total ambient glucose concentrations (top panel) were similar in magnitude despite the very large differences in percent complex and simple carbohydrate. Fasting and total plasma insulin concentrations paralleled plasma glucose concentrations very closely, and likewise were similar in magnitude. These same data are presented in Figure 2 as integrated areas under the plasma glucose and insulin response curves. When the data are expressed in this manner, significant differences between the diets emerge. Integrated response areas for glucose (left panel) were significantly greater for the 80/20 diet (2245 ± 199 mg/dl · h) than to either the 50/50 (2030 ± 157 mg/dl · h, $P < 0.05$) or the 20/80 (2008 ± 160 mg/dl · h, $P < 0.05$) diets. No significant differences in plasma glucose response, however, were

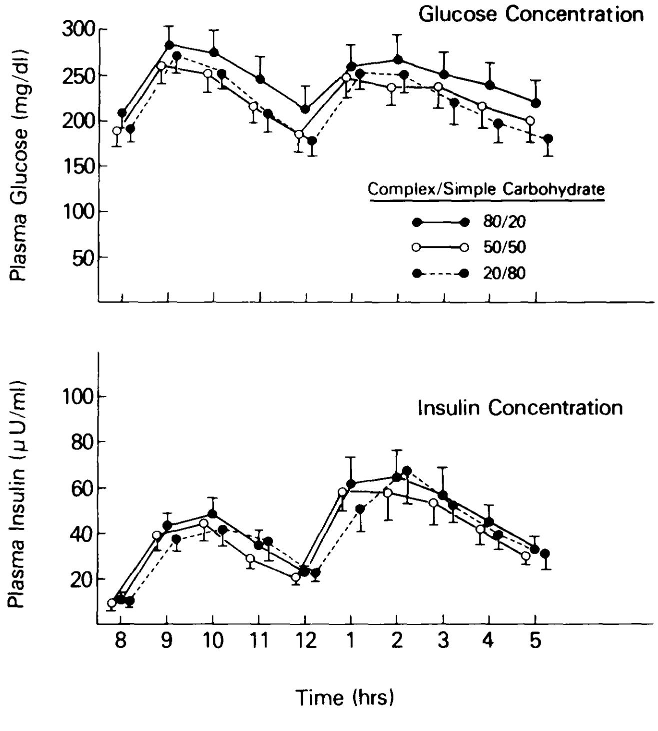

FIGURE 1. Mean (± SEM) changes in plasma glucose and insulin concentrations of 12 patients with NIDDM fed diets varying in the relative proportions of complex to simple carbohydrate.

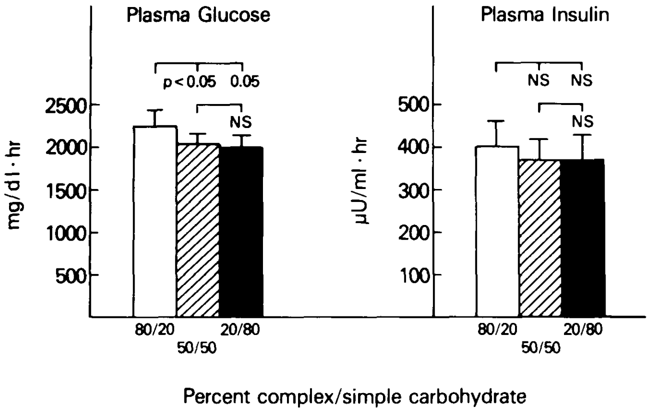

FIGURE 2. Mean (± SEM) response areas for plasma glucose and insulin in 12 patients with NIDDM fed diets varying in the relative proportions of complex to simple carbohydrate.

noted between the 50/50 and 20/80 diets. In contrast to the differences in glucose response, insulin response areas shown in the right portion of Figure 2 were not significantly different, with 401 ± 62, 370 ± 50, and 369 ± 60 μU/ml · h on the 80/20, 50/50, and 20/80 diets, respectively. These relationships were also true when incremental response areas above basal were calculated, and were independent of fasting plasma glucose concentrations.

Twenty-four-hour urinary glucose concentrations (expressed as g/24 h) were collected during the 3 diets and are presented in Figure 3. Total urinary glucose excretion was greatest during the 80/20 test meal (25.1 ± 9.1 g/24 h), substantially lower during the 50/50 diet (12.2 ± 4.5 g/24 h), and lowest during the 20/80 diet (9.7 ± 3.3 g/24 h). Significant differences ($P < 0.05$) were noted when the 80/20 diet was compared with the 20/80 diet. It is evident from Figure 3 that substantial quantitative differences in urinary glucose excretion occurred between the 80/20 and 50/50 diets. However, due to the large degree of variability in urinary glucose excretion on the 80/20 diet, these differences failed to reach the 5% level of significance ($P < 0.08$).

DISCUSSION

The results presented support our hypothesis that variations in the relative proportion of complex to simple dietary carbohydrate naturally occurring in foods will have no deleterious effect on glycemia in patients with NIDDM. In fact, both plasma glucose concentration and urinary glucose excretion were lowest when these patients consumed the diet highest in simple carbohydrate content (20/80 diet). Since both measurements of glycemic control provided essentially similar results, there seems to be no apparent reason why patients with NIDDM should avoid naturally occurring foods that are high in simple carbohydrates.

Since these findings appear to be at odds with currently accepted beliefs concerning the dietary treatment of NIDDM, it is incumbent on us to carefully consider possible reasons to account for our apparent discordant results. In this regard, we feel that at least two major issues must be addressed. First, dietary recommendations for patients with diabetes appear to be based on the belief that simple carbohydrate foods cause marked increases in plasma glucose response, and, thus, restriction of these simple carbohydrate foods is necessary to avoid wide excursions in plasma glucose concentrations. Despite the popular acceptance of this notion, it does not seem to be based on any large body of scientific evidence. In fact, data in support of this concept are seriously lacking, while evidence to the contrary is rapidly accumulating.[9,10] Nevertheless, this belief has become so entrenched in the clinical management of diabetes that virtually all dietary recommendations have included this concept.[1-3]

Second, there appears to be a general misunderstanding as to the composition of carbohydrate content. For example, a recent review on the dietary treatment of diabetes[3] states: "Simple carbohydrates are readily absorbed and cause hyperglycemia . . . . Such carbohydrates should compose 15 percent or less of the total dietary carbohydrate." Although this seems to be a reasonable recommendation based on current dogma with respect to the metabolic consequences of simple carbohydrates, it is not at all consistent with our current understanding of the composition of carbohydrate-rich foods. All of the carbohydrate in fruits and dairy products, and 50% to 100% of the carbohydrate in vegetables, is present as simple (mono- and disaccharides) carbohydrates. As such, the current American diet contains approximately a 50/50 distribution of complex and simple carbohydrates.[11,12] Thus, extreme limitations of fruits, vegetables, and dairy products would be necessary to restrict simple carbohydrates to 15% of total carbohydrates. For example, the extent of the dietary manipulations necessary to achieve 80% complex/20% simple carbohydrate diet is illustrated in Table 3.

Although the current results appear to be in conflict with the traditional concept as to the metabolic effects of simple and complex carbohydrates, they are quite consistent with recent data concerning the fact that plasma glucose and insulin responses to simple carbohydrates can vary widely as a function of the source of dietary carbohydrate. Crapo et al.[9] have documented lower plasma glucose and insulin responses to the ingestion of fructose when compared with glucose in well-controlled diabetic patients. Their observation helps to explain our results, since the constituent carbohydrates used in these diets changed from predominantly glucose to fructose when the complex to simple carbohydrate ratio was reduced from 80/20 to 20/80.

Another possible variable that could have contributed to

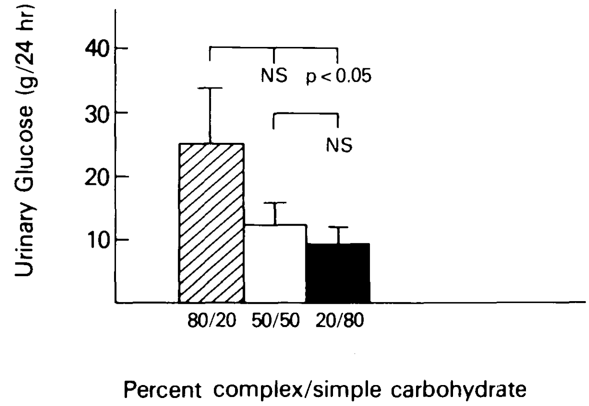

FIGURE 3. Mean (± SEM) urinary glucose excretion in 12 patients with NIDDM fed diets varying in the relative proportions of complex to simple carbohydrate.

our results is the fiber content of the diets. The 80% complex/20% simple carbohydrate diet contained less fiber, and provided only 56% (8.3 g/1000 kcal) of the dietary fiber content of the 20% complex/80% simple diet (14.9 g/1000 kcal), and these differences in the dietary fiber content could have produced the small difference (11%) in integrated glucose areas between the two diets. Thus, an alternative explanation for the decreased glucose response on the diet containing the most simple carbohydrate (20/80) could be formulated on difference in dietary fiber content.

Parenthetically, consideration of dietary fiber content in these diets illustrates an important point with regard to the association of dietary fiber and type of carbohydrate in present dietary patterns. That is, those foods in the American diet that provide the greatest amounts of dietary fiber (fruits and vegetables) contain the largest percentage of carbohydrate as simple, and conversely those containing essentially all complex carbohydrates (pasta, white rice, and refined breads) contain much less dietary fiber. Thus, if patients took seriously the goal of increasing consumption of both fiber and complex carbohydrates, they might find the advice somewhat confusing.

Finally, some comment on the significance of these findings in terms of the dietary management of diabetes is in order. The fact that the plasma glucose response area was significantly higher during the 80/20 diet indicates that differences in day-long glucose concentrations existed between these diets. The magnitude of this difference in quantitative terms (11% at most) was extremely small, and of questionable significance. Indeed, it could be argued that these relatively small differences observed in acute glucose response may not persist. Nevertheless, the present study demonstrates that diets differing widely in the percentage of naturally occurring, simple and complex carbohydrates resulted in essentially similar day-long glucose and insulin concentrations. Future dietary recommendations favoring restriction of foods on the basis of complex and simple carbohydrate content are not supported by these data. It is important to note, however, that the effects of the addition of refined simple carbohydrates were not included in these studies. Further studies are necessary to define the role of refined sugars on overall metabolic control in NIDDM.

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