Effects of Breakfast Cereals Containing Various Amounts of β-Glucan Fibers on Plasma Glucose and Insulin Responses in NIDDM Subjects

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OBJECTIVE — To determine whether increasing doses (amounts) of β-glucan present in an extruded breakfast cereal affect the glycemic and insulinemic responses in eight NIDDM subjects, compared with the same responses after a continental breakfast (bread, milk, cheese, ham).

RESEARCH DESIGN AND METHODS — Breakfast cereals were produced using various proportions of oat bran enriched in fiber, which contain an unusually high amount of a viscous polysaccharide, called β-glucan, and oat bran. The carbohydrate load was 35 g.

RESULTS — The maximum increases observed in plasma glucose after the breakfast cereal were 67% ($P < 0.05$), 42% ($P < 0.001$), and 38% ($P < 0.001$) with 4.0, 6.0, and 8.4 g β-glucan, respectively, compared with the continental breakfast. There was a linear inverse relationship between dose of β-glucan and plasma glucose peak or area under the glucose curve ($R^2 = 0.94$, $P < 0.05$). Postprandial insulin increase was only 59–67% ($P < 0.01$) as high as the continental breakfast after all three levels of β-glucan.

CONCLUSIONS — The 50% decrease in glycemic response that was observed after the ingestion of 35 g carbohydrate is estimated to occur with ~5 g β-glucan. This dose of β-glucan can easily be attained without the loss of taste by incorporating oat bran concentrate in products.

The plasma glycemic and insulinemic responses produced by the ingestion of a fixed carbohydrate load vary markedly according to the type of food consumed (1,2). Most of the cereal products have a higher rating on the glycemic index (GI) with some exceptions: 67 for bran buds with psyllium (43% fiber) and 72 for oat bran. Among breads, pumpernickel is rated the lowest at 66. Lower values are very difficult to reach and necessitate the use of crushed or flaked cereal grains (3–5).

The attenuation of the glycemic response to a meal can be achieved by the addition of viscous fibers (6), and long-term beneficial effects were obtained with diets that were supplemented with polysaccharide gums such as pectin, guar, or psyllium (7,8). The level of viscous polysaccharide intake ranged from 4 to 50 g, but guar was used essentially between 4 and 10 g. The effect was clearly dose dependent, as shown by Wolever et al. (9), who measured the GI of breakfast cereals enriched with four different amounts of psyllium, and Wood et al. (10), who has shown that there was a highly significant inverse linear relationship between plasma glucose and insulin response and the log viscosity of oat gum dissolved in water.

Oat contains a viscous fiber, β-glucan, that is a linear polysaccharide, (1–3)(1–4)-β-D-glucan, and that has swelling and viscosity properties similar to guar. It is found in normal rolled oats at ~4%, in commercial oat bran at 7–9%, and can be as high as 19% in specially processed bran fractions (11).

The aim of this study was to determine the relationship between the β-glucan content of a meal and the plasma glycemic and insulinemic responses in NIDDM subjects. For this purpose, NIDDM subjects received, on three separate occasions, a breakfast prepared with cooked extruded oat bran concentrate. Each of these cereal breakfasts provided the same amount of carbohydrate but had a β-glucan content ranging from 4 to 8.4 g. The glycemic and insulinemic responses were compared with those observed after ingestion of a continental breakfast (0 g β-glucan).

RESEARCH DESIGN AND METHODS

— Eight subjects with NIDDM were recruited at the diabetes clinics of the Polyclinique Médicale Universitaire, Lausanne. The subjects' anthropometric characteristics and clinical data are shown in Table 1. One subject was treated with diet alone, two with metformin, and five with metformin and a sulfonylurea. The experimental protocol was approved by the Ethical Committee of the Department of Internal Medicine, Hôpital Cantonal Universitaire Vandois, Lausanne, and each subject provided informed written consent.

Each subject was studied on four separate occasions. Experiments took place at the Polyclinique Médicale Universitaire and began in the morning after a 10- to 12-h fast. An indwelling cannula was inserted into an antecubital vein and was kept open with a slow drip of normosaline. This cannula served for the periodic withdrawal of blood samples. One of four breakfasts was consumed on each occasion. The composition of these four breakfasts is given in Table 2. The order in which the different breakfasts were served

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ANOVA, analysis of variance; GI, glycemic index.

Table 1—*Patient characteristics*

Patient	Sex (M/F)	Age (years)	Weight (kg)	Height (cm)	BMI (kg/m^2)	Duration of diabetes (years)	HbA_{1c} (%)
1	M	49	115.1	172	38.9	8.0	6.5
2	M	63	99.9	177	31.9	12.0	9.0
3	M	58	70.0	176	22.6	0.25	4.8
4	M	58	96.4	179	30.1	1.0	5.7
5	M	65	83.0	185	24.3	10.0	6.8
6	M	34	73.0	169	25.6	4.0	4.2
7	F	65	85.2	164	31.7	6.0	5.2
8	M	57	93.1	172	31.5	8.0	9.2

was varied for each subject (Latin square design). Blood samples were collected on two occasions in the basal state (−10 and 0 min) and every 30 min during the 4 h following ingestion of the breakfasts.

The breakfasts were composed of the extruded cereal enriched in fiber, including β-glucan consumed in 100 ml milk with 3 g table sugar (Table 2). They provided 35 g carbohydrate (expressed as hexose). The continental breakfast had its composition adjusted to match the proximal composition of the test meal with the median β-glucan concentration.

Plasma glucose was measured by the glucose oxidase method (Beckman Glucose Analyzer II) and plasma insulin measured by radioimmunoassay (12). Incremental glucose and insulin areas (0–240 min) were calculated as described previously, and concentrations below baseline were set as zero (13).

A mixture of oat flour, oat bran concentrate containing 15% β-glucan, and corn starch was cooked extruded on a Clextral BC 21 extruder. The conditions of extrusion were set to minimize β-glucan breakdown that would affect its rheological functionality and, consequently, its impact on the metabolic response to this meal.

The β-glucan content in the cereal was adjusted by varying the ratio of oat bran concentrate to oat flour so that one portion of 27 g of starch had 4.0, 6.0, or 8.4 g β-glucan (Table 2). For example, the breakfast cereal of meal 2 was made from 79% oat bran concentrate, 11% oat flour, and 7% starch (Ultratex, National Starch).

The oat bran concentrate (batch 4075) was provided by Swedish Protein AB, Väröbacka, Sweden, and contained 24.7% protein, 6.6% lipid, 32% carbohydrate, and 32.3% fiber (including 14.9% β-glucan) on a dry matter basis.

Analytical techniques

β-glucan in the extruded cereals was analyzed following the method described by McCleary and Nurten (14).

The cereals and bread were milled, and one-tenth of the amount given to the subjects was suspended in 100 ml of 10 mmol/l sodium phosphate buffer, pH 6.9 at 37°C. Starch was digested by adding 8 mg pancreatin (Sigma, St. Louis), and the suspension was stirred for 1 h at 37°C. The viscosity was measured at this temperature with a Bohlin VOR rheometer (C25 coaxial cylinder, 58^{s-1} shear rate).

Calculations and statistics

The area under the plasma glucose and insulin curves, calculated over a maximum of 4 h, and the maximal concentrations observed after ingestion of the meal were recorded for each experiment. Plasma glucose concentrations were expressed as incremental from baseline. Comparisons of means between breakfasts were performed with analyses of variance (ANOVAs) for repeated measures and followed by a multiple comparison LSD (least significant difference) test. Data were expressed as means ± SE.

Table 2—*Composition of the test meals*

	Composition	Quantity (g)	Energy (kcal)	Protein (g)	Lipid (g)	Carbohydrate (g)	Fiber (g)	β-glucan (g)	Viscosity (mPas)
Meal 1	Wholemeal								
	Bread	66	143	6.1	1.7	28	5	0	1.2
	Low-fat ham	28	34	5.4	1.3	—	—	—	
	Low-cal jam	30	7	—	—	2	—	—	
	Milk	100	35	3.3	0.1	5	—	—	
	Total	224	219	14.8	3.1	35	5	0	
Meal 2	Cereal	50	173	8.5	3	27	9.3	4	100
	Milk + sugar	103	35	3.3	0.1	8	—	—	
	Total	153	208	11.8	3.1	35	9.3	4	
Meal 3	Cereal	58	189	11.5	3.4	27	14.3	6	280
	Milk + sugar	103	35	3.3	0.1	8	—	—	
	Total	161	224	14.8	3.5	35	14.3	6	
Meal 4	Cereal	67	203	13.6	4	27	18.3	8.4	665
	Milk + sugar	103	35	3.3	0.1	8	—	—	
	Total	170	238	16.9	4.1	35	18.3	8.4	

Table 3—*Metabolic effects*

	Continental	4.0 g β-glucan	6.0 g β-glucan	8.4 g β-glucan
Plasma glucose (mmol/l)				
Basal	9.4 ± 1.0	9.5 ± 1.3	9.5 ± 1.1	9.5 ± 1.1
Delta max	3.8^a ± 0.4	2.6^b ± 0.5	1.6^c ± 0.2	1.5^c ± 0.3
	(100^a)	(67^b ± 10)	(42^c ± 4)	(38^c ± 7)
Area under curve (4 h)	6.8^a ± 1.2	4.7^a ± 1.1	2.8^b ± 0.6	2.5^b ± 0.6
(above basal value)	(100)	(71 ± 15)	(41 ± 6)	(35 ± 7)
Plasma insulin (mU/l)				
Basal	22 ± 5	24 ± 6	20 ± 6	22 ± 6
Max	69^b ± 14	46^c ± 10	43^c ± 10	41^c ± 10
	(100)	(67 ± 14)	(62 ± 14)	(59 ± 14)

Data are means ± SE. Numbers in parentheses indicate the relative values compared with the continental breakfast. Values with different superscripts are significantly different: $^{a,b}P < 0.05$; $^{b,c}P < 0.01$; $^{a,c}P < 0.001$.

RESULTS

Compared with a standard continental breakfast, all three cereal meals significantly decreased the peak and the average glucose and insulin increments (Table 3). The area under the response curve and the maximum increase of glycemia for 4 g β-glucan is 33% lower than for the continental breakfast ($P < 0.05$), but with 6.0 and 8.4 g, they reached around 60% ($P < 0.001$). All three doses of β-glucan reduced the insulin increment by approximately 35% ($P < 0.05$), compared with the continental breakfast. Significant attenuation of the insulin increase has already been reported with glucose solution (15) and bread (16) that were supplemented with guar. Our results suggest that the maximum effect of the hydrocolloid can already be achieved with 10% (6 g) β-glucan in the cereal.

Each breakfast cereal dispersed in water generated a different viscosity in relation to the β-glucan concentration (Table 2). There were significant inverse linear relationships between plasma glucose peak or area under the glucose curve (R^2 = 0.94, $P < 0.05$) and the amount or percent of β-glucan in the cereals, or log viscosity of β-glucan, measured as described above. These results confirm those reported by Wood et al. (10) and Wolever et al. (9) with healthy volunteers who consumed oat gum drinks or cereal flakes containing varying amount of psyllium, respectively.

Braaten et al. (17) recently reported that an oat bran meal containing 7–8% β-glucan (on weight of cereal) given as a porridge to diabetic subjects produced a similar attenuation of the glycemic peak as our extruded cereals containing the same concentration of β-glucan. The level of β-glucan found in normal oat flakes used to make the porridge is only 4%, which is too low to produce more than a 10% reduction in the blood glucose and insulin responses (5). The high potency of the β-glucan in the enriched oat bran might be due to intimate mixing of the polysaccharide in the bran flour and to its high solubility generated by the extrusion process. After ingestion, β-glucan swells slowly and entraps other components of the food, thus creating a very high viscosity within the food particles.

The volunteers were asked to rate the incidence of flatulence that occurred 8 h after each breakfast meal. Three volunteers rated high incidence after eating the cereals that contained 6.0 g β-glucan and five after the 8.4 g β-glucan meal. One volunteer also complained after the continental breakfast and the cereals with 4.0 g β-glucan.

CONCLUSIONS— The use of foods enriched with β-glucan, especially at breakfast, is obviously of potential interest in several clinical conditions, including IDDM and NIDDM patients, to reduce hyperglycemia and insulin need (18) and also in obese and dislipidemic subjects to reduce postprandial insulin. This may reduce other cardiovascular risk factors potentially linked with insulin, such as the activity of the sympathetic nervous system, blood pressure, plasma triglycerides, and/or cholesterol (19).

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