Metabolic Effects of Insoluble Oat Fiber on Lean Men with Type II Diabetes

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ABSTRACT

Oat products rich in water-soluble fiber improve glucose metabolism and lower serum cholesterol. To examine the safety, tolerance, and metabolic effects of a water-insoluble oat-hull fiber, eight lean men with non-insulin-dependent (type II) diabetes consumed a traditional diabetes diet for one week, followed by a control diet plus 30 g/day of insoluble oat fiber for two weeks in a hospital metabolic ward. On discharge, the subjects resumed their normal diet plus 30 g/day of insoluble oat fiber for an additional 10 weeks. The oat fiber was well accepted and produced no serious side effects. The hospital oat-fiber diet decreased fasting serum glucose levels by 13% ($P < 0.05$), low-density lipoprotein cholesterol by 8.9% ($P < 0.05$), and apolipoprotein B-100 by 17% ($P < 0.01$). Other serum lipid levels did not change significantly, and values returned to pretreatment levels during the ambulatory phase. Insoluble oat fiber may have beneficial metabolic effects in persons with type II diabetes, but further research is required to clarify these effects.

Dietary fiber offers therapeutic advantages for persons with diabetes (Anderson et al 1987). Water-soluble fibers such as oat products (Anderson and Gustafson 1988), guar (Jenkins et al 1980, Aro et al 1981), pectin (Jenkins 1979, Cerda et al 1988), and psyllium (Anderson et al 1988, Bell et al 1989) have specific cholesterol-lowering effects. They lower serum cholesterol, whereas water-insoluble fibers such as wheat bran do not (Anderson and Chen 1979).

Water-soluble fibers have a favorable effect on postprandial glycemia (Jenkins et al 1977, 1978; Fuessl et al 1986; Schwartz et al 1988), whereas water-insoluble fibers do not. Longer-term improvement of diabetes with fiber supplements has occurred with soluble (Cohen et al 1980) as well as insoluble fibers (Bosello et al 1980). Thus, the effects of water-insoluble fibers on diabetes are not well delineated.

This study of men with type II diabetes was designed to assess the safety, tolerance, and metabolic effects of a previously untested insoluble oat fiber in a hospital and an ambulatory setting. A similar insoluble oat fiber fed to rats had no significant effect on metabolic parameters (Lopez-Guisa et al 1988). Our findings demonstrate significantly lowered levels of serum glucose and low-density lipoprotein cholesterol (LDL-C) with consumption of oat-hull fiber during the hospital phase but not during the ambulatory phase of the study.

MATERIALS AND METHODS

Subjects

The subjects—eight lean men with type II diabetes—were admitted to the hospital metabolic research ward. Their baseline levels of serum cholesterol and triglyceride were 4.55–7.25 and 1.50–4.70 mmol/L, respectively. They were 30–70 years of age (mean, 62 years) with body mass indexes of less than 30 (body mass index = kg/m^2). All eight had had non-insulin-dependent (type II diabetes) for more than one year; four had cardiovascular disease and four had hypertension. Subjects with a history of liver or kidney disease, which might have interfered with interpretation of results, were excluded from the study.

Five subjects used diet alone for diabetes therapy and three used diet plus an oral agent (tolazamide, 250 mg three times per day; glyburide, 5 mg twice per day; or glipizide 2.5 mg twice per day). Other medications included enzyme inhibitors (two subjects), thiazides (two subjects), and beta blockers (two subjects). Potential candidates for the study were identified through the data base of the endocrine clinic at the Veterans Administration Medical Center (Lexington, KY). The study was approved by the research committee of the medical center the Human Investigation Subcommittee of the University of Kentucky. All subjects signed an informed consent statement before beginning the study.

Study Design

This was a self-controlled clinical study to investigate the safety, tolerance, and metabolic effects of an insoluble oat-fiber product for men with type II diabetes. For the hospital phase of the study, the subjects completed a one-week control diet and then continued for two weeks on the control diet plus 30 g/day of oat fiber. The men were ambulatory during the hospital phase and maintained their usual levels of physical activity. They were then discharged from the hospital and continued on a self-controlled weight-maintainance diabetes diet that included 30 g/day of oat fiber for an additional 10 weeks.

Diets

During the hospital phase, control and test diets resembled a typical American diet (Anderson et al 1989), with approximately 43% of energy as carbohydrate, 16% protein, 41% fat, and 350 mg/day of cholesterol. The diets provided 26.5 kcal/kg of body weight; this amount was increased or decreased by 300 kcal/day if weight changed more than 1 kg during the control period. The control diet provided about 8 g of dietary fiber per 1,000 kcal. The control and test diets, which included 30 g/day of oat fiber, were isocaloric and identical in composition.

Oat-fiber muffins were introduced gradually, beginning with one muffin on the first day and increasing by one muffin daily to a total of four muffins by the fourth day. Neither diet contained other high soluble fiber sources, such as oat products or dried beans. Diet composition was analyzed using a computerized nutrient data base (North and North 1988).

During the ambulatory phase, the subjects followed their usual diabetes diet but continued to include four oat-fiber muffins, which provided 30 g/day of oat fiber. The oat-fiber product (Better Basics White Advanced Oat Fiber) was provided by Williamson Fiber Products, Inc., Louisville, KY. This product, derived from oat hulls, was processed into elongated strands as opposed to granular particles. The processing resulted in a network of fibrous strands with an increased surface area.

Hospital Studies

Fasting serum glucose, cholesterol, and triglycerides and 24-hr urine glucose excretion were measured on admission to the hospital and daily during control and oat-fiber-supplemented diets. Serum levels of high-density lipoprotein cholesterol (HDL-C) and LDL-C were measured on admission and on the last three days of the control and test diets. Liver function tests, blood chemistries, and serum levels of apolipoprotein (apo) A-1 and

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B-100, total iron-binding capacity, iron, and zinc were measured on admission and at the end of each diet. Insulin sensitivity was also assessed at the end of each diet by using the frequently sampled intravenous glucose tolerance test of Bergman (Chen et al 1985). Blood pressure was measured three times daily. Body weights were recorded every morning. Food served and returned was weighed in the metabolic kitchen for calculation of nutrient, energy, and fiber intake.

All stools were collected, weighed, labeled, refrigerated, and then frozen at −20°C to assess gastrointestinal function. Both wet and dry stool weights were analyzed. Intestinal transit time was measured once on each diet using the Hinton method (Hinton et al 1969). A comprehensive questionnaire on gastrointestinal changes was given to the subjects on each diet.

Ambulatory Studies

After discharge from the hospital, the subjects returned for ambulatory clinic visits every other week for 10 weeks. Body weight, blood pressure, and fasting levels of serum glucose, cholesterol, triglycerides, and glycohemoglobin were measured at each visit. Levels of serum apos A-1 and B-100, HDL-C, LDL-C, zinc, iron, and total iron-binding capacity were measured at the last ambulatory visit. Each subject completed a gastrointestinal questionnaire at the second and last ambulatory visits. A two-week supply of oat-fiber muffins was distributed at each visit, and subjects were instructed to return uneaten muffins.

Measurements

Serum was analyzed for total cholesterol (Allain et al 1974), HDL-C (Finley et al 1978), and triglyceride concentrations (Bucolo and David 1973). LDL-C values were calculated (Friedewald et al 1972), and glucose was analyzed as previously described (Roy and Theigs 1974). Apos A-1 and B-100 were evaluated using single radial immunodiffusion kits (Diffu-Gen, Tago Inc., Burlingame, CA) by modifying the technique of Mancini et al (1965). Glycosylated hemoglobin was measured by the Corning electrophoresis method (Glycosylated Hemoglobin Set, Palo Alto, CA). Other serum chemistries were measured using a spectrum analyzer (Abbott Laboratories, North Chicago, IL).

Transit time was determined by documenting the time between ingestion of 40 radiopaque pellets and passage of 80% of the pellets. The appearance of the pellets in the stool was observed by serial radiographs. In the laboratory, collected stool samples were reweighed for wet weight and then lyophilized to determine dry weight measurements (Hinton et al 1969). The frequently sampled intravenous glucose tolerance test was performed as previously described (Chen et al 1985).

Statistics

Results were evaluated by a series of paired t tests on a statistical software program (Wilkinson 1988). Statistical means for all measurements were computed by averaging the last three days on each of the inpatient diets. A Fisher's exact test was used to analyze the results of the gastrointestinal questionnaire.

RESULTS

Hospital Phase

Except for fiber intake, nutrient intake on control and test diets (Table I) were similar and did not vary more than one standard deviation. Fasting serum glucose levels decreased significantly ($P < 0.05$) by 13% on the test diet (Table II), and urine glucose responses decreased in six subjects. Mean values decreased from 25 g/day on the control diet to 11 g/day on the test diet, although the average decrease was not significant because of the large variation in the quantity of glucose excretion. The k values (the percent of serum glucose fall per min) were measured to assess the frequently sampled intravenous glucose tolerance. Control k values averaged 0.37 and increased more than 16% to 0.42.

LDL-C levels decreased significantly ($P < 0.05$) by 8.9% on the test diet (Table II); HDL-C levels remained virtually unchanged (Table III). Total serum cholesterol levels decreased 7% on the test diet. Serum triglyceride levels remained virtually unchanged between the control and test diets. In the five men for whom serum apo measurements were available, apo A-1, a major component of HDL-C, increased slightly but not significantly. Apo B-100, a major component of LDL-C, decreased significantly ($P < 0.01$) by over 17%.

Body weight remained constant during control and test diets (Table III). Mean blood pressure decreased slightly but not significantly during the test diet, averaging 130/77 mm of Hg on the control diet and 127/75 mm of Hg on the test diet. Serum mineral responses—zinc, iron, and total iron-binding capacity—were all within the normal range and did not significantly change from the control to the test diet.

Stool wet weights increased from an average of 149 g/day on the control diet to 194 g/day on the test diet. Stool dry weights increased from 30 g/day on the control diet to 47 g/day ($P < 0.025$) on the test diet. Transit time decreased from 72 hr on the control diet to 63 hr on the test diet. Transit time could be determined in only five subjects; three were excluded because 80% of the markers did not go through the digestive system within five days, probably because of incomplete self-collection of stools. Although not significant, subjects reported an increase in bloating, cramping, and diarrhea and a decrease in constipation and abdominal gas on the test diet compared with the control diet. The oat-fiber muffins were well accepted; the subjects ate a mean of 96.6% of the muffins.

TABLE I
Nutrient Intake of Eight Lean Men with Type II Diabetes on Control and Oat-Fiber Diets[a]

Nutrient	Diet: Control	Diet: Oat Fiber
Energy, kcal	2511 ± 106	2,373 ± 69
Protein, g	101 ± 4	95 ± 3
Carbohydrate, g	270 ± 11	254 ± 7
Simple	131 ± 6	126 ± 4
Complex	135 ± 5	127 ± 4
Fat, g	115 ± 6	108 ± 3
Saturated	34 ± 3	30 ± 2
Monounsaturated	53 ± 3	47 ± 1
Polyunsaturated	24 ± 1	26 ± 1
Cholesterol, mg	347 ± 2	333 ± 10
Total fiber, g	19.8 ± 1	47 ± 1
Soluble fiber, g	6.0 ± 0.3	6.9 ± 0.2

[a]Values are the mean ± standard error of the mean of the last five days on each diet, which are representative for nutrients consumed throughout the study.

TABLE II
Serum Glucose and Low-Density Lipoprotein Cholesterol (LDL-C) Responses to Control and Oat-Fiber Diets in Eight Lean Men with Type II Diabetes (Hospital Phase)[a]

Subject	Glucose (mmol/L) Control (week 0)	Glucose (mmol/L) Oat Fiber[b] (week 3)	LDL-C (mmol/L) Control (week 0)	LDL-C (mmol/L) Oat Fiber[c] (week 3)
1	13.3	12.8	2.80	3.00
2	6.3	6.5	3.00	2.45
3	7.7	7.2	3.75	3.00
4	14.4	8.8	2.90	2.55
5	12.6	10.7	3.05	2.85
6	8.0	6.4	4.35	4.45
7	12.5	10.4	3.35	3.05
8	8.4	7.8	4.85	4.10
Mean	10.4	8.8	3.50	3.20
SEM[d]	1.1	0.8	0.25	0.25

[a]Values are the mean of the last three days on each diet.
[b]$P = 0.039$.
[c]$P = 0.036$.
[d]Standard error of the mean.

Ambulatory Phase

Fasting serum glucose levels rose during the ambulatory phase of the study and exceeded hospital control values by 8.7% after 10 weeks. Glucose levels sharply increased during the first two weeks and fluctuated by no more than 0.9 mmol/L for the next eight weeks. Serum glycohemoglobin values increased from 7.1 to 8.1%. The use of oral hypoglycemic agents remained constant for all subjects except subject 1, whose dose of tolazamide was gradually increased from 250 mg three times per day as an inpatient to 1,000 mg twice per day as an outpatient to control steadily rising serum glucose levels. He began insulin therapy on completion of the study.

Serum levels of total cholesterol, LDL-C, and triglyceride remained virtually unchanged during the ambulatory phase compared with hospital control values. HDL-C increased slightly (6%). Apo measurements were completed in five subjects. Apo A-1 values continued to be greater during the ambulatory phase than during the hospital phase. Apo B-100 values decreased by 7.8% compared with hospital control values.

Body weights fluctuated slightly but insignificantly; the largest difference in any subject was a 2-kg increase between the end of the hospital phase and the first visit of the ambulatory phase. This weight fluctuation was probably due to differences in weighing procedures. During the hospital phase, the subjects were weighed on an electronic scale before breakfast, wearing minimal clothing; during the ambulatory phase, they were weighed on a balance beam scale after breakfast, wearing heavier clothing.

Blood-pressure responses remained unchanged during the ambulatory phase compared with hospital control values. No significant changes in serum zinc or iron levels occurred during the ambulatory phase. Total iron-binding capacity at week 10 was 14% higher ($P < 0.025$) than during the hospital phase.

As in the hospital phase, the oat-fiber muffins were well accepted during the ambulatory phase as well; subjects consumed an average of 90.5% of the muffins. However, one subject had recurring diarrhea, which irritated his existing hemorrhoids. Muffins were completely discontinued for this man by the third ambulatory visit. Gastrointestinal responses were similar to those observed during the hospital phase. No significant changes in bloating, cramping, constipation, or abdominal gas were reported. Incidence of diarrhea remained unchanged compared with incidence during the hospital phase.

DISCUSSION

This study examined the safety, tolerance, and metabolic effects of an insoluble oat-fiber product processed from oat hulls. We found the oat fiber to be safe, with no serious side effects. Subjects tolerated the oat fiber well, as evidenced by high compliance in both phases of the study. Fasting serum glucose levels decreased significantly during the hospital phase but increased to levels above baseline during the first two weeks of the ambulatory phase. The controlled hospital environment may have enhanced these responses during the hospital phase. However, changes in serum LDL-C were not significantly correlated with changes in glucose.

Diabetic individuals are two to three times more likely to die from complications of coronary heart disease than are nondiabetic persons (Steiner 1981, Stout 1979). Thus, serum lipid levels should be aggressively managed in people with diabetes. In the present study, LDL-C levels decreased significantly during the hospital phase but returned to control values during the ambulatory phase. Most serum values returned to pretreatment levels during the ambulatory phase. A lack of a controlled diet or failure of subjects to return all uneaten muffins may have contributed to the rises in these levels.

Dietary fiber offers health benefits for most people (Kritchevsky 1988). Soluble fibers improve fasting and postprandial glucose values in diabetic individuals (Jenkins et al 1977, 1978, 1980; Fuessl et al 1986; Schwartz et al 1988). Certain soluble fiber-oat products, such as rolled oats and oat bran (Anderson and Bridges 1988), improve serum glucose and lipid levels in humans (Anderson et al 1984). The role of insoluble fiber in the improvement of blood glucose levels in persons with diabetes is less certain. It is sometimes difficult to distinguish between the effects of insoluble fiber and the effects of other factors that delay carbohydrate absorption, such as ingestion of foods that produce reduced glycemic responses (Wolever and Jenkins 1986, Wolever et al 1988). Insoluble fibers can reduce blood glucose in diabetic persons (Boscello et al 1980, Mayne et al 1982), but these reductions are often less pronounced then those observed with ingestion of soluble fibers (Wolever 1990). High-fiber diets containing a combination of soluble and insoluble fibers have been observed to delay glucose absorption (Rivellese et al 1980, Kay et al 1981).

The effect of insoluble fiber on serum lipid values in persons with diabetes also remains unclear. Insoluble fibers from wheat, soy, and apples improve serum cholesterol levels (Patel et al 1969, Mayne et al 1982, Lo et al 1986) in diabetic individuals. However, insoluble fiber from oats, such as oat hulls, did not significantly improve metabolic parameters when tested in rats (Lopez-Guisa et al 1988). Over time, a combination of soluble and insoluble fiber may best improve diabetes control (Simpson et al 1981, Ray et al 1983, Story et al 1985).

This study suggests that an insoluble oat fiber may have a beneficial effect on fasting serum glucose and LDL-C levels in persons with type II diabetes. However, significant decreases in these levels during the hospital phase were not maintained during the ambulatory phase. Further research is required to clarify the effects of insoluble oat fiber in both diabetic and nondiabetic persons.

TABLE III
Metabolic Responses to Oat Fiber in Eight Lean Men with Type II Diabetes[a]

	No. of Weeks						
	Hospital Phase		Ambulatory Phase				
Measurement	0	3	2	4	6	8	10
Glucose	10.4 ± 1.1	8.8 ± 0.8[b]	11.2 ± 1.3	11.4 ± 1.3	11.9 ± 1.7	12.6 ± 1.7	12 ± 1.4
Glycohemoglobin (%)	···	···	7.1 ± 0.6	7.1 ± 0.6	7.3 ± 0.6	8.3 ± 0.7	8.1 ± 0.5
Total cholesterol	5.50 ± 0.35	5.10 ± 0.30	5.35 ± 0.2	5.55 ± 0.20	5.40 ± 0.35	5.40 ± 0.50	5.40 ± 0.25
Triglycerides	2.78 ± 0.44	2.54 ± 0.26	2.62 ± 0.34	2.86 ± 0.34	3.02 ± 0.72	2.80 ± 0.42	2.70 ± 0.48
LDL-C[c]	3.50 ± 0.25	3.20 ± 0.25[b]	···	···	···	···	3.50 ± 0.35
HDL-C[c]	0.75 ± 0.05	0.70 ± 0.05	···	···	···	···	0.80 ± 0.05
Apoprotein A-1	91 ± 10	99 ± 11	···	···	···	···	102 ± 4
Apoprotein B-100	115 ± 20	95 ± 18[d]	···	···	···	···	107 ± 9
Body weight (kg)	86.8 ± 5.5	86.7 ± 5.4	88.7 ± 5.1	88.2 ± 5.4	88.5 ± 5.4	90.5 ± 5.6	90.6 ± 5.8

[a]Inpatient values represent the means of the last three days of each diet.
[b]Significantly different from control ($P < 0.05$).
[c]LDL-C = low-density lipoprotein cholesterol, HDL-C = high-density lipoprotein cholesterol.
[d]Significantly different from control ($P < 0.01$).

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