Original Research

Comparison of Hormone and Glucose Responses of Overweight Women to Barley and Oats

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Objective: To determine the effect of particle size (flour vs. flakes) on glycemic responses after oats and barley (Prowashonupana cultivar), which contain high amounts of soluble fiber, are consumed by overweight women.

Design: Ten women, average age 50 years and body mass index 30, consumed glucose (1 g/kg body weight) and four test meals (1 g carbohydrate/kg body weight; 2/3 of the carbohydrate from oat flour, oatmeal, barley flour, or barley flakes and 1/3 from pudding) in a Latin square design after consuming controlled diets for 2 days. Blood samples were collected at fasting and periodically after each meal.

Results: Peak glucose and insulin levels after barley were significantly lower than those after glucose or oats. Glucose areas under the curve (AUCs) after test meals compared with AUCs after glucose were reduced after both oats and barley (29–36% by oats and 59–65% by barley) ($p < 0.002$). Insulin AUCs after test meals compared with glucose AUCs were significantly reduced only by barley (44–56%) ($p < 0.005$). Indexes for insulin resistance (HOMA, MFFM, Cederholm) after the oat and barley meals were not different from indexes after the glucose meal. Glucagon and leptin responses did not significantly differ for the carbohydrates tested.

Conclusions: Particle size of the oats or barley had little effect on the glycemic responses. Both oat and barley meals reduced glycemic responses; the high soluble fiber content of this barley appeared to be a factor in the greater reduction observed.

INTRODUCTION

A variety of fiber components, especially soluble fiber, have been reported to have beneficial effects on glucose tolerance, particularly on postprandial glucose and insulin concentrations in normal people and people with impaired glucose tolerance [1–7]. Beneficial health effects also include improving glycemic control in diabetes [7–9], decreasing the risk for developing diabetes [10,11], and reducing blood lipids [12,13]. Increased incidence of abnormal carbohydrate metabolism, elevated blood glucose or insulin levels, was reported with increasing age and weight [14,15]. Obesity, especially abdominal adiposity, appears to be a strong marker for insulin resistance in women [16]. Hyperinsulinemia, an indication of insulin resistance, is also an indicator of potentially developing type 2 diabetes [17]. Individuals who can no longer augment insulin secretion or use circulating insulin to meet increased demand after glucose or a high-glycemic food develop glucose intolerance, which can develop into type 2 diabetes [18].

Controlled human feeding studies conducted at the Beltsville Human Nutrition Research Center found that foods containing high amounts of soluble fiber (such as oats or Oatrim) lower blood glucose and insulin responses whether consumed chronically or acutely; higher levels of soluble fiber were more effective than lower levels in lowering blood sugar [4–6]. Health claims for oats state that oats are effective in lowering blood cholesterol levels. Four servings per day are recommended, each serving containing at least 0.75 g β-glucan (the soluble fiber in oats), totaling 3 g/d of β-glucan [19]. However, the amount of fiber necessary for health benefits is not consumed in the usual

Address reprint requests to: Kay M. Behall, Building 307B, BARC-East, Diet and Human Performance Laboratory, Beltsville Human Nutrition Research Center, ARS, USDA, Beltsville, MD 20705-2350. E-mail: behall@bhnrc.arsusda.gov. Prowashonupana barley flakes and flour and partial financial support were provided by ConAgra, Omaha, NE. Presented in part at the Diet and the Metabolic Syndrome International Symposium. Ystad, Sweden, August 26, 1999. Abbreviations: AUC = area under the curve, BMI = body mass index, HOMA = homeostasis model assessment, TSH = thyroid stimulating hormone.

diets of Americans. Median total dietary fiber intakes reported during 1988–1991 for men and women in the United States were 17.0 and 13.8 g/d, respectively [20], approximately half the suggested level of intake [21,22]. Increasing whole-grain products such as oats and barley in the diet would increase intakes of both total and soluble dietary fiber. The benefits in reduced glycemic response by incorporating oats or barley may vary with the particle size of the grain as it is consumed. This experiment compared the effects of standard oats and Prowashonupana barley flour and flakes on blood glucose and glucoregulatory hormone responses.

MATERIALS AND METHODS

Ten women, 28–58 years of age, were selected for the study after clinical analysis of fasting blood and urine samples and a medical evaluation of their health history (Table 1). Subjects were selected based on the following criteria: 1) being weight stable for 6 mo before the study, 2) having more than 25% body fat, 3) taking no medication known to alter glucose metabolism or lipid metabolism, 4) completing a health history questionnaire, and 5) being medically evaluated (i.e., screened for underlying disease by a routine urinalysis and blood screen). Subjects were excluded if they had an abnormal fasting glucose concentration, had evidence of an infection, or were hypertensive. Subjects were ask to discontinue any vitamin or mineral supplements for the duration of the study. Protocol and purpose of the study were explained to the subjects both orally and in writing.

The study was approved by the Institutional Review Board of The Johns Hopkins School of Public Health and the U.S. Department of Agriculture Human Studies Committee. Medical supervision was provided by the Division of Human Nutrition, The Johns Hopkins University Bloomberg School of Public Health. All subjects completed the study.

Subjects consumed a controlled standardized menu containing 30% fat, 55% carbohydrate, and 15% protein for 2 d before and the day of each carbohydrate test meal. The standard diet was designed to contain a moderately high percentage of carbohydrate without foods known to lead to colonic gas production. The menu was identical during each of the five periods. Subjects were required to consume all foods presented and no others except for noncaloric beverages, salt, and pepper, the intakes of which were recorded. Subjects received and consumed the same amount of energy, which was based on their body weight, during all five periods. Nutrient content of the menu was similar to dietary recommendations [22].

Table 1. Baseline Characteristics of the 10 Subjects

Age (y)	50.1 ± 7.7 (37–60)*
Height (cm)	163.3 ± 12.0 (146–183)
Weight (kg)	88.7 ± 11.6 (69.4–102.5)
BMI†	30.3 ± 2.2 (25.8–32.9)

* Range.

† Body Mass Index = weight/height^2.

Fasting blood samples were collected after a 10-h fast. Subjects then consumed glucose (1 g/kg body weight) and four test breakfast meals consisting of 0.33 g/kg body weight of carbohydrate from pudding (predominantly sucrose) and 0.67 g/kg body weight of carbohydrate from oat flour, oatmeal, barley flour, or barley cereal for a total of 1 g carbohydrate/kg body weight. Treatment order was based on a Latin square design with an 11-d washout period. The test meals were weighed for each subject and cooked (in a microwave oven) with water the day of the tolerance test. Water used for cooking and for drinking during consumption of the test meals equaled the volume (3 g/kg body weight) consumed during the glucose tolerance test. Subjects were asked to consume the test meals within 10 min. Total carbohydrate averaged 73.7 and 76.1 g/test for oats and barley, respectively. β-Glucan consumption averaged 3.23 g for oat test meals and 12.1 g for barley test meals. Cereals (oatmeal, oat flour, barley flakes, and barley flour), β-glucan, and nutrient analysis (Table 2) were provided by ConAgra, Omaha, NE.

Blood samples were collected at fasting and at 30, 60, 120, and 180 min after the acute loads. Blood was centrifuged and plasma was separated and stored at −80°C until analyzed. Plasma was analyzed for glucose, insulin, glucagon, and thyroid-stimulating hormone (TSH). Glucose was determined on an automated spectrophotometric system (CentrificChem System 500, Union Carbide, Trace-America, Miami, FL). Insulin (ICN Biomedicals, Inc., Irvine, CA), glucagon, TSH (Diagnostics Products Corporation, Los Angeles, CA) and leptin (Linco Research, St. Charles, MO) were determined by radioimmunoassay. Two-hour-response area under the curve (AUC) was calculated by using the method of Gannon and Nutall [23], which uses postprandial differences above fasting concentrations for glucose and insulin.

Insulin resistance was calculated using the homeostasis model assessment (HOMA = $\text{insulin}_{\text{uU/ml}} \times \text{glucose}_{\text{mmol/L}}/22.5$) [24], Cederholm [$IR_{\text{Cederholm}}$ = m/mpg/log10(msi)] [25], and a method using a published index of glucose disposal rate corrected for fat-free mass based on fasting insulin and triglyceride concentrations (MFFM = EXP[2.63 − 0.28 × (log $\text{insulin}_{\text{nmol/L}}$) − 0.31 × (log $\text{triacylglycerol}_{\text{mmol/L}}$)]) [26]. Data were analyzed statistically with a mixed-models procedure for repeated-measures analysis of variance (PCSAS, version 8.2, SAS Institute, Cary, NC). Data were evaluated for the main

Table 2. Nutrient Value of Test Foods Grains (g/100 Dry Weight)

	Oats	Barley
Carbohydrate	67	70
β-Glucans	4	15
Protein	16	16
Fat	6	4
Moisture	9	9
Ash	2	2

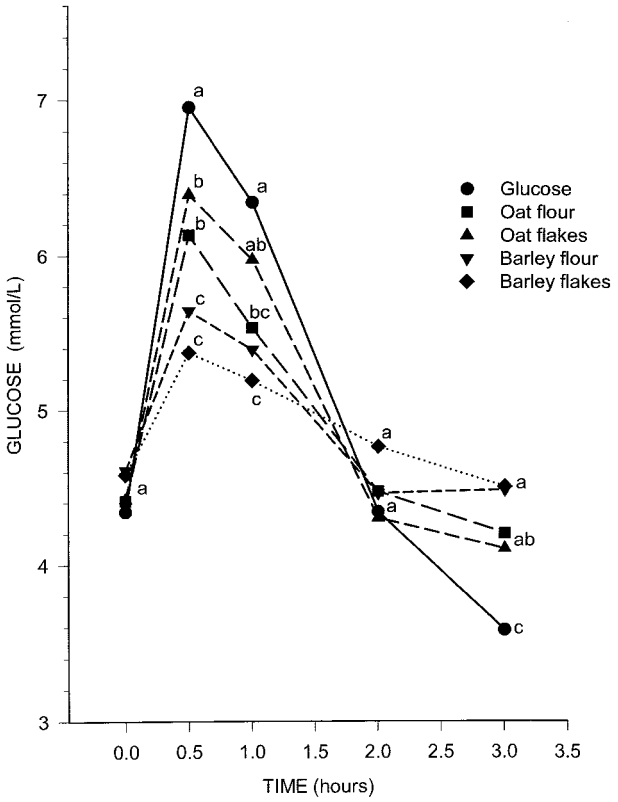

Fig. 1. Glucose response of 10 subjects to tolerance tests for glucose or grains. Least-square means ± SEM. Glucose was significantly different by time ($p < 0.0001$) and treatment-by-time interaction ($p < 0.002$).

effects of particle size (glucose, flakes, and flour), response (time), and period. Insulin values were log transformed for homogeneity. Data are reported as least-squares means and standard errors of the means (SEMs) and differences between groups were determined by least significant differences using the critical level of significance of $p < 0.05$.

RESULTS

No effects of the order of consumption of the five test meals were observed in glucose, insulin, glucagon, or leptin responses. Fasting glucose concentrations were significantly higher in the obese (body mass index [BMI] > 30.0, n = 6) than in the overweight (BMI 25–29.9, n = 4) subjects: 5.09 ± 0.14 *vs.* 4.78 ± 0.17 mmol/L ($p < 0.014$). Significant differences among the responses to the meals were observed for plasma glucose (treatment-by-time interaction, $p < 0.002$) (Fig. 1). Peak glucose concentrations occurred 0.5 h after the test meal regardless of the carbohydrate source. Peak glucose concentrations after both oat products and both barley products were significantly lower than that for glucose. Peak glucose responses within a grain (oat flakes *vs.* oat flour or barley flakes *vs.* barley flour) were not significantly different. The 2-h glucose AUC above fasting was significantly ($p < 0.002$) lower after both grains than after glucose (Table 3). Glucose AUC responses after test meals compared with after glucose were reduced 28–36% by oats and 59–65% by barley. Within a grain, glucose responses were not significantly different.

Fasting insulin concentrations were not significantly different ($p < 0.271$) between the overweight (50.3 ± 20.8 nmol/L) and obese (80.3 ± 17.0 nmol/L) subjects. Significant differences were observed in plasma insulin between the glucose tolerance test and grain meals (treatment-by-time interaction, $p < 0.001$) (Fig. 2). Peak insulin concentrations occurred 1 h after the test load regardless of the carbohydrate consumed, and concentrations after barley were significantly lower than those after glucose. Peak insulin responses within a grain were not significantly different. The insulin AUCs were significantly ($p < 0.005$) lower after the barley products (44–56%) than after glucose or either oat product (6–13% lower than glucose) (Table 3). No significant differences between the glucose and

Table 3. Fasting, Area under the Curve (AUC), and Calculated Insulin Resistance Values after the Glucose and Grain Meals*

	Meals					ANOVA
	Glucose	Oat Flour	Oatmeal	Barley Flour	Barley Flakes	
Fasting glucose (mmol/L)	4.29 ± 0.13	4.47 ± 0.13	4.43 ± 0.13	4.62 ± 0.13	4.51 ± 0.13	$p = 0.289$
Fasting insulin (pmol/L)	69.8 ± 15.2	64.4 ± 15.2	60.8 ± 15.2	75.4 ± 15.2	66.3 ± 15.2	$p = 0.691$
Fasting glucagon (ng/L)	42.6 ± 4.7	51.0 ± 4.7	37.9 ± 4.7	51.8 ± 4.7	48.7 ± 4.7	$p = 0.204$
Fasting leptin (μg/L)	14.0 ± 1.2	14.8 ± 1.2	13.0 ± 1.2	12.5 ± 1.2	11.6 ± 1.2	$p = 0.099$
Glucose AUC (mmol · min/L)†	171.4 ± 16.3^{a}	109.3 ± 16.3^{bc}	122.4 ± 16.3^{b}	70.0 ± 16.3^{cd}	60.6 ± 16.3^{d}	$p < 0.002$
Insulin AUC (nmol · min/L)	31.6 ± 3.1^{a3}	29.8 ± 3.1^{a}	27.6 ± 3.1^{a}	17.6 ± 3.1^{b}	13.8 ± 3.1^{b}	$p < 0.005$
Glucagon AUC (ng · min/L)	1510 ± 448	1090 ± 448	1530 ± 448	1177 ± 448	418 ± 448	$p = 0.424$
Leptin AUC (ng · min/L)	33.2 ± 36.3	17.6 ± 36.3	97.3 ± 36.3	30.3 ± 36.3	67.9 ± 36.3	$p = 0.506$
HOMA	1.93 ± 0.45	1.86 ± 0.45	1.90 ± 0.45	2.15 ± 0.45	1.89 ± 0.45	$p = 0.898$
MFFM	8.22 ± 0.22	8.27 ± 0.22	8.49 ± 0.22	8.17 ± 0.22	8.27 ± 0.22	$p = 0.055$
Cederholm	69.7 ± 6.2	64.6 ± 6.2	68.7 ± 6.2	68.0 ± 6.2	64.5 ± 6.2	$p = 0.719$

* Least-square means ± SEM. AUC based on plasma concentrations at 0–120 min.

† Within a row, values with different superscripts are significantly different ($p < 0.05$).

‡ Equations utilized for insulin resistant calculations obtained from cited references: HOMA [24], MFFM [26], Cederholm [25].

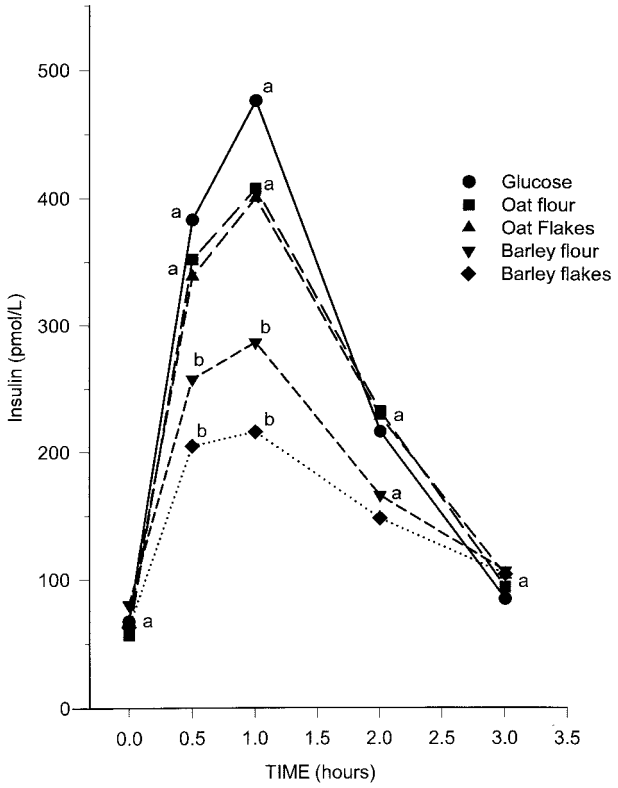

Fig. 2. Insulin response of 10 subjects to tolerance tests for glucose or grains. Least-square means ± SEM. Insulin was significantly different by time ($p < 0.0001$) and by treatment-by-time interaction ($p < 0.001$).

the oat or barley tolerance tests were observed in the HOMA, Cederholm, or MFFM indexes that included all subjects.

Calculated insulin resistance values based on the subject's fasting insulin values above (3 subjects) or below (7 subjects) 87.5 mmol/L are shown in Table 4. The subjects with high fasting insulin values were significantly different from subjects with low fasting insulin values by HOMA, Cederholm, and MFFM indexes. Analysis of insulin resistance showed no group-by-test interaction.

Fasting glucagon concentrations were significantly ($p < 0.041$) higher in the obese (50.9 ± 2.7 pmol/L) than the overweight (41.9 ± 3.3 ng/L) subjects. Fasting leptin concentrations were not significantly different ($p < 0.320$) between the obese (13.9 ± 1.3 ng/L) and the overweight (11.8 ± 1.6 nmol/L) subjects. The response of plasma glucagon but not leptin varied with time ($p < 0.007$ and $p < 0.14$, respectively). Glucagon averaged 46.3 ± 3.4 pmol/L at fasting and increased to 58.5, 56.6, 55.8, and 53.5 pmol/L at 0.5, 1, 2, and 3 h, respectively, after the tolerance test. No diet or diet-by-time interaction was observed for either glucagon ($p > 0.71$ and $p > 0.38$, respectively) or leptin ($p > 0.80$ and $p > 0.73$, respectively). AUCs for glucagon and leptin (Table 3) after the five carbohydrate meals were not significantly different ($p > 0.51$ and $p > 0.90$, respectively) in part because of the large standard error.

Table 4. Calculated Insulin Resistance Values by High and Low Fasting Insulin Values*

	Group		ANOVA
	High	Low	
HOMA†	3.19 ± 0.59[a]	1.41 ± 0.42[b]	$p < 0.020$
MFFM	7.68 ± 0.32[a]	8.54 ± 0.21[b]	$p < 0.033$
Cederholm	61.0 ± 5.8[a]	75.7 ± 3.8[b]	$p < 0.043$

* High group had fasting insulin concentrations above 87.5 mmol/L while the low group had fasting insulin concentrations below 87.5 mmol/L.

† Within a row, values with different superscripts are significantly different.

DISCUSSION

Numerous studies have examined the postprandial effects of consuming oats but few have reported glycemic response after barley consumption. Results of this study, in which oats and barley were fed as flour or flakes, indicate that the particle size of the oats and barley consumed had less effect on glycemic response than did the difference in soluble fiber content. Particle size has made a difference in glycemic response after consumption of meals containing wheat; higher plasma glucose and insulin responses (AUCs) were reported after consumption of a fine-ground flour meal than after meals of coarse flour or larger grain particles [27]. Obese subjects with ileostomies fed coarse and fine whole-meal flours had higher glucose and insulin response AUCs after the fine than after the coarse flour [28]. Similarly to the present study, particle size of whole wheat flour in bread did not significantly affect glucose or insulin AUCs [29]. Higher plasma insulin but not glucose response (peak concentrations and AUCs) was also reported after wheat-based meals containing fine *versus* coarse flour [30].

Particle size appears to exert the greatest effect on glycemic and insulin response when large food or grain particles are present. Jenkins *et al.* [31] reported a significant decrease in glycemic index (white bread baseline) when barley bread contained 50% (glycemic index of 62) and bulgur bread contained 75% (glycemic index of 69) or more of the available carbohydrate from barley kernels or cracked wheat kernels, respectively. Liljeberg *et al.* [32] observed significantly lower glycemic and insulin indexes after coarse bread products containing kernels from wheat, rye, or barley but not oats compared with white bread.

Soluble fiber from oats and other viscous fibers has generally been reported to improve glucose and insulin responses in normoglycemic and diabetic subjects [1–4,33]. Tappy *et al.* [34] reported that consumption of soluble fiber from oats by diabetics resulted in a significant reduction in postprandial glucose and insulin compared with a low-fiber breakfast that appeared to be dose dependent. Similarly, Jenkins *et al.* [35] reported significantly greater reduction in glucose response and AUC after 8.1 g β-glucan than after 4.4 g β-glucan or white bread in subjects with type 2 diabetes. Wood *et al.* [36] reported a significant reduction in postprandial insulinemia that

also appeared to depend on the amount of soluble oat fiber consumed.

In a few studies, oat-containing foods were fed to normal and hypercholesterolemic subjects without significant reductions in glucose and insulin concentrations [37–39]. A possible difference among the reported studies is the amount of soluble fiber consumed in the acute meal. Studies that reported little or no decrease in glucose or insulin response to the acute meal may have had soluble fiber content near or below the threshold needed to reduce glycemic response.

Fewer studies reported the effects of barley consumption on glucose and insulin responses than have reported the effects of oat consumption [39–41]. Liljeberg *et al.* [39] fed test meals containing common barley or high-fiber (Prowashonupana) barley as porridge or bread. Porridge made with the common barley did not lower glucose and insulin responses compared with white bread, but the high-fiber barley porridge significantly lowered responses. Glucose and insulin responses after bread made with either 50% common barley/50% high-fiber barley flour or a 20/80 ratio of flours were both significantly lower than the control white bread. To examine the effect of processing on starch digestion and absorption, Granfeldt *et al.* [41] compared Swedish oats and barley flakes differing in thickness—0.5 mm (thin) *versus* 1.0 mm (thicker). Thin oat and barley flakes and the thick barley flakes resulted in glucose and insulin responses not significantly different from those observed after the reference white bread. Consumption of the thick oat flakes resulted in significantly lower glucose and insulin responses than did the white bread.

Obesity, especially abdominal fat, has been associated with hormonal and metabolic changes such as hyperinsulinemia, increased the risk of insulin resistance, diabetes, and hyperlipidemia [43,44]. After examining a general population, McAuley *et al.* [26] reported that fasting insulin greater than 87.5 mmol/L (12.2 μU/dL) was as good as HOMA at predicting insulin resistance in a normoglycemic population. As a group, our subjects with fasting insulin concentrations above 87.5 mmol/L had significantly higher insulin resistance indexes calculated by the HOMA than did the subjects with lower fasting insulin (Table 4). Although our subjects were overweight or obese, none had impaired glucose tolerance. HOMA values of our group with higher fasting insulin (insulin resistance = 3.2) were between those reported for nondiabetic and impaired [44] and diabetic subjects [45], possibly indicating future glucose impairment. The insulin sensitivity index calculated with equations developed by McAuley *et al.* [26] incorporating insulin and triglyceride concentrations indicated that our subjects were at the low normal range and not yet insulin resistant (insulin sensitivity index < 6.3). Equations developed by Cederholm *et al.* [25], which include fasting and 2-h glucose and insulin concentrations from a tolerance test, showed that insulin sensitivity of the obese subjects reported here was similar to values reported by Cederholm *et al.* [25] for their obese normoglycemic subjects.

Glucagon and leptin fasting concentrations were within the expected ranges for overweight subjects. Some nonsignificant differences among the tolerance tests were observed in the AUCs. Lean normoglycemic subjects typically show a fall in glucagon values rather than the rise observed in diabetic subjects [46]. Iannello *et al.* [47] reported that glucagon total AUC (3-h tolerance test) increased only in obese subjects who were glucose impaired or had type 2 diabetes. The rise in glucagon secretion in response to a glucose load has been suggested as a contributing factor in insulin resistance and glucose intolerance [48]. Only when our subjects ate the barley flakes was the glucagon response to the tolerance test relatively flat. Although glucose and insulin concentrations of our subjects were relatively normal, the rise of glucagon after the tolerance test may indicate future impairment. Fasting leptin concentration were reported to be higher in women than in men [49,50] and higher in normoglycemic women than women with impaired glucose tolerance or diabetes [49]. The overweight and obese women in this study have leptin concentrations similar to the impaired and diabetic subjects of Panarotto *et al.* [49] even though they did not appear to have impaired glucose tolerance. Herrmann *et al.* [50] reported leptin increases during the day with peak level at night. Our tolerance test values would have occurred during the morning nadir. Herrmann *et al.* [50] observed differences in leptin responses over the course of the day with an earlier and greater rise after diets containing high-glycemic index foods compared with diets containing low-glycemic foods. Although the food consumed at breakfast did not significantly affect leptin response, the type of food consumed over the day did affect leptin response.

The common oat flakes and flour used in this study appear to have provided a level of soluble fiber that was the minimum (or below) required for a significant beneficial response because the peak response was nearer to that observed after glucose alone than to the response after barley. The high-fiber barley used here contained over 4 times the soluble fiber of the common oats and resulted in significantly greater glycemic reductions. A dose response for soluble fiber for lowering glucose and insulin postprandially has been reported by others [33,35,36]. The differences in glycemic response between the two grains can be accounted for by the difference in β-glucan content. Flour and flakes were generally comparable although the glucose AUC after oat flour was significantly lower than that after oatmeal. The thickness of the oat flakes used in the study was not known. Granfeldt *et al.* [41] showed this to be an important consideration in postprandial metabolic response. Our study demonstrates that regardless of form, flour or flakes, oat and barley consumption reduces glucose and insulin responses. The higher soluble fiber content resulted in a smoother response curve, lower peak values, and minimized the hypoglycemic effect that occurred 3 h after a high-sugar meal. These results demonstrate that beneficial reductions in glucose and insulin can result if sufficient soluble fiber is consumed; they

suggest that increasing the total oat and/or barley content of the American diet might lower the risk for type 2 diabetes.

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