Dietary Guar Gum Improves Insulin Sensitivity in Streptozotocin-Induced Diabetic Rats¹,²

David Cameron-Smith,³ Raymundo Habito, Michael Barnett and Gregory R. Collier

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ABSTRACT Although dietary recommendations for diabetics stress the need for increased carbohydrate and dietary fiber, the effectiveness of dietary fiber in improving insulin sensitivity remains controversial. The aim of this study was to compare the effects of a soluble fiber (guar gum) and an insoluble fiber (wheat bran) on insulin sensitivity in streptozotocin-induced (STZ) diabetic rats. Consequently, the rats were divided into two groups and one half were rendered diabetic with streptozotocin. The STZ diabetic and nondiabetic rats were further randomized and fed a diet containing dietary fiber (7 g/100 g diet) from either guar gum or wheat bran. The hyperinsulinemic clamp technique, combined with infusion of the glucose analog, 2-deoxyglucose (2DG), was utilized to examine insulin sensitivity. Bran-fed STZ diabetic rats were significantly (P < 0.001) hyperglycemic, which was ameliorated by guar gum. Insulin-mediated glucose disposal was increased by the guar diet compared with the bran diet in both the STZ diabetic rats (17.7 ± 2.2 vs. 11.8 ± 2.4 mL/(kg·min), P < 0.05) and the nondiabetic rats (20.5 ± 2.8 vs. 15.5 ± 1.5 mL/(kg·min), P < 0.05). The accumulation of 2DG in peripheral muscles reflected the changes in insulin sensitivity with a trend for increased 2DG uptake in the majority of analyzed tissues in rats fed the guar diet, both nondiabetic and STZ diabetic, compared with the bran-fed rats. Accompanying these alterations in insulin sensitivity, guar gum suppressed food intake in the hyperphagic diabetic rats by 20% (P < 0.001). The present results demonstrate the effectiveness of guar gum in improving insulin sensitivity in STZ diabetic rats and suggest that reduced food intake may be an important mechanism of action of guar in hyperphagic diabetic rats.


KEY WORDS: ・ rats ・ guar gum ・ diabetes ・ hyperinsulinemic clamp ・ insulin sensitivity

The beneficial actions of diets high in carbohydrate and fiber on insulin sensitivity in noninsulin-dependent diabetes mellitus (NIDDM)³ and insulin-dependent diabetes mellitus (IDDM) are well documented (Anderson et al. 1991, Fukagawa et al. 1990, Simpson et al. 1981). However, considerable debate exists as to the effectiveness of such diets given the potential adverse actions of high carbohydrate diets on plasma lipids (Grundy 1991). The supplementation of high carbohydrate diets with guar gum, a viscous galactomannan extracted from the Indian cluster bean (Cyamopsis tetragonolobus), has been demonstrated to effectively enhance insulin sensitivity in individuals with either NIDDM or IDDM (Ebeling et al. 1988, Lalor et al. 1990, Tagliaferro et al. 1985). The actions of guar gum to lower blood glucose levels may be the result of the increased viscosity of the stomach and small intestine gastrointestinal contents, impeding carbohydrate digestion and absorption. Increasing the viscosity of the gastrointestinal contents with guar gum (Cameron-Smith et al. 1994a) acts as a physical impediment to carbohydrate digestion and absorption (Johnson 1991, Leclere et al. 1994). This has been supported in numerous studies in which guar gum lowers the postprandial glucose response when mixed into a variety of test meals (Collier et al. 1986, Jenkins et al. 1977, Leclere et al. 1994).

The longer-term reductions in the postprandial rate of carbohydrate absorption with guar gum supplementation is thought to improve insulin sensitivity through the combined actions of reduced diurnal insulin excursions (Jenkins et al. 1989), lower postprandial counterregulatory hormone release (Collier et al. 1987) and reduced gastric inhibitory polypeptide secretion (Morgan et al. 1990). However, despite our knowledge of the whole-body improvements in carbohydrate metabolism, the tissue-specific improvements in carbohydrate metabolism following guar gum supplementation have not been investigated. Therefore, the aims of the present study are to investigate in streptozotocin-induced (STZ) diabetic rats the effects of guar gum, when incorporated into a high carbohydrate diet, on tissue-specific and whole-body insulin sensitivity. Alterations in basal and insulin-stimulated glucose metabolism were determined using the hyperinsulinemic clamp technique, in combination with infusion of labeled 2-deoxy-D-glucose, a

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³ To whom correspondence should be addressed.

Abbreviations used: BAT, brown adipose tissue; 2DG, 2-[(14)C]-2-deoxyglucose; EDL, extensor digitorum longus; GIR, glucose infusion rate; HGO, hepatic glucose output; IDDM, insulin-dependent diabetes mellitus; IR, 45-H-glucose infusion rate; MCR, metabolic clearance rate of glucose; NIDDM, non-insulin-dependent diabetes mellitus; Ra, glucose appearance; Rd, peripheral glucose disposal; RG, glucose utilization index; RS, red gastrocnemius; STZ, streptozotocin; WAT, white adipose tissue; WG, white gastrocnemius.
TABLE 1

<table>
<thead>
<tr>
<th>Ingredient</th>
<th>Brand diet</th>
<th>Guar diet</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>g/kg diet</td>
<td></td>
</tr>
<tr>
<td>Wheat flour</td>
<td>740</td>
<td>815</td>
</tr>
<tr>
<td>Casein</td>
<td>75</td>
<td>81</td>
</tr>
<tr>
<td>Butter</td>
<td>26</td>
<td>30</td>
</tr>
<tr>
<td>Mineral mixture</td>
<td>2.8</td>
<td>2.8</td>
</tr>
<tr>
<td>Vitamin mixture</td>
<td>0.6</td>
<td>0.6</td>
</tr>
<tr>
<td>Choline chloride</td>
<td>0.25</td>
<td>0.25</td>
</tr>
<tr>
<td>L-Methionine</td>
<td>0.35</td>
<td>0.35</td>
</tr>
<tr>
<td>Unprocessed wheat bran</td>
<td>155</td>
<td>—</td>
</tr>
<tr>
<td>Guar gum</td>
<td>—</td>
<td>70</td>
</tr>
</tbody>
</table>

1 Mineral mixture was supplied as the following (g/kg mineral mix): CaHPO4, 623.4; NaCl, 72.8; K3PO4, 216.5; K2SO4, 51.2; MgO, 23.6; MnSO4, 5.05; CaH2Fe, 5.9; ZnO4, 1.02; CuSO4, 0.6; KO3, 0.001; Na2SeO3, 0.005; Cr[KSO4]2, 0.78. All minerals were purchased from Sigma Chemical (St. Louis, MO).

2 The vitamin mix was supplied as the following (g/kg vitamin mix): thiamine mononitrate, 3; pyridoxine HCl, 3.5; nicotinamide, 1; α-calcium pantotenate, 8; folic acid, 1; β-biociatin, 0.1; cyanocobalamin, 0.005; cholecalciferol, 0.012; acetamethaphone, 0.025; retinyl acetate, 0.6; all-rac-α-tocopherol acetate, 0.025. Vitamin mix was purchased from Colborn Dawes (Wagga, Australia).

3 Food-grade unprocessed bran was purchased from Bunge (Bal- larat, Australia).

4 Food-grade guar gum was donated by Chemiplas (Sydney, Aus-

nonmetabolizable glucose analog which provides a sensitive in vivo measure of tissue-specific rate of glucose disposal (Kraegen et al. 1985).

MATERIALS AND METHODS

Animals and diets. All treatments and diets were formally approved by the Deakin University Animal Ethics Committee. Male Sprague-Dawley rats (body weight 100–120 g) were housed in a temperature-controlled room (22 ± 1°C) on a 12-h light/dark cycle. The animals were randomly assigned to two groups. One group was made diabetic with an intraperitoneal injection of 50 mg/kg body weight streptozotocin (Sigma Chemical, St. Louis, MO) prepared in 100 mmol/L of citrate buffer (pH 7.2). The nondiabetic group received 100 mmol/L citrate buffer. The diabetic and nondiabetic groups were further randomly subdivided and fed a diet containing dietary fiber (7 g/100 g diet) from either wheat bran or guar gum. The compositions of the diets are shown in Table 1. Both diets contained, as percentage of total energy, 69% carbohydrate, 12% fat and 19% protein. Rats were given free access to a diet and water. Daily food intakes were determined each morning by weighed difference. Food intakes were not corrected for spillage.

Hyperinsulinemic clamp. After 21 d of consuming the diets, the rats were placed in wire-bottom cages and food was withheld overnight. The food-deprived rats were anesthetized with intraperitoneal sodium thiopentone (75 mg/kg Nembutal, Abbott, Sydney, Australia) at 0900 h. Silastic cannulae were introduced into the right jugular vein for infusions and the left carotid artery for blood sampling. Tracheostomies were performed to allow for tracheal clearing. Throughout the experimental period, the body temperature of anesthetized rats was maintained at 36.5–37.5°C using heat lamps. Prior to the commencement of tracer infusions, blood samples (300 µL) were collected from rats food-deprived overnight into heparinized tubes for determination of plasma glucose, cholesterol and triglycerides. Basal rates of glucose turnover were determined by the isotope dilution of infused 3(H)-6-glucose (Du Pont, Wilmington, DE) as described previously (Kraegen et al. 1983). Glucose turnover was measured following a priming infusion 5-min priming dose, 88

kBg/(kg·min) followed by a constant dose [8.8 kBg/(kg·min)] of 3(H)-6-glucose (Du Pont, Boston, MA).

Following the basal infusion, insulin-stimulated rates of glucose turnover were measured following a primed (5-min) continuous exogenous insulin infusion. Insulin was added to the 3(H)-6-glucose infusion to achieve a dose of 18 pmol/(min·kg body weight) (Actrapid, Novo, Denmark). A variable rate of 250 mL glucose, containing 240 MBq/L 3H-6-glucose, was infused to maintain euglycemia. Triplicate blood samples (300 µL) were taken at 5-min intervals 70 min after initiation of the insulin infusion to determine plasma 3H specific activity.

In vivo insulin action in individual tissues. Insulin action within individual tissues in vivo was assessed using the nonmetabolizable glucose analog 2, 6-[3H]-2-deoxyglucose (2DG, Du Pont), as described by Kraegen et al. (1985). The 2DG was administered intravenously as a bolus (370 kBq) 85 min after the commencement of the glucose infusion. Blood samples were obtained 2, 5, 10, 15, 20, 30 and 45 min after the 2DG bolus administration. At the completion of the clamp, rats were administered a further intravenous lethal bolus of anesthetics (75 mg/kg, Nembutal), and the following tissues were rapidly removed and frozen in liquid nitrogen for subsequent analysis: soleus (which is composed predominantly of slow-twitch oxidative fibers), red gastrocnemius (WG, fast-twitch glycolytic fibers), and extensor digitorum longus (EDL, a mixture of fast-twitch oxidative and glycolytic fibers), brain, white adipose tissue (WAT), brown adipose tissue (BAT), heart and diaphragm.

Analytical procedures. Plasma glucose, cholesterol and triglyceride concentrations were determined using glucose oxido/peroxidase, CH30-PAP, and GLO-PAP methods, respectively, using commercial reagents (Boehringer Mannheim, Mannheim, Germany). Plasma immunoreactive insulin concentrations were determined by double antibody RIA (Linco Research, St Louis, MO). Plasma specific activities of 3H-glucose and 14C-2DG were measured in 50 µL plasma samples deproteinized with 25 µL each of 150 mmol/L Ba(OH)2 and 150 mmol/L ZnSO4. The suspensions were centrifuged at 10000 × g and the supernatant (50 µL) passed through an anion exchange column (Dowex 200–400 mesh, chloride form, Bio-Rad, Anaheim, CA). The samples were dried at 37°C to remove labeled H2O; the dried residue was resuspended in distilled water and counted by liquid scintillation counting (1215 Rackbeta, LKB Wallac, Finland).

Calculations. The rate of glucose appearance [Ra, mg glucose/(kg·min)] was determined, in steady state, as IR/SA, corrected for body weight (kg) where IR is the 3H-glucose infusion rate (Bg/min) and SA is the plasma glucose specific activity (Bg/mg glucose). Following insulin infusion, at steady-state plasma glucose concentrations, peripheral glucose disposal [Rd, mg glucose/(kg·min)] was calculated as Rd = IR/SA, Hepatic glucose output [HGO, mg/(kg·min)] was calculated as HGO = Rd − GIR, where GIR is the exogenous glucose infusion rate [mg/(kg·min), after correction for body weight] (Kraegen et al. 1985). The metabolic clearance rate of glucose [MCR, mL/(kg·min)] was calculated as MCR = [Vd × GIR]/[IR × GIR] where [Vd] is the plasma glucose concentration (mmol/L).

An estimate of individual tissue glucose metabolic rate, the glucose utilization index (Rg), was measured as the tissue accumulation of phosphorylated 2DG: Rg = [MCR × Tc] × dt

where C is the steady-state plasma glucose concentration (mmol/L), Tc (T) is the total phosphorylated 2DG accumulated in 45 min and C (T) is the integrated value for plasma 2DG specific activity over 45 min, as described in detail by Kraegen et al. (1985).

Statistical analysis. Data are shown as means ± SEM. Differences between groups were established using two-way (diet and diabetes) ANOVA, with repeated measures where appropriate. ANOVA was followed by Fisher’s least significant difference test (Snedecor and Cochran 1989), to compare mean values where appropriate. Logarithmic data transformation was applied to all data analyzed by ANOVA. Data analysis was carried out using Minitab statistical software (Mini-
The insulin-stimulated rate of glucose disposal and the insulin-suppressed rate of HGO are shown in Table 3. HGO did not differ among groups during hyperinsulinemia. The rate of glucose disposal (MCR) was significantly greater in both the nondiabetic and STZ-induced diabetic rats fed the guar-containing diet compared with the bran-fed rats.

Whole-body insulin sensitivity following bran or guar feeding in nondiabetic or STZ diabetic rats, as measured by the rate of glucose infused (GIR) to maintain euglycemia in the hyperinsulinemic state, is shown in Figure 3. In nondiabetic rats, the rate of glucose infusion to maintain euglycemia was 32% greater in those fed guar than in those fed bran. In STZ diabetic rats fed the guar gum diet, a significantly greater rate of glucose infusion was required to maintain euglycemia during hyperinsulinemia, compared with the STZ diabetic rats fed bran.

**Glucose utilization index in individual tissues.** The glucose utilization index (Rg) of individual tissues, measured as the tissue-specific accumulation of phosphorylated 2-deoxyglucose, during the hyperinsulinemic clamp are shown in Table 4. In nondiabetic rats, the guar diet tended to increase the Rg of all tissues measured, with the exception of white adipose tissue. However, significant differences between the bran- and guar-fed nondiabetic groups were measured only in the diaphragm and red gastrocnemius muscle. Similarly, in the STZ diabetic rats, glucose utilization was greater in the majority of tissues from rats fed the guar diet compared with the bran diet, although differences reached statistical significance only in brown adipose tissue.

**RESULTS**

**Body weight gain and food intake.** The growth rate of STZ diabetic and nondiabetic rats fed a high carbohydrate diet supplemented with either bran or guar is shown in Figure 1. At the commencement of the study, the STZ diabetic rats had lower body weights than the nondiabetic rats (136.2 ± 2.0 vs. 157.9 ± 3.7 g, respectively, P < 0.001). Growth was retarded by STZ treatment and unaltered by diet. No significant differences in growth rate were present in the nondiabetic rats fed either the bran- or guar-supplemented diet.

The effects of STZ-induced diabetes and fiber supplementation on daily food intakes are shown in Figure 2. STZ diabetic rats fed the bran diet were hyperphagic throughout the study, consuming on average 42.9 ± 1.0 g diet/d. In the STZ diabetic guar-fed rats, compared with the STZ diabetic bran-fed rats, food intake was lower at all weeks, reaching significance in the first and third weeks of the study. No significant differences in food consumption were evident between the bran- and guar-supplemented control groups.

**Hyperinsulinemic clamp.** The effects of the bran and guar diets in nondiabetic and STZ diabetic rats on basal (food-deprived overnight) and hyperinsulinemic clamp glucose and insulin concentrations are reported in Table 2. STZ administration did not significantly alter plasma insulin concentrations of food-deprived rats. STZ diabetes elevated plasma glucose concentrations, although within the STZ diabetic rats, the guar diet resulted in a markedly lower plasma glucose concentration than in rats fed the bran diet. Plasma cholesterol concentrations were elevated by STZ-induced diabetes (P < 0.001). Plasma triglyceride concentrations were elevated by STZ-induced diabetes and reduced by the guar diet in the nondiabetic rats.

The effect of the bran or guar diets in normal and STZ diabetic rats on basal and hyperinsulinemic glucose turnover is described in Table 3. Hepatic glucose output (HGO) was elevated in STZ diabetic rats compared with the nondiabetic groups. However, within the STZ diabetic rats, the guar diet resulted in a significant reduction in basal glucose turnover (P < 0.05) and an elevation in the MCR (P < 0.05).
induced diabetic rats and normal nondiabetic rats. The results demonstrate that in STZ-induced diabetic rats fed a high carbohydrate diet containing wheat bran for 3 wk, whole-body insulin sensitivity was significantly impaired, with significantly elevated plasma glucose concentrations following overnight food deprivation. However, the incorporation of guar gum into the diet of STZ diabetic rats markedly improved insulin sensitivity. In the food-deprived state, guar gum supplementation in STZ diabetic rats lowered both plasma glucose levels and hepatic glucose output (HGO), whereas the metabolic clearance rate of glucose (MCR) was elevated. Enhanced glucose disposal was also measured in the nondiabetic rats fed the guar gum–containing diet, consistent with the improvements in glucose tolerance measured previously (Track et al. 1982).

The development of hyperglycemia and insulin resistance in the STZ model of diabetes is preceded by the partial destruction of the pancreatic β-cell mass by STZ (Kruszynska et al. 1986); however, at the dose of STZ used in the current study, sufficient β-cell capacity remained to maintain adequate plasma insulin concentrations in rats deprived of food overnight. Therefore, in STZ diabetic rats, insulin resistance develops when both insulin secretion is reduced and plasma glucose levels are elevated. However, it has been suggested that it is the maintenance of chronic hyperglycemia which is the primary factor responsible for the development and maintenance of insulin resistance in both rodent models of diabetes and human NIDDM subjects (Rossetti et al. 1987, Yki-Jarvinen 1992).

Chronic hyperglycemia is detrimental to both insulin sensitivity and β-cell function (Yki-Jarvinen 1992). In STZ-induced and partially pancreatectomized diabetic rats, phlorizin treatment, which induces persistent glycosuria by inhibiting renal glucose reabsorption, normalizes blood glucose levels and restores peripheral insulin action, independent of the changes in insulin secretion (Listo et al. 1992, Rossetti et al. 1987). The present results demonstrate that the supplementation of a high carbohydrate diet with guar gum fed to STZ diabetic rats resulted in a pronounced reduction in plasma glucose concentrations in the food-deprived STZ rats without significant alterations to the insulin concentrations. Because the majority of the infused glucose load during hyperinsulinemia is cleared from the plasma by skeletal muscle (Beck-Nielsen et al. 1992), the detrimental actions of hyperglycemia are likely to be directed towards insulin-sensitive glucose transport and metabolism within skeletal muscle (Lang et al. 1991). In the current study, the improvements in insulin action following guar supplementation were shown to be mediated by increased peripheral tissue insulin sensitivity. This finding confirms previous studies in normal and NIDDM human subjects (Landin et al. 1992, Taglioferro et al. 1985). However, in the current study, the inability of similar levels of hyperinsulinemia to suppress the persistent hyperglycemia in the STZ diabetic bran-fed rats

### TABLE 2

**Body weight and plasma metabolite and insulin concentrations in wheat bran– and guar gum–fed nondiabetic and streptozotocin (STZ) diabetic rats**

<table>
<thead>
<tr>
<th>Dietary group</th>
<th>Nondiabetic</th>
<th>STZ diabetic</th>
<th>ANOVA (P)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Bran</td>
<td>Guar</td>
<td>Bran</td>
</tr>
<tr>
<td>Basal²</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Body weight, g</td>
<td>280.2 ± 6.1b</td>
<td>265.3 ± 10.5b</td>
<td>191.7 ± 10.2a</td>
</tr>
<tr>
<td>Glucose, mmol/L</td>
<td>5.9 ± 0.3a</td>
<td>5.3 ± 0.1a</td>
<td>15.7 ± 1.9c</td>
</tr>
<tr>
<td>Insulin, μmol/L</td>
<td>28.5 ± 2.6</td>
<td>41.3 ± 6.2</td>
<td>35.3 ± 7.0</td>
</tr>
<tr>
<td>Cholesterol, mmol/L</td>
<td>1.78 ± 0.09a</td>
<td>1.75 ± 0.06a</td>
<td>2.68 ± 0.2b</td>
</tr>
<tr>
<td>Triglycerides, mmol/L</td>
<td>1.11 ± 0.11b</td>
<td>0.76 ± 0.05a</td>
<td>1.36 ± 0.14b</td>
</tr>
<tr>
<td>Hyperinsulinemic clamp</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Glucose, mmol/L</td>
<td>5.2 ± 0.2a</td>
<td>4.9 ± 0.2a</td>
<td>8.5 ± 1.6c</td>
</tr>
<tr>
<td>Insulin, μmol/L</td>
<td>577.2 ± 45.1</td>
<td>520.6 ± 72.2</td>
<td>649.3 ± 59.3</td>
</tr>
</tbody>
</table>

¹ Values are expressed as means ± SEM; n = 9 for nondiabetic groups and 7 for STZ diabetic groups. Within rows, means with different superscript letters are significantly different (P < 0.05).
² Basal refers to values in rats that were deprived of food overnight.

### TABLE 3

**Glucose turnover variables in wheat bran– and guar gum–fed nondiabetic and streptozotocin (STZ) diabetic rats**

<table>
<thead>
<tr>
<th>Dietary group</th>
<th>Nondiabetic</th>
<th>STZ diabetic</th>
<th>ANOVA (P)</th>
</tr>
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<tbody>
<tr>
<td></td>
<td>Bran</td>
<td>Guar</td>
<td>Bran</td>
</tr>
<tr>
<td>Basal²</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>HGO, mg/(kg · min)</td>
<td>6.8 ± 0.4a</td>
<td>7.0 ± 0.7a</td>
<td>16.3 ± 2.6c</td>
</tr>
<tr>
<td>MCR, mL/(kg · min)</td>
<td>6.4 ± 0.4b</td>
<td>7.3 ± 0.7b</td>
<td>5.9 ± 0.8a</td>
</tr>
<tr>
<td>Hyperinsulinemic clamp</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>HGO, mg/(kg · min)</td>
<td>5.6 ± 0.7</td>
<td>4.3 ± 1.0</td>
<td>4.9 ± 1.7</td>
</tr>
<tr>
<td>MCR, mL/(kg · min)</td>
<td>15.5 ± 1.5a</td>
<td>20.5 ± 2.8b</td>
<td>11.8 ± 2.4a</td>
</tr>
<tr>
<td>Rd, mg/(kg · min)</td>
<td>14.2 ± 1.0</td>
<td>17.7 ± 1.9</td>
<td>13.0 ± 1.3</td>
</tr>
</tbody>
</table>

¹ Values are expressed as means ± SEM; n = 9 for nondiabetic groups and 7 for STZ diabetic groups. Within rows, means with different superscript letters are significantly different (P < 0.05).
² Basal, food-deprived overnight; HGO, hepatic glucose output; MCR, metabolic clearance rate of glucose; Rd, rate of glucose disappearance.
following the infusion of exogenous insulin, while allowing for the normalization of blood glucose concentrations in the STZ diabetic guar-fed rats, prevents the accurate use of calculations dependent upon isotope dilution for the comparison of the changes in peripheral glucose disposal. Nevertheless, this persistent hyperglycemia in the STZ diabetic bran-fed rats provides strong evidence for the marked changes in peripheral insulin action with the addition of guar to the diet of the diabetic rats.

Changes in the rate of glucose disposal in specific peripheral tissues were examined in the current study by measuring the accumulation of the nonmetabolizable glucose analog 2-deoxyglucose (2DG) in selected tissues (Kraegen et al. 1985). Insulin-sensitive glucose disposal tended to be greater in rats fed the guar diet in both the nondiabetic and the STZ diabetic groups, compared with the bran-fed rats, in all muscle groups, including several hindlimb muscles, the heart and diaphragm. However, the interpretation of the 2DG accumulation is confounded by the persistent hyperglycemia in the insulin-infused bran-fed diabetic animals, despite correction for plasma glucose concentrations in the calculation of 2DG tissue accumulation. Although it could have been expected that the combined actions of hyperglycemia and elevated plasma insulin concentrations may have acted to increase tissue 2DG accumulation in the diabetic rats fed the bran diet compared with the diabetic rats fed the guar diet. The failure to demonstrate increased 2DG accumulation in the diabetic bran-fed rats further emphasizes the considerable alterations in insulin sensitivity between the two STZ diabetic groups. Therefore, the improvements in insulin-sensitive glucose disposal in the STZ diabetic rats fed guar gum are likely to be the result of small increases in the rate of glucose disposal by all insulin sensitive tissues, rather than a large elevation in the rate of glucose disposal of isolated tissues.

Although the mechanism by which guar gum supplementation increased insulin action was not specifically addressed in this study, it can be speculated that differing mechanisms may account for the improvements in insulin action in the nondiabetic and diabetic rats. The ability of guar gum to suppress postprandial rises in blood glucose has been extensively documented in both human and animal studies (Collier et al. 1986, Jenkins et al. 1977, Track et al. 1982). This reduction in postprandial glucose and insulin excursions may be important in the improvements in insulin action measured using the euglycemic clamp and 2DG infusion in the nondiabetic animals. The importance of postprandial glycemia in determining insulin sensitivity in normoglycemic nondiabetic rats is supported by improvements in glucose tolerance and insulin action of a similar magnitude in normal rats fed starch diets of differing in vitro digestibility (Higgins et al. 1996).

In the STZ diabetic rats, in which the ability of the pancreas to secrete increased insulin in response to absorbed glucose is largely ablated by the streptozotocin treatment (Cameron-Smith et al. 1994b), reductions in postprandial glucose concentrations following the addition of guar to the diet may lead to improvements in insulin action via other mechanisms. As in previous studies, the STZ diabetic rats were hyperphagic (Katovich et al. 1991), with the bran-supplemented STZ diabetic rats

### TABLE 4

<table>
<thead>
<tr>
<th>Tissue</th>
<th>Nondiabetic</th>
<th>STZ diabetic</th>
<th>ANOVA (P)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Bran</td>
<td>Guar</td>
<td>Bran</td>
</tr>
<tr>
<td>Brain</td>
<td>7.27 ± 3.57</td>
<td>7.68 ± 2.03</td>
<td>8.35 ± 2.07</td>
</tr>
<tr>
<td>Soleus</td>
<td>1.51 ± 0.36</td>
<td>2.47 ± 0.54</td>
<td>1.89 ± 0.37</td>
</tr>
<tr>
<td>RG</td>
<td>2.20 ± 0.42a</td>
<td>4.00 ± 0.61b</td>
<td>3.09 ± 0.54ab</td>
</tr>
<tr>
<td>WG</td>
<td>0.83 ± 0.23</td>
<td>2.12 ± 0.66</td>
<td>1.78 ± 0.59</td>
</tr>
<tr>
<td>EDL</td>
<td>2.02 ± 0.61</td>
<td>3.27 ± 0.51</td>
<td>1.77 ± 0.45</td>
</tr>
<tr>
<td>WAT</td>
<td>0.70 ± 0.21ab</td>
<td>0.51 ± 0.14a</td>
<td>1.41 ± 0.48b</td>
</tr>
<tr>
<td>BAT</td>
<td>9.65 ± 2.41a</td>
<td>14.24 ± 2.83ab</td>
<td>6.56 ± 1.34a</td>
</tr>
<tr>
<td>Heart</td>
<td>12.74 ± 3.86</td>
<td>28.47 ± 7.17</td>
<td>12.33 ± 2.03</td>
</tr>
<tr>
<td>Diaphragm</td>
<td>4.77 ± 0.96a</td>
<td>11.03 ± 1.17b</td>
<td>8.52 ± 1.68b</td>
</tr>
</tbody>
</table>

|  |  |  |  |  |  |  |
|---|---|---|---|---|---|
|  |  |  |  |  |  |

1 Values are expressed as means ± SEM; n = 9 for nondiabetic groups and 7 for STZ diabetic groups. Within rows, means with different superscript letters are significantly different (P < 0.05). RG, red gastrocnemius; WG, white gastrocnemius; EDL, extensor digitorum longus; WAT, white adipose tissue; BAT, brown adipose tissue.
Beck-Neilsen, H., Vaag, A., Damsbo, P., Handberg, A., Hother Nielsen, O., Erik ble- and insoluble-®bre supplementation on post-prandial glucose tolerance,


improvements resulting from increased insulin sensitivity of

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LITERATURE CITED


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