High-fiber Diet in the Control of Diabetes in Rats

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Abstract

The effects of high-fiber diet on the metabolic states in streptozotocin-induced diabetic rats were investigated. The animals were divided into three groups: group A fed on a diet containing 5% of fiber (bagasse), group B paired-fed on a control diet and group C fed on a control diet ad libitum. The body weight gain was greater and the fasting blood sugar level was lower in A than B and C. The plasma triglyceride level was lowest in A, while no significant difference in the serum total cholesterol level was observed between A and B. Plasma glucagon levels were decreased in A and increased significantly in B and C. Plasma insulin levels were not changed in these groups.

These results support the theory that a high-fiber diet is an effective therapeutic regimen for the control of metabolic derangement in diabetics.

It has been suggested by Burkitt, Walker and Painter (1974) and Trowell (1972) that a fiber-depleted diet may play a causative role in the development of clinical diabetes mellitus. Since that time there has been much interest in the possibility of treating diabetics with a fiber-rich diet. In clinical studies, Jenkins et al., (1977) reported that the addition of fiber (guar and pectin) to meals resulted in a significant reduction in the postprandial glucose level in normal and diabetic subjects. Miranda and Horwitz (1978) also reported that mean plasma glucose in the low-fiber diet was significantly higher than that in the high-fiber diet in insulin-requiring diabetes. Since it is quite difficult in clinical studies to obtain the same conditions in each patient, we have employed experimental diabetic animals. For this purpose, streptozotocin-induced diabetic rats were used in the present study to investigate the effects of a high-fiber diet on the metabolic states in diabetes.

Evidence is presented in this communication that a high-fiber diet may be a useful means of relieving metabolic derangement in diabetes.

Materials and Methods

Male Wistar-strain rats weighing 180–200 g were housed in individual cages. Diabetes was induced by a single injection of streptozotocin (60 mg/kg of body weight) into the tail vein. Streptozotocin was dissolved immediately before use in a citric acid buffer (50 mm) adjusted to pH 4.5 and 0.3 ml of solution was injected. After the diabetic rats were fed with the control diet for one week, only those rats with fasting blood glucose 180 mg/dl or higher were used in the study. They were divided into three groups (six rats in each group). Rats in
Group A were fed on high-fiber diet (5% of which consisted of bagasse) ad libitum. Rats in Group B were paired-fed on the same energy as the control diet given in Group A. Rats in Group C were fed on the control diet ad libitum. The diet was given between 3 and 5 p.m. every day. The composition of the diets is shown in Table 1 and all the components were thoroughly mixed together. The bagasse (generously donated by Mitsui Seito Co.) was ground to particles similar in size to those of other constituents of the diets.

After fasting for 10 hr the rats were anesthetized with pentobarbital (50 mg/kg, ip) and 1 ml of blood was withdrawn from the jugular vein. Blood glucose was determined by a glucose oxidase method. Plasma triglyceride was assayed with the acetylacetone method (Sardesai et al., 1968) using a kit provided by Wako Junyaku Co. and total cholesterol was determined by the method of Zak-Henly (Zak, 1957). Immunoreactive insulin was assayed with the double antibody method using a kit provided by Daiichi Isotope Co. and immunoreactive glucagon was assayed with the double antibody method employing antisera 30K (Aguilar-Parada et al., 1968). Streptozotocin was purchased from the Upjohn Company, Kalamazoo, Michigan.

The results are representative of three independent but highly reproducible experiments.

Results

Fig. 1 demonstrated that the increase in body weight on the high-fiber diet (Group A) was significantly greater than in those on the control diet (Group B and Group C) on and after 20 days of the test. The increase in body weight in Group A was similar to that of normal rats (data not shown). No significant difference in the mean body weight was observed between Groups B and C.

Changes in food intake of each group during the experimental period are shown in Table 2. This shows that the intake in each group was gradually increased.

Mean blood glucose level in those on the high-fiber diet was significantly lower than that of the paired-fed group (Group B) after 10, 20 and 40 days (Fig. 2). The mean value of Group C was much higher than those of other groups after 30 and 40 days.

Fig. 3 shows that the plasma triglyceride level in those on the high-fiber diet was maintained at nearly the same level throughout the test period, while the level in Group B was gradually rose and the values were significantly higher than those in Group A after 20, 30 and 40 days. Although the mean values for triglyceride in Group C were much higher than those in other groups, no significant difference was observed after 20 days between Group B and C.

The levels of total cholesterol in Group C were significantly higher than those in Group A and B, while there was no significant difference between Group A and B (Fig. 4).

Plasma glucagon levels were significantly decreased to approximately 80% of the control value on the high-fiber diet after 20 days. In contrast, the levels were gradually raised on the control diets (Group B and C, Fig. 5). Plasma insulin levels were less than 3.8 μU/ml in all rats and no difference was detected among the groups.

Table 1. The composition of control and high-fiber diets

<table>
<thead>
<tr>
<th>Component</th>
<th>Control diet (g/100 g)</th>
<th>High-fiber diet (g/100 g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>α-cornstarch</td>
<td>66.85</td>
<td>61.85</td>
</tr>
<tr>
<td>Glucose</td>
<td>5.0</td>
<td>5.0</td>
</tr>
<tr>
<td>Casein</td>
<td>18.0</td>
<td>18.0</td>
</tr>
<tr>
<td>Corn oil</td>
<td>5.0</td>
<td>5.0</td>
</tr>
<tr>
<td>Minerals*</td>
<td>4.0</td>
<td>4.0</td>
</tr>
<tr>
<td>Vitamines**</td>
<td>1.0</td>
<td>1.0</td>
</tr>
<tr>
<td>Choline chloride</td>
<td>0.15</td>
<td>0.15</td>
</tr>
<tr>
<td>Bagasse</td>
<td>/</td>
<td>5.0</td>
</tr>
</tbody>
</table>

* This was identical with Harper’s mixture (Harper, 1959).
** Composition (per g).
Calciferol, 200 I.U.; dl-α-tocopherol acetate, 1.1 mg; thiamin·HCl, 1 mg; riboflavin, 1.5 mg; pyridoxine·HCl, 1 mg; calcium pantothenate, 5 mg; folic acid, 0.5 mg; cyabocobalamin, 1 μg; ascorbic acid, 37.5 mg; nicotinic acid, 10 mg; Vitamin A parmitate, 2500 I.U.
Fig. 1. Effect of high-fiber diets on body weight of streptozotocin-induced diabetic rats. After the diabetic rats were fed with the control diet for one week, they were divided into three groups (six rats in each group). Rats in Group A were fed on high-fiber diet. Rats in Group B were paired-fed on control diet. Rats in Group C were fed on control diet ad libitum. The composition of diets is shown in Table 1. The period of the test is indicated on the abscissa. The values in the figure are expressed as the average±S.E. in each group (n=6) and the values for Group A (*) on 20, 30 and 40 days are significantly higher than those for their respective counterparts in Groups B and C (p<0.05 by student’s test).

Table 2. Average daily intake of diet by three groups of rats during the experimental period

<table>
<thead>
<tr>
<th>Period</th>
<th>Group A</th>
<th>Group B</th>
<th>Group C</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-10 day</td>
<td>31±1.2 g</td>
<td>36±3.5 g</td>
<td>38±1.9 g</td>
</tr>
<tr>
<td>11-20 day</td>
<td>36±1.9 g</td>
<td>38±1.2 g</td>
<td>35±1.2 g</td>
</tr>
<tr>
<td>21-30 day</td>
<td>32±1.0 g</td>
<td>36±1.0 g</td>
<td>39±1.8 g</td>
</tr>
<tr>
<td>31-40 day</td>
<td>35±1.2 g</td>
<td>36±0.9 g</td>
<td>36±1.2 g</td>
</tr>
</tbody>
</table>

The results are average±SEM per day during each period.

Fig. 2. Effect of high-fiber diets on fasting blood glucose levels in streptozotocin-induced diabetic rats. The experimental procedures were as described under Methods and in the legend to Fig. 1. The values in the figure are expressed as the average±S.E. in each group (n=6) and the values for Group A (*) on 10, 20 and 40 days are significantly lower than those for their respective counterparts in Group B (p<0.05).

Discussion

Several lines of clinical investigation have demonstrated that high-fiber diets were therapeutically useful in reducing the blood glucose levels (Trowell, 1972). Jenkins et al. (1978) showed that viscosity had a considerable effect on transit time and absorption, and that guar, the most viscous substance in their test, was the most effective in decreasing postprandial glucose and insulin concentrations. It has been also suggested that the “unavailable” carbohydrates reduce the rate of diffusion of products of digestion.
Fig. 3. Effect of high-fiber diets on serum triglyceride levels in streptozotocin-induced diabetic rats. The experimental procedures were as described under methods and in the legend to Fig. 1. The values (mean±S.E., n=6) in the figure are expressed as a percentage of the control values for the respective group and those of Group A (*) on 10, 20, 30 and 40 days are significantly lower than those for their respective counterparts in Group B (p<0.05) and in Group C (p<0.01). The values before the test (control values) for Group A, B and C were 209±13 mg/dl, 197±11 and 218±10, respectively and no significant difference was observed among them.

Fig. 4. Effect of high-fiber diets on serum total cholesterol levels in streptozotocin-induced diabetic rats. The experimental procedures were as described under Methods and in the legend of Fig. 1. The values (mean±S.E., n=6) in the figure are expressed as a percentage of the control values of their respective groups. The difference in values between the respective counterparts in Groups A and B is insignificant. The values before the test (control values) for Group A, B and C were 84±5 mg/dl, 77±5, and 80±3, respectively and the difference among them is insignificant.

Fig. 5. Effect of high-fiber diets on plasma glucagon levels in streptozotocin-induced diabetic rats. The experimental procedures were as described under Methods and in the legend of Fig. 1. The values (mean±S.E., n=5) in the figure are expressed as percentage of the control values for the respective group. The values for Group A (*) on 10 and 20 days are significantly lower than those for Group B and C (p<0.01). The values before the test (control values) in Group A, B and C were 304±32 pg/ml, 273±25 and 323±29, respectively and the difference among them is insignificant.
towards the absorptive mucosal surface (Southgate, 1973). Other possible mechanisms for modifying hyperglycemia have been proposed, namely the release of gastrointestinal hormones which affect glucose metabolism, and the release of hormones of the endocrine pancreas.

Because of similar plasma insulin levels on high-fiber and control diets in the present study as well as in the previous report (Miranda et al, 1978), it is unlikely that the differences in blood glucose and triglyceride levels are directly insulin-mediated. The present study showed that the plasma glucagon level was lower on the high-fiber diet than on control diets in the streptozotocin-induced diabetic rats. This observation is consistent with that in diabetic patients (Miranda et al. 1978). It is possible that the changes in dietary fiber content lead to an altered secretion of various gastrointestinal hormones including GI-glucagon. Alternatively, the dietary fiber content may affect the pancreatic alpha cells directly and decrease the secretion of glucagon. The reason for the lower glucagon levels in the rats fed with high-fiber diets has not yet been elucidated. The lower glucagon levels in those on the high-fiber diet could, at least in part, explain the lower glucose and triglyceride levels on that diet, since glucagon causes the release of glucose and triglyceride from the liver and adipose tissue, respectively.

References