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Effects of Dietary Modification on Plasma Glucose and Insulin Sensitivity in Streptozotocin-induced Diabetic Rats

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ABSTRACT

There is substantial evidence that insulin sensitivity can be enhanced through appropriate dietary management. In this study, insulin sensitivity was evaluated using an insulin suppression test. Male Sprague-Dawley rats, were caused to be in a diabetic condition by the injection of streptozotocin, and divided into four groups. They were fed one of the following diets for 2 weeks : (group 1) a high-carbohydrate(CHO) low-fat and low-fiber diet, (group 2) a high-CHO low-fat and high-fiber diet, (group 3) a low-CHO high-fat and low-fiber diet, and (group 4) a low-CHO high-fat and high-fiber diet. Dietary fiber reduced plasma glucose levels significantly in the high-CHO low-fat diet groups(as comparison between group 1 and group 2 shows). In the low-CHO high-fat diet groups, dietary fiber tended to decrease plasma glucose levels at the end of the experiment, but not significantly(as comparison between group 3 and group 4 shows). The average steady state plasma glucose level in rats on the group 3 diet was the highest among all four groups($p<0.05$), indicating the poorest insulin sensitivity. However, high fiber increased insulin sensitivity in rats on the low-CHO high-fat diet(as shows by a comparison between group 3 and group 4). On the other hand, the high-CHO low-fat enhanced insulin sensitivity in rats on the low fiber diet(group 1 and group 3). The degree of enhancement of insulin sensitivity depends on the combination of CHO, fat, and fiber in the diet. In conclusion, this study demonstrates that a low-CHO high-fat low-fiber diet may be deleterious to diabetic rats. In view of insulin sensitivity enhancement, dietary fiber level is irrelevant, as long as the diet has a high-CHO and low-fat level. (*Korean J Nutrition* 30(9) : 1035~1044, 1997)

KEY WORDS : diet · diabetic rat · plasma glucose · insulin sensitivity.

Introduction

Diabetes Mellitus is a metabolic disorder which profoundly affects blood glucose levels and insulin sensitivity. Insulin resistance plays a role in the pathogenesis of diabetes mellitus. Insulin modulates glucose homeostasis mainly by inhibiting hepatic glucose output and/or by promoting glucose uptake from the plasma. Insulin resistance in diabetes can be related to an abnormal response to these functions as mentioned above. The following illustrates the probable chronological evolution of noninsulin-dependent diabetes mellitus(NIDDM). Insulin resistance, whether genetic or acquired, leads to secretion of more insulin as a compensatory reaction to higher levels of insulin. In this state, one may show either normal glucose tolerance or impaired glucose tolerance, but not diabetes. NIDDM may eventually develop in individuals suffering from chronic glucose intolerance and overloaded insulin release from the β-cells. In order to control diabetic conditions, diet has been emphasized with other therapies[1]. The Am-

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erican Diabetes Association has advised diabetic patients to limit their consumption of fat to less than 30% of total calories and to consume higher portions of carbohydrate(CHO) and fiber[2]. Dietary recommendations for patients with diabetes is influenced by a number of factors, such as presence of obesity, dependency on insulin therapy, and complications by other symptoms. According to Grundy[3], a high CHO diet should not be recommended to patients with severely impaired insulin secretion, because it may raise postprandial plasma glucose levels and serum triglyceride levels. But a high-CHO and low-fat diet can be recommended to obese NIDDM patients for the purpose of weight reduction[2]. The diets for diabetic patients should aim at lowering the plasma glucose level, blood cholesterol, and triglyceride levels that are major risk factors for atherosclerosis[4]. Atherosclerosis is commonly seen in patients with diabetes. In a long term study with streptozotocin(STZ)-induced diabetic rats, high-fiber diets decreased total cholesterol and increased HDL-cholesterol levels[5]. In the same study[5], vascular lesions were examined histologically, and found that a high-fiber diet(15gram%) prevented development of atherosclerosis. Other studies found that the deleterious effects of a high CHO diet can be minimized when it is provided along with high levels fiber[6][7].

Beneficial effects of high-CHO low-fat and high-fiber diets have been reviewed elsewhere[8]. A high-CHO low-fat and high-fiber diet decreases plasma glucose levels[7], and insulin requirements[9]. It also lowers plasma cholesterol level[10]. There beneficial effects of high-fiber diets on plasma glucose and lipid levels was also seen in several species, including diabetic rats[5], mice[11], and dogs[12]. The types of dietary fibers are important because of their variable effects on diabetes. It is well known that soluble dietary fiber, because of its viscous characteristics, is more effective than insoluble dietary fiber in reducing postprandial plasma glucose and insulin levels[13]. Since diabetic patients usually ingest dietary fiber as a mixture of insoluble and soluble dietary fiber, we used a combination of insoluble and soluble dietary fiber for the high fiber diet in the present study. The purpose of the study was to evaluate the effect of CHO, fat, and dietary fiber on insulin sensitivity in STZ-induced diabetic rats.

Materials and Methods

1. Animals

Male Sprague-Dawley rats(375~400g body weight) were housed individually in steel cages in a temperature controlled(21±2℃) room with a 12 hour light-dark cycle. They were fed ground Purina Rodent Laboratory Chow for the 10-day environmental adaptation period. The rats were put in a diabetic condition by femoral vein injections of STZ(26mg/kg B.W., Sigma Chemical Co., St. Louis, MO, U.S.A.) in 0.1M citrate buffer(pH 4.5). The advantages of a femoral vein injection over a tail vein injection are ease of administration and visibility, allowing a rapid confirmation of venous administration. It also required a lower dosage of STZ than with tail vein injection(40mg/kg B.W. for the same degree of hyperglycemia). Rats were in the fed state before and after STZ injection. Five days later, rats were not fed for 6 hours and blood was sampled from the tip of tail for measurements of initial plasma glucose and insulin concentrations. Body weight and food intake were measured every other day at the same hour of the day. Paper sheets for collecting spilled food were moderately wet because of the characteristic polyuria in diabetic rats. Therefore, the papers were dried for 24 hours at room temperature, spilled food was weighed, and food intake was calculated. On the last day of the experiment, blood samples were collected from the tip of the tail after 6 hours' fasting for measurements of final plasma glucose and insulin concentrations.

2. Diets

After an adaptation period, rats were divided into four groups and fed one of the following diets for 2 weeks : (group 1) high-CHO low-fat low-fiber diet, (group 2) high-CHO low-fat high-fiber diet, (group 3) low-CHO high-fat low-fiber diet, and (group 4) low-CHO high-fat high-fiber diet. The composition of the diets is shown in Table 1. For the high-CHO low-fat diets, 63% of total calories was derived from CHO and 15% of total calories came from fat. For the low-CHO high-fat diets, 38% of the total calories was from CHO and 40% came from fat. All diets

Table 1. Composition of experimental diets(g/100g diet)

Group	1	2	3	4
CHO	High	High	Low	Low
Fat	Low	Low	High	High
Fiber	Low	High	Low	High
Fiber				
Guar gum	0	5.65	0	5.65
Wheat bran[1)]	0	4.35	0	4.35
Cellulose	2.0	0	2.0	0
Carbohydrate				
Corn starch	61.10	51.32	43.43	35.61
Wheat bran	0	3.01	0	3.01
Fat				
Lard	5.83	5.11	19.69	17.43
Corn oil	0.63	0	0.63	0
Wheat bran	0	0.63	0	0.63
Protein				
Casein	21.34	16.96	25.15	20.35
Wheat bran	0	2.01	0	2.01
Vitamin mix[2)]	1.5	1.5	1.5	1.5
Salt mix[3)]	6.0	6.0	6.0	6.0
DL-methionine	0.4	0.4	0.4	0.4
Cholesterol	1.0	1.0	1.0	1.0
Cholic acids	0.2	0.2	0.2	0.2

1) Wheat bran from AACC(St. Paul, MN, U.S.A.) : dietary fiber 36.65%, fat 5.33%. carbohydrate 25.40%, protein 17.00%, water 9.54%, and ash 6.10%

2) Vitamin mix(g/kg diet) : inositol 0.375g, ascorbic acid 0.075g, Ca-pantothenate 0.0375g, thamine-HCl 0.0225g, pyridoxine-HCl 0.0225g, nicotinic acid 0.0225g, Menadione 0.01875g, riboflavine 0.0075g, p-aminobenzoic acid 0.0075g, folate 0.0045g, biotin 0.0001875g, Vit E (Rovimix AD_3 325/325) 0.00345g, Vit B_{12}($Merch_2$+Mannitol) 0.0225g, Cholone-Cl(70% solution) 1.0725ml

3) Salt mix(g/kg diet) : $CaCO_3$ 20.4g, $CaHPO_4$ 3.6g, K_2PHO_4 19.26g, KI 0.012g, NaCl 10.08g, $FeSO_4H_2O$ 0.6g, $MgSO_4$ 5.82g, $MnSO_4H_2O$ 0.1536g, $ZnCO_3$ 0.036g, $CrKSO_412H_2O$ 0.024g, $CuSO_45H_2O$ 0.0198g

contained the same proportion of protein(22% of total calories as protein). The low-fiber diets contained 2gram% cellulose by weight and high-fiber diets contained 10gram% dietary fiber.

In the high-fiber diet, a 3 : 2 mixture of soluble dietary fiber and insoluble dietary fiber was used. This ratio was similar to human diet patterns. For the source of soluble dietary fiber, 5.65g of guar gum/100g diet was used because it is known to be effective for improving blood glucose level in diabetic patients[8)14)]. For the source of insoluble dietary fiber, 11.86g of wheat bran/100g diet was used. The amount of dietary fiber in the wheat bran was 36.65gram%(provided by the American Association of Cereal Chemists, St. Paul, MN, U.S.A.), with 92% as insoluble dietary fiber[15)]. Thus, the amount of 11.86g of wheat bran per 100g diet equals 4g of insoluble dietary fiber and 0.35g of soluble dietary fiber. In the low-fiber diet, 2gram% of cellulose was used to prevent diarrhea, which occurred in the preliminary study in diabetic rats fed the fiber-free diet. Diabetic rats seem to be more susceptible to diarrhea when they are fed a fiber free diet, and it might be associated with polydipsia. Even though the source of the dietary fiber(cellulose) in the low-fiber diets was different from the high-fiber diets(guar gum and wheat bran), it was believed that such low amounts of insoluble fiber(cellulose) did not affect glucose and insulin response[11)].

Wheat bran itself is 25.5% carbohydrate ; therefore, the corresponding amount of carbohydrate was subtracted from the corn starch in group 2 and 4. Wheat bran is also 17.0% protein, so the amount of protein was likewise subtracted from casein in group 2 and 4. However, all diets were isonitrogenous(18.2Kcal/g protein in the diet). Small amounts of corn oil were added to the low-fiber diets to compensate for the amount of fat contained in the wheat bran of the high-fiber diets, since the fatty acid composition of corn oil is similar to that of wheat bran[16)].

3. Insulin suppression test

Insulin sensitivity was determined using an in vivo insulin suppression test[17)]. This technique allows animals to dispose of identical glucose loads under the same external insulin stimulus, while suppressing endogenous insulin secretion using an infusion of epinephrine and propranolol. The greater plasma glucose disposal per unit of insulin, the greater the insulin sensitivity. The infusate contained 8mg of glucose/kg B.W./min of glucose(Abbott Laboratories, North Chicago, IL, U.S.A.), 0.08μg of epinephrine/kg B.W./min, (American Quinine Pospital Division, Shirley, NY, U.S.A.), 1.7μg of propranolol hydrochloride/kg B.W./min(Inderal, Ayerst Laboratories Inc., NY, U.S.A.), 2.5mU of insulin/kg B.W./min (Regular Iletin II, Eli Lilly Co, Indianapolis, IN, U.S.A.), 65μg of bovine albumin/kg B.W. /min(Baxter Healthcare Corporation, Glendale, CA, U.S.A.), and 234μg of NaCl/Kg B.W./min.

At the end of the 2-week experimental period, food was withdrawn at 08 : 00 hour, and infusions were started at 14 : 00 hour and terminated after 160 min. Rats were anesthetized with 65mg of sodium pentobarbital/kg B.W. intraperitoneally. Infusate was administrated via the right internal jugular vein cannulation. Body temperature was kept constant through a heating pad under the rats. Blood samples were collected at 10-min intervals from 120 min to 160 min of the infusion period from the tip of the tail into heparinized microtubes.

4. Glucose and insulin measurements

Blood samples were centrifuged at 4℃, and plasma was separated and frozen at −20℃ for future analysis of glucose and insulin concentration. Plasma glucose concentration was determined by the glucose oxidase method with a Beckman Glucose Analyzer 2(Beckman Instruments, Fullerton, CA, U.S.A.). Plasma insulin levels were determined using radioimmunoassay with rat insulin standard(Novo, Copenhagen, Denmark). The steady state plasma glucose(SSPG) and insulin(SSPI) were calculated by averaging the values of glucose and insulin in plasma samples obtained every 10 min during the 120~160 min infusion period.

5. Statistical analysis

Statistical analysis was performed using a Statview 512^+ package program(Brainpower Inc., Calabasas, CA, U.S.A.), an analysis of variance. For the differences among the groups, Scheffe F-test was used. Student's t-test was also used as appropriate. A p value less than 0.05 was considered statistically significant.

Results

Table 2 shows the body weight and daily food consumption. Initial body weights were comparable among all four groups. After two weeks of feeding, mean body weights of group 2 and group 4 were significantly greater than that of group 1. Daily food consumption of rats in the high-fiber diet group (group 2 and 4) was 20-25% lower than that of rats on the low-fiber diet(group 1 and 3), regardless of CHO and fat. This phenomenon may be due to satiety induced by the high-fiber diet.

Table 3 shows that initial plasma glucose concentrations were similar among the groups. The final plasma glucose level was compared to the initial plasma glucose level, and high fiber diets significantly reduced plasma glucose levels(△ −86±41mg/dL) in group 2. However, high fiber did not significantly decrease plasma glucose(△ −6±50mg/dL) in group 4. In contrast, plasma glucose levels were increased in both low-fiber diet groups(△ +125±65 mg/dL in group 1 and △ +152±48 mg/dL in group 3). Rats in group 2 showed the lowest final plasma glucose level. Both initial and final plasma insulin levels were found to be similar in all groups tested.

Fig. 1 shows SSPI levels in STZ-induced diabetic rats. The SSPI levels of group 1 and 2 were 12.6±2.6ng/ml(n=6), and 13.3±0.9ng/ml(n=10), respectively. And the SSPI levels of group 3 and 4 were 10.3±2.1ng/ml(n=6) and 12.2±1.8ng/ml(n=6), respectively. Therefore, the SSPI of diabetic rats were also comparable among all groups.

Table 2. Body weight and daily food intake in STZ induced diabetic rats on varied amounts of carbohydrate(CHO), fat, and dietary fiber for 2 weeks

Group	1	2	3	4
CHO	High	High	Low	Low
Fat	Low	Low	High	High
Fiber	Low	High	Low	High
(n)	(6)	(10)	(6)	(6)
Body weight(g)				
Initial	386±71[1)]	388±4	388±7	30±5
Final	368± 9[2),a]	395±5[b]	385±6[a,b]	390±7[b]
Food intake(g/day)				
	27.3±1.7[a]	20.3±1.7[b]	25.1±0.7[a]	19.9±1.5[b]

1) Values represent mean±SEM.
2) Values with the different superscripts within a line are significantly different($P<0.05$).

Table 3. Initial and final plasma glucose and insulin concentration in STZ induced diabetic rats

Group	1	2	3	4
CHO	High	High	Low	Low
Fat	Low	Low	High	High
Fiber	Low	High	Low	High
(n)	(6)	(10)	(6)	(6)
Glucose(mg/dL)				
Initial	363±16[1)]	371±20	386±25	386±28
Final	483±66[2),a]	286±47[b]	539±41[a]	380±71[a,b]
Insulin(ng/ml)				
Initial	0.12±0.04	0.14±0.02	0.19±0.02	0.25±0.06
Final	0.19±0.05	0.27±0.03	0.26±0.10	0.22±0.04

1) Values represent mean±SEM.
2) Values with the different superscripts within a line are significantly different($P < 0.05$).

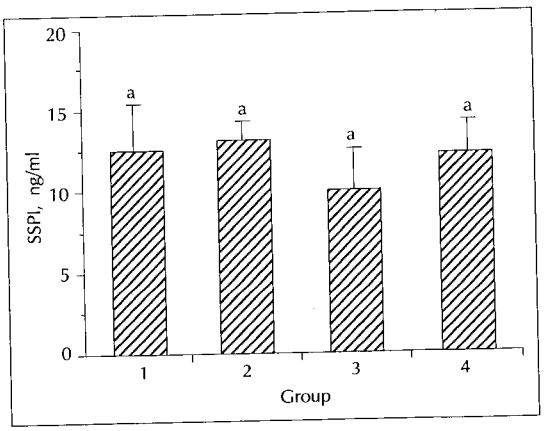

Fig. 1. Steady state plasma insulin(SSPI) concentration during insulin suppression test in STZ-induced diabetic rats on varied amounts of carbohydrate(CHO), fat, and dietary fiber.

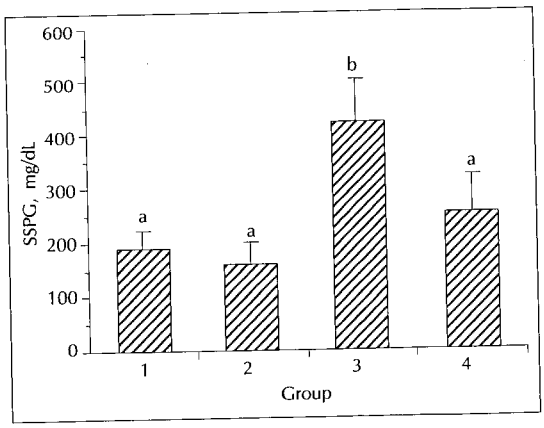

Fig. 2. Steady state plasma glucose(SSPG) concentration during insulin suppression test in STZ-induced diabetic rats on varied amounts of carbohydrate (CHO), fat, and dietary fiber.

Fig. 2 shows SSPG in the STZ-induced diabetic rats. The SSPG level in group 3(423±72mg/dL, n=6) was significantly higher($p<0.05$) than those of rats on any other diets. In rats on the low-CHO high-fat diet, the SSPG level of rats in group 4(243±79mg/dL, n=6) was significantly lower than that of rats in group 3. Therefore, the effect of fiber on insulin sensitivity was seen in rats fed the low-CHO high-fat diet. For rats fed the high-CHO low-fat diet, there was no significant difference in SSPG levels between the low fiber-fed group(group 1, 184±29mg/dL, n=6) and the high fiber-fed group(group 2, 155±28mg/dL, n=10). When the low-fiber groups were compared, the mean SSPG level of group 1 was significantly lower than that of group 3, indicating that the high-CHO low-fat diet enhances insulin sensitivity in rats on the low-fiber diet.

Discussion

The results in the present study demonstrate that low-CHO high-fat low-fiber diets appear to be detrimental to insulin sensitivity in STZ-diabetic rats. In contrast, a high-CHO low-fat diet appear to be beneficial. The function of insulin to promote glucose utilization is in proportion to the level of plasma glucose seen in Table 3(correlation coefficient=0.67 between final plasma glucose level and SSPG, $p<0.001$). The effect of the high-CHO on improving insulin sensitivity is significantly greater in the low-fiber diet(group 1 vs group 3), but seems to be masked in the high fiber diet(group 2 vs group 4). Moreover, the effect of high fiber on improving insulin sensitivity is significantly greater in rats on the low-CHO high-fat diet(group 3 vs group 4). These results suggest that there is an interaction between amounts of CHO, fat, and fiber in their dietary ef-

fect on improving insulin sensitivity($p=0.001$, using ANOVA). Recently, Cameron-Smith, et al.[18] reported that in STZ-induced diabetic rats, a guar gum diet is better in improving insulin sensitivity than a wheat bran diet. They suggested that the improvement in insulin sensitivity by guar gum diets may be related to the reduction in postprandial glucose level and the inhibition of urinary glucose loss. In our study, rats on the low-CHO high-fat low-fiber diet showed the lowest insulin sensitivity among all groups. In this particular diet, the fat proportion was increased more than twice that in the low fat diet, while the CHO proportion was decreased. Therefore, high fat levels in this diet probably contribute to deterioration in the insulin sensitivity.

The source of dietary fiber is as crucial to successfully improving glucose control the amount of the dietary fiber[13)20)21)22)]. For example, water soluble dietary fiber, such as guar gum and pectin, effectively delays glucose absorption in the gastrointestinal tract [23)]. It flattens the postprandial glucose and insulin rise in both healthy[24)25)] and diabetic individuals[26)27)]. In addition, the digestibility of the starch may affect glucose metabolism. Resistant starch, which is known to be neither digested nor absorbed in the small intestine of healthy people, reduces postprandial plasma concentrations of glucose, lactate, insulin, and gastric inhibitory polypeptides in healthy individuals [28)]. Among the digestible starches, amylopectin is more quickly digested and absorbed than amylose. A waxy corn starch that is high in amylopectin produces larger postprandial glucose in healthy rats than high amylose corn starch[29)]. Therefore, amylopectin seems to promote the development of insulin resistance. Studies of the effect of wheat bran on glucose metabolism are inconclusive. It was reported that the postprandial glucose response was reduced after 24 days of ingestion of meals containing 20g/day of wheat bran in healthy individuals[30)]. A recent study has shown that breakfast cereals containing 6.3g guar gum reduced the postprandial glucose in healthy persons[31)]. In contrast, Munoz and coworkers[32)] reported no change in normal healthy persons who ate 26g/day of wheat bran for 30 days. It was also reported that wheat bran has beneficial effects for reducing plasma glucose by inhibiting pancreatic enzymes[33)]. However, the types of wheat bran, particle sizes, and even harvesting season may affect the results. In the present study, a mixture of soluble and insoluble dietary fiber was used for the high fiber diets. It has been reported that consumption of high fiber meals composed of natural foodstuff with soluble and insoluble dietary fiber, reduced postprandial hyperglycemia in NIDDM patients[34)]. For the low-fiber diets in our study, 2gram% of cellulose was added. It has been reported that eating high amounts of cellulose of 10gram% for 5 weeks decreased intestinal glucose absorption in normal healthy rats[35)]. In neonatally STZ-induced diabetic mice, feeding of chow diet with added 20gram% of cellulose for 8 weeks improved pancreatic insulin secretion stimulated by a 30mM glucose solution[11)]. However, it was presumed that such low amounts of cellulose(2gram%) would not affect any parameters in our study.

The mechanism of the effect of dietary fiber on improving insulin sensitivity is not clearly known. However, it has been reported that dietary fiber increases viscosity in the lumen and thickness of the unstirred layer, consequently the absorption of nutrients is delayed[36)]. The smaller postprandial rise of plasma glucose and insulin with an increased intake of dietary fiber may be associated with an increased insulin sensitivity. A possible mechanism for improving insulin sensitivity may be attributed to a cellular insulin action. The glucose disposal rate in the major peripheral insulin target tissues, such as a skeletal muscle, was markedly reduced in the NIDDM subjects[37)]. This reduction may cause a failure in signaling between glucose transport system and insulin receptor. Moreover, this could be a genetic problem since abnormal sequences in the genes for the glucose transporter and insulin receptor were found in some NIDDM subjects[38)]. However, this genetic abnormality may not be considered as a major cause since it has not been found in all of the NIDDM subjects. The insulin receptors on the adipocytes, liver, erythrocytes, and skeletal muscle of NIDDM may have defects in their autophosphorylation-kinase activity[38)]. The chronic hyperglycemia may decrease insulin receptor kinase functions, and the magnitude of the reduction is correlated with the degree of hypergly-

cemia. The decrease in the receptor kinase is reversible by reducing the blood glucose concentration. In addition, Olwfsky and Reaven[39] reported that there was an inverse correlation between the plasma insulin level and insulin binding to the monocytes. The high-CHO low-fat high-fiber diet appears to increase in vitro insulin binding to blood monocytes in both patients with insulin-dependent diabetes mellitus(IDDM)[40] and NIDDM[41]. This agrees to our results of increased insulin sensitivity with the high-CHO low-fat high-fiber diet.

Another possible mechanism for the role of dietary fiber in enhancing insulin sensitivity may be attributed to actions of other hormones. Plasma glucagon in diabetic rats is usually higher than in normal rats, and the high fiber diet caused significantly lower pancreatic immunoreative glucagon levels in diabetics than did the low-fiber diet[42]. In obese NID DM subjects, the high-fiber diet lowered pancreatic polypeptide, a pancreatic fluid inhibitor, and decreased levels of motilin, which is a stimulator of gastric and small intestine motility[43]. It has also been reported that dietary fiber or resistant starch reduced levels of postprandial gastrointestinal peptide[44][45], which is a potent insulin stimulator. Fatty acids or glucose entering the gut wall during the absorptive process[15] stimulate gastrointestinal peptide secretion. Since dietary fiber alters the absorptive area of the intestinal wall, the absorption rates of the nutrients would be slow and their stimuli to release the gastrointestinal peptide would seem to be low. In contrast, it has been reported that a meal with guar gum and pectin did not change the gastrointestinal peptide level, even though these fibers improved glucose tolerance in NIDDM patients[46]. Jenkins and coworkers[25] have also demonstrated that guar gum decreased plasma glucose and insulin curves of the oral glucose tolerance test, but did not alter levels of enteroglucagon and the gastrointestinal peptide. Based on these studies, the relationship between hormonal changes mediated by dietary fiber and insulin sensitivity is unclear.

The other potential mechanism for dietary fiber enhancing insulin sensitivity may be through alterations in short chain fatty acid levels. Short-chain fatty acids are produced from colonic fermentation of dietary fiber in rodents and humans[47][48][49]. They are readily absorbed from the large intestine and distributed to peripheral tissues in the body. In diabetic subjects, a high-fiber diet increased the plasma acetate level. The alteration in the acetate level may influence glucose metabolism, and consequently it may be associated with increased insulin sensitivity[50]. In isolated rat hepatocytes, acetate increased the citrate level in cells incubated with glucose[51] and altered hepatic glucose metabolism[52]. In isolated pancreatic islets of normal healthy rats, acetate increased glucose-induced insulin secretion[53]. An in vivo study with rats also demonstrated a potentiating effect of acetate in glucose-induced insulin secretion[54]. However, other study reported that acetate did not improve glucose tolerance in healthy humans[55]. Recently it was reported that when propionate was orally supplied in obese rats, the plasma glucose level was lowered[56]. It was suggested that propionate may inhibit amylolytic activity and reduce postprandial plasma glucose and insulin response[57]. The mechanism of short chain fatty acids for improving insulin sensitivity needs further studies to delineate its action.

In conclusion, the results of the present study show that in STZ-induced diabetic rats on a low-CHO high-fat diet, high-fiber diets increased the efficiency of insulin-stimulated glucose uptake. High-CHO low-fat diets also increased this efficiency in STZ-induced diabetic rats on a low-fiber diet. These results suggest two things : first, a high-carbohydrate diet is effective in improving insulin sensitivity in the diabetic who ingests either a low amount of dietary fiber or a high level of dietary fiber ; and second, a high fiber diet is also beneficial to the diabetic who has a low-CHO high-fat diet.

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