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LONG TERM EFFECTS OF BARLEY BREAD PRODUCTS ON METABOLIC CONTROL OF NON INSULIN DEPENDENT DIABETES MELLITUS

BY

KUSUM GOSAIN

A thesis submitted to the Faculty of Graduate Studies and Research in partial fulfillment of the requirements for the degree of **MASTER OF SCIENCE**

IN

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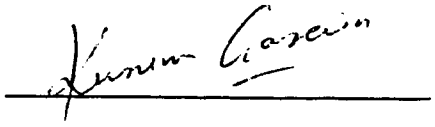

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The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies and Research for acceptance, a thesis entitled '**Long Term Effects of Barley Bread Products on the Metabolic Control of Non Insulin Dependent Diabetes Mellitus**' submitted by **Kusum Gosain** in partial fulfillment of the requirements for the degree of **Master of Science in Foods** and Nutrition.

Dr. T. K. Basu (Supervisor)

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ABSTRACT

Soluble fiber (SF) is known to have beneficial effects on the glycemic response and lipid profile. Barley contains β-glucan as a source of SF. The present study was undertaken to investigate the effects of barley bread products on glycemic, insulinemic and lipidemic response, in eleven free-living male subjects with non-insulin dependent diabetes mellitus (NIDDM). This was a randomized and crossover-designed experiment for a total period of 24 weeks.

A variety of barley bread products were developed from high β-glucan barley flour and cracked barley. NIDDM subjects were randomly assigned to either barley bread products (BBP) or to white bread products (WBP), each for a period of 12 weeks. One group consumed BBPs first and then switched over to WBPs while the other group did vice-versa. Dietary assessment was carried out through four 48-h dietary recalls during the each dietary period. Eight hour plasma glucose and serum insulin profiles were obtained at 0, 12 and 24 weeks. Similarly, fasting plasma lipid parameters including, total cholesterol, low-density lipoprotein cholesterol (LDL-C), high-density lipoprotein cholesterol (HDL-C) and triglyceride concentrations were measured.

No significant difference was found in the total energy, carbohydrates, protein and fat intakes during the two study periods. Mean total dietary fiber (DF) intake was 28 g/d and 39 g/d during WBP and BBP periods, respectively. The body weight of the subjects remained stable throughout the study. Fasting plasma glucose and serum insulin did not change significantly during the two dietary periods. However, 73% of the subjects

showed a consistent decreasing trend in their total area under curve (AUC) for plasma glucose response. The total AUC for insulin was increased significantly ($p < 0.05$) during BBP period. The insulin/glucose ratio was also increased significantly ($p < 0.05$) during peak 1 (4-h, breakfast) during BBP period. A consistent decreasing trend in the mean plasma levels of total cholesterol and LDL-C was exhibited by 64% of the subjects during BBP period. Although there was no significant change in the HDL-C concentration, however, 73% of the subjects showed an increase in their HDL-C concentrations. The LDL/HDL ratio decreased significantly ($p < 0.05$) during the BBP period as compared to WBP period. Starch, SF, DF and β-glucan from BBPs were negatively correlated ($p < 0.05$) to plasma triglycerides. The percentage of fat from the total energy was positively correlated ($p < 0.05$) to the insulin/glucose ratio for peaks 1 and 2. No side effects from BBPs were reported by the subjects. The compliance of the subjects to the BBPs was good.

Overall, these results suggest that the incorporation of the BBPs into the usual diet of the NIDDM subjects may potentially improve their lipidemic control, and hence BBPs may prove to have an important role in the nutritional management of NIDDM subjects.

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INTRODUCTION

Non-insulin dependent diabetes mellitus (NIDDM) is the consequence of a deficiency in insulin action or of insulin secretion, or a combination of the two. NIDDM accounts for over 85% of diabetes worldwide and is associated with signigicant of morbidity and mortality resulting from its microvascular, macrovascular, and neuropathic complications.

Medical nutritional therapy is the cornerstone of treatment for NIDDM patients. The aims of dietary therapy is to maintain as near-normal blood glucose levels as possible and to achieve optimal serum lipid levels while maintaining optimal nutrition. According to recommendations of the American Diabetes Association (ADA) [1994], approximately 10% to 20% of the daily caloric intake should be derived from protein and distribution of energy from fat and carbohydrate can vary and be individualized based on the nutritional assessment and treatment goals. Soluble fiber (SF) is a beneficial component for the diet of individuals with diabetes. A fiber intake of 40 g per day is recommended by the ADA [1992]. The most important attributes of SF are its potential for lowering postprandial glucose and insulin response in individuals with or without diabetes and its ability to lower plasma total and low-density lipoprotein cholesterol (LDL-C) concentrations.

Barley is unique among cereals as it contains a relatively high concentration of mixed-linked, nonstarchy polysaccharides, β-glucans. These β-glucans can vary in degree of solubility in water and in relative acid viscosity. The waxy, hulless cultivars of barley are consistently higher in total dietary fiber (DF) and SF. Barley has long been used in the malting and brewing industries and for animal feed but very little is used in human foods. The unique properties of barley suggest that it has great potential for use in the human diet and in particular for the diet of diabetic individuals. Barley flour is the key to its incorporation into food products like bread, muffins, cookies, pasta, noodles and other snacks. Barley bread products have not been used in long-term human studies.

Research proving the beneficial effect of barley bread products in treatment of non-insulin dependent diabetics is lacking.

The present study was undertaken to determine the long term effects on glycemic, insulinemic and lipid profile by incorporating the high β-glucan barley bread products in the diets of free-living NIDDM male subjects through biochemical, clinical and dietary assessment.

MANAGEMENT OF NIDDM

Clinical diabetes is a syndrome characterized by chronic hyperglycemia and disordered carbohydrate, lipid and protein metabolism. The underlying cause of diabetes is either an absolute deficiency of insulin secretion or a reduction in the biologic effectiveness of insulin (or both). It is associated with the development of specific microvascular complications and of non-specific macrovascular diseases. It is a universal health problem affecting individuals of all stages of development. Diabetes is the sixth leading cause of death (fourth by disease) in the United States [Pi-Sunyer, 1993]. It afflicts more than 14 million Americans and is on the increase in the United States and most other countries of the world [Anderson, 1993]. The number of cases reported is increasing rapidly with the aging of the population, changes in lifestyle and improvement in diagnosis [WHO, 1985]. NIDDM, more commonly called type II diabetes, is the predominant form of diabetes in all populations [Jarret, 1989]. In certain groups, such as among the Pima Indians of Arizona, the prevalence of NIDDM is about 50% in adults over the age of 35 years [Knowler et al, 1978]. Eighty-five percent or more of all cases of diabetes are attributed to NIDDM.

For the proper management of patients with diabetes, up-to-date knowledge regarding the nature of the particular type of diabetes and the available treatment regimens is very important. The medical management of patients relies heavily on nutrition treatment and dietary control. Other components of medical management include the use of exogenous insulin or oral hypoglycemic agents and exercise. Although oral sulfonylurea agents facilitate insulin secretion and increase insulin sensitivity in certain individuals, they are too often used as a substitute rather than a support for diet and exercise therapy [Anderson et al., 1987]. Moreover, long-term effects, risks, and benefits of these agents are not known. Hypocholesterolemic drug therapy frequently is poorly tolerated and associated with side effects such as constipation, heartburn, abdominal pain, and nausea [Grundy et al., 1981]. Diet is the keystone for successful

management. Despite advances in our knowledge of the clinical course of diabetes, controversy persists over the most appropriate dietary guidelines. According to the American Dietetic Association [1994], the nutrition recommendations and principles for people with diabetes mellitus should include an individually developed dietary prescription based on metabolic, nutrition and lifestyle requirements. The goals of medical nutrition therapy for NIDDM should include the maintenance of as near-normal blood glucose levels as possible and the achievement of optimal serum lipid levels. According to current dietary guidelines of the ADA [1994] approximately 10 to 20% of the daily caloric intake should be derived from protein. The distribution of energy from fat and carbohydrate can vary and should be **individualized** based on the nutrition assessment and treatment goals. If elevated LDL-C (low density lipoprotein cholesterol) is the primary problem, the National Cholesterol Education Program step 2 diet guidelines, in which <7% of total energy is from saturated fat, 30% or less of energy is from total fat, and dietary cholesterol <200 mg/d should be implemented. In the case of elevated triglycerides and very-low density lipoprotein cholesterol, <10% of energy each from saturated and polyunsaturated fats and up to 20% of energy from monounsaturated fat and a moderate intake of carbohydrates should be recommended [American Dietetic Association, 1994].

Extensive investigation of the pathophysiology of NIDDM have identified two defects in endocrine function: insulin resistance and insulin deficiency [Taylor et al., 1994]. Despite general agreement that both defects are present in most patients with established NIDDM, many authorities have debated the question of which defect is the primary cause. According to Reaven [1988] and DeFronzo [1988], impaired insulin sensitivity represents a key metabolic derangement in diabetes. Insulin is a hormone that elicits multiple biological responses. Among its biological actions, insulin accelerates glucose transport into muscle and adipose tissue, regulates the activities of intracellular enzymes, and regulates the transcription of selected genes. Pancreatic insulin secretion is subject to regulation by multiple factors. Although the concentration of glucose in plasma is the most important regulator of insulin secretion, other regulatory influences

are important as well (e.g., amino acids, circulating hormones, neurotransmitters, paracrine factors) [Taylor et al., 1994]. Patients with NIDDM have a diminished response to exogenously administered insulin [DeFronzo, 1992] and are resistant to the action of endogenously secreted insulin. Both cross-sectional and longitudinal studies have demonstrated that patients are hyperinsulinemic even before the plasma glucose has become elevated to the point where it satisfies the diagnostic criteria for diabetes [Reaven, 1988, Martin et al., 1992]. The rate of glucose disposal is reduced, and suppression of impaired hepatic glucose output to a given concentration of insulin has been demonstrated with a glucose-clamp technique [Taylor and Agius, 1988]. Gannon and Nuttall [1987] observed that in normal individuals after the ingestion of a glucose load, the time required for the peripheral plasma glucose concentration to return to the fasting concentration was 1.5 h and for insulin concentration it was 3 h. However, in untreated mildly NIDDM male subjects it takes 4-5 h for plasma glucose to return to the fasting concentration and insulin concentrations were still modestly elevated 5 h after the ingestion of glucose load.

Glucose tolerance is dependent on a complex interaction among several physiological processes, including first phase and second phase insulin secretion, insulin clearance, insulin sensitivity, and the propensity of a high glucose concentration (independent of insulin) to enhance glucose utilization [Bergman, 1989]. The plasma glucose concentration is variably elevated depending on the severity of insulin insensitivity and of β-cell unresponsiveness to a raised circulating glucose concentration [Nuttall and Gannon, 1991]. An abnormality in the usual pulsatile pattern of insulin secretion is also present [Leahy, 1990] as well as an increase in the ratio of proinsulin to insulin in the circulation [Taylor and Agius, 1988]. The pathogenesis of NIDDM remains unknown. The β-cell mass is either normal or only modestly reduced and the ability to synthesize insulin is intact. However, the maximal capacity to secrete insulin may be impaired [Leahy, 1990]. Thus, several abnormalities in insulin and glucose metabolism have been identified in people with NIDDM.

SOLUBLE FIBER AND GLUCOSE ABSORPTION

Since the suggestion of Trowell [1975] that diabetes may be a fiber-deficiency disorder, dietary fiber (DF) has become an important and effective addition to a diabetic diet. DF is the component of the diet that is not digested or absorbed in the small intestine, due to the absence of enzymes that digest it [Sels et al., 1991]. Nevertheless, DF play an important role in human nutrition.

These substances have been classified in many different ways. However, from a metabolic standpoint, it is most useful to classify them according to their degree of solubility in water [Nuttall, 1993]. The components considered generally soluble include pectin, gums and mixed linked β-glucans. Pectin and gums are found in fruits, legumes and certain seeds, while β-glucans occur predominantly in barley and oats [Newman et al., 1989a]. The water-insoluble fibers include cellulose, lignin and certain hemi-celluloses, present principally in wheat, mostly grain products and vegetables [Vinik and Jenkins, 1988].

Soluble fiber (SF) and insoluble fiber often exhibit distinctly different physiological effects [Shinnick et al., 1989]. It is the SFs that have shown promising results in the treatment of hypercholesterolemia and hyperglycemia. The most important attributes of SF are its potential for lowering postprandial glycemia in individuals with and without diabetes [Anderson, 1985]. SF are fermented to short-chain fatty acids in the colon and contribute little to fecal bulk. The insoluble fibers, on the other hand, are largely responsible for increasing the bulk of the feces but have little metabolic effects [Vinik and Jenkins, 1988]. In addition, SF appear to prolong the rate of gastric emptying and intestinal transit time [Holt et al., 1979]. The insoluble fibers have the opposite effects, reducing the rate of gastric emptying and intestinal and colonic transit time [Eisenhans et al., 1980].

Current estimates of the DF intake of adults in the United States range from 10 to 30 g/day [American Diabetes Association. 1987]. In a survey of 200 Canadian males, Kay et al [1980] reported mean DF consumption was 19 g/day, about half of which was cereal fiber. However, the consumption of SF is not known. The ADA [1992] recommends a daily consumption of 40 g DF. In the position of the American Dietetic Association [1993], food, not DF supplements, are recommended as the best means of increasing daily consumption of DF. The Canadian Diabetes Association [1989] has recommended increases in dietary carbohydrate to come from unrefined starchy foods such as whole grain cereals and breads, legumes and tubers.

Viscosity has been reported as important in determining the effectiveness of SF in lowering glycemic response. Jenkins and coworkers [1978] compared the effects of different fibers on gastrointestinal physiology. They administered various plant fibers orally with glucose and sugars (lactulose and xylose). The SF, such as guar gum and pectin, significantly prolonged the mouth-to-cecum transit time, either by delaying gastric emptying or by prolonging the time for intestinal passage. Guar gum, a water-soluble galactomannan from the Indian cluster bean *Cyanopsis tetragonolobus*, appears to impair glucose absorption and is also known to form a very viscous gel when added to water [Jenkins et al., 1978]. Jenkins et al [1978] considered the latter property to be potentially important mechanistically. To test this hypothesis, they correlated the viscosity of the gel formed when a fiber mixed in water with the effect of that fiber (12 g) on the glucose rise after ingestion of 50 g glucose in normal subjects. SF were most effective in reducing the rise in blood glucose and insulin; the higher the viscosity of the SF, the greater the response. The addition of insoluble fibers, including wheat bran or cellulose, were ineffective in altering the blood glucose response to a meal [Jenkins et al., 1978].

In a double blind, placebo-controlled, crossover study by Landin et al [1992], ten grams guar or placebo granulate was given three times a day for six weeks to 25 healthy non-obese middle-aged men. 6% decrease in fasting blood glucose ($p < 0.001$), 11% in cholesterol ($p < 0.001$) and 15% in triglycerides ($p < 0.05$) were seen during guar treatment when compared with placebo. Insulin sensitivity, measured with the

euglycemic-clamp technique, also increased ($p < 0.01$) during guar treatment. However, the shortcomings of guar gum are that its incorporation into the palatable meals is not easy and also some mild side effects such as flatulence, bloating and diarrhea have been reported by some subjects [McIvor et al., 1985; Aro et al., 1981]. Long-term studies were not possible due to the poor palatability of purified guar gum. An ideal way to achieve the maximum fiber effect might be to incorporate this SF into starchy foods [Vinik and Jenkins, 1988]. In another trial by Jenkins et al [1980b], 14-26 g/d of guar incorporated in crispbread was fed to IDDM and NIDDM subjects for a period of 52-weeks. Incorporation of guar resulted in a better metabolic control as estimated by a decrease in glucosuria and a reduction of insulin. The study by Uusitupa et al [1989] failed to show an improvement in glycemic control with guar gum. The effect of guar gum also depends on the way it is administered. When guar gum is completely mixed with food (e.g., baked into bread), a reduction in blood glucose and insulin is observed, whereas the effect of sprinkling guar gum onto a meal [Jenkins et al., 1976], given in capsule [Cohen et al., 1980] or taken before a meal [Jenkins et al., 1979] is more variable. Groop and coworkers [1993] investigated the long-term effects (48 wk) of 15 g guar gum/d on glycemic control and insulin secretion in 15 diet treated subjects with NIDDM. Guar gum and placebo (wheat flour) were administered as granulated preparations mixed with fluid or food. Guar gum improved long-term glycemic control, postprandial glucose tolerance and lipid concentrations. The C-peptide response to a test meal increased with time during guar gum treatment, whereas the insulin response remained unchanged. A decreased molar ratio of insulin to C-peptide suggests that guar gum may increase hepatic insulin extraction.

In a recent study by Braaten et al [1991] the effects of oat gum on plasma glucose and insulin have been compared to the effects of guar gum. Oat gum, a SF isolated from oats, was prepared; approximately 80% of this oat gum was (1→3),(1→4) β-D-glucan (oat β-glucan) [Wood et al., 1989]. This highly viscous polysaccharide is present in commercial rolled oats at a concentration of 4% and in commercial oat bran at 7-10%, and can be as high as 19% in specially processed bran fractions [Wood et al., 1989].

Nine healthy fasting subjects were fed 14.5 g of specially prepared oat gum with 50 g glucose to compare with the response to guar gum with glucose and to glucose alone. The plasma glucose and insulin responses were greater after the glucose intake as compared to responses after both gum meals at 20 and 60 min. intervals ($p < 0.01$). The responses to oat and guar meals were nearly identical. The results of this study established that the viscosity of an oat gum solution approaches that of guar and is more palatable than guar. One distinct advantage of SF from oats as compared, to guar, is that oat β-glucan is readily available in a functionally useful edible form [Braaten et al., 1991].

Librenti et al [1992], recently studied the effects of preprandial ingestion of 7 g of soya fiber or an equal amount of purified cellulose on serum glucose and insulin of eight patients with NIDDM. The glycemic profiles after soya ingestion were lower than those after cellulose ingestion and the use of soya fiber did not carry any undesirable side effects. Pastors et al [1991] investigated the ability of psyllium fiber to reduce postprandial serum glucose and insulin concentrations. Eighteen NIDDM patients in a crossover design took two doses of psyllium or placebo (6.8 g); one dose before breakfast and the other before dinner. No psyllium fiber or placebo was given at lunch in order to measure the residual or second-meal effects. For meals eaten immediately after psyllium ingestion, maximum postprandial glucose elevation was reduced by 14% at breakfast and 20% at dinner relative to placebo. Postprandial insulin concentrations measured after breakfast were reduced by 12% relative to placebo. However, some concern exists about the use of psyllium-containing products because of the possibility of allergic reactions in sensitized individuals [Lantner et al., 1990]. Some researchers, however, failed to detect significant postprandial glucose blunting when psyllium fiber [Jarjis et al., 1984] or soya fiber [Thomas et al., 1988] was administered to NIDDM patients or when pectin was administered to non-diabetic patients [Sandhu et al., 1987]. These discrepant findings may be due in part to the type of test meal given with the fiber. For example, in psyllium fiber [Jarjis et al, 1984] and soya fiber [Thomas et al., 1988] trials where no effect was observed, the fiber was administered with a liquid test meal.

Different studies have used different types of fiber that may have variable effects, and also there appears to be a wide range of dose levels that have been used. In some of the studies SF and insoluble fibers, whose effects may counteract each other, have been used in combination. Studies that examined acute effects or studies carried out for only short term in a metabolic ward may not necessarily apply in the home environment [Vinik and Jenkins, 1988].

There are several different methods used by different groups to calculate the area under the blood glucose response curve, and each one gives different results for the same blood glucose data [Wolever et al., 1990]. Therefore, when comparing the results of different studies, it is necessary to determine the method by which the areas under the curve (AUC) have been calculated. Both total and incremental AUC have been used to study glycemic response, and it is still unclear whether area below baseline should be subtracted when estimating incremental AUC [Jenkins et al., 1981; Nuttall et al., 1984]. It has been suggested that negative areas (below baseline) should not be subtracted and that points below baseline should be ignored and replaced by zero [Wolever and Jenkins, 1986].

The current dietary guidelines for individuals with diabetes include individualization based on the nutrition assessment and treatment goals. Less than 10% of the total energy is recommended from saturated fat and up to 10% of energy from polyunsaturated fats, leaving 60% to 70% of the total energy from monounsaturated fats and carbohydrates [American Dietetic Association, 1994]. The previous dietary guidelines for diabetic patients included a low fat diet rich in carbohydrates (up to 60 to 70%). Recent studies, however, suggest that high carbohydrate diets may accentuate hypertriglyceridemia, reduce serum high density lipoprotein cholesterol (HDL-C) concentrations, and may even worsen hyperglycemia and raise plasma insulin [Grundy, 1986; Coulston et al., 1987; Garg et al., 1988]. In some diabetic patients, there appears to be an increased excursion of plasma glucose after a high-carbohydrate meal [Garg et al., 1988]. The compensatory response to a high-carbohydrate diet in some NIDDM patients may not be sufficient to offset an increased intake of carbohydrate [Grundy, 1991]. β-cell

response to dietary carbohydrates may be blunted in NIDDM subjects compared with normal individuals, thereby high resistance to the peripheral insulin action may not be overcome by a limited increase in insulin secretion induced by a high-carbohydrate diet [Grundy, 1991]. However, the extent to which a patient can compensate for an increased carbohydrate intake depends on the stage of NIDDM. In early stages, the compensation may be complete but with a greater decline in β-cell function, compensation may be inadequate to prevent a higher average level of glucose when the diet is high in carbohydrate [Grundy, 1991]. Garg et al [1994] undertook a randomized, crossover study involving 42 NIDDM patients to compare the long-term effects of substituting monounsaturated fats for carbohydrates on glucose, insulin and lipoprotein levels. The high-carbohydrate diet provided 55% of the total energy as carbohydrates and 30% as fat. The high monounsaturated fat diet provided 45% of the total energy as fat and 40% as carbohydrates. As compared to high monounsaturated fat diet, the high-carbohydrate diet increased fasting plasma triglyceride levels by 24% and increased daylong plasma triglyceride, glucose and insulin values by 10%, 12% and 9%, respectively [Garg et al., 1994].

Glycemic index (GI) is a classification of foods based on their blood glucose response to a starchy food, white bread [Wolever et al., 1991]. The first classification of the carbohydrate foods according to their glycemic response was published by Otto et al [1973]. A high GI indicates that the dietary carbohydrate elevates plasma glucose faster than a carbohydrate of a lower GI. A reduced rate of starch uptake is particularly beneficial to diabetes, because a lowered postprandial glucose response lowers the insulin demand [Jenkins et al., 1983]. Researchers have slightly different aims when looking at postprandial glucose response to carbohydrates. Jenkins's group made an assumption that there is a positive correlation between the GI and insulin responses [Jenkins et al., 1982]. For many years Reaven and Coulston have argued that it is important to measure the insulin response, especially as hyperinsulinemia may be a risk factor for coronary artery disease [Coulston et al., 1984]. Hollenbeck et al [1986] suggested that the GI was

inadequate to evaluate the physiological impact of dietary components on blood glucose response.

The amylose and amylopectin (polysaccharides hydrolyzed in the human small intestine) are present in various ratios in food starches and their ratio is known to affect the glycemic response [Frost et al., 1993]. Goddard et al [1984] observed that high amylose rice caused lower blood glucose and insulin responses as compared to low amylose rice. The beneficial effect of high-amylose varieties was attributed to a reduced rate of enzymatic digestion due mainly to formation of complexes between amylose and lipids. Behall et al [1989] compared high- and low-amylose diets in a controlled crossover study in which high-amylose starch replaced normal starch (low amylose, high amylopectin) in baked goods. Lower glycemic and insulin responses were found during the high-amylose diet and simultaneously cholesterol fell by 6% and triglycerides by 19% compared with the low-amylose diet. The effect of processing and cooking affects to susceptibility of the starch to enzyme digestion probably due to the dispersal of amylose [Brand et al., 1985]. The mechanism for lowered metabolic responses in the presence of high-amylose starch is probably a lowered rate of amylosis.

'Resistant starch' (RS) is a term used to describe starch that is resistant to pancreatic amylase [Cummings and Englyst, 1987]. Bjorck [1993] has recently demonstrated that high amylose corn flour, which is high in RS, produces a lower glycemic and insulin response. In a recent study by Granfeldt et al [1994] postprandial glycemic and insulinemic responses and satiety with various barley products were evaluated in normal subjects. The rate of in vitro starch digestion and the content of in vitro RS were also studied. The boiled intact and milled kernels from four barley genotypes with different amylose-amylopectin ratios (7-44%) were tested. All barley products elicited lower metabolic responses and higher satiety scores when compared with white wheat bread. The lente behavior of boiled flours was probably due to the viscous properties of β-glucans. The boiled intact kernels produced lower glucose and insulin responses as compared to boiled flours. The high-amylose products released

starch more slowly from a dialysis tubing during enzymatic incubation of the chewed samples compared with the corresponding products with less amylose.

Brand et al [1991] studied 16 outpatients with well-controlled NIDDM and normal lipid profiles, and fed them a low-GI diet (oats, pasta, and legumes) or a high-GI diet (wheat-flour products and potatoes) in a 2 x 12-wk crossover design. The amount of fat and the quantity and type of DF remained the same for both diets. It was found that glycemic control improved on the low-GI diet as compared to the high-GI diet ($p < 0.05$). Mean glycosylated hemoglobin at the end of the low-GI diet was 11% lower than at the end of the high-GI diet. According to Jenkins et al [1994] certain small intestinal effects of lente carbohydrate may be mimicked by altering food frequency (e.g., nibbling vs. gorging). In an acute study they confirmed that when 50 g glucose in solution was taken over a period of 180 min. (sipping) as opposed to being drunk in 5 min. (bolus), there was a dramatic reduction in the insulin-response area [Jenkins et al., 1990]. Bjorck et al [1994] have suggested that the glycemic response after carbohydrate-rich foodstuffs depends to a high degree on the food structure. They demonstrated that bread containing whole grains causes lower blood glucose excursions than the same bread in which the same grains are ground to flour. Similarly, Jarvi et al [1994] demonstrated that a meal containing white bread and apple puree resulted in 24% difference in GI compared to a meal containing pasta made from exactly the same amount and type of wheat and an intact apple. Thus, the exact same food may affect blood glucose and serum insulin concentration differently after a meal, depending on characteristics like particle size, cellular structure, and degree of gelatinization. Interestingly, second-meal effects of DF have also been reported by some authors. Second-meal effect is that the DF ingested in one meal affects the glucose rise after the subsequent meal, even though fiber was not ingested with the second meal. Jenkins et al [1980a] reported second-meal effects of DF with ingestion of guar and Pastors et al [1991] with pectin. The mechanism by which this occurs is unknown. Schwartz et al [1988] and Jenkins et al [1980a] proposed that it may be caused by a residual effect of the fiber on glucose absorption or it may be attributable to an increased glucose utilization rate.

Naismith et al [1991] compared the effect of wheat and barley fed to healthy and diabetic rats. Healthy rats showed no significant differences in blood glucose concentrations, weight gain or water consumption after six weeks. However, diabetic rats who were fed barley showed lower blood glucose concentrations, lower water consumption and lower weight loss than rats fed wheat [Naismith et al., 1991]. The improved glycemic control by barley was suggested to be caused by its content of chromium (5.69 μg/g) rather than its fiber content [Mahdi and Naismith, 1991]. Indeed, chromium is a component of the glucose tolerance factor which increases or potentiates the action of insulin [Mahdi and Naismith, 1991].

Several possibilities have been considered regarding the mechanism of action of the viscous gels in diminishing the rate of glucose absorption after a glucose load. They include: an effect on gastric emptying, an effect on the diffusion of glucose toward the brush border of the intestine, a change in the unstirred layer adjacent to the mucosa in the intestinal lumen, an effect on the convective transfer of both glucose and water toward the brush border, an effect on the rate of enzymatic digestion of foods in the intestinal lumen, and an effect on the release of regulatory gut harmones into the circulation [Nuttall, 1993]. Depending on the nature of the DF, human studies have shown that the transit time of digested fiber-rich food from mouth to cecum can be delayed [Tinker and Schneeman, 1989]. Hypothetically, a prolonged intestinal transit time may result in an increase in the absorption of nutrients. Edwards et al [1988] demonstrated that SF, by increasing the viscosity of food and thereby decreasing the intestinal movement, delays the absorption of nutrients. Blackburn et al [1984] have shown that in diabetic subjects, although there is a delay in gastric emptying and glucose levels are reduced, there is no correlation between the two, suggesting that this mechanism might contribute but cannot be the sole mechanism contributing to the reduced postprandial responses. Blackburn et al, on the basis of small intestine perfusion studies in normal subjects, suggested that fiber inhibits intestinal motility and thus decreases convection. Eisenhans et al [1980] in an in vitro study demonstrated that the thickness of the unstirred layer may be increased by the tendency of the SF to form gels and thus effectively create a gel-filtration system

in the gut. However, studies in humans showed that only with pectin was there evidence of an increase in the thickness of the unstirred water layer. The major effect on the glucose absorption rate of a very viscous gel such as guar gum is an impairment in the convective movement of both glucose and water in the intestinal lumen toward the absorptive surface of the intestine [Blackburn et al., 1984]. The convective movement of the two is facilitated by the mixing action of the intestinal motor activity. It is also possible that some impairment in digestive enzymatic activity in the lumen and an alteration in hormonal secretion by cells in the gut mucosa are playing a role [Sandhu et al., 1987]. Gut hormones especially enteroglucagon, gastric inhibitory polypeptide (GIP), and somatostatin may independently reduce satiety and/or substrate utilization [Vinik and Jenkins, 1988]. The response of GIP, a stimulus for insulin secretion, was more attenuated in healthy diabetic subjects and in patients with postgastrectomy dumping syndrome after control meals [Morgan et al., 1979]. After ingestion of DF pancreatic glucagon levels were reduced [Miranda et al., 1978] whereas somatostatin levels were found to be increased [Shimoyama et al., 1982]. All these hormones involved in glucose homeostasis have a complex interrelationship which varies with blood glucose levels and thus also with daily DF ingestion [Beck and Villaume, 1987].

According to O'Dea [1990], there is a possibility that products of carbohydrate fermentation in the large intestine, e.g., short-chain fatty acids (SCFA), may be partially responsible for improvement in blood glucose control. Animal experiments have shown that intragastric infusions of acetate decrease plasma glucose levels [Asplund et al., 1985] and intraportal infusions of propionate stimulate insulin secretion [Wolever et al., 1991]. Reduced fasting serum glucose levels and maximum insulin increments have been reported during oral glucose tolerance test (OGTT) after oral propionate supplementation for seven weeks [Ventor et al., 1990]. Thornburn et al [1993] found that carbohydrate fermentation enhances the suppression of hepatic glucose production and free fatty acid levels by oral glucose in man.

Further studies are required to clearly demonstrate the importance of these hormonal and metabolic alterations for long-term diabetes control. Mechanistically, the

ability of the DF to form viscous gel and thus impair convective transfer of glucose and water to the absorptive surface of the intestine appears to be of greatest importance [Nuttall, 1993].

SOLUBLE FIBER AND LIPID METABOLISM

In the past, management of diabetes focused primarily on control of blood glucose. Today, diabetologists are becoming increasingly aware that the appropriate therapy should not only help improve blood glucose control but also help prevent cardiovascular disease. Death caused by heart disease occurs two to three times more often among persons with diabetes [Anderson, 1987]. The lipid abnormalities consistently seen with diabetes include hypertriglycerdemia and reduced serum HDL-C, changes in serum total cholesterol and LDL-C [Walden et al., 1984; Howard, 1987].

Hypertriglycerdemia is common in individuals with NIDDM and its cause appears to result primarily from increased endogenous triglyceride synthesis [Ginsberg and Grundy, 1982]. The reduction in plasma triglyceride concentrations in individuals with NIDDM is associated with improved glycemic control and is probably related to a reduction in very-low density lipoproteins (VLDL) triglyceride secretion, secondary to a fall in free fatty acid (FFA) concentration, which occurs with improvements in glycemic control [Greenfield et al., 1980]. Low plasma HDL-C concentrations frequently occur in NIDDM individuals [Hollenbeck et al., 1986].

Hollenbeck and Coulston [1991] suggested that diets containing conventional quantities of fat, in which saturated fat is replaced by unsaturated fat and dietary cholesterol reduced, result in the desired reductions in total and LDL-C concentrations. This is achieved without adverse effects of increased postprandial glucose and insulin concentrations, increased fasting and postprandial total and VLDL triglyceride concentrations, and decreased fasting HDL-C concentrations. Riccardi and Rivellese [1991], after reviewing several studies in this regard, concluded that a diet low in cholesterol and saturated fat should be recommended to all diabetic patients to prevent

cardiovascular disease. They recommended an increase in consumption of fiber-rich foods and unsaturated fat to replace foods rich in saturated fat and cholesterol.

Viscous fibers such as pectin, psyllium, guar and oat bran have been shown to reduce serum cholesterol and triglyceride in both humans [Shinnick et al., 1988; Anderson and Gustafson, 1988; Kirby et al., 1981] and animals [Chen et al., 1984]. On the other hand, insoluble nonviscous fibers, such as cellulose or wheat bran, have been reported to be relatively ineffective in lowering serum cholesterol [Gariot et al., 1986]. Dry oats provide 7.2 g SF per 100 g and dry oatmeal contains 5.0 g SF per 100 g [Anderson and Bridges, 1988]. Over the past 15 years Anderson and coworkers have reported research findings involving diets rich in oat fiber. Total cholesterol decreased 13 to 23 % in subjects with hyperlipidemia who consumed 50 to 100 g oat bran per day along with their low fat and low calorie diet for 2 to 3 weeks [Anderson et al., 1984, 1987, 1991]. LDL-C was lowered by 12 to 24%. A smaller daily supplement (25 g) of oat bran provided in the form of ready-to-eat cereal, reduced total cholesterol by 5% and LDL-C by 8% [Anderson et al., 1991]. Storch et al [1984], studied the effects of oat bran supplementation in 12 healthy subjects with normal serum cholesterol levels. Subjects were randomly assigned to either 50 g oat bran or wheat bran supplemented diets for 6 weeks. Dietary cholesterol and fat intakes increased during both diets. Despite the increase, oat bran supplementation lowered serum cholesterol by an average of 12%. No significant change in serum cholesterol was observed with wheat bran supplementation. Kirby et al [1981] alternated control and test diets differing only by the inclusion of 100 g oat bran/d. Oat bran diets lowered serum total cholesterol 13% and LDL-C 14% with no significant change in HDL-C levels when compared with control diets.

Wheat fiber, on the other hand, has not shown very promising results. Gariot et al [1986], while looking at the long-term effects of the addition of 20 g wheat bran (7 weeks) to the diet of four healthy male subjects, found no change in plasma cholesterol and triglycerides. HDL-C and LDL-C remained stable when compared to basal values. Kestin et al [1990] found very similar results in a recent study.

Martinez and coworkers [1991] compared the effects of barley versus wheat on hypercholesterolemic chicks fed fats from five different sources. All chicks fed barley diets had lower total and LDL-C than those fed wheat regardless of the fat source. Fadel et al [1987] demonstrated the hypocholesterolemic property of barley in chicks. Chicks were fed diets based on either two varieties of barley, Washonupana and Franubet, with and without supplemental β-glucanase. Both varieties of barley chosen were hulless, only Washonupana had waxy starch. Washonupana barley caused significant reduction in both total (-16%) and LDL-C (-30%), which were reversed when the diet was supplemented with β-glucanase. This indicated that β-glucan was the factor responsible for the effect. The chicks exhibiting hypocholesterolemia had significantly greater lipid content in their excreta, an indication of interference with absorption. Ranhotra and coworkers [1991] studied the effects of oat and barley fractions on the lipidemic response in rats. Barley bran and flour were more effective in lowering blood and liver cholesterol compared with oat bran and flour. HDL-C (high density lipoprotein cholesterol) levels were appreciably elevated in rats fed barley bran and flour.

Hypocholesterolemic effects of barley on humans have also been reported. In a study by Newman et al [1989b] wheat and barley products providing 42 g of DF were incorporated into the normal diets of 14 free-living volunteer men for 28 days. Subjects who consumed barley and who had average or low pre-treatment levels had no significant effects. However, for those subjects who had higher initial levels, total and LDL-C were reduced. In a study by McIntosh et al [1991] 21 hypercholesterolemic men were provided with comparable barley and wheat foods for each of 28 days in a crossover-design. Consumption of barley relative to wheat foods was associated with a significant fall in both plasma total cholesterol (6%) and in LDL-C (7%), whereas triglyceride and glucose concentrations did not change significantly. McIntosh et al [1991] suggested that the soluble fraction of β-glucan, because of its viscosity and possible influence on the absorption of nutrients from the small intestine, may be more nutritionally relevant than total β-glucan in relation to a hypocholestrolemic effect. Zhang et al [1991] in a crossover design study fed 10 subjects with or without brewer's spent grain, which is the residue of

barley after the brewing of beer. Six subjects with low daily excretion of bile acids had lowered serum LDL-C and apoprotein B levels after supplementation with brewer's spent grain. These authors concluded that the β-glucan fraction of brewer's grain is not playing a major role in the hypocholesterolemic effects. They suggested that, instead, the effects of the pentosan and lignin fraction should be considered, as they observed high proportions of these fractions in the fiber component of brewer's spent grain.

Increased use of high-fiber foods may indirectly decrease serum lipids because of reduced fat and cholesterol intake [Swain et al., 1990, Connor, 1990]. Ideally, the only dietary difference between the fiber group and the control group should be fiber intake. A meta-analysis of 10 oat studies found that substitution of carbohydrates for fats and cholesterol was not responsible for the majority of the total cholesterol reduction [Ripsin et al., 1992]. The initial serum cholesterol value may affect the results because those subjects with higher values may be more responsive to SF [Ripsin et al., 1992]. There may be an age-gender interaction in response to fiber, as one study found that older (>50 years) women had the biggest reduction in serum cholesterol [Keenan et al., 1991]. However, this finding was not supported by the results of a meta-analysis of oat studies [Ripsin et al., 1992]. Change in body weight might also affect total cholesterol [Glore et al., 1994]. In 871 middle-aged men, a 1-kg change in body weight was associated with a 0.05 mmol/L change in total cholesterol [Kastan et al., 1992].

The exact mechanisms by which SF exert their hypocholesterolemic effects have not been elucidated. However, several mechanisms have been proposed. One possible mechanism is that DF or their short-chain fatty acid (SCFA) products may alter cholesterol absorption, bile acid absorption, or metabolism in the gut [Kirby et al., 1981], either as a result of decreased diffusion due to the viscous nature of the SF or as a result of decreased micelle formation due to binding of bile acids and/or lipids to the fiber [Anderson et al., 1986a]. Bacteria in the colon convert primary bile acids into secondary bile acids which are less well absorbed. Less bile acids returns to enterohepatic circulation so the liver degrades more cholesterol to meet the body pool size of bile acids, decreasing the amount of cholesterol available for lipoproteins synthesis [Anderson et al.,

1986b]. Results of many studies are consistent with this hypothesis [Kirby et al, 1981; Kay, 1982; Judd and Truswell, 1981]. SFs are almost completely fermented in the colon to SCFAs, namely acetate, propionate, and butyrate [Cummings, 1981]. These SCFAs are thought to be absorbed into the portal vein and inhibit hepatic cholesterol synthesis. These fatty acids may also mediate the hypocholesterolemic effects of SF [Chen and Anderson, 1984]. The increased fecal loss of bile acids coupled with reduced hepatic cholesterol synthesis may decrease hepatic secretion of VLDL cholesterol, a precusor of LDL-C. Some sterol balance studies in humans have shown that enhanced fecal elimination of sterols resulting from an increased DF intake is balanced by increased cholesterol synthesis [Miettinen, 1987; Miettinen and Tarpila, 1989]. Arjamandi et al [1992] demonstrated that SF, by enhancing fecal neutral sterol excretion, may cause liver depletion of cholesterol, which results in a higher rate of liver cholesterol synthesis.

According to Wang et al [1992], small intestinal viscosity seems to be involved in the physiological effect of barley in the reduction of plasma cholesterol concentrations in chicks. The negative correlation between viscosity of small intestinal digesta and digestibility of lipids and protein indicates that a viscous environment in the small intestine reduces absorption of lipids, protein and possibly other dietary nutrients. Viscosity may act as barrier preventing the contact of digestive enzymes with their substrates, thickening of the unstirred layer of the mucosa and prevention of formation of micelles required for absorption of lipids.

Other components of DF sources have been shown or suggested to have cholesterol-reducing ability. Qureshi and coworkers [1986] have shown that a component of barley, α-tocotrienol, inhibits hepatic cholesterol synthesis and reduces serum cholesterol in chickens. Qureshi and coworkers [1986] reported the isolation and characterization of cholesterol suppressive compounds from an ether extract of barley. Two of the compounds were identified as d-α -tocotrienol and a triglyceride, 1,3-dilinoleoyl-2 γ-linolenioylglycerol. These compounds function to suppress the first rate-limiting enzyme, 3-hydroxy-3-methyl glutaryl coenzyme A (HMG-CoA), in the biosynthesis of cholesterol and other isoprenoids. It is therefore quite likely that barley

has two distinct hypocholesterolemic constituents that are complementary in action. It has also been suggested that insulin may play a role in cholesterol regulation. Insulin increases cholesterol synthesis [Flodin, 1986]. SF, on the other hand, reduces postprandial hyperglycemia and associated insulin elevations, which may reduce cholesterol synthesis.

BARLEY

Barley is the fourth largest cereal crop of the world. However, it is mostly used for animal feed, some for malt, and very little for human food [Bhatty, 1987]. Barley consumption in western countries is negligible at present [Bhatty, 1992]. In North America and Europe, barley is used mainly for brewing and as livestock feed. Canada is the third largest producer of barley in the world but it is grown mainly for malt [Harapiak, 1989]. The malting industry uses only about 10% of the total Canadian production of barley, nearly all the remainder (85%) is used for animal feed [Rossnagel et al., 1981]. Even in Asia, where pearled barley is an important dietary cereal, it is gradually being replaced by rice and wheat as economic conditions improve [Bhatty 1986].

The high fiber content, poor visco-elastic properties for the production of yeast leavened products and resulting poor organoleptic properties when cooked are among the reasons that barley is seldom used in human foods [Bhatty 1987].

STRUCTURE AND COMPOSITION OF BARLEY β-GLUCAN

Barley contains a high concentration as well as a wide range of the non-starch polysaccharide, mixed linked β- (1→3), (1→4)-D-glucans (β-glucan) [Bhatty 1992]. The presence of β-(1→3)-linkages in the β-glucan chain provide these compounds distinctive physiochemical properties, including water solubility [Fincher and Stone, 1986] and a high relative viscosity in solution [Wood, 1986]. Based on their extractability in water, β-glucans may be divided into soluble and insoluble fractions. An aqueous solution of β-

glucans extracted from barley flour is viscous and the degree of viscosity is elated to molecular weight and concentration of β-glucans [Bengtsson et al., 1990]. Great variability among barley cultivars can exist in cell wall thickness, total amount and degree of solubility of β-glucan, viscosity and possible association with other components such as protein [Newman et al., 1989b]. Structurally, barley β-glucan is very similar to the oat β-glucan. Barley is unique among cereals in that almost all of β-glucan is present in the endosperm, compared to 47-48% in wheat and oats [Bhatty, 1993]. Both oat and barley grains have a variable and significant fraction of the non-starch polysaccharide as β-glucan and ≤50% of this may be soluble [Aman and Graham, 1987].

BARLEY CHARACTERISTICS

GENETIC VARIATION: The nutritional qualities of the kernel are determined by both genotype and environmental growing conditions [Newman et al., 1989a]. Thus, genetically controlled factors can be utilized to produce significant influences on the nutritional quality of the barley.

TWO-ROWED VERSUS SIX-ROWED BARLEY: Barley has three spiklets at each rachis node, and these are alternately positioned. In six-rowed types all three spiklets are fertile, whereas in two-rowed only the central spiklet is fertile [Newman et al., 1991b]. The nutritional implications of two- versus six-rowed barley have not been fully investigated. However, a study carried out by Lehtonen and Alkasalo [1987] in Finland indicated that the content of β-glucan is significantly higher in two-rowed varieties than in six-rowed ones.

HULLED VERSUS HULLESS BARLEY: In hulled (covered) barley the flowering glumes (lemma and palea) are fused and strongly adhere to the caryopsis (grain) [Bhatty, 1986]. This is the most common barley used for malting or animal feeds. For food consumption the lemma and palea or hull of covered barley must be removed by abrasion or pearling, producing the familiar pearl barley. The hulless barley is a group in which the husk falls free on threshing without adhering to the grain [Bhatty, 1986]. Hulless

barley is a relatively new variety in Canada - commercially available for only the last few years. The hulless barley has potential for use in human foods as it requires no pearling to remove the hull, thus retaining nutrients in the outer layer of the endosperm that would otherwise be lost in processing [Newman et al., 1991b]. In terms of size, density, color and overall physical appearance, hulless barley is very similar to wheat.

WAXY VERSUS NON WAXY BARLEY: Another important genetic trait of barley is the presence of genotypes varying in amylose-amylopectin ratio. Waxy genotypes are known to contain more SF [Newman and Newman, 1991] which could be of interest in relation to glucose and lipid metabolism. Hulless barley has high total and SF contents and a higher β-glucan level than most covered barley and oats [Aman and Graham, 1987; Newman and Newman, 1991; Bhatty, 1987].

PROCESSING OF BARLEY

It is feasible to develop a low β-glucan or a high β-glucan barley for use in human foods [Bhatty, 1992]. Barley can be milled, pearled, malted, brewed, flaked, popped, crisped or steel cut to meet variety of food and beverage processing needs [Newman and McGuire, 1985]. According to Ranhotra and coworkers [1991] the bran fraction of barley may be dry milled to yield 70% flour and 30% bran. Barley flour and bran have the most potential in food applications. Barley flour is a versatile ingredient and may be used for making cookies, muffins, cakes and flat breads or used as a food thickener. Similarly, barley bran has many applications in ready-to-eat cereals, high fiber breads, cookies and muffins [Bhatty, 1992]. Barley flour is similar in color to wheat flour but barley flour has a higher water absorption and alkaline water retention capacity [Bhatty, 1987].

A serious drawback of using cereal fractions rich in β-glucans in feeding studies has been their highly viscous and gummy nature when wet [Klopfenstein, 1988]. Klopfenstein and Hosney [1987] showed that β-glucan fractions from oats, barley, wheat

and sorghum could be freeze-dried and successfully incorporated into white pan bread. Berglund et al [1992] compared a test bread containing 26% barley flour to a control containing 26% whole-wheat flour. A waxy, hulless cultivar of barley, high in β-glucan and DF was used for barley bread. The texture, flavor and overall acceptability of barley bread as rated by a consumer panelists were not significantly different from the whole-wheat bread. Most of the food products like carrot spice bars, low-fat blueberry muffins, chocolate chip cookies etc. prepared with waxy, hulless barley in this experiment were liked by the sensory panel. Berglund and coworkers concluded that waxy, hulless barley can be successfully substituted for wheat flour in many food products in amounts ranging from 25 to 100%. Newman et al [1990] studied the effects of using 100% barley flour in the production of muffins using four different cultivars of barley. Muffins made from the hulless and waxy cultivars, as well as the wheat, were more tender than the hulled and short awned cultivar. A trained panel preferred the barley muffins over the wheat muffins. Recently in a study by Mary Pick [M.Sc thesis, 1994], the beneficial effects of the incorporation of the oat bran concentrate bread/bread products in the diet of NIDDM subjects on the glycemic, insulinemic and lipidemic responses were developed. It is therefore to be anticipated that the biological effects of oat bran concentrate bread/bread products observed in NIDDM subjects would extend to barley as well.

OBJECTIVES OF THE PRESENT STUDY

The unique properties of barley suggest that it is desirable for the human diet and in particular for the diet of diabetic individuals. Only a few human studies have reported the postprandial glucose and insulin responses to barley products. Barley bread products have not been used in long-term human trials and there has been no assessment of the effect of the barley bread products on glucose, insulin and lipid metabolism in diabetes.

Hypothesis: A beneficial effect on the glycemic, insulinemic and lipid response will be derived by the long term incorporation of high fiber barley bread products into the diets

of male NIDDM subjects. This would be dervied by measuring plasma glucose, total cholesterol, triglycerides, high density lipoprotien cholesterol, low density lipoprotein cholesterol, glycosylated hemoglobin and serum insulin. Area under curve for plasma glucose and serum insulin will also be calculated.

The proposed study was undertaken essentially with the following **objectives**:

1. To determine the effects of long term use of waxy, hulless barley bread products, incorporated as a dietary staple, on blood glucose, insulin and lipid parameters.
2. To evaluate the relationships between dietary and biochemical data.

METHODOLOGY

SUBJECTS

The study comprised eleven adult male subjects with NIDDM, recruited through the Metabolic Day Care Unit of the University of Alberta Hospitals and the Metabolic Clinic of Misericordia Hospital, Edmonton, Alberta. All subjects underwent a baseline evaluation, including a physical examination and screening laboratory tests. The criteria used for the selection of the subjects are summarized in **Table 1**.

Subjects meeting the study entry criteria were enrolled in the study. A subject information questionnaire was completed by all the participants. The subjects were fully informed of the experimental nature of the investigation. The study was conducted on an outpatient basis. The study protocol was approved by the Ethics Review Committee of the Faculty of Agriculture, Forestry and Home Economics of the University of Alberta and the University of Alberta Hospitals, Edmonton.

The subject profile information for each subject is summarized in **Table 2**. The mean age and body weight of the subjects were 51.2 ± 6.5 years and 83.5 ± 0.4 kg, respectively. The mean body mass index (BMI) was 27.4 ± 0.12 kg/m^2. The mean duration of diabetes was 1.86 ± 1.5 years. Seven out of 11 subjects controlled their diabetes with diet and oral sulfonylureas and the other controlled their diabetes with diet alone. The biochemical characteristics of the subjects at the study entry are summarized in **Table 3**.

RESEARCH DESIGN

To test the proposed hypothesis a randomized cross-over experimental design was chosen. The study lasted for 24 weeks, with two 12 weeks periods. Six randomly chosen

Table 1. Selection Criteria for the Subjects at Study Entry

Inclusion Criteria	Exclusion Criteria
Free-living NIDDM male individuals	Use of lipid-lowering medication
Age between 20 to 60 years	Clinical evidence of autonomic neuropathy
Diabetes controlled by diet or diet/oral hypoglycemic agents (sulfonylureas only)	Body mass index[1] >35 kg/m^2
Glycosylated hemoglobin[2] <10%	Residents of the greater Edmonton area for at least six months prior to the study; available for regular follow ups
Plasma total cholesterol <7 mmol/L	
Plasma triglycerides <5 mmol/L	Renal, hepatic, gastrointestinal or thyroid disease or complicating condition causing undue diet modification
Eight or more starch choices/day in the diet plan	

[1] Body Mass Index (body weight, kg/height, m^2)
[2] HbA_{1c}

Table 2. Subject Profile Information

Subject No.	Age (years)	Height (cm)	Weight (kg)	BMI[1] (kg/m^2)	Duration of Diabetes (years)	Therapy
1	50	177	91.0	29.1	4.0	Diet + SU[2]
2	58	177	75.4	24.1	3.0	Diet
3	52	158	65.0	26.1	1.0	Diet +SU
4	58	192	103.5	28.1	2.0	Diet + SU
5	51	180	93.6	28.9	1.0	Diet
6	49	180	101.2	31.2	1.5	Diet
7	34	157	67.4	27.3	1.0	Diet + SU
8	57	177	80.5	25.7	0.25	Diet + SU
9	51	169	80.0	28.0	0.5	Diet + SU
10	52	178	77.8	24.6	0.5	Diet
11	51	169	82.7	28.9	5.0	Diet + SU
Mean	51	174	83.5	27.4	1.86	-
SD[3]	6.5	10.5	-	-	-	-
± SEM[4]	-	-	0.4	0.1	1.5	-

[1] Body Mass Index
[2] Sulfonylurea Drugs
[3] Standard Deviation
[4] Standard Error of Mean

Table 3. Biochemical Characteristics of NIDDM Subjects at the Study Entry

Variable	Mean ± SEM[1]	Range
HbA_{1c}[2] (%)	7.1 ± 0.1	5.9 - 10.5
Plasma Glucose (mmol/L)	7.8 ± 0.24	5.3 - 13.5
Serum Insulin (μU/ml)	15.5 ± 0.99	9.0 - 34.0
Plasma Cholesterol (mmol/L)	5.3 ± 0.13	4.1 - 7.2
LDL Cholesterol (mmol/L)	4.1 ± 0.13	3.0 - 5.7
HDL Cholesterol (mmol/L)	0.87 ± 0.03	0.6 - 1.1
Plasma Triglycerides (mmol/L)	1.7 ± 0.94	0.8 - 3.5

[1] Standard Error of Mean
[2] Glycosylated Hemoglobin

subjects ate the barley bread products (BBP) first and the remainder ate the control white bread products (WBP). The subjects served as their own controls.

During the study period medical management for each subject was provided by Dr. Ellen Toth, of the University of Alberta Hospitals, Edmonton. The dietary intake of the subjects was closely monitored. Subjects were seen at three week intervals for dietary assessments, anthropometric measurements, and for discuss adherence to the diet. Any questions or problems arising were also discussed during these sessions. Individualized diet plans were formulated for all subjects providing approximately 55% of total calories as carbohydrates, 30% as fat and 15% as protein. Each diet plan incorporated a minimum of eight servings per day of bread and bread products as starch exchanges. The importance of maintaining body weight was emphasized. Throughout the study, subjects continued their normal daily activities and exercise habits. A supply of frozen bread products to last two to three weeks period was provided at a time. A record of bread products consumed by each subject was kept.

DIETARY ASSESSMENT

The 48-hour food recall method was used to obtain the dietary information. Dietary data was obtained for two days at the study entry. Eight days dietary data was obtained for each dietary period. In this way a total of 18 days of dietary intake were assessed quantitatively for each subject. Recalls for the WBP and BBP periods included a minimum of one weekend day and a maximum of two weekend days. Each subject was asked to recall all food items including beverages consumed over the previous 48-hour period. Food models constructed according to Nutrition Canada [Health and Welfare Canada, 1973] specifications were used in order to estimate the portion size of the food products consumed. All the recorded dietary data were coded using standardized coding procedures. A computer program based upon the Canadian Nutrient File [Health and Welfare Canada, 1985] was used to calculate the daily nutrient intake of each subject. The Canadian Nutrient File was supplemented with data from USDA Handbook #8 [Watt

and Merrill, 1975; United States Department of Agriculture, 1976-1993]. Values for DF and cholesterol were added to the nutrient data base from Southgate's tables [Paul and Southgate, 1978]. Daily nutrient intakes for total calories, carbohydrate, sugar, starch, DF, protein, fat, cholesterol, saturated fat, monounsaturated fat and polyunsaturated fat were calculated for each subject.

ANTHROPOMETRIC MEASUREMENTS

The anthropometric measurements for body weight, height, upper mid-arm circumference (MAC), triceps skinfold thickness (TSF) and mid-arm muscle circumference (MAMC) were obtained at the end of periods 1 (12 wk.) and 2 (24 wk.) for each subject.

BREAD AND BREAD PRODUCTS

For the present study, barley flour and cracked barley were provided by Dr. James Helm (Lacombe). A blend of several varieties of hulless two-rowed waxy barley were used to obtain a high β-glucan barley flour. This flour contained 13.6% of DF, 5.7% of SF and 6.9% of β-glucan. Cracked barley contained 11.9% DF, 5.1% SF and 7.1% of β-glucan [Edney, 1994]. Particle size of the barley flour (50 g) was determined by sieving analysis [Donelson and Yamazaki, 1972], using nest of sieves with openings of 850, 425, 250, 180 and 150 μm. Sieving was carried out for one hour, after which the overs of each sieve were carefully collected and weighed. The overs weighed 3.0, 19.0, 23.6, 2.4 and 0.5 g, respectively. White bread and buns were bought from the Save-On-Foods (local grocery store), Edmonton. Barley bread and buns, barley and white flour muffins and cookies were made at Patient Support Centre, University of Alberta Hospitals, Edmonton. White flour and barley pasta were made at Pasta Time/Bella Festa (wholesale pasta store), Edmonton. Soaked cracked barley was used in barley bread and muffins along with barley flour (Cracked barley was soaked overnight as 1 part barley to

1.5 parts water). Barley flour was also provided to the subjects to be used according to their personal liking as an ingredient for different recipes. All bread products were frozen at –29°C until required for distribution to the subjects. The DF, SF and β-glucan content of the BBP is summarized in **Table 4**. At the end of the study, each subject completed a questionaire on the overall acceptability and the side effects from the barley bread products.

BLOOD SAMPLE COLLECTION

Following an overnight fast, all subjects reported to the Clinical Investigation Unit (CIU), University of Alberta Hospitals. An intravenous catheter with normal saline was inserted into the patient's arm to allow multiple blood sampling. Blood samples for lipid and glycosylated hemoglobin analysis were collected at 0 min. Blood samples for the 8-hour day profile for glucose and insulin were drawn at time 0 and at 30 min. intervals for eight hours. However, samples were drawn at 15 min. intervals for one hour following breakfast and lunch. A total of 21 blood samples were collected for each profile day for plasma glucose and insulin measurements.

On the day of blood sample collection, breakfast, lunch and snacks were served to the subjects from the CIU kitchen. Bread products (control or barley) were representative of the study period completed. Breakfast was served immediately following the fasting blood sample at 0 hour, a snack was served 2 hours following breakfast, lunch at 4 hours and a snack at 6 hours. Subjects were discharged following collection of the last sample. Blood samples for lipid, glucose and insulin analysis were centrifuged and then stored at –20°C until the biochemical analysis.

ANALYTICAL METHODS

Fasting blood glucose, glycosylated hemoglobin (HbA_{1c}), plasma total cholesterol, HDL-C, LDL-C and triglycerides were determined. In addition, 8-hour

Table 4. Dietary Fiber per Barley *B*read Exchange Consumed by NIDDM Subjects

Bread Product	DF[1]	SF[2]	β-glucan
Barley Bread (1.3 cm slice)	0.86	0.36	0.47
Barley Bun	1.51	0.64	0.81
Barley Muffin	1.49	0.64	0.81
Barley Cookie (15g)	0.92	0.39	0.47
Barley Pasta (90 g uncooked)	4.06	1.70	2.06
Barley Cereal (234 ml cooked)	5.44	2.28	2.76

[1] Dietary Fiber
[2] Soluble Fiber

plasma glucose and insulin profiles were also conducted. University of Alberta biosafety workplace regulations regarding human body fluids (level II biohazardous substances) [Workplace Hazardous Materials Information System, 1989] were followed throughout the biochemical analysis and while handling the blood samples. All the samples were analyzed randomly in triplicate. The absorbance of the samples was measured using a Perkin Elmer UV/VIS Spectrophotometer Lambda 3 B. For control of accuracy, Accutrol Normal Chemistry Control sera (Sigma Diagnostics, Cat. No. 2034) was used in all biochemical parameters measured in plasma samples.

Determination of Total Cholesterol

Using a Sigma Diagnostics kit (catalogue # 352), total cholesterol was measured in the plasma samples. This method measures cholesterol enzymatically and is a modification of the method of Allain et al [1974]. The enzymatic reactions involved in this procedure are as follows:

1.) Cholesterol Esters + $H_2O \xrightarrow{\text{Cholesterol Esterase}}$ Cholesterol + Fatty Acids

2.) Cholesterol + $O_2 \xrightarrow{\text{Cholesterol Oxidase}}$ Cholest-4-en-3-one + H_2O_2

3.) $2H_2O_2$ + 4-Aminoantipyrine + p-Hydroxygenzenesulfonate $\xrightarrow{\text{Peroxidase}}$ Quinoneimine Dye + $4H_2O$

The Quinoneimine dye is a color complex and the amount of color produced at the end of the reaction is directly proportional to the total cholesterol content in the sample.

Cholesterol reagent was prepared by reconstituting it with deionized water and mixing it well by inversion and occasional swirling. A series of tubes containing 1.0 mL reagent were set for blank, calibrator, control and test samples. To these tubes was added 0.01 mL of deionized water, calibrator, control and samples. All the tubes were mixed by gentle inversion and incubated for 5 min. at 37°C. The absorbance of the samples was read on a spectrophotometer at 500 nm against the reagent blank. To convert cholesterol values (mg/dL) into mmol/L, these values were multiplied by 0.0259 [SI Manual, 1985].

Determination of Triglycerides

Triglyceride concentration in plasma samples was measured by enzymatic determination using a Sigma Diagnostic kit (catalogue # 336). This procedure is a modification of the method of Bucola and David [1973]. Triglycerides are hydrolyzed by lipase to glycerol and free fatty acids. The glycerol is then measured by coupled enzyme reactions catalyzed by glycerol kinase, glycerol-1-phosphate dehydrogenase and diaphorase. The enzymatic reactions involved in the assay are as follows:

1.) Triglycerides $\xrightarrow{\text{Lipoprotein Lipase}}$ Glycerol + Fatty Acids

2.) Glycerol + ATP $\xrightarrow{\text{Glycerol Kinase}}$ G-1-P +ADP

3.) G-1-P + NAD $\xrightarrow{\text{G-1-PDH}}$ DAP+ NADH

4.) NADH + INT $\xrightarrow{\text{Diaphorase}}$ Formazan + NAD

ATP: adenosine-5-triphosphate; G-1-P: glycerol-1-phosphate; ADP: adenosine-5-diphosphate; NAD: nicotinamide adenine dinucleotide; DAP: dihydroxyacetone phosphate, G-1-PDH: glycerol-1-phosphate dehydrogenase; INT: 2-[p-iodophenyl]-3-p-nitrophenyl-5-phenyltetrazolium chloride.

Formazan is highly colored and has an absorbance maximum at 500 nm. The intensity of the color produced is directly proportional to the triglycerides concentration of the sample.

Triglyceride reagent was prepared by reconstituting it with deionized water. A series of tubes were set for blank, calibrator and for each test samples and 1.0 mL of reagent was pipetted into each tube. After the addition of 0.01 mL of water, calibrator and test samples to respective tubes, they were incubated for 15 min. at 37°C. All the samples were read at 500 nm against the blank. Triglyceride values (mg/dL) were multiplied by 0.0113 to convert the results into mmol/L [SI Manual, 1985].

Determination of HDL Cholesterol

HDL-C was assayed enzymatically (Sigma Diagnostics kit, catalogue # 352-3) based on the method described by Warnick et al [1982]. According to this method VLDL and LDL are first selectively precipitated followed by separation of the supernatant containing HDL which is then assayed to determine HDL-C concentrations.

HDL-C reagent was prepared by reconstituting it with deionized water. A series of tubes for control and test samples were set. Aliquot of control and plasma sample (0.5 mL) and HDL-C reagent (50 μL) were pipetted into the respective tubes and centrifuged for at least 5 min. at 2000 rpm. Another series of blank, calibrator, controls and samples were set. Cholesterol reagent (1 mL) was pipetted into each tube. Subsequently, 0.05 mL of deionized water, calibrator or clear supernatant from the aliquots of control and plasma samples was added and mixed by gentle inversion. All the tubes were incubated for 10 min. at 37°C. The absorbance of all the samples were read against the reagent blank at 500 nm on a spectrophotometer. To convert the results into mmol/L, HDL-C values (mg/dL) were multiplied by 0.0259 [SI Manual, 1985].

Determination of LDL Cholesterol

The cholesterol content of LDL was determined indirectly by using the formula validated by Friedwald et al [1972]. This method requires the measurement of plasma total-cholesterol, triglycerides and HDL-C. The following formula was used to estimate LDL-C (mmol/L):

$$\text{LDL-C} = \text{Total Cholesterol} - (\text{HDL-C} + \text{Triglycerides}/5)$$

Determination of Glycosylated Hemoglobin

Glycosylated hemoglobin (HbA_{1c}) was determined in whole blood by high performance liquid chromatography (BioRad Diamat) at the Department of Laboratory Medicine, University of Alberta Hospitals.

Determination of Insulin

Thirty-three sets of 21 serum samples (collected durintg 8-h day profile) were randomly analyzed at the Muttart Diabetic Research and Training Centre using Pharmacia Insulin RIA 100 radioimmunoassay kits (Kabi Pharmacia Diagnostics AB, Uppsala, Sweden, 1993). Pharmacia insulin RIA is a double antibody radioimmunoassay. Insulin in the sample competes with a fixed amount of ^{125}l-labelled insulin for the binding sites on the specific antibodies. Bound and free insulin are separated by addition of a a second antibody immunoadsorbent followed by cetnrifugation and decanting. The radioactivity in the pellet is then measured. The radioactivity is inversely proportional to the quantity of insulin in the sample.

Determination of Glucose

Plasma glucose determination was performed enzymatically using Sigma Diagnostic kits (catalogue # 510). The Sigma procedure is essentially that of Raabo and Terkildsen [1960]. In the presence of glucose oxidase, glucose is transformed into gluconolactone which reacts with water to form gluconic acid and hydrogen peroxide. In the presence of peroxide, hydrogen peroxide oxidizes the colorless o-dianisidine to a reddish-brown dye. The final color intensity is proportional to the glucose concentration. Thirty-three sets of 21 samples (collected during 8-h day profile) were analyzed randomly. The principle of this method is as follows:

1.) Glucose + $2H_2O_2$ + O_2 $\xrightarrow{\text{Glucose Oxidase}}$ Gluconic Acid + $2H_2O_2$

2.) H_2O_2 + o - dianisidine [Colorless] $\xrightarrow{\text{Peroxidase}}$ Oxidized o - Dianisidine [Brown color]

Enzyme solution, color reagent, and combined enzyme-color reagent solution were prepared according to the directions given by Sigma procedure. Protein free filtrates of the blank, standard and plasma samples were prepared by deproteinizing using barium hydroxide and zinc sulfate solution. The clear filtrates (0.5 mL) were then transferred to series of clean tubes and mixed with combined enzyme-color reagent solution (5.0 mL). Tubes were then incubated in a water bath at 37°C for 30 min. At the end of the incubation period, all samples were measured, using blank as reference, at 450 nm. The plasma glucose values (mg/dL) were expressed in mmol/L by multiplying them by 0.0555.

AREA UNDER CURVE (AUC) FOR GLUCOSE AND INSULIN

AUC for glucose and insulin responses were calculated by the method of Wolever and Jenkins [1986] using the following formula:

$$\text{Area} = \left[A + B + C + D/2\right]t + \left[\frac{(D \times D)t}{2(D + E)}\right]$$

where A, B, C, D and E represents positive glucose/insulin increments, and t the time interval between the blood samples. The resulting area is termed as 'incremental' area under the curve and defines the area beneath the blood glucose/insulin response curve above the level of fasting blood glucose/insulin. The glycemic/insulinemic response areas were divided into two 4-hour periods to evaluate separately the response to the part 1 (breakfast) and part 2 (lunch). Glucose and insulin excursions were calculated as the difference between the highest blood glucose/insulin and the fasting glucose/insulin concentration for peaks #1 (part 1) and #2 (part 2) [Jenkins et al., 1983]. Glucose/insulin maximum values during both peaks were determined. Insulin-glucose ratios were

expressed as the ratio of peak serum insulin value by peak plasma glucose value [Morgan et al., 1979].

STATISTICAL ANALYSIS

All the biochemical and dietary data for the WBP and BBP periods were analyzed by analyses of variance (ANOVA) using SAS GLM [SAS, 1985]. Sources of variation for the crossover design [Peterson, 1985] were group (g = 2), subjects within group (s = 5, 6), time (t = 2) and dietary period (dp = 2). Groups were based on the sequence or the order in which the subjects took their diets. The differences for mean plasma glucose and insulin profiles between the two dietary periods were analyzed by analysis of variance. Correlations between biochemical and dietary variables were computed within dietary period by subject using repeated measures analysis of variance. Sources of variation were the same as for the crossover analyses of variance.

Differences between the study entry period and study period for dietary and biochemical data were compared using ANOVA (SAS GLM). Sources of variation were groups, subjects within groups, study and group*study.

Correlations between change in biochemical parameters i.e., AUC for blood glucose and insulin, total cholesterol, LDL-C and triglycerides values (values for WBP period minus values for BBP period) and the amount of DF, SF and β-glucan from BBP consumed in barley period were calculated using pairs of the two values for each subject.

RESULTS

The present study investigated the long-term effects of barley bread products on the glycemic, insulinemic and lipid status of NIDDM subjects. The study was a randomized crossover design which allowed subjects to serve as their own controls. Each period of the study, white bread products (WBP) and barley bread products (BBP), was 12 weeks in length. The mean study entry characteristics of the subjects are shown in Tables 2 and 3. Out of 11 subjects, seven (#1, 3, 4, 7, 8, 9, 11) were on oral medication (sulfonylurea drugs). The dietary, anthropometric and biochemical data obtained after the end of each study period were compared.

DIETARY INTAKE

The mean daily nutrient intake of subjects at the study entry (SE) is given in **Table 5**. The mean total energy intake of the subjects was 2089 ± 88 kcal/d. Carbohydrate, protein, fat and sugar intake of the subjects were 59%, 17%, 24% and 16% of the total energy intake, respectively. Dietary fiber intake was 28.5 ± 2.3 g/d. Saturated, monounsaturated and polyunsaturated fatty acid intake of the subjects at the SE was 20 ± 1 g/d, 21 ± 1 g/d and 13 ± 1 g/d, respectively. The percentage of energy derived from saturated, monounsaturated and polyunsaturated fatty acid was 9%, 9% and 6%, respectively. An average polyunsaturated/saturated fatty acid (P/S) ratio of the subject's diet was 0.7 ± 0.1. Dietary cholesterol intake of the subjects at the SE was 279 ± 30 mg/d. The mean daily nutrient intake of the subjects during WBP and BBP periods is summarized in **Table 6**. There were no significant differences either in the intake of total energy or in the percentage of energy derived from carbohydrate, protein and fat between the two periods. No significant change was observed between the intake of carbohydrate, protein and fat (g/d) between the WBP and BBP periods; the intake of starch was, however, significantly ($p \leq 0.05$) higher during the BBP period as compared

Table 5. Mean Daily Nutrient Intake of NIDDM Subjects at Study Entry

Variable	Mean ± SEM[1]	Range
Energy (kcal/d)	2089 ± 88	1390 - 3058
Carbohydrate		
Total (g/d)	310 ± 16	189 - 566
% of kcal	59 ± 1	41 - 74
Dietary Fiber (g/d)	28.5 ± 2.3	16.2 - 53.9
Sugar (g/d)	83 ± 5	25 - 116
% of kcal from sugar	16 ± 0.8	5 - 23
Starch (g/d)	208 ± 13	116 - 475
Sugar/Starch Ratio	0.44 ± 0.03	0.16 - 0.8
Protein		
Total (g/d)	86 ± 4	53 - 118
% of kcal	17 ± 1	11 - 27
Fat		
Total (g/d)	59 ± 2	30 - 88
% of kcal	24 ± 1	13 - 35
Cholesterol (mg/d)	279 ± 30	75 - 812
Saturated Fat		
Total (g/d)	20 ± 1	12 - 28
% of total kcal	9 ± 0.4	5 - 11
Monounsaturated Fat		
Total (g/d)	21 ± 1	9 - 34
% of total kcal	9 ± 0.4	4 - 13
Polyunsaturated Fat		
Total (g/d)	13 ± 1	3 - 29
% of total kcal	6 ± 0.4	1 -11
P/S[2] Ratio	0.7 ± 0.1	0.22 - 1.12

[1] Standard Error of Mean
[2] Polyunsaturated /Saturated Fatty Acid

Table 6. Mean Daily Nutrient Intake of NIDDM Subjects During Study

Dietary Variable	WBP Period	BBP Period
	Mean ± SEM[1]	
Energy (kcal/d)	2227 ± 49	2311 ± 49
Carbohydrate		
Total (g/d)	333 ± 9	357 ± 9
% of total kcal	60 ± 1	61 ± 1
Sugar (g/d)	85 ± 6	83 ± 6
% of kcal from sugar	15 ± 1	15 ± 1
Starch (g/d)	220 ± 6	251 ± 6*
Sugar/Starch Ratio	0.40 ± 0.04	0.37 ± 0.04
Protein		
Total (g/d)	89 ± 2	94 ± 2
% of total kcal	16 ± 0.2	16 ± 0.2
Fat		
Total (g/d)	60 ± 2	59 ± 2
% of total kcal	24 ± 1	23 ± 1
Cholesterol (mg/d)	288 ± 28	334 ± 28
Saturated Fat		
Total (g/d)	20 ± 0.8	18 ± 0.8
% of total kcal	8 ± 0.3	7 ± 0.3*
Monounsaturated Fat		
Total (g/d)	23 ± 1	22 ± 1
% of total kcal	9 ± 0.3	8 ± 0.3
Polyunsaturated Fat		
Total (g/d)	12 ± 0.6	12 ± 0.6
% of total kcal	5 ± 0.2	5 ± 0.2
P/S[2] Ratio	0.63 ± 0.03	0.68 ± 0.03

[1] Standard Error of Mean
[2] Polyunsaturated/Saturated Fatty Acid
* Significant at $p \leq 0.05$

to the WBP period. The sugar/starch ratio did not change during the BBP and WBP periods. There was no significant difference in the intake of dietary cholesterol and saturated fat (g/d) between the two periods. However, saturated fat as a percentage of total calories was significantly lower ($p \leq 0.05$) in the BBP period as compared to the WBP period. The P/S ratio was similar for the two periods.

In order to ensure that enough bread products were consumed during the study, all the subjects were advised to include at least eight servings of bread/bread products daily. The mean bread/bread products consumption of the subjects was 9.7 ± 0.5 bread choices per day in the WBP and 9.8 ± 0.5 in the BBP periods.

The mean dietary fiber (DF) intake of the NIDDM subjects during the WBP and BBP study periods is shown in **Table 7**. The DF intake was significantly higher during BBP period as compared to WBP period. The reported side effects by the subjects assessed from the questionnaire completed at the end of the study were minimal. Two subjects experienced diarrhea and one subject had upset stomach during the first week on BBPs. All the subjects liked the taste of BBPs.

ANTHROPOMETRIC MEASUREMENTS

The anthropometric measurements of NIDDM subjects during WBP and BBP period are shown in **Table 8**. The mean body weight and body mass index (BMI) of the subjects did not change during the study. The arm circumference, triceps skinfold thickness (TSF), percentile for TSF and calculated mid-arm circumference (MAMC) of the subjects were also unchanged.

BIOCHEMICAL ASSESSMENT

The mean glycosylated hemoglobin (HbA_{1c}) level at the SE was $7.1 \pm 0.1\%$. It did not change significantly during WBP ($7.3 \pm 0.1\%$) and BBP periods ($7.3 \pm 0.1\%$).

Table 7. Mean Dietary Fiber Intake of NIDDM Subjects

Variable	WBP Period	BBP Period
	Mean ± SEM[1]	
DF (g/d)	27.8 ± 2.2	38.6 ± 2.2**
DF from barley (g/d)	-	9.8 ± 0.7
SF from barley (g/d)	-	4.1 ± 0.31
β-glucan from barley (g/d)	-	5.2 ± 0.38

[1] Standard Error of Mean
** Significant at $p \leq 0.01$

Table 8. Mean Anthropometric Measurements for NIDDM Subjects

Variable	WBP Period	BBP Period
	Mean ± SEM[1]	
Weight (kg)	82.2 ± 0.4	82.1 ± 0.4
BMI[2] (kg/m^2)	27.1 ± 0.1	27.1 ± 0.1
Arm Circumference (cm)	32 ± 0.04	32 ± 0.04
TSF[3] (mm)	15 ± 0.4	15 ± 0.3
Percentile for TSF[4] (%)	65 ± 3	67 ± 3
MAMC[5] (cm)	27.3 ± 0.1	27.3 ± 0.1

[1] Standard Error of Mean
[2] Body Mass Index
[3] Triceps Skinfold Thickness
[4] Adapted from "A guide for anthropometric classification of Canadian adults for use in nutritional assessment", prepared by Dr. M. Jette for National Health and Welfare, Canada.
[5] Mid Arm Muscle Circumference

Table 9 summarizes the blood glucose data for the SE, WBP and for the BBP periods. No changes were observed in the fasting plasma glucose levels between the WBP and BBP periods. The total incremental area under glucose curve (8 hr) was 20% lower (ns) in the BBP period than in the WBP period. Similarly, the area under the glucose curve for breakfast (4 hr) and lunch (4 hr) during BBP period were found to be reduced by 20% and 19%, respectively, when compared to WBP period. Although the reduction in the area under the glucose curve during BBP period was not found to be statistically significant, it was noteworthy that eight out of 11 (73%) subjects showed a trend of a decrease in the glucose curve (**Figure 1**). The mean 8-hour plasma glucose profile for the WBP and BBP period for NIDDM subjects is shown in **Figure 2**. There was a trend toward lower glycemic responses during the BBP period.

Serum insulin parameters for NIDDM subjects during the SE, WBP and BBP periods are summarized in **Table 10**. Like glucose, no significant change was observed in the fasting serum insulin levels for the WBP and BBP periods. The mean maximum serum insulin values for peaks 1 and 2 were 13% and 10%, respectively, higher (ns) in the BBP period than in WBP period. Compared to the WBP period, insulin excursions for NIDDM subjects were increased by 21% and 16% (ns) for peaks 1 and 2, respectively, during the BBP period. The mean insulin peaks for breakfast and lunch were reached almost at the same time for the WBP and BBP periods. The insulin/glucose ratios were found to be 40% significantly higher ($p \leq 0.05$) for peak 1 and 19% higher (ns) for peak 2 in the BBP period as compared to the WBP period (Table 10). It was of interest, however, that unlike glucose, the total area under the insulin curve was significantly higher in the BBP period than in the WBP period. Thus, there was a 21% increase ($p \leq 0.05$) in the total (8 hr) incremental area under the insulin curve during the BBP period as compared to WBP period. Increases of 20% (ns) and 19% ($p \leq 0.05$) were observed in the part 1 (breakfast) and part 2 areas (lunch), respectively, during the BBP period as compared to WBP period. **Figure 3** shows the mean 8-hour serum insulin profile in NIDDM subjects after the WBP and BBP periods.

Table 9. Blood Glucose Parameters for NIDDM Subjects During Study

Variable	Study Entry	WBP Period	BBP Period
		Mean ± SEM[1]	
HbA_{1c}[2] (%)	7.1 ± 0.1	7.3 ± 0.1	7.3 ± 0.1
Fasting Plasma Glucose (mmol/L)	7.80 ± 0.24	7.67 ± 0.25	8.06 ± 0.25
Glucose Response Area (mmol.min/L)			
Total Area (8 hr)	834 ± 163	1055 ± 71	841 ± 71
Part 1 Area (4 hr)	554 ± 95	636 ± 49	508 ± 49
Part 2 Area (4 hr)	280 ± 74	412 ± 35	333 ± 35
Peak #1 Glucose Response (mmol/L)			
Maximum	12.24 ± 0.49	12.39 ± 0.33	12.05 ± 0.33
Excursion	4.84 ± 0.51	4.72 ± 0.28	3.99 ± 0.28
Peak #2 Glucose Response (mmol/L)			
Maximum	10.67 ± 0.46	11.24 ± 0.38	11.47 ± 0.38
Excursion	3.27 ± 0.51	3.57 ± 0.41	3.41 ± 0.41

[1] Standard Error of Mean
[2] Glycosylated Hemoglobin

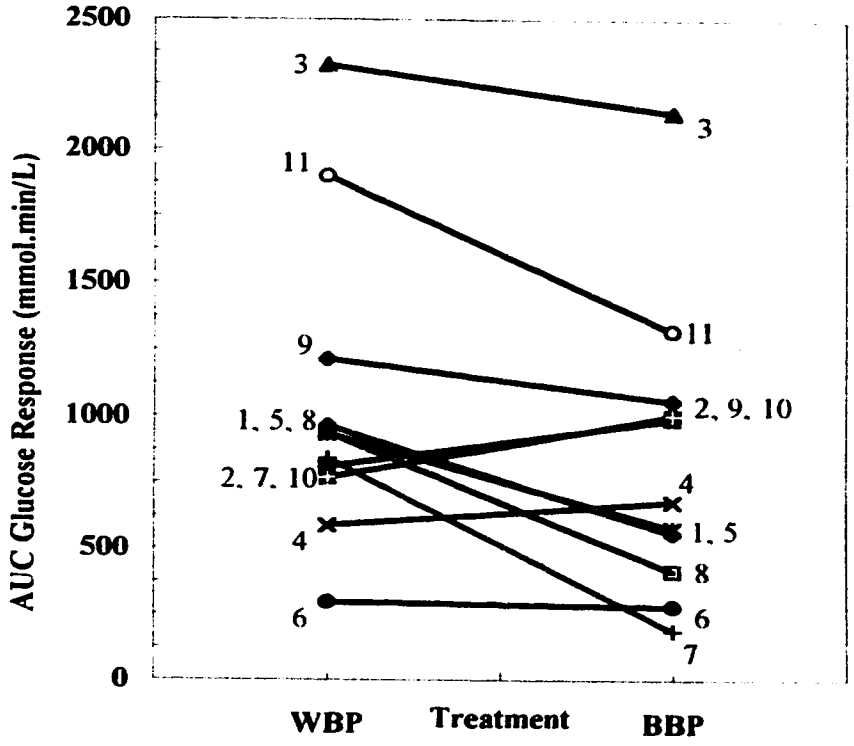

Figure 1: Diagram depicting trends of the area under curve (AUC) for 8-h glucose response in WBP versus BBP periods in individual subjects.

FIGURE 2. MEAN 8-HOUR PLASMA GLUCOSE PROFILE

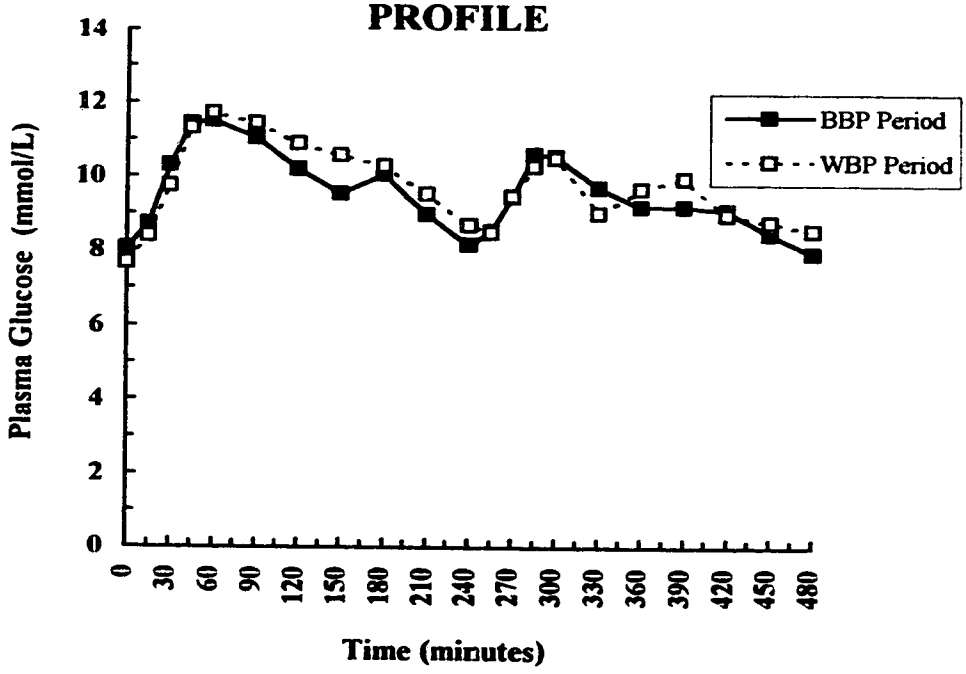

Figure 2: Diagram showing area under glucose curve for 11 NIDDM subjects during WBP and BBP periods.

Table 10. Blood Insulin Parameters for NIDDM Subjects During Study

Variable	Study Entry	WBP Period	BBP Period
		Mean ± SEM[1]	
Fasting Plasma Insulin (μU/ml)	15.5 ± 1	15.8 ± 0.7	14.3 ± 0.7
Insulin Response Area (μU.min/ml)			
Total Area (8 hr)	11760 ± 1051[ab]	10266 ± 804[a]	12982 ± 804[b]
Part 1 Area (4 hr)	5249 ± 552	4208 ± 576	5263 ± 576
Part 2 Area (4 hr)	6511 ± 733[ab]	6058 ± 462[a]	7718 ± 462[b]
Peak #1 Insulin Response (μU/ml)			
Maximum	60.9 ± 4.3	50.15 ± 5.2	57.63 ± 5.2
Excursion	44.9 ± 4.7	34.32 ± 5.4	43.38 ± 5.4
Peak #2 Insulin Response (μU/ml)			
Maximum	68. 8 ± 4.4	62.78 ± 3.9	69.75 ± 3.9
Excursion	52.7 ± 4.6	46.75 ± 3.8	55.50 ± 3.8
Insulin/glucose Ratio			
Peak #1	11.8 ± 2.1[ab]	7.24 ± 1.3[a]	11.97 ± 1.3[b]
Peak #2	22.4 ± 7.1	14.34 ± 7.6	17.59 ± 7.6

[1] Standard Error of Mean

[ab] Means not followed by the same letter in each row are significantly different from each other at $p \leq 0.05$

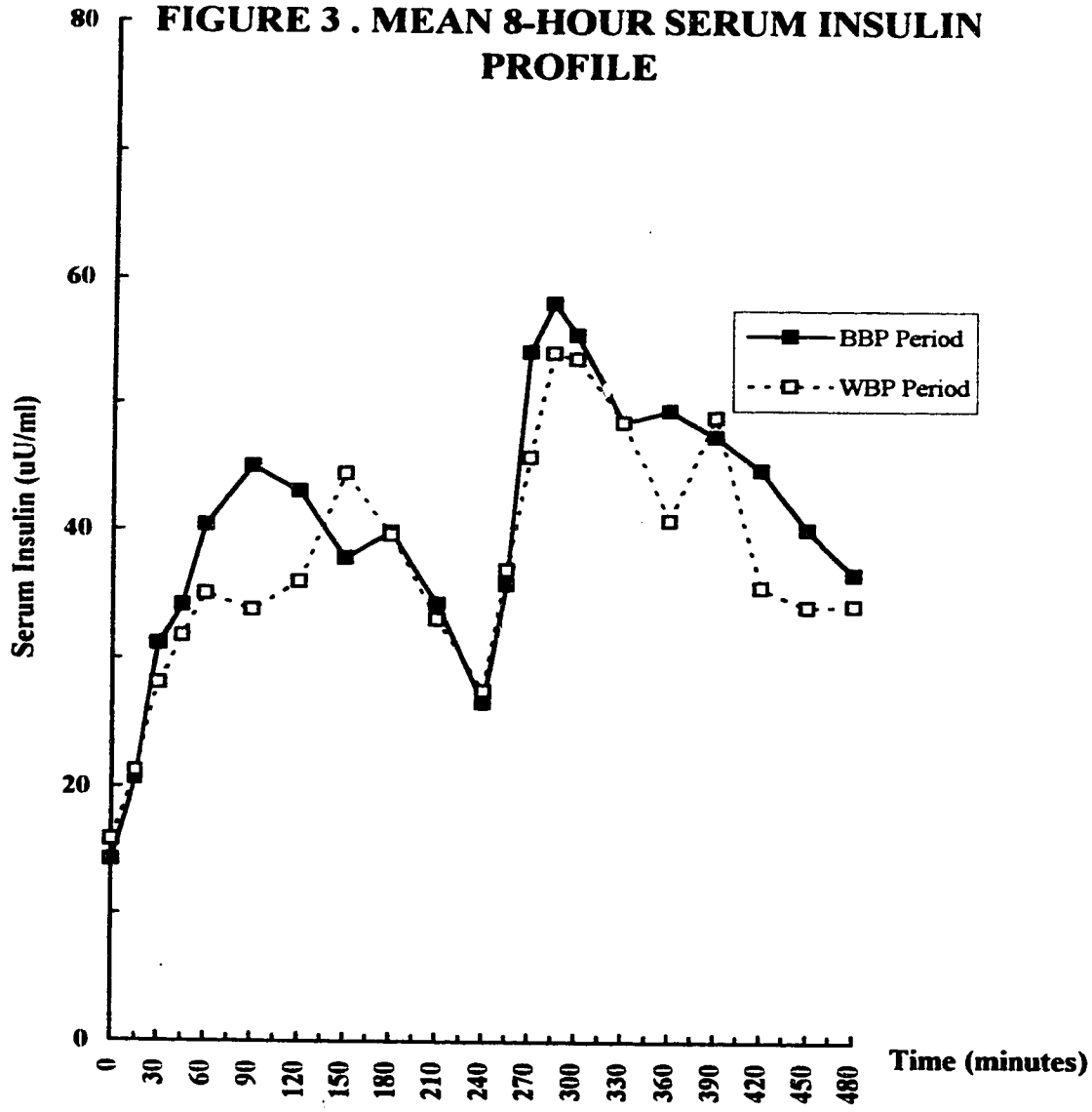

Figure 3: Diagram showing area under insulin curve for 11 NIDDM subjects during WBP and BBP periods.

Table 11 summarizes the daily DF, soluble fiber and β-glucan intake from barley bread products in all the subjects during the BBP period. It also shows the change in total glucose and insulin areas in each subject. Subjects consuming more dietary fiber from barley bread products experienced a reduction in the area under the glucose curve (except for the two subjects i.e., #2 and 10, in which the area under the glucose curve was increased). There was no effect of sulfonylurea or the diet sequence on the glucose and insulin levels.

The results for the mean plasma lipid values for NIDDM subjects for the SE, WBP and BBP periods are summarized in **Table 12**. Mean plasma total cholesterol (C) and LDL-C were decreased by 0.16 mmol/L and 0.19 mmol/L (ns), respectively, and HDL-C was increased by 0.04 mmol/L (ns) in the BBP period as compared to the WBP period. It was noteworthy, however, that 64% of the subjects showed a decreasing trend in plasma total and LDL-C concentrations during the BBP period as compared to WBP period (**Figure 4** and **5,** respectively). Plasma LDL-C was significantly ($p \leq 0.05$) decreased during BBP period as compared to the study entry level. Eight out of 11 subjects (73%) exhibited an increasing trend in plasma HDL-C while on barley bread products (**Figure 6**). Plasma HDL/total-C ratio was 11% significantly higher ($p \leq 0.05$) during BBP period when compared to SE. Plasma LDL/HDL-C ratio was 18% significantly lower ($p \leq 0.05$) during BBP period as compared to study entry. Plasma LDL/HDL-C ratio was 8% lower ($p \leq 0.05$) during BBP as compared to WBP period. Nine out of 11 subjects (82%) showed a consistent decreasing trend in the plasma LDL/HDL-C ratio during the BBP period as compared to WBP period (**Figure 7**). Plasma triglycerides showed only a slight decrease (ns) during BBP period as compared to WBP period, however, six out of 11 subjects (55%) showed a decreasing trend in their plasma triglyceride concentration (**Figure 8**).

Table 13 summarizes the changes in response of individual subjects in their plasma lipid parameters during the WBP and BBP periods. It also shows the corresponding daily intake of dietary fiber, soluble fiber and β-glucan from BBPs for each subject. The subjects consuming more soluble fiber and β-glucan from BBPs (#1, 2,

Table 11. Glucose and Insulin Response/ Barley Intake of Individual NIDDM Subjects

Subject No.	DF[1] Barley (g/d)	SF[2] Barley (g/d)	β-glucan Barley (g/d)	AUC[3] Glucose Δ[4] (mmol.min/L)	AUC Insulin Δ (μU/ml)
1	11.7	5	6.2	-406	+7885
2	15.7	6.7	8.5	+183	+3825
3	8.7	3.7	4.7	-182	-9015
4	5.1	2.2	2.7	+94	+6195
5	14.6	6.2	7.3	-357	-2355
6	8.8	3.7	4.8	-16	-782
7	9.	4.1	5.3	-653	+3667
8	10.3	4.4	5.5	-525	+2962
9	6.2	2.6	3.3	-156	-1511
10	10.6	4.5	5.8	+238	-240
11	6.4	2.7	3.5	-577	-404
Mean	9.8	4.1	5.2	-214	+2716

[1] Dietary Fiber
[2] Soluble Fiber
[3] Area Under Curve
[4] Change in Response

Table 12. Mean Plasma Lipid Values For NIDDM Subjects

Biochemical Variable	Study Entry	WBP Period	BBP Period
		Mean ± SEM[1]	
Total Cholesterol (mmol/L)	5.30 ± 0.13	5.12 ± 0.15	4.96 ± 0.15
LDL[2] Cholesterol (mmol/L)	4.11[a] ± 0.13	3.91[ab] ± 0.13	3.72[b] ± 0.13
HDL[3] Cholesterol (mmol/L)	0.87 ± 0.03	0.89 ± 0.03	0.93 ± 0.03
Triglycerides (mmol/L)	1.70 ± 0.94	1.60 ± 0.06	1.55 ± 0.06
HDL/Total Cholesterol Ratio	0.17[a] ± 0.01	0.18[ab] ± 0.01	0.19[b] ± 0.01
LDL/HDL Ratio	4.89[a] ± 0.21	4.39[ac] ± 0.13	4.02[b] ± 0.13

[1] Standard Error of Mean
[2] Low Density Lipoprotein
[3] High Density Lipoprotein
[abc] Means not followed by the same letter in each row are significantly different from each other at $p \leq 0.05$

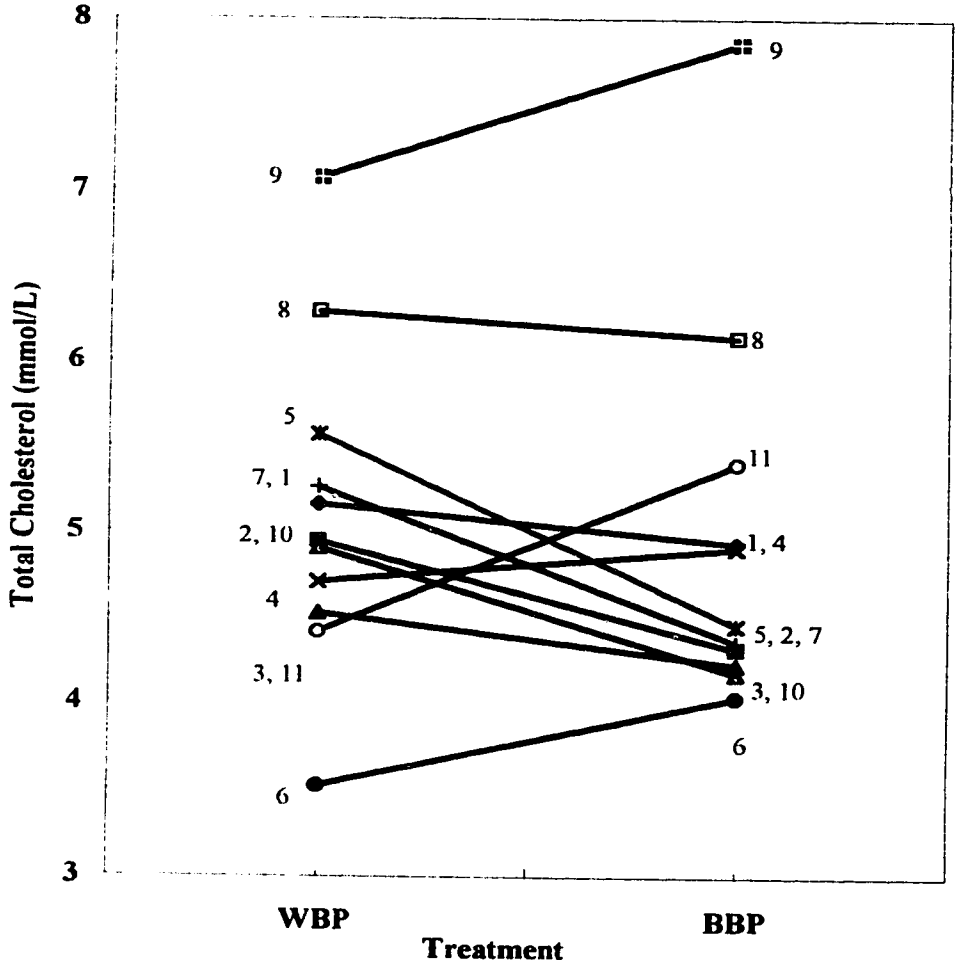

Figure 4: Diagram depicting trends of the plasma total cholesterol in WBP and BBP periods in individual subjects.

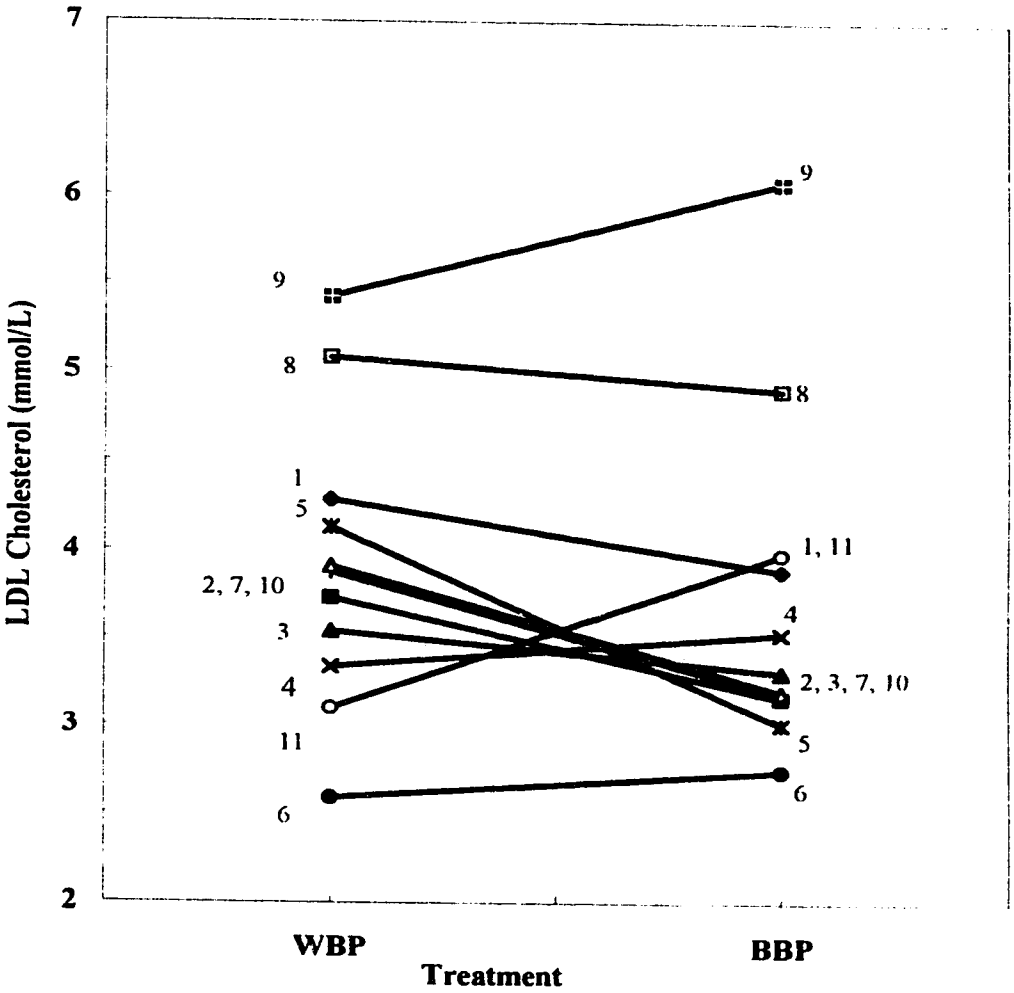

Figure 5: Diagram depicting trends of the plasma LDL cholesterol in WBP versus BBP periods in individual subjects.

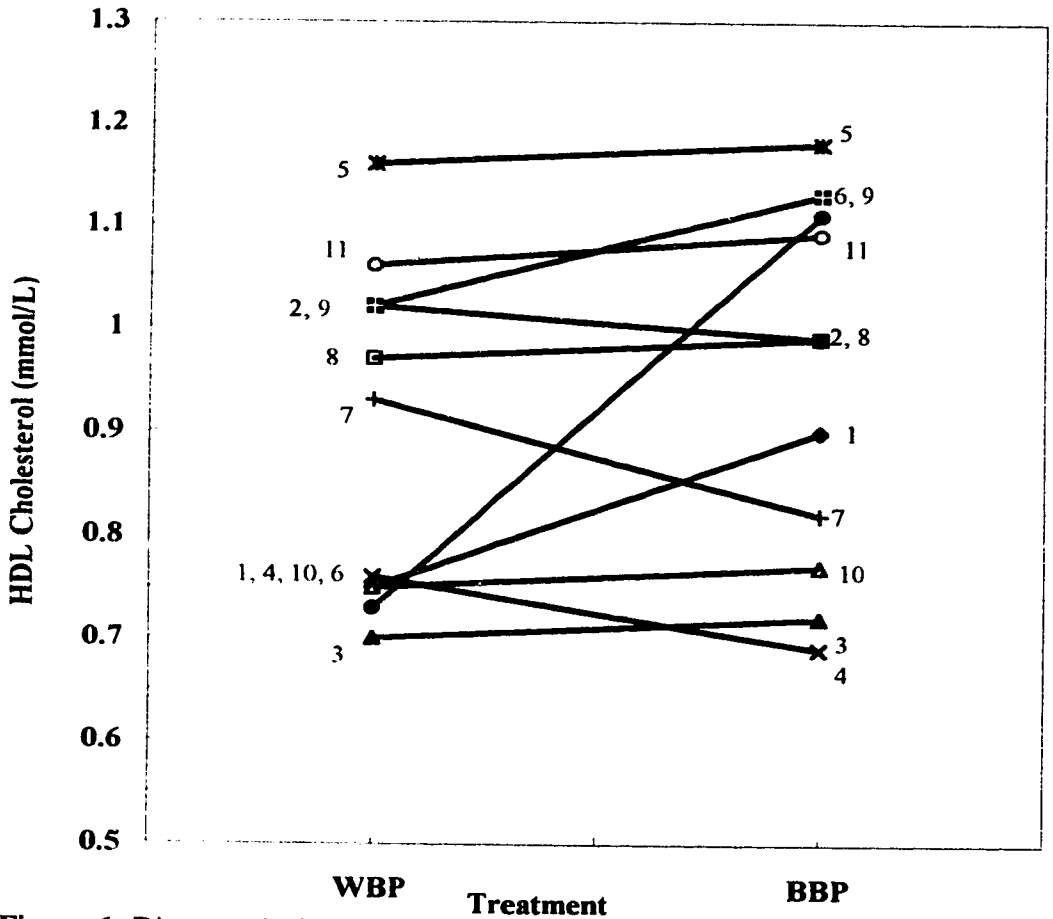

Figure 6: Diagram depicting trends of the plasma HDL cholesterol in WBP versus BBP periods in individual subjects.

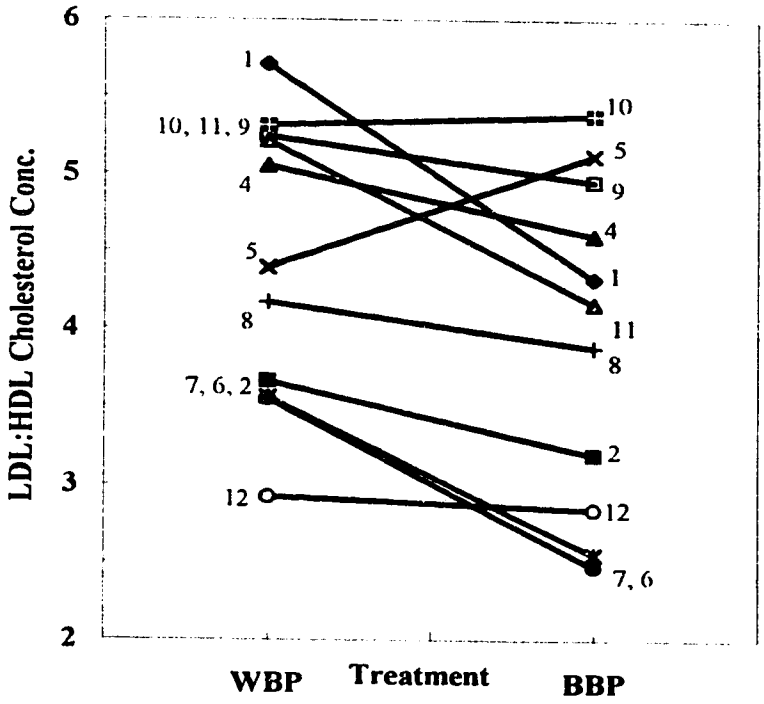

Figure 7: Diagram depicting trends of the plasma LDL:HDL concentration in WBP versus BBP period in individual subjects.

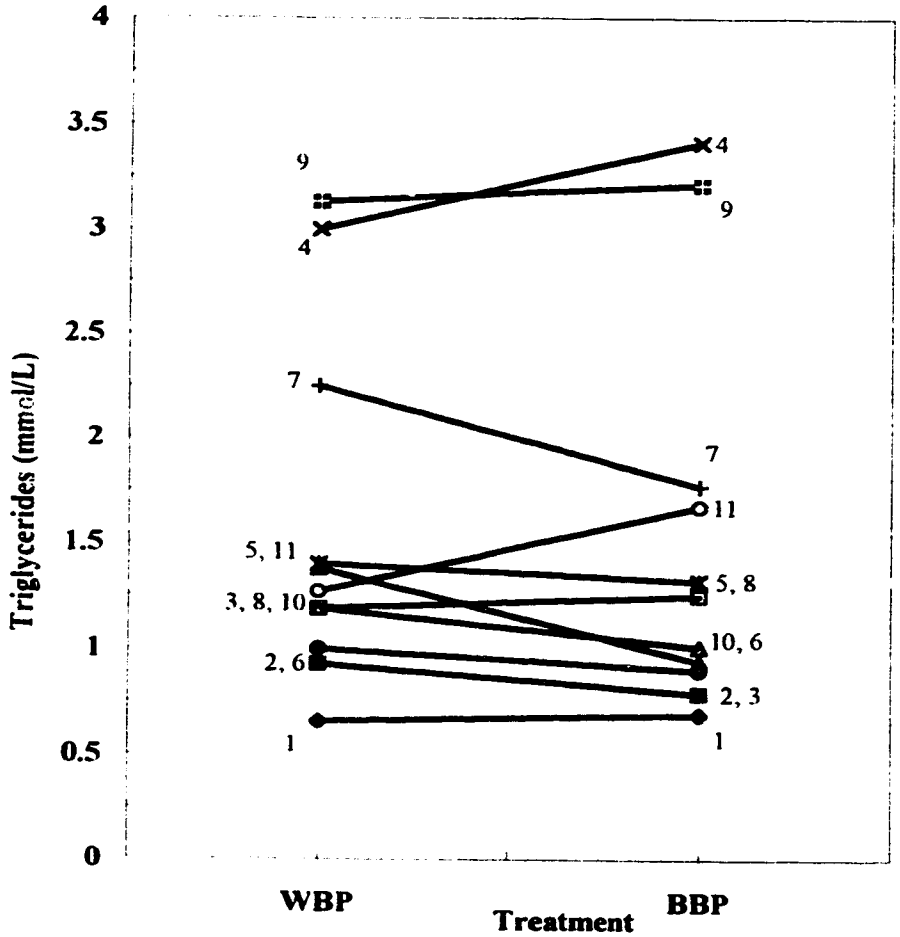

Figure 8: Diagram depicting trends of the plasma triglycerides concentration in WBP versus BBP periods in individual subjects.

Table 13. Lipid Response/Barley Intake of Individual NIDDM Subjects

Subject No.	DF[1] Barley (g/d)	SF[2] Barley (g/d)	β-glucan Barley (g/d)	Total-C[3] Δ[4] (mmol/L)	LDL[5]-C Δ (mmol/L)	TG[6] Δ (mmol/L)
1	11.7	5	6.2	-0.23	-0.39	+0.03
2	15.7	7	8.5	-0.63	-0.57	-0.12
3	8.7	3.7	4.7	-0.30	-0.23	-0.44
4	5.1	2.2	2.7	+0.20	+0.19	+0.41
5	14.6	6.2	7.3	-1.12	-1.12	-0.08
6	8.8	3.7	4.8	+0.51	+0.15	-0.10
7	9.8	4.1	5.3	-0.91	-0.70	-0.48
8	10.3	4.4	5.5	-0.15	-0.18	-0.06
9	6.2	2.6	3.3	+0.78	+0.66	+0.08
10	10.6	4.5	5.8	-0.73	-0.71	-0.18
11	6.4	2.7	3.5	+0.99	+0.88	+0.40
Mean	9.8	4.1	5.2	-0.16	-0.19	-0.50

[1] Dietary Fiber
[2] Soluble Fiber
[3] Total Cholesterol
[4] Change in Response
[5] Low Density Lipoprotein
[6] Triglycerides

5, 7, 8, 10) experienced a greater reduction in their plasma total, LDL-C and triglyceride levels. Those subjects who consumed less soluble fiber and β-glucan from BBPs (# 4, 6, 9, 11) did not show any reduction in their plasma lipid values.

The relationship between dietary and biochemical parameters is summarized in **Table 14**. Significant negative correlation were found between plasma triglyceride and starch, DF, SF and β-glucan from BBPs ($p < 0.05$). Sugar was positively correlated to the area under the glucose curve ($r = 0.72$, $p \leq 0.05$). The sugar/starch ratio was positively correlated to the area under the glucose curve ($r = 0.66$, $p \leq 0.05$). The percentage of energy derived from carbohydrates was found to be inversely related to insulin/glucose ratio for peak 1 ($p = 0.006$). Total dietary fat (g) was positively correlated to the area under the insulin curve ($r = 0.65$, $p \leq 0.005$). Fat as percentage of total calories was positively correlated to insulin/glucose ratio during peak 1 and 2 ($p \leq 0.005$).

Table 14. Relationships Between Dietary and Biochemical Parameters of NIDDM Subjects

Dietary Variable	Biochemical Variable	Correlation Value	Probability
Starch Barley	Plasma Triglyceride	-0.69	0.02
SF[1] Barley	Plasma Triglyceride	-0.67	0.03
β-Glucan Barley	Plasma Triglyceride	-0.71	0.02
DF[2] Barley	Plasma Triglyceride	-0.67	0.03
Sugar (g)	AUC[3] Glucose	0.72	0.02
Sugar:Starch	AUC Glucose	0.66	0.04
Fat (g)	AUC Insulin	0.65	0.04
Carbohydrates %	Insulin:Glucose Peak #1	-0.80	0.006
Fat %	Insulin:Glucose Peak #1	0.84	0.003
Fat %	Insulin:Glucose Peak #2	0.66	0.04

[1] Soluble Fiber
[2] Dietary Fiber
[3] Area Under Curve

DISCUSSION

Eleven male subjects (ages 34-58 years) fulfilling the study entry criteria were enrolled in the study. All the subjects were non-insulin dependent diabetic males and were living in their homes. The mean BMI value of the subjects at study entry was 27.3 ± 0.1 kg/m^2 (range, 24.1-31.2 kg/m^2). The mean duration of diabetes in these subjects was 1.86 ± 1.5 years (range, 0.25-5.0 years). Seven subjects controlled their diabetes with diet and oral sulfonylureas and four subjects with diet alone. Mean glycosylated hemoglobin of the subjects at the study entry was 7.1 ± 0.1% indicating fairly good metabolic control of the subjects. Mean fasting plasma glucose value was 7.8 ± 0.29 mmol/L (range, 5.3-13.5 mmol/L). Mean plasma total cholesterol level of the subjects at the study entry was 5.3 ± 0.13 mmol/L. Five out of the 11 subjects were hypercholesterolemic i.e., with the total cholesterol levels of more than 5.18 mmol/L [National Cholesterol Education Program, 1988]. Mean plasma LDL-C concentrations of the NIDDM subjects at the study entry was 4.1 ± 0.13 (range 3.0-5.7 mmol/L) and mean plasma triglyceride concentrations of the subjects was 1.7 ± 0.94 mmol/L. Three out of the 11 subjects had their plasma triglyceride concentrations higher than 2.15 mmol/L.

Dietary data for the subjects obtained at the study entry revealed that the mean energy intake from carbohydrates, protein and fat was 59, 17 and 24%, respectively. Compared to a group of American NIDDM subjects the subjects of this study consumed somewhat fewer calories (2089 vs 2348 kcal) and a much lower percentage of their total calories as fat (24% vs 34%) [Schmidt et al., 1994]. The subjects in the present study consumed a relatively low fat diet with mean total consumption of 59 g of fat per day. In the present study 9% of mean daily energy intake was derived from saturated fat and mean daily intake of dietary cholesterol was 279 mg/d. The mean DF intake at the study entry was 29 g/d. It was fairly good as compared to average intake of 19 g/d in men in Canada as reported by Kay et al [1980] and 10 to 13 g/d in United States reported by the ADA [1987].

In the present study, 48-food recall method was used to assess the dietary intake. However, the total calories reported by the subjects in the present study seems to be low considering the BMI (range, 24.1-31.2 kg/m^2) of these subjects. And the subjects in the present study did not lose any weight throughout the study. There seems to a possibility the actual dietary intake was under reported. Tarasuk and Beaton [1991] undertook a study to describe the patterns of variation in daily intake that exist within individuals. Examination of observed within-subject variation in the energy intake of 29 adults participating in the Beltsville one-year study suggest that individuals possess characteristic patterns of variability in total food intake. According to the authors of this study, up to 37% of the total variance observed for a subject could be explained by the long- and short-term patterns identified in food intake. One of the disadvantage of using 48-hour recall method is the inability of two day intake to describe usual diet. However, in the present study minimum of one weekend day and maximum of two days were included to overcome the variation of weekday from weekend. Another disadvantage of 48-hour recall method is the long term memory required. There is possibility that the information is both quantitatively and qualitatively inaccurate. VanStaveren et al [1988] reported that between 3 and 7 recalls were necessary to adequately estimate the habitual fat intake of an individual.

The present study was undertaken to evaluate the long-term effects of the BBP on the metabolic control of NIDDM subjects. The genotype of barley used in the present study was a two-rowed waxy hulless barley which has high SF. Barley bread and bread products were made from high β-glucan barley flour and cracked barley. These bread products were incorporated in the usual diet pattern of each NIDDM subject. Nutrition recommendations for diabetic subjects suggest that the level of fiber intake should be about 40 g/d [Canadian Diabetes Association, 1989]. The objective of the study was to incorporate eight exchanges of bread/bread products containing barley flour and cracked barley into the diets of the subjects in order to achieve DF intake of about 40 g/d. This objective was met as the mean bread exchange consumption of the subjects during barley period was 9.7. Mean DF intake during the BBP and WBP periods was 38.6 ± 2.2 g/d

and 27.8 ± 2.2 g/d, respectively. Mean daily DF, SF and β-glucan intake from BBP during the BBP period was 9.8, 4.1 and 5.2 g/d, respectively. The BBP were well accepted by the subjects in this study. The implementation and adherence to the prescribed diet was achieved by seeing each subject regularly and by providing an intensive diet counseling.

There were no significant differences between two study periods in the intake of carbohydrates, protein and fat. Most of the NIDDM subjects were overweight. However, the objective was to maintain body weight otherwise it would have clouded the interpretation of the results. The mean total energy was not significantly different during the two dietary periods. However, subjects consumed less calories in WBP period (2227 kcal) as compared to BBP period (2311 kcal), but this did not affect the body weight. The percentage of total energy derived from the carbohydrates was 60% and 61% in WBP and BBP periods, respectively. The percentage of calories contributed by protein in the present study was 16% in both dietary periods. This is in accordance with the recommendations of the ADA [1994]. The daily intake of starch was significantly less during the WBP period than during the BBP period (251 g vs 220 g). However, this was expected as there was a parallel increase in the calorie intake during the BBP period. High-fiber diets containing substantial amounts of fiber-rich starchy foods have been successfully used by several investigators [Anderson et al., 1978; Jenkins et al., 1980a; Rivellese et al., 1980]. The percentage of total energy derived from fat during the WBP and BBP periods was 24% and 23%, respectively. The total saturated fat (g/d) did not change significantly during two dietary periods. However, a significant change ($p \leq 0.05$) was observed in the percentage of energy derived from saturated fat between the two periods (7% during BBP vs. 8% during WBP period). Neither the percentage of total calories from polyunsaturated fat (5% during both periods) nor the P/S ratio for the two periods changed significantly.

The subject's compliance with the study protocol was good. The subjects liked the taste of the BBP which could be one of the reasons for the good compliance. The various BBP such as bread, buns, muffins, cookies and pasta provided a variety in the

diets of subjects, which could be another reason for the adherence to the study protocol. The repeated recalls, using standardized interview techniques, enabled us to obtain reliable estimates of usual intake of the subjects. The use of repeated recalls for assessment of dietary intake at the study entry and during the study periods was appropriate methodology for relating food consumption to clinical status. Keys [1979] reported that seven days of dietary data is the minimum to measure subject's usual food consumption. In the present study dietary intake for a total of eight days of the subjects was assessed for each study period to obtain a representative estimate of their usual food intake. Each period included a minimum of one weekend day and a maximum of two weekend days which helped to account for daily variation in food choices. The use of three dimensional food models and measuring utensils to estimate the serving portions, the use of Nutrition Canada methodology [Health and Welfare Canada, 1973] and probing questions added to the accuracy in data collection. Subjects were provided with an intensive diet counseling required to accomplish the prescribed diets. Adherence to the prescribed diets was also promoted by individualizing the diet plans and meeting regularly with each subject [Kushner, 1993]. At the study entry dietary intakes were assessed by two day (48-hour recall) for the purpose of evaluating dietary patterns only. The individualized diet plans for each subject were formulated on the basis of the information obtained.

GLYCEMIC RESPONSE

Eight out of 11 (73%) subjects showed a trend of decrease in the total incremental area under glucose curve in the present study (Figure 1). The area under the glucose curve for breakfast (4-h) and lunch (4-h) during BBP period were found to be reduced by 20% and 19% (ns), respectively, when compared to WBP period. The results of the present study are in accordance with other studies involving NIDDM subjects [Braaten et al., 1994]. Braaten et al [1994] have recently reported the effects of oat gum and oat bran in NIDDM subjects as compared to farina. They found that the mean 3-h AUC values for

glucose were significantly lower for oat bran and wheat farina with oat gum as compared to wheat farina meal. In the subjects with diabetes, the rise in plasma glucose levels was slower, higher, and remained elevated longer than in the control subjects.

No significant differences in the fasting plasma glucose were found between the two study periods. Data regarding the effects on fasting glucose is more controversial, with some studies reporting a decrease [Lalor et al., 1990; Uusitupa et al., 1990] while others reporting no change [Wilson et al., 1989] during guar gum administration in NIDDM subjects. Granfeldt et al [1994] in a recent study with different barley products found no change in the fasting glucose in healthy subjects. Landin and coworkers [1992] measured glucose disposal with euglycemic-clamp technique and found an increased glucose disposal rate with guar treatment. They suggested that it reflects enhanced glucose utilization in skeletal muscle.

In the present study, 8-h plasma glucose day profiles were used to assess the glucose metabolism in the NIDDM subjects. Gannon and Nuttall [1987] have demonstrated that NIDDM subjects required 4-5 h for plasma glucose to return to the fasting concentrations as compared to 1.5 h in the normal subjects. Eight hour plasma glucose profile provided a better assessment of the glycemic response in the present study. Area under the glucose response curve was calculated by the method of Wolever and Jenkins [1986]. The incremental area calculated by this method accounts for the area above the fasting plasma glucose level. According to LeFloch et al [1990] the incremental AUC accurately describes the glycemic response to food.

Glycosylated hemoglobin (HbA_{1c}) is a valuable parameter in judging dietary influences on blood glucose status, especially in NIDDM. Depending on the amount of the glucose in the blood, it can be incorporated into hemoglobin where it builds a stable, largely irreversible complex, making it a reliable indicator of the blood glucose status [Kristen et al., 1992]. HbA_{1c} makes up 4-6% of total hemoglobin in healthy men and women. This value increases up to 20% in patients with diabetes mellitus, according to severity of the blood glucose surplus [Bunn, 1981]. In the present study, the mean HbA_{1c} levels did not change significantly during the two study periods. While evaluating the

glucose parameters, Singer et al [1989] reported that glycosylated hemoglobin may take longer to show an effect than either plasma glucose or insulin levels.

The recent dietary recommendations [ADA, 1994] for NIDDM subjects involves 10-20% of the daily energy intake from protein, 30% or less of energy intake from total fat and less than 10% of energy from saturated fat. The distribution of energy from fat and carbohydrate can vary and be individualized based on the nutrition assessment and treatment goals. ADA also stated that first priority should be given to the total amount of carbohydrate consumed.

Viscous gums have been shown to delay intestinal transit in animals [Meyer and Doty, 1989] and in human studies [Jenkins et al., 1978]. A study by Begin and coworkers [1989] demonstrated that both oat gum and guar gum delay intestinal transit in rats. The main factor determining the slower absorption caused by SF seems to be their viscosity [Jenkins et al., 1978]. Jenkins et al [1978] demonstrated that hydrolyzed (less viscous) guar gum was ineffective in reducing postprandial glucose rise. SF may delay gastric emptying, slowing carbohydrate uptake [Holt et al., 1979]. High viscosity is thought to act as a barrier preventing the contact of digestive enzymes with their substrates and thickening the unstirred layer near the mucosa causing a delay in glucose absorption. β-glucans present in BBP have a high viscosity and have a potential for improving glycemic control. The mechanisms responsible for beneficial effect of BBP on glycemic response require further investigation.

DF may also affect the secretion of gut hormones, especially enteroglucagon, gastroinhibitory polypeptide (GIP), and somatostatin; these hormones may independently reduce satiety and/or substrate utilization [Vinik and Jenkins, 1988]. Somatostatin delays the absorption of carbohydrate and glucose from the small intestine and could be partly mediating the effects of fiber. Further studies are needed in this area.

Thornburn et al [1993] reported that barley contains more fermentable carbohydrates as compared to brown rice. Glucose tolerance improved after the barley meal which was primarily due to 30% reduction in hepatic glucose production. This effect was most likely a result of increased production of short chain fatty acids (SCFA)

from carbohydrate fermentation. They summarized that fermentation of carbohydrate may play a role in improving postprandial glycemia after high-fiber, high-carbohydrate diets [Thornburn et al., 1993]. Propionate has been shown to decrease glucose production by inhibiting gluconeogenesis and increasing glycolysis in rat hepatocytes [Anderson and Bridges, 1984]. Naismith et al [1991] observed lower glucose concentrations in the barley fed diabetic rats and attributed the beneficial effect of barley might be explained by its very high content of chromium (5.69 μg/g) [Mahdi and Naismith, 1991].

The degree to which the fiber is mixed with carbohydrate foods may influence the degree to which the rate of absorption of dietary carbohydrate is reduced. Intimate mixing of fiber with the food has been suggested as being necessary for efficacy [Fuessl et al., 1986]. However, simply mixing viscous fiber with foods results in a gummy texture and a reduction in palatability. One solution to the tradeoff between efficacy and palatability may be to incorporate SF into manufactured foods. In the present study, the barley flour and cracked barley were incorporated into the bread and bread products. The compliance of the subjects to the barley bread products was found to be very good.

Factors other than fiber are also responsible for effect on the glycemic control. For example, the food structure of carbohydrate component, rather than molecular size, is an important determinant in postprandial glucose and insulin responses [Jarvi et al., 1994]. In a study conducted by Jarvi et al [1994], the meals were planned to achieve large differences in glycemic index (GI) of the starchy foods with no difference in the nutrient and chemical composition. In the first part of the study when a meal containing pasta made from durum wheat and an apple was compared to a meal containing bread made from durum wheat and a pureed apple, the former meal resulted in 24% lower GI. In the second part of the study, parboiled rice, red kidney beans, and bread made from whole wheat grains were compared with sticky rice, ground red kidney beans, and bread made from ground wheat grains. Twenty nine percent lower GI was observed with the meal containing whole grains. The results of the study showed prominent differences in blood glucose and serum insulin responses among complex meals of different food structure, even if the meals had the same nutrient and chemical composition.

Another factor believed to be responsible for the differences in blood glucose and insulin responses is the amylose-amylopectin ratio. The importance of high amylose diet has been reported in several studies [Behall et al., 1988; Amelsvoort and Weststrate, 1992; Goddard et al., 1984]. The physical form of a carbohydrate in food can have profound effects on its rate of digestion and absorption [O'Dea et al., 1980]. For example, marked differences in metabolic responses have been observed when the natural physical form of the rice (whole vs ground) was disrupted [O'Dea et al., 1980]. The cause for reduced enzyme availability of starch in high-amylose products is not clear, but could be related to the tendency of amylose to recrystallize or to interact with lipids [Holm et al., 1983] or to the retrogradation of amylose with food processing [Behall et al., 1988]. The extent to which a food is chewed is also important determinant of the metabolic responses to it [Holm and Bojork, 1992].

In most conventional bread products, the starch is rapidly digested and absorbed, thus resulting in unfavorably high glucose and insulin responses [Wolever et al., 1988]. Snow and O'Dea [1981] have reported that starch in bread is hydrolyzed faster as compared to starch in cooked cereal. Important amounts of starch enter the large bowel daily. The quantity of starch that escapes digestion and absorption in the small intestine i.e., resistant starch (RS), has been estimated to be 10% of the total starch consumed in an average Western diet [Liljeberg and Bjorck, 1994]. This makes the RS the major substrate for the colonic microorganisms [Cummings and Englyst, 1991]. Jenkins et al [1987] suggested that RS may improve the glucose and cholesterol metabolism through the free fatty acids produced during fermentation in the colon and RS may have fiber-like effects. Thornburn et al [1993] have demonstrated that there is a reduction in hepatic glucose output in response to a rise in SCFA's after a high non-starch polysaccharide diet.

In a recent study by Granfeldt et al [1994], all the barley products used elicited favorably low metabolic responses. The boiled intact barley kernels gave notably low postprandial metabolic responses as compared to boiled barley flours, emphasizing the importance of food structure. Waxy genotypes are known to contain more SF [Newman

and Newman, 1991a]. As discussed earlier, due to the quantitative importance of bread in the diet, bread could constitute an important vehicle for RS in the diet. Granfeldt et al [1994] found that the high RS content in the high-amylose porridge (5.6%, starch basis) was probably related to a high amylose content. The impact of amylose-amylopectin ratio on the metabolic response for the barley products was marginal. However, high-amylose kernels gave a significantly lower insulin index than the corresponding normal kernels. The genotype used in the present study was a two-rowed waxy hulless barley which has high SF. Granfeldt et al [1994] also observed that all the barley products gave higher satiety values than the white reference bread. It could be attributed to the fact that all the barley products contained three to four times more undigestible material (16-21%, dry basis) than white bread (5%, dry basis). Holt et al [1992] in a recent study showed an inverse correlation between satiety and glycemic and insulin responses to seven starchy foods. However, in contrast to these studies Hollenbeck et al [1986] reported no significant differences in a day long plasma glucose and insulin responses following an increase in the DF content of the diet from 11 to 27 g/1000 kcal. Their results are in good agreement with results of DelToma et al [1988] confirming that it is not merely the quantity but rather the quality and source of DF which is responsible for changes in postprandial glucose and insulin responses.

In the present study 61% of the energy was derived from carbohydrates during BBP period. The mean total DF during BBP period was 38.6 g/d. Twenty five percent of the DF intake was from barley bread products. SF and β-glucan obtained from BBP were 42% and 53%, respectively, of the DF from barley bread products. The results of the present study show that the glycemic control of NIDDM subjects improved in 73% of the subjects as shown by the individual trends in total area under glucose response curve.

In the present study, sugar (g) and sugar-starch ratio were both positively correlated ($p < 0.05$) to area under glucose response curve ($r = 0.72, 0.66$, respectively).

The design of the present study does not allow the mechanisms involved in improvement of glycemic response to be distinguished. It is possible that greater benefits would have been achieved if the BBP had been consumed by the subjects for a longer

period and the SF from BBP had been higher. More studies are necessary to fully understand how SF affect postprandial glucose metabolism and to allow firm dietary recommendations for patients with NIDDM to be made.

INSULINEMIC RESPONSE

No significant change was observed in the fasting serum insulin levels for the two dietary periods. This is similar to the results of Granfeldt et al [1994] who also compared barley products to white bread. Landin et al [1992] also found that fasting serum insulin concentrations were unaffected in the healthy subjects after guar treatment, in spite of the increased response in skeletal muscle and adipose tissues. Landin and coworkers [1992] explained it by the possibility of insulin concentrations already low in their subjects and thus it might be difficult to detect a further reduction. Smith and Holm [1982] and Uusitupa et al [1984] have reported decreased insulin concentrations during guar treatment, both in the fasting and postprandial states, in insulin-resistant conditions.

Eight hour area under insulin curve was determined in the present study. Serum insulin returns to the baseline more slowly than plasma glucose. Analyzing data for only 3 h, as done in some studies, will considerably underestimate the serum insulin response to a meal. In the present study, 8 h insulin profile provided a better estimate of the insulinemic response. Area under the insulin curve were calculated by the method of Wolever and Jenkins [1986]. The area calculated by this method is termed as 'incremental' AUC and defines the area beneath the serum insulin response curve above the level of fasting serum insulin

Unlike glucose, the total AUC for insulin was significantly higher in the BBP period than in the WBP period. During the BBP period there was a 21% increase ($p \leq 0.05$) in the total (8-h) incremental area under insulin curve. Increases of 20% (ns) and 22% ($p \leq 0.05$), were observed in part 1 (4-h, breakfast) and part 2 area (4-h, lunch), during the BBP period, respectively. The results of the present study are in contrast to many studies which have reported a lower insulinemic levels in response to SF. Braaten

et al [1994] observed that oat bran and oat gum meals reduced the insulin responses in a group of subjects with diabetes with different degrees of insulin secretory capacity when compared to control wheat farina. They observed that in diabetic subjects oat bran appear to induce a higher insulin response as compared to wheat farina with oat gum after meal ingestion. This was explained by the authors for the higher protein content of the oat bran meal. Several other recent studies have shown that the glycemic response to dietary carbohydrates can be greatly attenuated by the addition of protein [Nuttall et al., 1985; 1984]. Chew et al [1988] compared six mixed meals of different ethnic origins and found that all the meals gave higher plasma insulin responses than did oral glucose. They suggested that the factors such as protein, fat, and other components of a mixed meal act as insulin secretagogues. Fat may increase GIP levels which may potentiate effects of glucose stimulated insulin secretion. The protein and fat content in the present study was similar for the two study periods.

Krezowski et al [1987] studied the effect of high-carbohydrate foods as single meal foods on glucose and insulin response on eight NIDDM subjects. They observed that oatmeal ingestion result in the greatest meal insulin area in terms of the absolute area when compared with other high-starch foods. The results were found to be of interest, but the reason for the increased insulin response were not known. Their results indicated that the insulin response cannot be predicted by the glucose response. In a recent study Groop et al [1993] observed no change in insulin concentrations with guar gum treatment together with decreased ratio of insulin to C-peptide throughout the postprandial period. Since C-peptide measurements provide a better estimate of insulin secretory rate than peripheral insulin measurements, the increased C-peptide concentration seem to represent a true enhancement of insulin secretion [Groop et al., 1993]. The increased C-peptide response suggests that guar gum treatment stimulates rather than suppresses insulin secretion. According to the authors this might be explained by increased hepatic extraction of insulin. In the present study C-peptide response was not determined.

Cohen et al [1992] reported that a meal with a low-glycemic response result in an earlier insulin peak as compared to a meal with high-glycemic response in six obese

NIDDM subjects. The integrated insulin response areas of the two meals did not differ but the peak insulin level occurred one hour earlier in the low-glycemic effect meal. In the present study the mean maximum serum insulin values were 13% and 10% higher (ns) for peak 1 and peak 2 during the BBP period as compared to the WBP period, respectively. The mean insulin excursion of subjects in the BBP period were 21% and 16% higher (ns) for peaks 1 and 2 than in the WBP period, respectively. In the present study, total dietary fat (g) was positively correlated ($p \leq 0.05$) to the area under insulin curve ($r = 0.65$).

Braaten et al [1991] found that the plasma insulin/glucose ratio was reduced after the oat and guar gum plus glucose meals as compared to the glucose drink alone. This suggested that insulin secretion was reduced more when gum was added than could be accounted for by the plasma glucose alone. However, in the present study, the insulin-glucose ratios were found to be 40% higher ($p \leq 0.05$) for peak 1 in the BBP period as compared to the WBP period. The results of the present study show that the percentage of total daily energy derived from fat was positively correlated to insulin-glucose ratio during peaks 1 ($r = 0.84$, $p < 0.005$) and 2 ($r = 0.66$, $p < 0.05$). The percentage of energy derived from carbohydrates was found to be inversely related to insulin-glucose ratio for peak 1 ($r = -0.80$, $p \leq 0.01$).

The factors which are found to be responsible for differences in blood glucose responses are also found to be responsible for differences in blood insulin responses. These factors are namely; food structure [Jarvi et al., 1994], amylose-amylopectin ratio [Behall et al., 1988], formation of resistant starch [Liljeberg and Bjorck, 1994] and the presence of viscous dietary fiber [Jenkins et al., 1978]. Mechanical processing such as fine grinding of carbohydrate-rich foods also has effects on postprandial blood insulin levels. Ground rice caused faster blood sugar increases and higher insulin responses in non-diabetic and NIDDM volunteers than unground rice of the same kind [O'Dea et al., 1980]. Liljeberg et al., [1992] reported that bread with 20% white wheat flour and 80% intact kernels from wheat, rye or barley reduces postprandial glucose and insulin responses compared with white wheat bread.

Dietary protein and fat are also known to decrease blood glucose response and enhance insulin secretion. In normal and NIDDM subjects protein stimulates insulin secretion and thus reduces the blood glucose response to a carbohydrate meal. When 10, 30 and 50 g protein was added to 50 g glucose loads in NIDDM, insulin secretion was significantly increased only after 30 and 50 g, and the glycemic response was significantly reduced only after the addition of 50 g protein [Nuttall et al., 1984]. Consistent with this was a study where the addition of 21.2 g protein to 51.4 g carbohydrate and 10.3 g fat had no significant effect on the glycemic response in NIDDM, but was associated with a significantly enhanced insulin response [Simpson et al., 1985]. The addition of fat to carbohydrates results in a similar blood insulin level as after carbohydrates alone, despite the reduced blood glucose level [Collier and O'Dea, 1983]. This enhanced postprandial insulin secretion may be due to the large increase in GIP levels seen after a fat meal [Collier and O'Dea, 1983]. GIP has been proposed as a hormone which potentiates insulin secretion [Sarson et al., 1984]. Plasma GIP has been ascribed an inhibiting effect on hepatic insulin extraction [Groop et al., 1986]. As the change in the ratio of insulin to C-peptide correlated positively with the change in the GIP response [Groop et al., 1986], it seems possible that guar gum exerted its effect on glucose tolerance by interfering with gut hormones. Decreased GIP secretion would thus lead to increased hepatic extraction of insulin.

High viscosity is thought to act as a barrier preventing the contact of digestive enzymes with their substrates and thickening the unstirred water layer near the mucosa causing delay in the absorption. Liljeberg and Bjorck [1994] undertook a study to clarify the effects of organic acids generated during the dough fermentation. They found a lowering of postprandial glucose and insulin responses with the coarse sourdough bread containing 80% barley kernels. Sourdough fermentation involves a considerable number of heterogeneous metabolic and fermentation reactions. In the course of carbohydrate fermentation, the lactic acid bacteria of the sourdough transform glucose into lactic acid [Seibel and Brummer, 1991] and, in addition, small amounts of acetic acid, ethanol and carbon dioxide are formed.

Both obesity and NIDDM are associated with reduced insulin sensitivity [Kolterman et al., 1981]. Although both reduced β-cell function and insulin sensitivity contribute to hyperglycemia in NIDDM, the relative importance of improvements in each of these to the lowering of glycemic levels after diet treatment is not clear.

Polonsky et al [1994] recently undertook a study to define the effects of weight loss on 24-hour insulin secretion rates (ISRs) and insulin clearance rates in subjects with varying degrees of glucose intolerance. In the patients with overt NIDDM average ISRs did not change as a result of weight loss, despite 50% fall in the plasma glucose. There data demonstrate that weight loss that leads to an improvement in insulin sensitivity also causes significant increases in rates of insulin clearance. The increase in insulin clearance after weight loss presumably relates to the associated increase in insulin-receptor binding and insulin sensitivity [Polonsky et al., 1994]. Weight loss was not a target in the present study as it would have made it difficult to interpret the effect of BBP on the insulin response.

In a recent study by Hosker et al [1993] 15 newly diagnosed NIDDM subjects showed improvement in fasting plasma glucose after three months diet treatment. The improvements in fasting plasma glucose were found to be associated with an increase in virtually all measures of β-cell insulin secretion including fasting C-peptide, Continuous Infusion of Glucose with Model Assessment (CIGMA) achieved plasma insulin and C-peptide, and CIGMA-modeled β-cell secretion. (CIGMA is a simple glucose infusion method for the determination of insulin sensitivity and β-cell function in subjects with residual endogenous insulin secretion). However, in contrast to this, measures of insulin sensitivity showed no significant change during diet therapy, including fasting plasma insulin, CIGMA-modeled insulin sensitivity, and suppression of plasma non-esterified fatty acids (NEFAs). There was no correlation between the amount of weight lost and the fall of plasma glucose, which suggested that the improvement in glycemic control was not directly related to the modest amounts of weight loss in their study. The improvements in various measurements of the β-cell insulin secretion might be attributed to the low-fat, high-carbohydrate diet in normal and diabetic subjects. In the present

study, the serum insulin levels increased significantly after the BBP period as compared to the WBP period. This is indicative of the fact the β-cell insulin secretion increased with BBP. An improvement in β-cell secretion in presence of no weight loss in the present study, may be an important mechanism in the improvement of glycemic levels in the treatment of NIDDM subjects.

In NIDDM subjects a disproportionate elevation of proinsulin has also been described, and proinsulin-like immunoreactivity makes up greater proportion of serum immunoreactive insulin (IRI) [Ward et al., 1987]. The biological significance of proinsulins are not fully understood, but they are biologically less active than insulin [Galloway et al., 1992]. However, a limited information is available on the response of proinsulin to different diabetic therapies. The starch present in food products also seem to stimulate the secretion GIP I hormone in the gastrointestinal track. The increased serum insulin levels observed in the present study could be explained by this.

Direct measurements of hepatic glucose output and insulin sensitivity before and after dietary intervention would clarify the mechanism(s) by which SF ameliorate or worsen metabolic control in NIDDM. In conclusion, the present study provides practical information in regards to the long-term effects of BBP in individuals with NIDDM. More investigation is required to clarify the role of BBPs on the insulin response and peripheral insulin sensitivity in NIDDM individuals .

LIPID RESPONSE

The plasma total cholesterol decreased from 5.12 ± 0.15 mmol/L during WBP period to 4.96 ± 0.15 mmol/L (3%) during BBP period. Plasma total-cholesterol decreased 6% during BBP period as compared to study entry period. When the trends of plasma total-cholesterol in individual subjects were analyzed, seven out of 11 (64%) subjects showed a decreasing trend during BBP period (Figure 5). There is data supporting a direct linear relationship between plasma cholesterol concentrations and cardiovascular mortality in diabetic and nondiabetic individuals [Rosengren et al., 1989].

This indicates that there is no clear threshold separating individuals with high or normal plasma cholesterol levels. The results of the Lipid Research Clinics Coronary Primary Prevention Trial [1984] predicted a 2% reduction in coronary heart disease for every 1% reduction in plasma cholesterol.

Results of a meta-analysis of oat products by Rispin et al [1992] indicated that oat products supplying 3 g SF per day or more were effective in reducing total-cholesterol. Effect size was influenced by intake of SF and initial cholesterol levels. The initial plasma-cholesterol level may affect the results because the subjects with higher values may be more responsive to SF. The variability in the total-cholesterol response between various trials could be explained by the fact that SF is an incomplete measure of consumption; other components of the fiber (for example β-glucan) as well as the way in which it is prepared may play a role in its mechanism of action [Slavin 1987]. Swain et al [1990] found that oat bran was not superior to wheat bran in ability to lower total-cholesterol. The negative results of his trial are attributable to the low initial total-cholesterol level of those subjects (4.8 mmol/L). In a metabolic ward trial Anderson et al [1991a] reported 9% reduction in plasma total-cholesterol levels; this can be explained in part by the high initial cholesterol level of the subjects (6.9 mmol/L) and by the higher intake of SF (13.4 g). Newman et al [1989b] reported the hypocholesterolemic effects of barley in healthy men. When 14 volunteer men ate either barley or wheat diet providing 42 g/d of DF, barley subjects who had normal pre-treatment plasma total and LDL-C levels showed no significant effects, whereas in subjects who had higher pre-treatment levels, plasma total-cholesterol and LDL-C were reduced. In contrast to the hypothesis that initial serum cholesterol values influences the response to fiber, the results of a review of 77 human studies by Glore et al [1994] revealed that the average total cholesterol reduction for subjects with hypercholesterolemia and subjects with normocholesterolemia was 10.9% and 10.6%, respectively. However, the average reduction in plasma LDL-C was greater for the subjects with hypercholesterolemia (13.6%) than for the subjects with normocholesterolemia (9.9%). In the present study, the plasma LDL-C was 10% significantly ($p \leq 0.05$) lower during BBP period as

compared to the study entry values. When the trend in plasma LDL-C in individual subjects were observed, seven out of 11 (64%) subjects showed a decreasing trend during BBP period as compared to WBP period (Figure 6). It was observed that out of four subjects who did not show a decrease in their plasma LDL-C, three subjects had consumed less SF (< 3.0 g/d) from BBPs as compared to the subjects whose plasma LDL-C was lowered while on BBP (Table 13). According to the National Cholesterol Education Program [1988] even a 5% decrease in serum cholesterol may translate into a 10% decrease in cardiovascular mortality. Change in body weight may also affect total-cholesterol. In a study by Kastan et al [1992], in 871 middle-aged men, a 1-kg change in body weight was associated with a 0.05 mmol/L change in total-cholesterol. In the present study there was no significant change in the body weight during the two dietary interventions.

The results revealed that there was a significant inverse relation between starch, DF, SF and β-glucan from BBP and plasma total-cholesterol and LDL-C. This shows that the higher the starch, DF, SF, and β-glucan from BBP, the lower the total-cholesterol and LDL-C. Fruit exchanges from BBP were negatively correlated with plasma triglycerides. Similarly, as the bread exchanges from BBP increased in the diet of NIDDM subjects, the plasma triglyceride concentrations decreased.

Hypertriglycerdemia has been associated with an increased incidence of coronary artery disease (CAD) in diabetic population in both cross-sectional and prospective studies [Carlson et al., 1979; Fontbonne et al., 1989]. Hypertriglycerdemia is common in individuals with NIDDM and it appears to result primarily from increased endogenous triglyceride synthesis [Greenfield et al., 1980]. Plasma triglyceride concentrations may fall in response to improved glycemic control. It is probably related to a reduction in VLDL triglyceride secretion, secondary to a fall in free fatty acid concentrations, which occur with improvements in glycemic control [Greenfield et al., 1980]. In the present study, 64% of the subjects showed a decreasing trend in plasma triglyceride levels during BBP period as compared to WBP period (Figure 7). Plasma triglyceride concentrations

was found to be negatively correlated to the starch, SF, DF and β-glucan from BBPs ($p < 0.05$).

Low HDL-C concentrations have also been shown to be associated with an increased risk for CAD in individuals with diabetes [Castelli et al, 1977], and there is evidence that the reduced HDL-C levels seen in individuals with NIDDM also is associated with enhanced atherosclerosis observed within this syndrome [Beach et al., 1979]. In the present study there was no significant difference in the plasma HDL-C between the two dietary interventions. It is in accordance with other studies which have also shown no change in the HDL-C with DF interventions. McIntosh et al [1991] observed no change in HDL-C with barley foods in 21 hypercholesterolemic men. Kastan et al [1992] found no change in the HDL-C concentration with oat or wheat bran treatment. They observed a significant reduction in total and LDL-C concentrations during oat bran period. The resulting higher HDL/LDL-C ratios on the oat bran diet were interpreted as a indicator of reduced cardiovascular risk. HDL/LDL-C ratio is a more sensitive predictor of atherosclerotic vascular risk [Schonfeld, 1985]. Anderson and Gustafson [1988] observed 22% and 17% increase in HDL/LDL-C ratios when hypercholesterolemic male subjects consumed 47 g/d of total DF and 17 g/d of SF from oat and bean products. In the present study, though there was no significant change observed in HDL-C during WBP and BBP periods, however, eight out of the 11 (73%) subjects showed an increasing trend in their plasma HDL-C concentrations (Figure 8). The LDL/HDL-C ratio was 11% significantly lower ($p \leq 0.05$) during the BBP period as compared to WBP period. LDL/HDL-C ratio was also 18% lower ($p \leq 0.05$) during BBP period when compared to study entry values. This is in accordance with the results of Vuorinen-Markkola et al [1992]. They observed 18% decrease in LDL/HDL-C ratio in diabetic subjects with 5 g of guar four times a day for 6 wk each. In the present study, HDL-C/total cholesterol ratio was 11% lower ($p \leq 0.05$) during BBP period as compared to study entry values. Diets reducing total cholesterol and LDL-C without reducing HDL-C are considered to be highly desirable for the prevention of CAD in humans [Grundy, 1987].

Increased use of high-fiber foods may indirectly decrease serum lipids because of reduced fat and cholesterol intake [Swain et al., 1990; Connor, 1990]. Ideally, the only dietary difference between the two dietary interventions should be in fiber intake. Analysis of three recent studies [Vuorinen-Markkola et al., 1992; Landin et al., 1992; Anderson et al., 1992] by Glore et al [1994] provided evidence that the results were not attributable to any significant decrease in fat or cholesterol consumption, though saturated fat intake was higher in the group consuming the guar gum supplement than in the group consuming placebo [Vuorinen-Markkola et al., 1992]. Martinez et al [1991] carried out a study to compare the effects of barley diets supplemented with different fat sources on lipid metabolism in chicks. Results of their study indicated that the high SF content of barley exerts a hypocholesterolemic effect in chicks regardless of dietary fat source, possibly mediated through lowered fat absorption [Martinez et al., 1991]. In the present study, there was no difference between the intake of saturated fat (g/d) during the BBP and WBP periods.

In spite of extensive research on the role of DF on lipid metabolism, the mechanisms for the hypolipidemic action of SF have remained elusive. Several possible mechanisms have been proposed. SF alters cholesterol metabolism at gastrointestinal, hepatic, and peripheral sites [Anderson, 1985]. SF may bind bile acids and cholesterol in the intestine, thereby increasing their fecal excretion. This interrupts the enterohepatic circulation of bile salts; these actions interfere with intestinal micelle formation and reduce fat absorption [Anderson, 1987]. The mechanism of action for β-glucans has been suggested to be a result of intestinal viscosity created by the hydrophilic nature of the β-glucans. According to Fadel et al [1987], β-glucans in barley diets create a viscous environment in the digestive tract and thereby cause poor absorption of dietary nutrients and reduce growth rate. Viscosity may act as a barrier preventing the contact of digestive enzymes with their substrates, thickening of the unstirred layer of the mucosa and prevention of formation of micelles required for absorption of lipids [Wang et al., 1992]. Short-chain fatty acids (SCFA) are major fermentation products of fiber in the colon and are almost completely absorbed into the portal vein [Cummings, 1981]. SCFA are

absorbed into the portal vein and may inhibit hepatic and peripheral cholesterol synthesis and increase LDL-C clearance [Anderson, 1985]. Most SF are almost completely fermented in the colon and SCFA (predominantly acetate, propionate, and butyrate) represent approximately 70% of the metabolic end products [Cummings, 1981]. Several studies have suggested that SCFA fermentation products of plant fiber may have an important effect on hepatic cholesterol synthesis and serum cholesterol concentrations [Anderson and Bridges, 1984; Chen et al., 1984; Ventor and Vorster, 1989]. Propionate inhibits cholesterol synthesis in vitro [Anderson and Bridges, 1984]; however, there is controversy regarding whether propionate concentrations in vivo are sufficient to significantly affect synthesis [Illman and Topping, 1985].

McIntosh et al [1991] attributed the hypocholesterolemic effects of barley to the level of the β-glucan component of non-starch polysaccharides (NSP) found in barley and oats. Newman et al [1987] reported that the hypocholesterolemic effects of barley can be reduced or annulled by the addition of β-glucanase to barley diets fed to chickens, which breaks down the β-glucan. Shinnick et al [1988] observed oat gum to be more effective than oat bran, and β-glucan is the main component of oat gum. In this respect, it is the solubility in water of the β-glucan, its viscosity, and influence on the absorption of nutrients in the small intestine that probably account for its biological effect on plasma cholesterol concentrations.

Barley also contains a fat-soluble constituent, tocotrienol, reported to repress HMG-CoA reductase, the rate limiting enzyme for cholesterol synthesis [Qureshi et al., 1986]. The tocol content of barley grain is 30.5 mg/kg [Barnes, 1983]. The tocotrienol as percent of tocols are 81% in barley. This measure (tocotrienols as percent of total tocol) reflects more closely the cholesterol-suppressive pattern of barley grain than does the measure of the quantity of α-tocotrienol [Qureshi et al., 1986]. In the present study, this could be one factor in the reduced LDL/HDL ($p < 0.005$) ratio observed after the subjects consumed BBPs for 12 weeks as compared to WBP period.

The chemical composition of starch, that is, the amylose/amylopectin ratio has shown to influence the starch bioavailablity. Holm et al [1983] attributed the beneficial

effects of high-amylose varieties to a reduced rate of enzymic digestion due mainly to formation of complexes between amylose and lipids. In a study by Behall et al [1989] long term intake of a high-amylose diet improved fasting triglyceride and cholesterol levels in healthy subjects more than a corresponding high-amylopectin diet. The beneficial effect of high-amylose diet was discussed in terms of a flattened insulin response following ingestion of the high-amylose diet.

The present study shows that the incorporation of BBP in the diets of NIDDM subjects helps in lowering the plasma total-C and LDL-C concentrations with no adverse effect on the plasma HDL-C concentrations. The results also showed that with an increase in the consumption of DF, SF and β-glucan from barley bread products the plasma total-C, and LDL-C are lowered. The LDL/HDL-C ratio was significantly lowered with the incorporation of BBP in the diets of NIDDM subjects.

The commonest side effects associated with DF intake are gastrointestinal; diarrhea, flatulence, bloatedness, anorexia, and abdominal pain [Cummings and Englyst, 1987]. The frequency of these side effects can usually be reduced by gradual phased increase in fiber intake. In most subjects, these side effects are transient and subside within one week of continuous fiber intake [Council of Scientific Affairs, 1989]. In the present study, reported side effects resulting from consumption of barley products were minimal. Half the subjects reported the problem of gas after consumption of BBP. However, the problem subsided after one or two weeks of consumption of BBP. None of the side effects were sufficiently serious to necessitate the discontinuation of BBP. Subject's compliance to barley products during the study period was good.

Although there is some evidence that large amounts of DF may inhibit the absorption of some ingested minerals, instances of clinically important deficiencies of vitamins or minerals (including calcium and iron) induced by DF have not been found [Kay, 1982; Vinik and Jenkins, 1986]. The assumption is that Western diets are sufficiently enriched in micronutrients to compensate for any inhibitory effect of fiber on the intestinal absorption of these substances [Sandstead et al., 1979]. Moreover, DF intake for period of >6 months had no significant adverse effects on trace element and

vitamin homeostasis [Garg et al., 1990; Van Duyn et al., 1986]. Long-term studies suggest that there is a metabolic adaptation to increased fiber intake and that after several months, normal mineral balance is reestablished [Anderson et al., 1980a].

CONCLUSION

Nutritional management is the cornerstone of the treatment for the NIDDM subjects. The present study was undertaken to investigate the long-term effects of BBP on the glycemic, insulinemic and lipidemic parameters of the NIDDM subjects.

The results of the present study indicated that the long-term incorporation (12 wk.) of BBP in the usual diet pattern of NIDDM subjects is potentially effective in improving lipid profile of these subjects. Subjects compliance to the barley products during the study was good. All the subjects liked the taste of barley products. The various barley products such as bread, muffins, cookies and pasta helped to provide a variety in the diets of the subjects.

DF has frequently been associated with some side effects. In the present study, while on BBP some of the subjects also experienced side effects such as feeling of fullness, gas problem and diarrhea; however, these side effects did not last very long and subsided within one or two weeks of the BBP consumption.

One problem in using barley flour is to provide sufficient amounts of the SF to demonstrate a treatment effect using a small number of subjects while still maintaining a tolerable meal volume. The solution to this problem could be the use of purified fiber so as to provide a high level of β-glucan. The objective in the present study was to incorporate eight exchanges of barley products in the daily diets of subjects. The subjects in the present study were taking 9.7 exchanges of BBP, even then the mean daily β-glucan consumption of the subjects was 5.21 g. However, even at this level BBP showed very promising results with regards to glycemic and lipidemic responses. Future studies should be designed to incorporate higher level of β-glucan from BBP in the diets of diabetic subjects so as to clearly understand its effect on the metabolic control of

diabetes. The design of the present study did not allow identification of the underlying mechanisms involved in the improvement of glycemic and lipidemic profile.

BBP in the present study were better tolerated as compared to other soluble dietary fibers such as guar, psyllium and pectin, and their use did not produce any side effects. The higher acceptability by the subjects, together with its palatability and easy incorporation in the preparation of food could favor the introduction of BBP in the standard diet of NIDDM patients, allowing for better control of glycemic, insulinemic and lipid responses.

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