We examined the inhibitory effect of a single ingestion of bread containing resistant starch (bread containing about 6 g of resistant starch derived from tapioca per 2 slices) (test food) on the postprandial increase in blood glucose in male and female adults with a fasting blood glucose level between 100 and 140 mg/dl. Bread not containing resistant starch (placebo) was used as the control.

The study was conducted in 20 subjects (9 men and 11 women with a mean age of 50.5 ± 7.5 years) using the crossover method, with a single ingestion of either bread containing resistant starch or the placebo. Blood glucose and insulin were measured before ingestion, and at 0.5, 1, 1.5, and 2 h after ingestion. The blood glucose level before ingestion was stratified into a borderline group (blood glucose level ≥ 111 mg/dl) and a normal group (blood glucose level < 110 mg/dl), with the upper limit of the normal range defined as 110 mg/dl. Postprandial increases in both blood glucose and blood insulin were significantly inhibited in subjects in the borderline group who took the test food in comparison with the placebo group (blood glucose: p < 0.05 and p < 0.01 at 1 and 1.5 h after ingestion respectively; insulin: p < 0.05, p < 0.01 and p < 0.05 at 1, 1.5, and 2 h after ingestion respectively).

These results indicate that bread containing resistant starch is useful for prevention of lifestyle-related diseases such as diabetes mellitus, and as a supplementary means of dietetic therapy.

Key words: resistant starch; bread; blood glucose; insulin

Diabetes mellitus is said to have a close relationship with dietary habits in lifestyle-related diseases. The number of patients with mild type 2 diabetes mellitus, which accounts for 90% or more of all diabetic patients, is steadily increasing in Japan, as carnivorous dietary habits prevail. Diabetes mellitus is known to complicate serious multiple organ disorders such as diabetic retinopathy, diabetic nephropathy, and diabetic neuropathy, and it affects vital prognosis as a risk factor for circulatory disorders including arteriosclerosis and myocardial infarction. It has been reported that dietary therapy and exercise therapy are fundamental to the management of mild type 2 diabetes mellitus, and that daily control of blood glucose level is the key to a good prognosis and future QOL in diabetic patients.

Indigestible dextrin, wheat albumin, guava polyphenol, Touchi-extract, and t-arabinose are foods known to inhibit an increase in blood glucose, and foods containing these substances have been labeled and approved as foods for specified health uses. These functional foods induce no adverse reactions, as observed with drugs, and are attracting attention in terms of high safety. Resistant starch is another functional material, which differs from these materials. It is known to have an effect common to some dietary fibers in the small and large intestines, by increasing the indigestible portion, and has recently drawn attention as a food with a low glycemic index (GI). It is assumed that the physiological effect of resistant starch is due to its minimal digestion in the small intestine, and becoming a substrate for fermentation by intestinal flora. The former is associated with modification of glucose and lipid metabolism. A decreasing effect on blood glucose and insulin by a single-dose administration of resistant starch and a decreasing effect on total cholesterol by repeat-dose administration have been reported in animal studies. The latter is associated with an effect on the function of the large intestine, and in an ulcerative colitis rat model, serum transglutaminase activity—an index of tissue repair—increased significantly, demonstrating a healing effect.

Against this background, Yamazaki Baking Co., Ltd., has focused on the physiological effect of these resistant materials. We examined the inhibitory effect of a single ingestion of bread containing resistant starch (bread containing about 6 g of resistant starch derived from tapioca per 2 slices) (test food) on the postprandial increase in blood glucose in male and female adults with a fasting blood glucose level between 100 and 140 mg/dl. Bread not containing resistant starch (placebo) was used as the control.

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starches and is developing a bread containing tapioca-derived resistant starch. In this study, the inhibitory effect of a single ingestion of bread containing resistant starch on increases in blood glucose was investigated in subjects with untreated borderline diabetes mellitus whose fasting blood glucose level was 100 and 140 mg/dl, using the double-blind crossover method with a placebo control.

**Subjects and Methods**

**Subjects.** The subjects in this study were paid volunteers recruited by Soiken. Adult men and women with untreated borderline diabetes mellitus, who showed a fasting blood glucose level between 100 and 140 mg/dl in the preliminary examination, were selected from those registered to the untreated subject data bank at Soiken. Patients were excluded if they showed allergic symptoms to the study food, were judged by a doctor to need urgent administration of antidiabetic drugs, had severe anemia or a serious ongoing disease, were taking oral drugs periodically or supplements affecting blood glucose level, or had donated 200 ml of blood within 1 month, or more than 400 ml of blood within 3 months before the start of the study. Based on the result of the preliminary examination conducted on May 22 or 29, 2004, 24 subjects were enrolled in the study who met the above criteria and were approved by the investigators. These 24 subjects were divided into 2 groups matched by their fasting blood glucose level, HbA1c, body height, body weight, BMI, and age by a doctor who was not directly involved in the study (Hiroshi Hirata, former Associate Professor of the Third Department of Internal Medicine of Okayama University). But, only 20 subjects (9 men and 11 women with a mean age of 50.5 ± 7.5 years) were finally enrolled, because 4 subjects were excluded who showed remarkable deviations and abnormal values in the baseline values (hematology test values and blood pressure). There was no significant difference in body weight, BMI, blood pressure, pulse rate, blood glucose level (Test food group: 110.0 ± 9.7 mg/dl, Placebo group: 109.3 ± 7.9 mg/dl), HbA1c (Test food group: 5.6 ± 0.4%, Placebo group: 5.6 ± 0.4%), fructosamine (Test food group: 246.3 ± 53.6 mmol/l, Placebo group: 246.6 ± 48.9 mmol/l), glycated albumin (Test food group: 16.1 ± 2.3%, Placebo group: 16.1 ± 2.2%), or insulin (Test food group: 5.3 ± 2.8 mU/ml, Placebo group: 5.1 ± 2.7 mU/ml) between the groups before ingestion of each study food (paired t-test).

The study was conducted with the approval of the ethics committee of Soiken (chairperson, Masaharu Inoue, a lawyer), in accordance with the concept of the Helsinki Declaration (adopted in 1964, revised in ’75, ’83, ’89, ’96 and 2000), and written consent was obtained from the subjects after a full explanation of the contents and method of the study by the doctor.

**Study food.** Two types of bread (about 140 g/2 slices of each bread, 6 slices/loaf), were provided by Yamazaki Baking Co., Ltd., one containing resistant starch derived from tapioca, with about 6 g of resistant starch/2 slices (test food), and the other not containing resistant starch (placebo). The placebo used as the control was confirmed to be indistinguishable from the test food in taste, smell, and appearance. The nutrient compositions of the test food and the placebo are shown in Table 1.

The resistant starch used in this study belongs to RS type3. It is represented as retrograded amylose. Retrograded amylose was prepared by the method described previously.11) Briefly, tapioca maltodextrins (dextrose equivalent < 10) were dissolved in hot water. The pH was adjusted to 4.0 and the solution was cooled to an optimum temperature (50°C) for the activity of a debranching enzyme (iso-amylase) which was added, and the mixture was incubated for a prolonged period. The reaction was terminated by heat-inactivation of the enzyme. Finally, the mixture was spray-dried. The retrograded amylose contained 50% or more resistant starch of dry weight. The test food was prepared by sponge dough methods using food ingredients, such as the retrograded amylose.

According to the method proposed by McCleary,12) total resistant starch contents of the study foods were determined using resistant a starch assay kit (Megazyme International Ireland.).

**Study schedule and method of ingestion.** This study was conducted using the placebo-controlled, double-blind, single-ingestion crossover method. The study schedule is shown in Fig. 1. The study was conducted on a first day (June 5, 2004) and a second day (June 19, 2004). The tests were conducted 2 weeks apart, in the same time zone, and with the same dietary contents. The environment, including the temperature and humidity of the test room, was standardized so that there would be no differences between the test days.

On the test days, the subjects underwent blood collection and ingested 2 slices of the study food (bread) with 300 ml of water for 15 min followed by antecubital venous blood collection at 0.5, 1, 1.5, and 2 h after ingestion.

**Table 1. Compositions of Study Foods**

<table>
<thead>
<tr>
<th>Item</th>
<th>Test food</th>
<th>Placebo</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water (g)</td>
<td>53.8</td>
<td>53.5</td>
</tr>
<tr>
<td>Energy (kcal)</td>
<td>370</td>
<td>351</td>
</tr>
<tr>
<td>Protein (g)</td>
<td>12.3</td>
<td>13.2</td>
</tr>
<tr>
<td>Lipid (g)</td>
<td>6.6</td>
<td>5.3</td>
</tr>
<tr>
<td>Carbohydrate (g)</td>
<td>65.2</td>
<td>66.0</td>
</tr>
<tr>
<td>Mineral (g)</td>
<td>2.1</td>
<td>2.0</td>
</tr>
<tr>
<td>Sodium (mg)</td>
<td>701</td>
<td>703</td>
</tr>
<tr>
<td>Resistant starch (g)</td>
<td>6.0</td>
<td>0.9</td>
</tr>
</tbody>
</table>

Each content is expressed per 2 slices (about 140 g) of bread (6 slices per loaf). Resistant starch is treated as a carbohydrate.
The subjects were instructed to finish dinner by 21:00 on the day prior to the test and to come to the hospital without breakfast on the day of the test. They were instructed to consume normal quantities of food and drink, and to take normal exercise, and to abstain from excess eating or drinking or exercise during the study period.

**Test methods.** Blood sampling, measurements of blood pressure, pulse rate, body weight and height, and a medical examination/inquiry were conducted for all subjects at the Soiken Clinic (Director of Hospital, Ken Miyatsuka).

**Blood test.** On both test days, antecubital venous blood was collected at 5 time points: before ingestion of the study food, and at 0.5, 1, 1.5, and 2 h after ingestion. In the first blood examination, before ingestion of the study food, blood glucose, insulin, HbA1c, fructosamine, glycated albumin, blood cell components (white blood cells, red blood cells, hemoglobin, hematocrit, MCV, MCH, MCHC, and platelets), GOT, GPT, LDH, y-GTP, total bilirubin, total protein, A/G ratio, albumin, ALP, urea nitrogen, uric acid, creatinine, electrolytes (Na, K, Cl, Ca, Mg), total cholesterol, HDL-cholesterol, and triglyceride were determined. At 30 min after ingestion and thereafter, only blood glucose and insulin were measured. The area under the blood concentration-time curve (AUC) and the incremental curve (AUIC) in blood glucose and insulin were calculated according to the trapezoidal rule.

These laboratory studies were conducted by Sakai Bio-Clinical Laboratory (Mitsubishi Kagaku BCL Group).

**Blood pressure and pulse rate.** Blood pressure and pulse rate were measured before ingestion of the study food on both test days. Blood pressure was measured once using a mercury manometer in the left arm, with the patient seated, after a rest for 10 min or longer.

**Body weight, body height and body mass index (BMI).** Body weight was measured before ingestion of the study food on both test days. Height was measured only at the preliminary examination, and the BMI was calculated from these measurements.

**Medical examination.** On the test day, the doctor performed a medical examination and inquiry to see if there was any subjective symptom or occurrence of adverse events.

**Consumption of nutritional components from meals, alcohol consumption, and amount of exercise.** The subjects were instructed to record their alcohol consumption during the study period and meals and exercise (measured by a pedometer) for the 3 d before the test on a meal/exercise record form. Their consumption of nutritional components (energy, protein, lipids, and carbohydrates), alcohol consumption, and amount of exercise were calculated from these data.

**Statistical analysis.** Measurement values are presented as mean ± standard deviation. Statistical analysis was conducted using SPSS, Ver. 11 (SPSS Inc.) and a paired t-test was performed for inter-group comparisons. The significance level was set at 5% or less by the two-sided test.

For blood glucose and insulin, stratified analysis was performed by dividing the subjects into 2 groups: a normal group (blood glucose level ≤ 110 mg/dl) and a borderline group (blood glucose level ≥ 111 mg/dl) in addition to the statistical analysis on all subjects. The normal and borderline ranges were discriminated with 110 mg/dl as the borderline level for blood glucose. Subjects with a blood glucose of 111 mg/dl or higher before ingestion of the study food on either or both test days were categorized as borderline, and those with a blood glucose level of 110 mg/dl or lower as normal.

**Results**

**Blood glucose and insulin**

**All subjects**

The blood glucose, insulin profiles, and AUC are shown in Tables 2 and 3, and the profiles of the net change in blood glucose levels (Δ blood glucose) and the amount of change in insulin levels (Δ insulin) are shown in Fig. 2. Blood glucose and insulin in the test food group reached peaks at 1 h after ingestion followed by decreases by 2 h after ingestion. Blood glucose and insulin in the placebo group reached peaks at 1 h and
1.5 h after ingestion respectively, and decreased subsequently by 2 h after ingestion.

Blood glucose, Δ blood glucose and AUC did not differ significantly between the groups up to 2 h after ingestion.

Insulin levels in the test food group were significantly lower than in the placebo group at 1 h and 1.5 h after ingestion, as was the AUC. Similarly, the Δ insulin in the test food group was significantly lower than in the placebo group at 1 h (test food group: 46.1 ± 23.4 μU/ml, placebo group: 55.8 ± 33.5 μU/ml, p < 0.05) and at 1.5 h (test food group: 42.4 ± 20.4 μU/ml, placebo group: 56.7 ± 31.4 μU/ml, p < 0.01) after ingestion, as was the AUC (test food group: 67.5 ± 29.7 μU/h/ml, placebo group: 83.7 ± 47.7 μU/h/ml, p < 0.05).

Subjects in the borderline group (blood glucose level ≥ 111 mg/dl)

Blood glucose and insulin profiles and AUC are shown in Tables 2 and 3, and the profiles of Δ blood glucose and Δ insulin are shown in Fig. 3. Blood glucose and insulin in the test food group reached peaks at 1 h after ingestion followed by a decrease by 2 h after ingestion. Blood glucose and insulin in the placebo group reached peaks at 1 h and 1.5 h after ingestion respectively, and decreased subsequently by 2 h after ingestion.

The blood glucose level in the test food group was significantly lower than in the placebo group at 1.5 h after ingestion. Δ Blood glucose was also significantly lower in the test food group than in the placebo group at 1 h (test food group: 87.0 ± 26.0 mg/ml, placebo group: 99.0 ± 27.8 mg/ml, p < 0.05) and at 1.5 h (test food group: 63.8 ± 36.7 mg/ml, placebo group: 84.9 ± 29.7 mg/ml, p < 0.01) after ingestion, as was the AUC (test food group: 119.9 ± 45.7 mg/h/ml, placebo group: 141.9 ± 41.7 mg/h/ml, p < 0.05).

### Table 2. Changes in Levels of Blood Glucose after Ingestion

<table>
<thead>
<tr>
<th>Item</th>
<th>Subject</th>
<th>Group</th>
<th>Before ingestion</th>
<th>After ingestion (h)</th>
<th>AUC (mg/h/ml)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.5</td>
<td>1</td>
</tr>
<tr>
<td>All subjects</td>
<td>Test food</td>
<td>110.0 ± 9.7</td>
<td>184.3 ± 19.9</td>
<td>196.3 ± 30.8</td>
<td>175.3 ± 41.9</td>
</tr>
<tr>
<td>(n = 20)</td>
<td>Placebo</td>
<td>109.3 ± 7.9</td>
<td>184.1 ± 21.3</td>
<td>199.5 ± 32.4</td>
<td>182.2 ± 37.8</td>
</tr>
<tr>
<td>Blood glucose</td>
<td>Test food</td>
<td>116.3 ± 6.4</td>
<td>187.0 ± 16.4</td>
<td>203.3 ± 24.2</td>
<td>180.0 ± 34.8</td>
</tr>
<tr>
<td>(mg/dl)</td>
<td>Placebo</td>
<td>113.8 ± 5.7</td>
<td>191.9 ± 18.9</td>
<td>212.8 ± 28.6</td>
<td>198.7 ± 31.5</td>
</tr>
<tr>
<td>Borderline group</td>
<td>Test food</td>
<td>100.5 ± 4.8</td>
<td>180.1 ± 24.8</td>
<td>185.8 ± 38.0</td>
<td>168.1 ± 52.6</td>
</tr>
<tr>
<td>(n = 12)</td>
<td>Placebo</td>
<td>102.5 ± 5.5</td>
<td>172.4 ± 20.1</td>
<td>179.5 ± 28.6</td>
<td>157.5 ± 34.1</td>
</tr>
<tr>
<td>Normal group</td>
<td>Test food</td>
<td>100.5 ± 4.8</td>
<td>180.1 ± 24.8</td>
<td>185.8 ± 38.0</td>
<td>168.1 ± 52.6</td>
</tr>
<tr>
<td>(n = 8)</td>
<td>Placebo</td>
<td>102.5 ± 5.5</td>
<td>172.4 ± 20.1</td>
<td>179.5 ± 28.6</td>
<td>157.5 ± 34.1</td>
</tr>
</tbody>
</table>

Subjects with a blood glucose of 111 mg/dl or higher before ingestion of the study food on either or both test days were categorized as the borderline group. Subjects with a blood glucose of 110 mg/dl or lower before ingestion of the study food on either or both test days were categorized as the normal group. Each value is expressed as the mean ± SD. Blood samples were collected before and at 0.5, 1, 1.5, and 2 h after study food ingestion. AUC is the area under the blood glucose concentration-time curve from 0 to 2 h after ingestion. Significant difference by inter-group comparison: *p < 0.05, **p < 0.01 (paired t-test).

### Table 3. Changes in Levels of Insulin after Ingestion

<table>
<thead>
<tr>
<th>Item</th>
<th>Subject</th>
<th>Group</th>
<th>Before ingestion</th>
<th>After ingestion (h)</th>
<th>AUC (μU/h/ml)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.5</td>
<td>1</td>
</tr>
<tr>
<td>All subjects</td>
<td>Test food</td>
<td>5.3 ± 2.8</td>
<td>37.6 ± 17.6</td>
<td>51.4 ± 24.7</td>
<td>47.7 ± 21.9</td>
</tr>
<tr>
<td>(n = 20)</td>
<td>Placebo</td>
<td>5.1 ± 2.7</td>
<td>42.5 ± 33.2</td>
<td>60.9 ± 35.6</td>
<td>61.9 ± 33.2</td>
</tr>
<tr>
<td>Insulin (μU/ml)</td>
<td>Test food</td>
<td>5.7 ± 2.9</td>
<td>34.0 ± 14.2</td>
<td>50.0 ± 19.2</td>
<td>49.2 ± 21.2</td>
</tr>
<tr>
<td>(n = 12)</td>
<td>Placebo</td>
<td>5.4 ± 2.3</td>
<td>39.2 ± 22.4</td>
<td>62.2 ± 31.2</td>
<td>69.1 ± 35.6</td>
</tr>
<tr>
<td>Normal group</td>
<td>Test food</td>
<td>4.8 ± 2.7</td>
<td>43.0 ± 21.5</td>
<td>53.6 ± 32.6</td>
<td>45.4 ± 24.3</td>
</tr>
<tr>
<td>(n = 8)</td>
<td>Placebo</td>
<td>4.7 ± 3.3</td>
<td>47.6 ± 46.5</td>
<td>58.9 ± 43.6</td>
<td>51.0 ± 27.8</td>
</tr>
</tbody>
</table>

Each value is expressed as the mean ± SD. Blood samples were collected before and at 0.5, 1, 1.5, and 2 h after study food ingestion. AUC is the area under the insulin concentration-time curve from 0 to 2 h after ingestion. Significant difference by inter-group comparison: *p < 0.05, **p < 0.01 (paired t-test).
Insulin levels in the test food group were significantly lower than in the placebo group at 1 h and 1.5 h after ingestion, as in the AUC. Insulin in the test food group was also significantly lower than in the placebo group at 1 h (test food group: 44 ± 3 U/ml, placebo group: 56 ± 8 U/ml, p < 0.05), at 1.5 h (test food group: 43 ± 20 U/ml, placebo group: 63 ± 34 U/ml, p < 0.01) and at 2 h (test food group: 28 ± 9 U/ml, placebo group: 38 ± 20 U/ml, p < 0.05) after ingestion, as in the AUC (test food group: 65.1 ± 25.0 µU-h/ml, placebo group: 86.8 ± 44.7 µU-h/ml, p < 0.05).

Subjects in the normal group (blood glucose level ≤ 110 mg/dl)

Blood glucose and insulin profiles and AUC are shown in Tables 2 and 3, and the profiles of Δ blood glucose and Δ insulin are shown in Fig. 4. Blood glucose and insulin in the test food group and in the placebo group reached peaks at 1 h after ingestion followed by decreases by 2 h after ingestion.

No significant difference was noted between the groups in blood glucose, Δ blood glucose, insulin, or Δ insulin up to 2 h after ingestion.

Physical examination

The results of the physical examination (characteristics of subjects) before ingestion of the study food are shown in Table 1.

No significant difference was noted between the groups in the physical examination findings (body weight, BMI, systolic blood pressure, diastolic blood pressure, pulse rate).

Other blood tests

The significantly higher value of MCV (p < 0.05) seen in the test food group in comparison to the placebo group was a slight inter-group difference within the normal range. No significant change was noted in the blood tests other than MCV (white blood cells, red blood cells, hemoglobin, hematocrit, MCV, MCH, MCHC, platelets, GOT, GPT, LDH, γ-GTP, total bilirubin, total protein, A/G ratio, albumin, ALP, urea nitrogen, uric acid, creatinine, Na, K, Cl, Ca, Mg, HbA1c, fructosamine, glycated albumin, total cholesterol, HDL-choles-
terol, and triglyceride), and those items were within the normal range (paired \( t \)-test).

Medical examination

Medical examination was performed carefully by the doctor before and after ingestion of the study food to detect any gastrointestinal, skin, or central nervous system symptoms, but no adverse factors were found.

Consumption of nutritional components from meals and amount of exercise

No significant inter-group difference was noted in the consumption of nutritional components such as energy, protein, lipids and carbohydrates, alcohol consumption, or the amount of exercise, which are factors that influence blood glucose (paired \( t \)-test).

Discussion

It was formerly believed that starch was digested completely in the lumen and epithelium of the small intestine. Hence, starch was evaluated only as a source of energy and its nutritional significance tended to be ignored. Englyst et al.\(^{13}\) noticed that a fraction of starch was transported to the lower gastrointestinal tract without digestion and absorption, and named this fraction “resistant starch (RS).” Subsequently, it was shown that many types of RS were present in foods. RS is defined as “a general term for starches and their partial hydrolysates that are not digested or absorbed in the small intestinal lumen of healthy persons.”\(^{14} \) RS is classified into 3 types by their chemical characteristics (RS1 to RS3); the resistant starch used in this study corresponds to RS type3.\(^{15}\) RS type3 is said to be retrograded starch formed when a starch is gelatinized once and left to cool.\(^{15}\) The physiological effects of RS3 have been demonstrated in animal experiments, and include an inhibitory effect on postprandial increase in blood glucose and insulin, and a blood lipid reducing effect.\(^{16}\)

Bread is frequently taken in daily meals. In the present study we prepared bread containing about 6 g of resistant starch for daily ingestion, and examined its effect on postprandial blood glucose in 20 subjects who showed a fasting blood glucose level between 100 and 140 mg/dl in the preliminary examination. Stratified analysis was performed for blood glucose and insulin measured over time after ingestion of the study foods, by dividing the subjects into 2 groups according to their baseline blood glucose levels: a normal group (blood glucose level \( < 110 \) mg/dl) and a borderline group (blood glucose level \( \geq 111 \) mg/dl). Postprandial increases in blood glucose and insulin were significantly inhibited in the borderline subjects in the test food group in comparison with the placebo group, but no significant difference was noted between the two groups in normal subjects. Borderline subjects were assumed to show hyperglycemia after ingestion of a large amount of carbohydrate due to lowered insulin secretion. It was assumed that increases in blood glucose and insulin were significantly inhibited in this study because absorption of glucose in the resistant starch was delayed.\(^{10}\) By contrast, in the normal group, in which insulin secretion was intact and the postprandial blood glucose level relatively low, delayed absorption of glucose was not reflected in the blood glucose level, and increases in blood glucose and insulin were not inhibited. This suggests that there is no risk of inducing hypoglycemic disorders due to excessive decreases in the blood glucose level, even when a person with a lower blood glucose level has taken a resistant starch. It has also been reported that indigestible dextrin has the same mechanism of action in the inhibition of blood glucose increase, exhibited an effect on subjects who had a higher baseline blood glucose level, and readily showed an increase in postprandial blood glucose, while it had no effect on subjects who had a lower baseline blood glucose and whose postprandial blood glucose level was not readily increased (as there was no need to decrease the blood glucose level).\(^{17,18}\) This agrees with the findings of this study.

Fig. 4. Changes in \( \Delta \)blood Glucose and \( \Delta \)insulin after the Ingestion in the Normal Group.

Subjects with a blood glucose of 110 mg/dl or lower before ingestion of the study food on either or both test days were categorized in the borderline group. Each value is expressed as the mean ± SD of 8 subjects. There was no significant difference by inter-group comparison (paired \( t \)-test).
In the analysis of all the subjects, a significant decrease was noted in insulin only, although there was no significant decrease in the blood glucose level, after ingestion of the test food (strangement between blood glucose and insulin secretion). A similar phenomenon has also been shown in patients with abnormal glucose tolerance and normal subjects practicing regular physical exercise, and an unfavorable phenomenon of decreased insulin secretion without normalization of blood glucose level has been reported in patients with abnormal glucose tolerance. While the causes of such phenomena are unknown, it is possible that there is a deviation in the target range for blood glucose control in patients with abnormal glucose tolerance. The strangement between blood glucose and insulin secretion noted in the test food group in this study is a phenomenon resembling the above-mentioned phenomena and may be explained similarly by a deviation in the target range for blood glucose control. In any case, insulin secretion in the test food group actually decreased significantly without normalization of the blood glucose level. This, however, did not result in any increase in blood glucose (but rather a slight decrease as compared with the placebo group) and therefore the resistant-starch bread was considered to be still medically useful because it was estimated to have improved insulin resistance.

Such results resemble the inhibition of insulin secretion by indigestible dextrin after malt dextrin loading, although it did not remarkably inhibit the blood glucose increase. Since this indigestible dextrin inhibited secretion of glucagon-like peptide 1 (GLP-1: potent enhancer of insulin secretion substance in the intestinal, skin, central nervous system symptoms, hypoglycemia, or so on) were found after ingestion.

The above findings indicate that bread containing resistant starch only quietly increased postprandial blood glucose and insulin levels, and alleviated the risk of the occurrence of diabetes mellitus in borderline diabetic patients (fasting blood glucose level \( \geq 110 \text{ mg/dl} \)). Since bread is one of the principal foods, bread containing resistant starch might be a useful food for prevention of lifestyle-related diseases, and as a supplementary means to dietary therapy.

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**References**

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