Effect of Fiber on Protein, Fat and Calcium Digestibilities and Fecal Cholesterol Excretion

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Summary Five female subjects were given four types of test diets containing various levels of protein for four consecutive 5-day periods and their dietary fiber and feces were collected throughout the experimental period. Diet A was a high-fiber, low-protein diet containing brown rice. Diet B was a semi-purified, low-protein diet containing agar agar as the sole source of dietary fiber. Diet C was a low-fiber, normal-protein diet containing polished rice. Diet D was a high-fiber, normal-protein diet containing brown rice. A fecal marker was given at breakfast on the first day of each five-day test period and on the day after the end of the experiment.

Fecal weight increased during the period on high-fiber diets (diets A and D). The apparent digestibilities of protein and fat were significantly depressed by high-fiber diet. Fecal excretion of calcium did not increase on the high-fiber diets. A decrease in the apparent digestibility on a high-fiber, low-protein diet was partly due to the low intake of calcium during this period. Fecal excretion of cholesterol increased markedly during the periods on high-fiber diets. The difference between the intake and fecal excretion of dietary fiber suggested that the fiber was partially digested in the colon.

Key Words dietary fiber, Japanese meal, digestibility, protein, fat, calcium, fecal cholesterol, fecal fiber

Epidemiological studies (1,2) have suggested that persons eating high-fiber diets have low incidences of nutritional and digestive disorders such as diverticulosis, colon cancers and cardiovascular diseases. A high-fiber diet also results in appetite satisfaction and in a decrease of obesity, since fiber may affect the digestibilities of other nutrients, such as sources of nitrogen, energy and minerals (3,4).

The effects of dietary fiber on the absorption of nutrients have been studied in Australian and English subjects (5,6), South African Negros (7), Nigerians (8) and

1 金子佳代子，西田京子，谷田淳子，長里美，小池五郎
Cameroonians (9). These studies showed that wheat bran or a fiber-rich diet influenced the absorptions of the major food components, protein, fat and minerals.

We report here on the short-term effects of a high intake of dietary fiber including rice bran, seaweed and mushrooms, which are normal constituents of Japanese cuisine.

MATERIALS AND METHODS

Five female college students aged 18 to 20 year participated in this experiment. Their average weight was 49.6 ± 5.1 kg (SD) and their average height was 155.6 ± 5.4 cm. The subjects were given four test diets (A–D) containing graded levels of protein and dietary fiber for four consecutive 5-day periods (A–D), and feces were collected throughout the 20-day experimental period. Energy intake was estimated based on the subjects' weights and normal levels of activity; values ranged from 32 to 41 kcal/kg·day, or 1,700 to 1,900 kcal/day. As a fecal marker, 0.5 g of carmine was given at breakfast on the first day of the period on each diet and on the day after the experimental period. The compositions of the test diets and the feces excreted were determined, and apparent digestibilities of nitrogen, fat and calcium were calculated. Fecal excretions of cholesterol and dietary fiber were also determined.

Diet. Diet A was a high-fiber, low-protein diet containing brown rice, egg, tofu, corn, konjac (devil's tongue), potatoes, vegetables, fruits, seaweed (wakame, kombu and hijiki), mushrooms and agar agar.

Diet B was semi-purified, low-protein diet containing corn starch, sugar, shortening, soy protein isolate (SPI), mineral mixture, vitamin mixture and agar agar as the sole source of dietary fiber.

Diet C contained a normal level of protein and lower dietary fiber content than diet A or D. The diet included polished rice, egg, tofu, pork, tuna, milk, vegetables and fruits.

Diet D contained a normal level of protein and a high content of dietary fiber, and included brown rice, egg, tofu, pork, tuna, milk, corn, konjac, potatoes, vegetables, fruits, seaweed (wakame, kombu and hijiki), mushrooms and agar agar.

The components of these diets are shown in Table 1. Brown rice and polished rice were soaked in water for one hour and then cooked in a pressure cooker. Seaweed and mushrooms were cut into small pieces and boiled until they were soft.

2 The daily intakes of minerals in the mineral mixture were as follows: CaPO₄·2H₂O 2 g, CaCO₃ 0.9 g, KH₂PO₄ 2 g, KHCO₃ 3.5 g, MgO 0.6 g, FeSO₄·7H₂O 60 mg, MnSO₄·4H₂O 3 mg, CuSO₄·5H₂O 8 mg, KI 0.2 mg, ZnCl₂ 5 mg, Na₃MoO₄·2H₂O 0.2 mg, Cr₂(SO₄)₃·15H₂O 1 mg, AlK(SO₄)₂·12H₂O 30 mg, and NaSeO₃ 0.008 mg.

3 The daily intakes of vitamins in the vitamin mixture were as follows: retinyl palmitate 2,000 IU, vitamin D₂ 300 IU, thiamin hydrochloride 10 mg, riboflavin 4 mg, pyridoxine hydrochloride 6 mg, niacinamide 50 mg, cyanocobalamin 10 μg, ascorbic acid 150 mg, α-tocopheryl acetate 10 mg, and Ca pantothenate 30 mg.

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enough to eat. These foods and other vegetables and potatoes were then cooked with sugar, salt and soy sauce.

**Analyses.** The pH of feces was measured with a pH meter (Horiba 6201-10T) immediately after collection. Then the feces from marker to marker were pooled. The compositions of pooled feces and the test diets were determined by the following methods.

Water was estimated from the loss of weight when the samples were lyophilized. Then the nitrogen content was determined by the Kjeldahl method. Fat was measured by the method reported by Southgate (10). Calcium was measured by the method of Kramer-Tisdall (11), and phosphate was measured by the method of Bell and Doisy (12). Cholesterol was extracted with chloroform-methanol overnight and then measured enzymatically (13). Dietary fiber was determined as hemicellulose, cellulose and lignin as described by Van Soest and Wine (14).

The apparent digestibilities of protein, fat and calcium were calculated as follows:

\[ D = \frac{I - F}{I} \]

where \( D \) is the apparent digestibility, \( I \) is the intake and \( F \) is the fecal output of nitrogen, fat or calcium.

**RESULTS**

**Fecal weight and pH**

The wet and dry weights, water contents and pH values of the feces are shown
Table 2. Wet and dry weights of feces and fecal pH.*

| Experimental period | A       | B       | C       | D       |
|---------------------|---------|---------|---------|---------|
| Wet weight (g/day)  | 276 ± 61<sup>bc</sup> | 120 ± 21<sup>ad</sup> | 126 ± 32<sup>ad</sup> | 242 ± 33<sup>bc</sup> |
| Dry weight (g/day)  | 44.0 ± 9.8<sup>bc</sup> | 19.2 ± 3.4<sup>ad</sup> | 25.2 ± 6.4<sup>ad</sup> | 41.0 ± 5.6<sup>bc</sup> |
| Water content (%)   | 84 ± 2  | 84 ± 3  | 80 ± 5  | 83 ± 5  |
| pH                  | 6.8 ± 0.2<sup>b</sup> | 7.4 ± 0.5<sup>a</sup> | 7.2 ± 0.6 | 7.0 ± 0.6 |

*The mean ± SD for five subjects. <sup>a</sup>Significantly different from the value for period A (p < 0.05). <sup>b</sup>Significantly different from the value for period B (p < 0.05). <sup>c</sup>Significantly different from the value for period C (p < 0.05). <sup>d</sup>Significantly different from the value for period D (p < 0.05).

Table 3. Digestibilities of protein, fat and calcium.*

| Experimental period | A       | B       | C       | D       |
|---------------------|---------|---------|---------|---------|
| Protein             |         |         |         |         |
| Intake N (g/day)    | 3.76    | 3.78    | 9.90    | 9.57    |
| Fecal N (g/day)     | 1.67 ± 0.58<sup>bc</sup> | 0.71 ± 0.26<sup>ad</sup> | 0.97 ± 0.35<sup>ad</sup> | 1.8 ± 0.61<sup>bc</sup> |
| Digestibility (%)   | 55.5 ± 6.0<sup>b</sup> | 81.2 ± 3.7<sup>ac</sup> | 90.2 ± 1.5<sup>bd</sup> | 81.2 ± 2.0<sup>c</sup> |
| Fat                 |         |         |         |         |
| Intake fat (g/day)  | 51.0    | 51.0    | 52.0    | 45.4    |
| Fecal fat (g/day)   | 21.2 ± 7.9<sup>bc</sup> | 6.34 ± 1.54<sup>ad</sup> | 7.80 ± 1.28<sup>ad</sup> | 23.5 ± 2.6<sup>bc</sup> |
| Digestibility (%)   | 54.1 ± 7.4<sup>bc</sup> | 87.4 ± 2.7<sup>ad</sup> | 85.0 ± 2.5<sup>ad</sup> | 48.3 ± 5.8<sup>bc</sup> |
| Calcium             |         |         |         |         |
| Intake Ca (mg/day)  | 364     | 1,098   | 441     | 595     |
| Fecal Ca (mg/day)   | 369 ± 43<sup>b</sup> | 890 ± 299<sup>abcd</sup> | 339 ± 115<sup>b</sup> | 491 ± 163<sup>b</sup> |
| Digestibility (%)   | -1.5 ± 11.6<sup>bc</sup> | 18.9 ± 7.0<sup>a</sup> | 23.4 ± 7.6<sup>a</sup> | 17.3 ± 5.5<sup>a</sup> |

*The mean ± SD for five subjects. <sup>a</sup>Significantly different from the value for period A (p < 0.05). <sup>b</sup>Significantly different from the value for period B (p < 0.05). <sup>c</sup>Significantly different from the value for period C (p < 0.05). <sup>d</sup>Significantly different from the value for period D (p < 0.05).

in Table 2. During the periods when subjects received diets rich in dietary fiber (periods A and D) their fecal wet and dry weights increased, but the percentage water content did not change. The fecal pH was slightly lower during periods of intake of high fiber diet than during those of intake of low fiber.

**Digestibilities of protein, fat and calcium**

The apparent digestibilities of protein (nitrogen), fat and calcium are shown in

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Table 4. Dietary intake and fecal excretion of cholesterol.

| Experimental period | A  | B  | C  | D  |
|---------------------|----|----|----|----|
| Intake (mg/day)     |    |    |    |    |
| Fecal excretion* (mg/day) | 672 ± 254bc | 390 ± 117a | 420 ± 149ad | 558 ± 197c |

*The mean ± SD for five subjects. a Significantly different from the value for period A (p<0.05). b Significantly different from the value for period B (p<0.05). c Significantly different from the value for period C (p<0.05). d Significantly different from the value for period D (p<0.05).

Table 5. Dietary intake and fecal excretion of dietary fiber (g/day).*

| Experimental period | A  | B  | C  | D  |
|---------------------|----|----|----|----|
| Total (H+C+L) Intake | 18.2 | 0.01 | 11.8 | 16.2 |
| Fecal excretion     | 12.5 ± 4.2bc | 0.92 ± 0.37ac | 4.57 ± 1.19bd | 10.5 ± 3.1bc |
| Hemicellulose (H) Intake | 1.32 | 0.01 | 1.54 | 2.85 |
| Fecal excretion     | 3.62 ± 1.60bc | 0.18 ± 0.15ad | 0.41 ± 0.32ad | 3.03 ± 0.91bc |
| Cellulose (C) Intake | 8.58 | trace | 3.18 | 8.02 |
| Fecal excretion     | 5.51 ± 2.38b | 0.44 ± 0.21ad | 3.28 ± 1.13b | 5.03 ± 2.19b |
| Lignine (L) Intake  | 8.34 | trace | 7.14 | 5.35 |
| Fecal excretion     | 3.46 ± 1.59bc | 0.33 ± 0.10ad | 0.95 ± 0.33ad | 2.48 ± 0.62bc |

*The mean ± SD for five subjects. a Significantly different from the value for period A (p<0.05). b Significantly different from the value for period B (p<0.05). c Significantly different from the value for period C (p<0.05). d Significantly different from the value for period D (p<0.05).

Table 3. The absorptions of protein during periods when the subjects received diets with low fiber contents (periods B and C) were about 80–90% at each protein intake level. Increase in the fiber intake resulted in a significant decrease in the digestibility of protein at both levels of protein intake.

The fat contents of the four test diets were almost the same. The absorption of fat from fiber-rich diets was significantly lower than those from low-fiber diets.

The digestibilities of calcium in diets B, C and D were about 20%, whereas that
in diet A was almost zero (−1.5%). Dietary fiber did not affect calcium absorption at a normal level of protein intake, but decreased it significantly at a low level of protein intake.

**Fecal cholesterol excretion**

Table 4 shows the intake and fecal excretion of cholesterol. The cholesterol contents of the low-protein diets (diets A and B) were very low, whereas those of diets C and D were normal for Japanese. Dietary fiber increased the excretion of fecal cholesterol, irrespective of the cholesterol content of the diet.

**Fecal excretion of dietary fiber**

The intake and fecal excretion of dietary fiber and its constituents, hemicellulose, cellulose and lignin, are shown in Table 5. The dietary fiber content was very low in the semi-purified diet (diet B), and higher in diets A and D than in diet C. Fecal excretion of dietary fiber increased during the periods of intake of high-fiber diets (periods A and D).

**DISCUSSION**

Many investigators have reported that fecal weight is increased by a high-fiber diet (5–17). The bowel transit time is increased by wheat bran and sorghum bran (5, 16), but decreased by fruits and vegetables (15) in the diet. We previously reported that fecal weight is increased by a high consumption of seaweed and mushrooms (18). The present study showed that the high-fiber diet containing rice bran, seaweed and mushrooms customarily eaten by Japanese also markedly increased fecal weight and decreased fecal pH. Increase in fecal weight might be associated with increased excretion of constituents of the food and endogenous products in the feces, and would result in change in the chemical and microbiological constituents in the bowels.

The apparent digestibilities of protein and fat were significantly decreased during periods of intake of a fiber-rich diet. It might be associated partly with increased losses of endogenous excreta. Wheat bran (5, 6), sorghum (9) and fruits and vegetables (15) have been reported to decrease the digestibilities of protein and fat. However, in the present study the decrease in digestibility of fat was much larger than that of protein. We also observed a significant decrease in the digestibility of fat upon intake of well-milled rice with germ (19), as well as seaweed and mushrooms (18). Furthermore, Miyoshi et al. (20) reported a significant decrease in digestibility of fat when the diet contained brown rice. Thus, there may be a significant change in fat absorption when rice bran and/or seaweed and mushrooms are added to experimental diets.

The apparent digestibility of calcium was quite low when subjects were given a high-fiber, low-protein diet. As fecal excretion of calcium during the diet A period did not increase as compared to that in periods C and D, it was assumed that low calcium absorption at a low level of protein intake.
calcium intake was the cause of this low apparent digestibility. Reinhold et al. (21) and Cummings et al. (22) reported that a high-fiber diet decreased calcium digestibility. However, Farrel et al. (5) found no significant difference in calcium digestibilities in subjects on diets with and without wheat bran, although there was much variation among individuals. Furthermore, some investigators have suggested that the excretion of fecal cations is increased by consumption of wheat bran (23) and that phytic acid forms stable complexes with metals (24). Further careful studies are needed on whether a high-fiber diet including rice bran and/or seaweed and mushrooms affects the absorption of calcium or not.

Fecal cholesterol excretion increased during ingestion of fiber-rich diets. The intake of cholesterol from the normal-protein diet (diet D) was higher than that from the low-protein diet A, but the fecal excretion of cholesterol while eating these two diets was not significantly different. Since bile salts are adsorbed by lignin and other plant fibers and excreted in the feces (25), it is possible that dietary fiber in the test diets in this study bound dietary and endogenous cholesterol, and that the conjugated compounds were only poorly absorbed by the small intestine and mainly excreted in the feces.

The total contents of dietary fiber in test diets A, C and D were similar to those in normal Japanese diets as reported by Mori (26), although the amounts of different types of fiber were not the same. Fecal excretion was greater than the intake of dietary fiber during the period on diet B, but smaller than the latter during the other two dietary periods. Since the difference between the intake and excretion of dietary fiber is mainly due to fiber digestion in the gut, a considerable amount of the fiber in diets A, C and D seemed digestible. In Western-style diets, large proportions of hemicellulose and cellulose are digested by microflora in the gut (5,27,28), whereas little if any lignin is digested (5,27). Thus, polysaccharide fibers are partially digested in the colon. However, the extent of absorption of various nutrients is still not clear. Previously we found that a negligible amount of energy is bioavailable from seaweed and mushrooms although there was much variation among individuals (18). The digestibility of fiber seems to depend on its chemical structures, the bacterial flora in the bowel and the duration spent in the colon. Further studies are required to determine the effects of fiber on energy balance in human subjects.

We conclude from this short-term study that a high-fiber diet reduces the digestibilities of protein, fat and sometimes calcium as well. Further studies are required on the kind of fiber in test diets that has these effects and on the effects of long-term administration of high-fiber diets. The increased fecal excretion of fat and cholesterol when subjects are fed high-fiber diets suggests that fiber may influence the metabolism of cholesterol and triglyceride.

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