Hiroshima J. Med. Sci.
Vol. 67, No. 1, 1~5, March, 2018
HIMJ 67–1

Effects of Different Types of Dietary Fibers on Fermentation by Intestinal Flora

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ABSTRACT

Purpose: A treatment for chronic constipation is dietary fiber intake. This study aimed to determine the effects of different types of dietary fibers on the microbiota in the large intestine.

Methods: Nine healthy volunteers participated in this study. Breath hydrogen test was used to determine the dietary fiber fermentations. The presence of hydrogen in the breath indicates intestinal bacterial activities. Participants fasted overnight and ate white bread (200 g) with 10 g of each type of dietary fiber: (1) cellulose, (2) soy fiber, (3) guar gum, and (4) control (without any dietary fiber). Samples were collected before and every 1 hour after eating, for 8 h. Another test compared the effects between cellulose and guar gum with a loaded food, which activates intestinal fermentation, and samples were collected using the same methods.

Results: During 8 h of measurements, breath hydrogen concentration in the soy fiber group were higher than that of the control, but were not significantly different. Changes in the guar gum group were similar to those in the control. However, breath hydrogen concentrations in the cellulose group did not increase even after eating white bread that caused large intestinal fermentation 2.9 ± 0.7 ppm, which was significantly lower than that of the guar gum group (7.4 ± 1.7 ppm, $p < 0.01$). In the study with a well-fermented food intake, cellulose reduced breath hydrogen concentrations, but its difference with that of the guar gum group was statistically non-significant.

Conclusion: Cellulose might have a suppressive effect on large intestinal fermentation. Therefore, this compound may be beneficial in treating chronic constipation.

Key words: *intestinal flora*, *dietary fiber*, *breath hydrogen*, *fermentation*

Microorganisms in the lower gut ferment dietary fibers and produce hydrogen, methane, and carbon dioxide gases. Some portion of these gases enters the blood stream and is excreted via the lungs[15,16,22]. The hydrogen breath test, which is based on the premise that hydrogen gas in humans is produced exclusively by colonic fermentation, uses expired hydrogen levels as indirect indicators of disturbances in the intestinal flora[12,15,17]. The test is widely used to detect a battery of non-structural gastrointestinal disorders, particularly carbohydrate malabsorption, small intestinal bacterial overgrowth, and irritable bowel syndrome. The breath test is also used in food metabolism studies and various indicators of intestinal flora[1–4,13,18,19,23,25–29].

Dietary fiber is one of the most important tools for the treatment of constipation, as it increases the volume of feces and adds water[7,14]. However, some of the fibers cause excessive fermentation in the intestines, which may lead to diarrhea or gas production [20]. Determining the good dietary fiber with less fermented substrate for the treatment of constipation is difficult. Therefore, this study aimed to compare different types of dietary fibers and determine suitable treatment measures to resolve constipation.

PATIENTS AND METHODS

Basal analysis: fasting breath hydrogen data on healthy Japanese subjects

A total of 35 healthy volunteers (21 men and 15 women, aged 21–65 years) fasted after their usual dinner until the following morning (~0800) when hydrogen breath tests were conducted at Hiroshima University School of Medicine. End-alveolar breath samples were obtained by having the subjects exhale end-expiratory samples into 500-ml plastic bags fitted with stopcocks. Samples were analyzed for hydrogen concentration with a HCMA-T1™ Gas Chromatograph (Abilit Corporation, Osaka, Japan). Data were presented as normalized breath-hydrogen concentrations in parts per million (ppm).

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Effects of dietary fiber intake on breath hydrogen concentration

Nine healthy volunteers (5 men and 4 women) were finally recruited in this study, with the mean age of 35.4 years. All participants fasted >12 h after their evening meal until the following morning. At 7 am, they ate 200 g of white bread with 10 g of dietary fiber. Tested dietary fibers were (1) cellulose, (2) soy fiber, (3) guar gum, and (4) control (without eating any dietary fiber). These dietary fibers were purified powder without any impurities (provided by Ajinomoto Co. Inc. Japan). All subjects tested three kinds of dietary fibers and control. Each test was performed with at least 7 days interval. An hour before and after feeding for 8 h, breath hydrogen samples were collected using the following methods.

Another test was conducted to determine the difference between guar gum and cellulose on intestinal fermentation. The same healthy volunteers ate 10 g of guar gum or cellulose plus one hamburger. The hamburger was a commercially available product, named "Cheese Burger" (containing buns, beef putty, sliced cheese, and baked onion; McDonald's, Japan). The hamburger was well fermented compared with the white bread because it not only contains bread but also beef, cheese, and onions. If guar gum or cellulose could reduce the fermentation in the large intestine, changes in the excretion of breath hydrogen could be different. Time schedule for fasting, breath sample collection, or interval of the study was same with the above examination.

Hydrogen breath test

End-alveolar breath samples were obtained into 500-ml plastic bags fitted with stopcocks. The bags used the GaSampler System (Quintron Instruments, Milwaukee, WI) as described previously[30]. The subjects were instructed to exhale as deeply as possible, to obtain alveolar air, directly into the apparatus via a mouthpiece. A 5-ml aliquot of each breath sample was transferred to a silicone-greased plastic syringe fitted with a three-way plastic stopcock. Samples were analyzed for H_2 concentration using a HCMA-T1™ Gas Chromatograph (Abilit Corporation, Osaka, Japan). Data were presented as normalized breath-H_2 concentrations in ppm. During the 8-h study period, any foods or drinks containing sugar were not allowed.

Statistical analysis

All measured results were expressed as means concentration. Data were analyzed using the Student's *t*-test, with $p < 0.05$ used to indicate a significant difference.

Ethical considerations

This study was approved by the Medical Ethics Committee of Hiroshima University School of Medicine, and signed informed consent was obtained from all participants. The study was conducted in accordance with the Declaration of Helsinki.

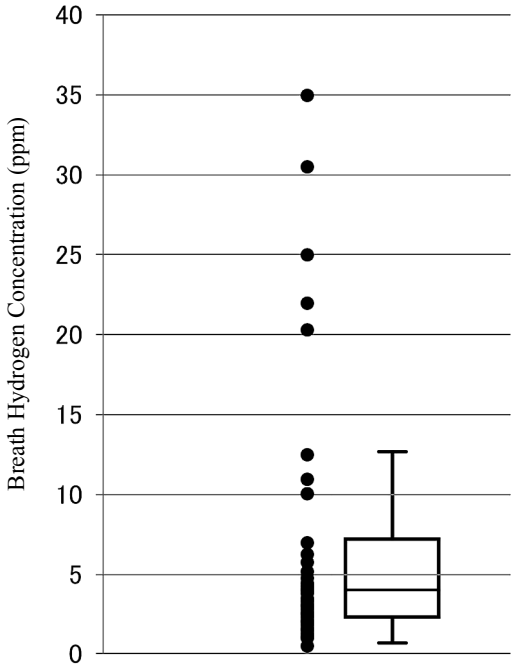

Figure 1 Fasting breath hydrogen data on healthy Japanese subjects. The average of breath hydrogen concentration in fasting status was 7.2 ± 8.7 ppm. In all subjects except five with diabetes, the concentration of breath hydrogen in fasted status was stable with less than 15 ppm.

RESULTS

Basal analysis: fasting breath hydrogen data on healthy Japanese subjects

The breath hydrogen concentrations of 35 healthy subjects were determined after overnight fasting (Figure 1), revealing an average of 7.2 ± 8.7 ppm. Five subjects with increased hydrogen concentrations of >20 ppm were classified as having diabetes (HgA1c was >6.0%). The 23 subjects with an increase of <10 ppm were classified as normal metabolizers. These results indicated that fasting breath hydrogen concentration of healthy subjects was stable within 10 ppm.

Effects of dietary fiber intake on breath hydrogen concentrations

Figure 2 shows the changes of breath hydrogen concentration after intake of each dietary fiber. The control group, who ate white bread only without any additional dietary fiber, showed increased breath hydrogen concentrations 5 h after intake. This change means the intestinal contents (white bread) were fermented when reaching the large intestine. In the soy fiber group, the concentrations were higher than those in the control group, but were insignificantly different. The changes in the guar gum group were similar to those in the control group. Interestingly, breath hydrogen concentrations in the cellulose group did not increase even after eating white bread which caused fermentation in the large intestine. The concentration 8 h after cellulose intake was 2.9 ± 0.7 ppm, which was significantly lower than that of the guar gum group (7.4 ± 1.7 ppm, $p < 0.01$). This result suggested that cellulose itself was less fer-

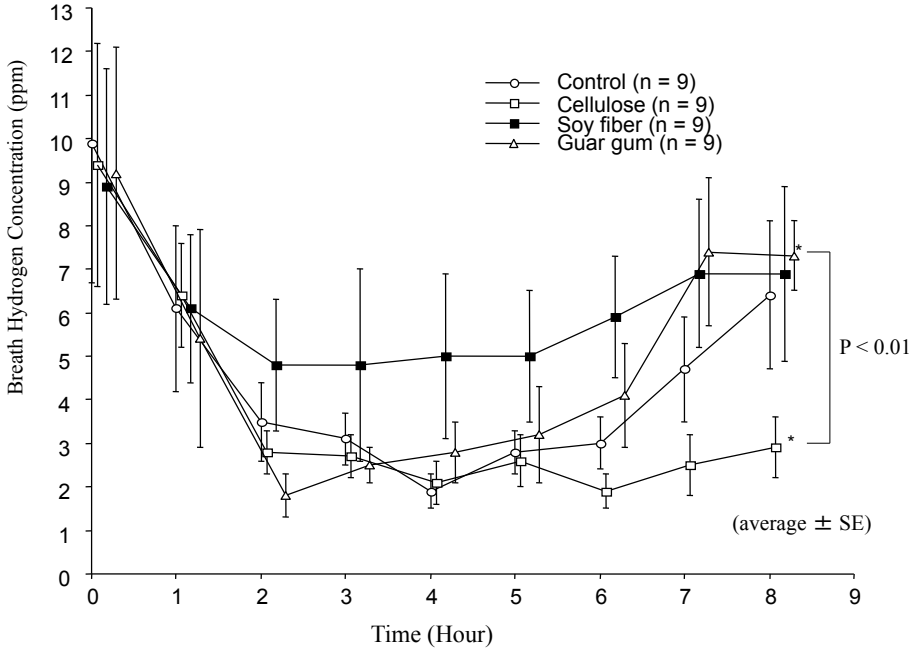

Figure 2 Changes of breath hydrogen concentration after intake of each dietary fiber. In the soy fiber group, the concentration were higher than the control group while they were not significantly different. The changes of the guar gum group were similar to the control group. The concentration of the cellulose group were not increased even after eating white bread. The concentration after 8 hours of cellulose intake was 2.9 ± 0.7 ppm, and it was significantly lower than that of guar gum group (7.4 ± 1.7 ppm, $p < 0.01$, Student's *t*-test).

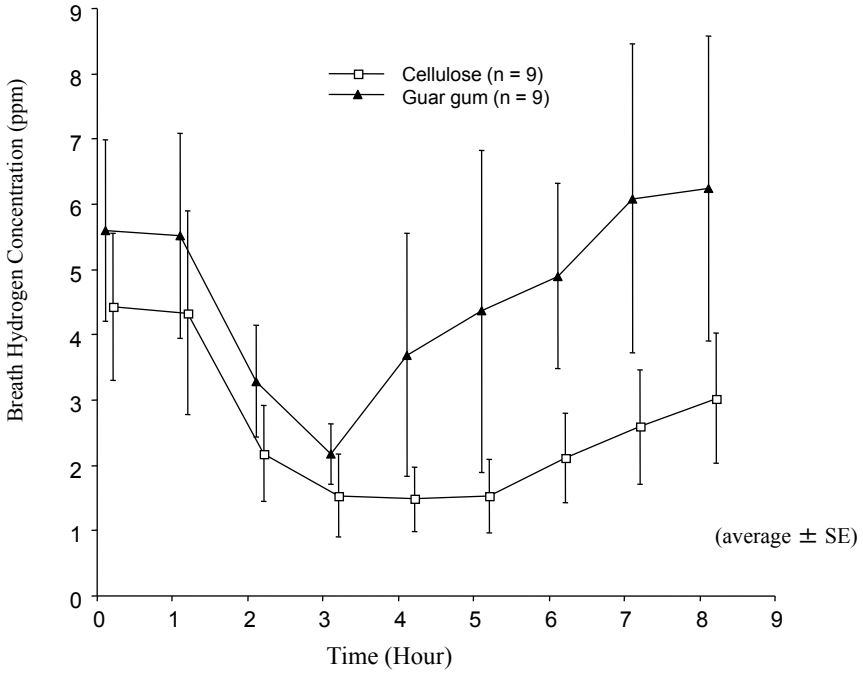

Figure 3 Comparison between cellulose and guar gum with well fermented food intake. The concentrations of breath hydrogen in cellulose group were lower than that in guar gum group, although the difference did not reach statistically significant ($p = 0.06$, Student's *t*-test).

mented in the large intestine and thus might suppress fermentation of the eaten dietary fiber.

Another study using well-fermented additional food also demonstrated difference between guar gum and cellulose (Figure 3). The breath hydrogen concentrations after 8 h in the cellulose group (2.9 ± 1.2 ppm) were lower than that in the guar gum group (6.0 ± 2.1 ppm), although the difference was not statistically significant ($p = 0.06$). In these studies, none of the subjects reported adverse events or withdrawal.

DISCUSSION

The health benefits of dietary fiber have been well known. For the treatment of constipation, dietary advice is based on the intake of dietary fiber[5,8,31]. Dietary fibers

are resistant to enzyme hydrolysis in the small intestine and unabsorbed in the large intestine. The fibers retain water and increase the volume of feces making it bulky and also reduce the intestinal transit time. As side effects of dietary fibers, they sometimes cause gas production and diarrhea resulting from excessive fermentation. As each individual has different intestinal flora, compatibility of dietary fibers varies. Ideal fibers are water-soluble, unabsorbed, and less fermented to avoid such side effects. However, studies that determine the effects of different types of dietary fibers were limited. Thus, in the present study, we investigated the bacterial reaction after eating dietary fibers using breath hydrogen test.

Hydrogen is not produced by the metabolism of mammalian cells. It is only formed in the body by the bacterial fermentation of carbohydrates in the intestine. The anaerobic fermentation of carbohydrates results in the production of carbon dioxide, methane, and hydrogen. These gases are consumed by bacteria or are quickly absorbed into the blood stream[12,15–17]. Individual hydrogen production can be studied by a breath test using lactulose (4-*O*-b-D-galactopyranosyl-D-fructose) as a substrate[9–11,22]. This synthetic carbohydrate is not absorbed in the small intestine and is fermented in the large intestine. The fermentation process and subsequent metabolic processes result in gas production, which are absorbed by the colonic mucosa and exhaled. Therefore, breath hydrogen measurements provide a semi-quantitative assessment on the quantity of soluble carbohydrates reaching the large intestine[6,24].

Levine et al.[19] measured breath hydrogen concentrations to determine the association between individual fecal microflora and fermentation of dietary fibers. They were able to associate anaerobic species with hydrogen production, suggesting that breath hydrogen concentration reflects anaerobic activities in the large intestine. Previous measurements regarding the activity of colonic anaerobes had been based on bacterial counts in the feces or mucosal tissues. However, a fecal sample from a patient is not easy to collect and the costs of the counts are high. Moreover, bacterial counts do not always reflect the activity of the flora.

The healthy volunteers in this study had breath hydrogen concentrations of 0–40 ppm. As most cases were within 10 ppm, the baseline concentration was stable in many subjects. However, hydrogen concentrations (>25 ppm) were high in some cases. Those patients were classified as diabetic (HbA1c of >6.0%), because glucose metabolic abnormalities greatly influence the concentration of fasting breath hydrogen[18]. In other words, breath hydrogen concentration in healthy subjects is a reliable tool to determine the anaerobic activity of intestinal flora.

In this study, we compared three types of dietary fibers that were commonly used to resolve constipation. Guar gum is a polysaccharide composed of galactose and mannose as a typical fermentable fiber, by adding a significant amount of guar gum to foods or supplements as natural dietary fiber. Soy bean is also used as dietary fiber containing various kinds of carbohydrates, such as disaccharide, trisaccharide, and tetrasaccharide. Cellulose was identified as a difficult to decompose dietary fiber[19]. These dietary fibers were commercially available and commonly used in various foods, but the difference of influences to intestinal bacteria had not been investigated.

Different effects of these dietary fibers on the fermentation in the colon were demonstrated in this study. Interestingly, the breath hydrogen concentration in the soy fiber group was higher than that in other groups during the early periods after intake. While the difference was insignificant, soy fiber might have a stimulant effect on intestinal bacteria. Cellulose significantly reduced the fermentation in the intestine, compared with other dietary fibers and even without eating any dietary fiber. An additional study using well-fermented food intake still demonstrated reduced effects on the fermentation compared with guar gum, although the difference did not reach statistical significance. Now, there are two questions: first, why could cellulose reduce the fermentation in the large intestine? and second, was this reduction beneficial for the colonic metabolism?

Even in the recent meta-analysis, the most effective type of fiber on treating chronic constipation remains unclear[7]. Some studies attempted to investigate the difference of fibers based on the microbiota; however, the potential relationship between cecal microbiota and dietary fiber was still unclear[21]. One of the reasons of this issue was heterogeneity of colonic microbiota. As the heterogeneity may influence the results, each person demonstrates different effects of dietary fiber on constipation, especially its side effects such as diarrhea or excessive gas production.

Our results indicated the reduction of fermentation in the large intestine, which slightly varied between the study subjects. These results may suggest that cellulose was not affected by different colonic microbiota because it was difficult to decompose, which means that cellulose causes less side effects. Moreover, as fermentation may lead to intestinal gas and water production, reduction of fermentation could prevent diarrhea. In conclusion, although further investigation is needed, cellulose may be a favorable tool for the treatment of chronic constipation without any harmful effects.

(Received November 8, 2017)
(Accepted December 4, 2017)

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