Fundamental physiochemical properties of dietary fibers used in enteral nutrition formula

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Abstract

Although enteral nutrition has become more widely used in nutritional therapy, there are complications associated with nutritional support through tube feeding, including diarrhea, gastroesophageal reflux, and vomiting. To prevent these complications, some dietary fibers have been added to enteral nutrition formulas. In this study, we verified the fundamental physiochemical properties of the dietary fibers used in enteral nutrition formulas. We found that sodium alginate (SA) had the highest viscosity and the longest drying time, while had more water holding capacity than other dietary fibers, including resistant maltodextrin, partially hydrolyzed guar gum, soy dietary fiber, and low methyl ester pectin (LMP). LMP and SA was solidified by artificial gastric juice. These results suggest that SA in enteral nutrition formulas is solidified in the stomach. Therefore, its use may reduce the risk of gastroesophageal reflux and vomiting. SA was less fermented, indicating that it has a high molecular weight in the colon, thereby maintaining its viscosity and water-holding capacity, and thus contributing to maintaining fecal volume.

Keywords: dietary fibers, enteral nutrition formula, physiochemical properties

I Introduction

Enteral nutrition is the first choice of nutrition therapy for patients without gastrointestinal tract impairment. Enteral access is a way to supply a nutrition formula through feeding tubes such as nasogastric tubes, percutaneous endoscopic gastrostomy (PEG) feeding tubes, and jejunostomy feeding tubes. It is used for patients whose oral nutrient intake is insufficient to meet their estimated needs. Although it has become more widely used, there are complications associated with nutritional support through tube feeding, including diarrhea, gastroesophageal reflux (GER), and vomiting. These problems reduce patient quality of life.

Dietary fiber has been reported to help minimize diarrhea in patients receiving enteral nutrition, particularly in non-critically ill patients. Thus, dietary fibers such as resistant maltodextrin (RMD) and partially hydrolyzed guar gum (PHGG) are popularly used in clinical nutrition. In particular, PHGG was added to nutrition formulas globally to prevent diarrhea. Most nutrition formulas are liquids and have low viscosity, which may be responsible for the occurrence of GER. Since GER is a serious complication, its occurrence in patients receiving liquid nutrition formula makes the continuation of enteral nutrition difficult. To address this problem, semi-solid enteral nutrition formulas were developed. These nutrition formulas are highly viscous and contain insoluble dietary fibers such as soy dietary fiber (SDF). Due to their high viscosity, semi-solid enteral nutrition formulas are typically administered through a large-diameter PEG feeding tube. Recently, a new type of nutrition formula has been administered to clinical patients. This formula is in a liquid state when administered through a nasogastric tube and transforms to a semi-solid state in the stomach prior to reverting to the liquid state within the intestines.
This new formula contains low methoxyl pectin (LMP) \(^{12}\). The clinical usefulness of another new type of formula using sodium alginate (SA) that changes state from a liquid to a semi-solid depending upon pH was reported in a recent multicenter study \(^{13}\). This formula was postulated to reduce the risk of GER and to improve the appearance and condition of the feces.

Because so many enteral nutrition formulas are widely used, we focused on the popular dietary fibers, such as RMD, PHGG, LMP, SA, and SDF, used in various enteral nutrition formulas. This study described the fundamental physiochemical properties of the dietary fibers included in enteral nutrition formulas.

### II Materials and Methods

1. **Samples**

   RMD (Pinefiber C) and PHGG (Sunfiber\(^R\) R) were purchased from Matsutani Chemical Industry Company and Taiyo Kagaku Co. Ltd., respectively. LMP (GENU\(^R\) pectin LM-104AS-J) was obtained from CP Kelco. SA, which is found in a new type of formula (Mermed\(^R\), Terumo Corporation), was obtained from Kaneka Corporation. SDF (FIBRIM\(^R\) 2000) was purchased from DuPont Corporation. The characteristics of the dietary fibers in this study are shown in Table 1. RMD has a molecular weight (MW) of 2,000 Da \(^{14}\), PHGG has a MW of 20,000 Da \(^{15}\), LMP has a MW of 140,000-200,000 Da \(^{16}\), SA has a molecular weight (MW) of 32,000-400,000 Da \(^{17}\), and SDF is a complex of water-soluble and -insoluble dietary fibers; therefore, we estimated its MW to be \( \geq 550,000 \) Da based on the MW of soybean water-soluble polysaccharide derived from “okara” \(^{18}\). The artificial gastric juice was disintegration test solution 1, pH 1.2, from Kanto Chemical Co., Inc.

2. **Viscosity of the dietary fiber solutions**

   The viscosity of the dietary fiber solutions with concentrations between 1.0% and 10% w/w was measured using a calibrated Brookfield digital viscometer (Model DV-H\(^+\), Brookfield Engineering Laboratories, Inc., USA), spindle No. 6 at 6 rpm \(^{19}\). The measurements were performed at 25°C.

3. **Settling volume (SV) in water**

   SV in water was measured as described by Takeda and Kiriyama \(^{20}\). SV (mL/g) was defined as the volume occupied by 1 g of air-dried dietary fiber when placed in a graduated cylinder filled with water. The volume was recorded after a 24-h period of equilibration with water.

4. **The water weight of the dietary fiber pellet obtained after centrifugation**

   The water weight of the dietary fiber solution after centrifugation was measured as described by McConnel et al. \(^{21}\). Dietary fiber (10%, W/W) was added to a 50 mL centrifuge tube containing excess water. The resulting solution was centrifuged at 14,000 \( \times g \) for 1 h at 20°C. The supernatant was discarded and the pellet weighed. The difference in weight between the dietary fiber originally added and the pellet obtained after centrifugation was defined as the water weight of the dietary fiber pellet.

5. **Drying times of the dietary fiber solutions**

   The drying times of the dietary fiber solutions were measured using oven-drying methods for moisture determination \(^{22}\). The length of time needed for 5 g of dietary fiber solution to dry at 135°C was measured and recorded as the drying time. A forced-draft oven (MX-50, A&D Company, Japan) was used in this experiment.

6. **Solidification of the dietary fiber solutions by artificial gastric juice**

   Twenty grams of dietary fiber solution were added to 10 g of artificial gastric juice and mixed well at 25°C. The mixture was filtered through a sieve (50 mesh) and the weight of the solid materials on the sieve was measured.

7. **Statistical analysis**

   All analyses in this study were performed in triplicate. The resulting values are expressed as the means ± standard deviations. Multiple comparisons by Dunnett’s test were used to evaluate the statistical significance of each variable, calculated using EXCEL toukei version 7.0 (ESUMI, Co., Ltd). Values of \( p<0.05 \) were considered statistically significant.

<table>
<thead>
<tr>
<th>Sample</th>
<th>Solubility</th>
<th>Molecular weight</th>
<th>Estimated energy value (kcal/g)</th>
<th>Fermentation by microorganisms</th>
</tr>
</thead>
<tbody>
<tr>
<td>RMD</td>
<td>Soluble</td>
<td>2,000</td>
<td>1</td>
<td>Less</td>
</tr>
<tr>
<td>PHGG</td>
<td>Soluble</td>
<td>20,000</td>
<td>2</td>
<td>Well</td>
</tr>
<tr>
<td>LMP</td>
<td>Soluble</td>
<td>140,000-200,000</td>
<td>2</td>
<td>Well</td>
</tr>
<tr>
<td>SA</td>
<td>Soluble</td>
<td>32,000-400,000</td>
<td>0</td>
<td>Less</td>
</tr>
<tr>
<td>SDF</td>
<td>Mainly insoluble</td>
<td>( \geq 550,000 )</td>
<td>0.7</td>
<td>Less</td>
</tr>
</tbody>
</table>

RMD: resistant maltodextrin, PHGG: partially hydrolyzed guar gum, LMP: low methyl ester pectin, SA: sodium alginate, SDF: soy dietary fiber
II Results

1. The viscosities of the dietary fiber solutions
The measured viscosities of the dietary fiber solutions with concentrations between 1.0% and 10% w/w are shown in Fig. 1. The viscosities of the RMD and PHGG solutions were low, with values lower than 15 mPa·s, but the viscosities of the SA and LMP solutions were very high. The viscosity of the SDF solution increased acutely at 10% w/w. SDF expanded by absorbing water at this concentration so that its viscosity was higher than those of RMD, PHGG, and even though LMP. In this study, SA had the highest viscosity than other dietary fibers.

2. SV of dietary fibers
As shown in Table 2, SDF had a settling volume of 10.0 ± 0.4 mL. RMD, PHGG, LMP, and SA were dissolved in water; thus, the settling volume of these fibers could not be measured. SDF was insoluble-dietary fiber, so insoluble materials were measured for a settling volume.

3. The water weight of the dietary fiber pellet obtained after centrifugation
The water weight of the SDF pellet obtained after centrifugation was 10.9 ± 0.3 g/0.1 g of SDF. RMD, PHGG, LMP, and SA were also dissolved in water; thus, their water weights of the dietary fiber pellet obtained after centrifugation could not be measured.

4. Drying time of the dietary fiber solutions
As shown in Fig. 2, the drying times of the RMD and PHGG solutions were almost the same at every concentration, but the drying times of the SA and LPM solutions were longer than those of the RMD solutions. The drying time of the SA solution was the longest. Thus, SA held water in its structure. The drying time of SDF was longer only at 10% w/w concentration. SDF expanded sufficiently by absorbing water and captured water in its structure at high concentration.

Table 2. Settling volume of dietary fibers

<table>
<thead>
<tr>
<th>Sample</th>
<th>Settling volume (ml/g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>RMD</td>
<td>n. d.</td>
</tr>
<tr>
<td>PHGG</td>
<td>n. d.</td>
</tr>
<tr>
<td>LMP</td>
<td>n. d.</td>
</tr>
<tr>
<td>SA</td>
<td>n. d.</td>
</tr>
<tr>
<td>SDF</td>
<td>10.0 ± 0.4</td>
</tr>
</tbody>
</table>

n. d.: not detected

Values are mean ± standard deviation of 3 trials.

RMD: resistant maltodextrin, PHGG: partially hydrolyzed guar gum, LMP: low methyl ester pectin, SA: sodium alginate, SDF: soy dietary fiber

Fig. 1. Relationship between viscosity and concentration in the dietary fiber solutions
Results are presented as mean ± standard deviation of 3 trials.

*p<0.01, **p<0.001 vs. RMD
RMD: resistant maltodextrin, PHGG: partially hydrolyzed guar gum, LMP: low methyl ester pectin, SA: sodium alginate, SDF: soy dietary fiber
5. Solidification of the dietary fiber solutions

As shown in Table 3, LMP and SA were solidified by artificial gastric juice, while RMD, PHGG, and SDF were not. When reacted with acid like artificial gastric juice, LMP and SA precipitated and formed a gel because of their high MW more than approximately 32,000 Da. On the other hand, RMD, LMP, and SDF did not form gel.

Table 3. Solidification of the dietary fiber solutions by artificial gastric juice

<table>
<thead>
<tr>
<th>Sample</th>
<th>The solid materials of 1.0 % the dietary fiber solutions (g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>RDM</td>
<td>n. d.</td>
</tr>
<tr>
<td>PHGG</td>
<td>n. d.</td>
</tr>
<tr>
<td>LMP</td>
<td>16.3 ± 0.2</td>
</tr>
<tr>
<td>SA</td>
<td>17.7 ± 0.5</td>
</tr>
<tr>
<td>SDF</td>
<td>n. d.</td>
</tr>
</tbody>
</table>

n. d.: not detected

Values are mean ± standard deviation of 3 trials.

RMD: resistant maltodextrin, PHGG: partially hydrolyzed guar gum, LMP: low methyl ester pectin, SA: sodium alginate, SDF: soy dietary fiber

IV Discussion

Some dietary fibers are used in enteral nutrition formulas to prevent complications in patients receiving nutrition therapy. However, to the best of our knowledge, the fundamental physiochemical properties of these fibers have not yet been compared. RMD and PHGG are popularly used in liquid and semi-solid enteral formulas, respectively, while SDF is used in semi-solid enteral nutrition formulas as a dietary fiber. Recently, LMP and SA have been used in new types of nutrition formulas. Thus, we examined the fundamental physiochemical properties of RMD, PHGG, LMP, SA, and SDF. Other gelling additives, such as agar, are used in semi-solid nutrition formulas and immediately gel at room temperature, making it difficult to compare their properties to those of the dietary fibers described above.

RMD and PHGG have long been used as dietary fibers in enteral nutrition formulas. In particular, PHGG has been used to prevent diarrhea. However, enteral nutrition formulas are administered as liquids. This makes GER a common serious complication in patients receiving enteral nutrition which complicates the continuation of enteral nutrition. Semi-solid enteral nutrients have been developed to prevent feeding-related GER. These nutrients have high viscosity, and therefore, are typically administered through a large-diameter PEG tube. SDF has been used as part of semi-solid enteral formulas. Recently, a new type of formula, which exists as a liquid when administered through a nasogastric tube, changes to a semi-solid state in the stomach, and reverts to a liquid state within the intestines, has been administered to clinical patients.

RMD, PHGG, LMP, and SA are water-soluble dietary fibers. By contrast, SDF is mainly a water-insoluble dietary fiber.
fiber. RMD and PHGG have low MW, whereas LMP, SA, and SDF have high MW. Thus, SA, LMP, and SDF are more viscous. Among the water-soluble dietary fibers examined in this study, SA had the highest MW. Consequently, it had the highest viscosity and the longest drying time. Therefore, it had the highest water-holding capacity among the water-soluble dietary fibers. By contrast, SDF contains cellulose, which is a water-insoluble compound with a high MW. SDF expanded by absorbing water; thus, its viscosity was higher than that of RMD and PHGG.

Furthermore, LMP and SA were solidified by artificial gastric juice. These results suggest that SA included in new enteral nutrition formula is solidified in the stomach. Therefore, it may contribute to a reduced risk of GER and vomiting. By contrast, RMD, PHGG, and SDF were not solidified.

In a previous study, pectin in the form of LMP was fermented by Bacteroides strains from the human colon \(^{23}\). The estimated available energy from pectin was 2 kcal/g, while that from depolymerized SA was 0 kcal/g \(^{29}\). Like SA, LMP had a high water-holding capacity but was fermented in the human colon. Therefore, SA was used because it had a higher MW than depolymerized SA and, consequently, was less fermented. SA would exist in a high-MW form in the colon, thereby maintaining its viscosity and water-holding capacity. Thus, the fecal volume would be increased. SA, LMP, and SDF were shown to have water-holding capacities. SA, in particular, is postulated to prevent diarrhea. This dietary fiber is mainly involved with fecal bulk. On the other hand, LMP was fermented. Degreased LMP reduced viscosity and water-holding capacity and was used by the microbiota.

When PHGG was administered to healthy male volunteers, the total count and percentage of Bifidobacterium spp. and Lactobacillus spp. in feces increased. In contrast, other bacteria, including Clostridium spp., Clostridium perfringens, Enterobacteriacaeae, and Streptococcaeceae, were decreased with PHGG intake \(^{25}\). RMD supplementation tended to increase fecal Bifidobacterium populations during the treatment period, altering the bacterial populations between baseline and treatment \(^{26}\), but Lactobacillus populations were not different from control. Thus, PHGG was fermented by luminal microbiota rather than RMD, resulting in increased proportions of total bacteria, Bifidobacterium, and Lactobacillus and enhanced short-chain fatty acid production in humans. PHGG would, therefore, contribute less to increasing fecal volume than RMD.

The administration of depolymerized SA to healthy volunteers resulted in an increased ratio of Bifidobacterium to total bacteria and decreased number of Bacteroidaceae \(^{27}\). The fecal volatile basic nitrogen and fecal pH also decreased. These results suggest that the administration of depolymerized SA contributes to an improvement in the intestinal environment. SA using in this study was larger than depolymerized SA; thus, SA was speculated to be fermented in the human colon. Further investigation on the fermentation of SA is required.

V References

論文

経腸栄養剤に配合されている食物繊維の基礎的な物理化学的性質
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キーワード：食物繊維、経腸栄養剤、物理化学的性質

概要

経腸栄養療法がより普及しているが、下痢、胃食逆流、および嘔吐のような経腸栄養に伴う合併症がある。これらの合併症を防ぐために、いくつかの食物繊維が経腸栄養剤に配合されている。本研究では、経腸栄養剤に用いられる食物繊維の基本的な物理化学的性質を検討した。アルギン酸ナトリウムは最も粘度が高く、難消化性デキストリン、グァーガム分解物、低メトキシルベクチン、大豆食物繊維よりも保水力が大きかった。低メトキシルベクチンとアルギン酸ナトリウムは、人工胃液で固化した。アルギン酸ナトリウムは、胃内で固化が起こることにより胃食逆流や嘔吐のリスク低減に寄与していると推察された。アルギン酸ナトリウムは、低発酵性とされていることから、大腸内において高分子であり、それによって粘度および保水力を維持すると考えられた。これは、糞便量の維持に寄与する。