Effect of Mechanical Properties of Model Food Hydrogels on Their Digestibility Using Gastric Digestion Simulator

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Abstract

In recent years, with the increase in the global population and changes in economic conditions, there is an increasing demand for functional foods with controlled digestibility that can provide an optimized nutrient absorption profile considering the health and age of the consumer. Physical digestion is particularly important for the breakdown of solid foods and the resulting reduction in size can promote chemical digestion. Food digestion by the body in the digestive tract includes ingestion, swallowing, gastric digestion, and intestinal digestion and breakdown into small-sized components until nutrients can be absorbed. However, evaluation of gastric digestion of solid foods poses challenges compared to digestion in the oral cavity, and warrants further study. This study focused on the mechanical properties of solid foods as they are among the most important factors influencing gastric digestion behavior. As mechanical properties of hydrogels can be easily varied by adjusting the formulation and concentration of the gelling agents, hydrogels with different mechanical properties were used as the solid food model and the effects of their mechanical properties on gastric digestion behavior were evaluated. Studies on food digestion have been conducted using *in vivo* experiments. However, the obtained *in vivo* data are pertaining to the stomach and small intestine are limited because of the burden on subjects. *In vitro* experiments, such as those based on a model established using a shaking flask, have become popular in recent years, although gastric physical digestion has not been considered in the flask-shaking digestion experiments. Therefore, a gastric digestion simulator (GDS) was used to enable the simulation and direct observation of food particle disintegration induced by simulated antrum contraction waves and the effects of the mechanical properties of the model food hydrogels on digestibility were evaluated.

Chapter 2 presents the verification of the similarity of the physical environment of the GDS to that of the human stomach. *In vitro* experiments were performed using agar hydrogel beads with different concentrations and were subjected to the GDS conditions maintained in a manner similar to the human *in vivo* experiments reported in previous studies. The disintegration behavior of these agar hydrogel beads was observed, and the half-residence time of intact beads was calculated. The half-residence time of intact beads increased markedly beyond a certain threshold concentration of agar similar to that observed in the *in vivo* experiments. The findings suggest that the GDS exhibits a high similarity to the physical digestion environment of the human stomach.

Chapter 3 presents information on the investigation of the effects of mechanical properties on the gastric physical digestion of solid foods using the GDS. As solid food models, 5-mm hydrogel cubes with different fracture stresses and fracture strains were prepared by varying the concentrations of agar and native gellan gum. *In vitro* GDS experiments were performed using these hydrogels cubes. These hydrogel cubes disintegrated because of fracture and abrasion experienced during *in vitro* gastric digestion in the presence of simulated antrum contraction waves in the GDS. The degree of hydrogel cube disintegration was affected by their fracture strain rather than their fracture stress and was suppressed when the fracture strain was greater than 30%. Additionally, the comprehensive evaluation of the obtained findings was used to propose a model of the disintegration mechanism according to the mechanical properties of the hydrogel.

In Chapter 4, based on the findings of physical digestion, the effects of the physical and chemical digestion in the gastrointestinal tract on the nutritional components present in solid foods were evaluated. Four types of starch-containing hydrogels exhibiting different mechanical properties were prepared as a model food using hydrogels containing corn starch. Their physical digestion (caused mainly by gastric disintegration) and chemical digestion (i.e., starch hydrolysis) characteristics, occurring mainly in the small intestine, were analyzed using a continuous-type GDS equipped with continuous gastric secretion and with the conduction of subsequent small intestinal digestion experiments. The results indicated that even in the case of equivalent nutritional components, the emptying behavior from the stomach into the small intestine and the digestion behavior of model food hydrogels differed depending on their mechanical properties.

In conclusion, the effect of the mechanical properties of hydrogels used as a model of solid foods on digestibility was systematically evaluated using an *in vitro* digestion simulator. The findings obtained provide useful insights for understanding the digestion behavior of solid foods with different mechanical properties and a framework for designing functional foods with optimum nutrient absorption profiles.