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Integrated Response to a Meal

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Abstract

The article presents a brief overview of the responses of the GI tract and its associated pancreatic and biliary systems to a meal. These responses are specifically regulated by complex and interacting neural, hormonal, and paracrine pathways. Stimuli for various responses are multiple and include anticipation, senses of olfaction, taste and hearing, and chemical and mechanical stimuli of meal constituents. The overall result of the integrated response is assimilation of nutrients and elimination of wastes from the GI tract.

Keywords

GI tract; integrated response; meal

The integrated response to a meal represents a complex set of regulated GI secretory and motor behaviors designed to perform digestion and absorption of a meal and elimination of its wastes. These secretory and motor behaviors are regulated by neural, hormonal, and paracrine signaling responses. The responses to a meal are distinct from those that occur between meals. The time during the meal-related responses is often referred to as the digestive phase, whereas the time between meals is often referred to as the interdigestive phase. The complex set of signals activated by the meal lead to important motor behaviors such as movement, storage, mixing and grinding; and secretory behaviors such as secretion of ions, water, bile acids, and digestive enzymes.

The combined goal of the motor and secretory behaviors is assimilation of nutrients from both solid and liquid portions of a meal. This is accomplished by conversion of the meal by both physical and chemical means to molecules that can be absorbed across the epithelium of the GI tract.^{1–3} There are multiple and interacting processes that accomplish this task, including grinding and mixing the meal contents with ions, water and digestive enzymes in the mouth, stomach, exocrine pancreas, biliary tract, and small intestine. The addition of up to 8.5 liters of water and ions per day to intraluminal contents from secretions of salivary glands, stomach, pancreas, biliary tract, and small intestine is an essential part of the digestive process because the action of the digestive enzymes added to the meal act in an aqueous media with specific ionic and pH requirements.

The biliary tract also secretes bile acids into the GI tract where they act as detergents to bring the fat in the meal into a soluble state for action of lipolytic digestive enzymes. Finally, and importantly, almost all the water, ions, and bile acids are absorbed back into the body from the distal small intestine and colon so that only about 0.2 liters of water is lost in the stool each day.

As indicated above, the motor and secretory behaviors of the GI tract that accomplish digestion and absorption of meal nutrients are highly regulated. That is, the motor and secretory behaviors that occur during a meal are distinct from those that occur in the fasting state, and the behaviors are different with different meal constituents. As an example, with meal stimuli such as anticipation, sight, smell, or taste, there is an activation of neural pathways in the central nervous system leading to efferent neural signals mediated by cranial nerves (especially the facial nerve and the vagal nerve) that mediate several responses to prepare the GI tract for a meal.⁴ Some examples include salivary, gastric, pancreatic, and biliary secretions.

Meal contents in the stomach stimulate another set of responses that occur because of activation of both mechanoreceptors resulting from the volume of the meal and chemoreceptors from sensing of specific nutrient molecules. Responses to the meal during the gastric phase are mediated by neural, hormonal, and paracrine pathways.³ The resulting responses include addition of gastric secretions to the meal along with mixing and grinding the meal contents to small particles before meal contents leave the stomach to enter the small intestine. The gastric secretions are acidic due to addition of hydrochloric acid. The importance of the acidic environment relates to the fact that the protease pepsin is added to the meal in the stomach and the optimal activity of pepsin occurs at an acidic pH. Also, the acidic environment is important for killing microorganisms that can be present in meal contents. The secretion of hydrochloric acid in the stomach is regulated by neural, hormonal, and paracrine pathways.⁵ The neural pathways include both nerves intrinsic to the stomach and those extrinsic in the vagus. The hormonal pathway includes gastrin and the paracrine pathway includes histamine.

When the contents of the meal reach the first part of the small intestine, there are numerous regulatory pathway activations that are calibrated by the size of the meal as well as its contents. Meal contents in the duodenum can regulate the rate of delivery of gastric contents to the intestine by altering the reservoir function of the stomach and the mixing and grinding function.⁶ Studies of gastric emptying show that both osmotic and caloric factors in the meal can regulate duodenal entry of the contents of the meal. As a simple example, solutions with high osmolarity empty much more slowly than isotonic saline.⁷ In fact, studies in humans show that for liquid meals, the rate of gastric emptying is a function of caloric content so that the stomach empties at a rate of approximately 200 kcal/h. Also of importance is that the stomach empties solids at a slower rate than liquids because during a meal only particles <2 mm in diameter are permitted to pass the pylorus as described in more detail in the paragraph below on gastric function.^{8–10} A 600–800 kcal meal requires 3–4 hours to completely empty from the stomach.³ The effects of the meal on gastric emptying are mediated by the hormone, cholecystokinin, and neural pathways.^{11–13}

The stomach has 3 integrated motor responses during a meal. These are receptive relaxation; mixing, grinding, and sieving; and emptying.¹⁻³ Receptive relaxation of the fundus and body of stomach occur during the first part of the meal to accommodate the volume of the meal without increased pressure. Receptive relaxation provides the reservoir function of the stomach and is largely mediated by vagal nerve pathways.¹⁴ Mixing, grinding, and sieving of the meal, which start after the initiation of the meal, are due to antral peristaltic contractions, occurring at a rate of 3 per minute, and pyloric contractions. The antral contractions grind the meal into small particles and mix it with secretions from the stomach as well as salivary glands. The antral peristaltic waves terminate in contraction of the pylorus so that only liquids or particles <2 mm pass into the duodenum.³ This is an important function to increase the surface area of interaction of food particles and the digestive processes in the small intestine.

Emptying of gastric contents into the duodenum is a result of coordination of the antro-pyloro-duodenal motor activity.^{1,3,9,14} In addition, the reservoir function participates in emptying by regulation of fundus tone. That is, with a duodenal caloric load, emptying of the stomach is slowed as a result of decreased tone in the fundus and body of the stomach, decreased amplitude of contraction in the antrum, increased amplitude of contraction of the pylorus, and increased amplitude of contraction in the duodenum. The overall result is more accommodation of the meal in the proximal stomach, increased resistance of passing contents through the pylorus and duodenum, and slowing of emptying of meal contents.

The meal in the upper intestine also stimulates pancreatic and biliary secretions into the gut lumen using the hormones cholecystokinin and secretin and neural pathways.¹ Of note, secretin stimulates secretion of fluid rich in sodium bicarbonate from both the exocrine pancreas and the biliary tract. Secretin release in the intestine is activated by gastric acid that enters the duodenum from the stomach. Thus, the small intestine returns the pH of the meal contents to neutrality using secretin and the pancreatic and biliary bicarbonate secretion systems. This is important because digestion that takes place in the small intestine from the activity of both pancreatic digestive enzymes and small intestinal surface enzymes requires a neutral pH for optimal activity.

Finally, the meal contents in the upper intestine stimulate release of glucose-insulinotropic peptide, which enhances glucose-stimulated insulin secretion from the endocrine pancreas.¹⁵

These examples provide an overview of the intricate regulatory mechanisms that are at play during a meal and are necessary for its assimilation.

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