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DIGESTIVE SYSTEM -1

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LEARNING OBJECTIVES

1. Describe the functional anatomy and role of the digestive system.
2. Describe the production of gastric acid in the stomach.
3. Describe the time course of acid secretion in the fed and fasted states

OVERVIEW

The digestive system provides nutrients, water, and electrolytes to the cells of the body from the external environment. Food enters the oral cavity and is propelled by muscular contractions through the gastrointestinal (GI) tract moving towards the anus. At various points along the GI tract, acid, digestive enzymes, and buffers are added to facilitate the breakdown of complex foods (such as steak and rice) into simple molecules (such as amino acids, glucose, and fatty acids). These products are then absorbed into the body and delivered to the liver. The various secretions of the GI tract (enzymes, mucus, and water) sum to about 7 liters. This fluid is reabsorbed to prevent dehydration. Unabsorbed nutrients and waste products are eliminated from the body as feces (100 mL – 500mL per day).

ANATOMY

The digestive system includes the gastrointestinal tract and accessory organs (Fig 1).

The gastrointestinal tract is a muscular tube about 5 meters in length. It includes the mouth, pharynx, esophagus, stomach, small intestine and large intestine (colon). **Voluntary control occurs at the top and bottom** of the tube. Movement through the rest of the gastrointestinal tract is involuntary and unidirectional from mouth to anus.

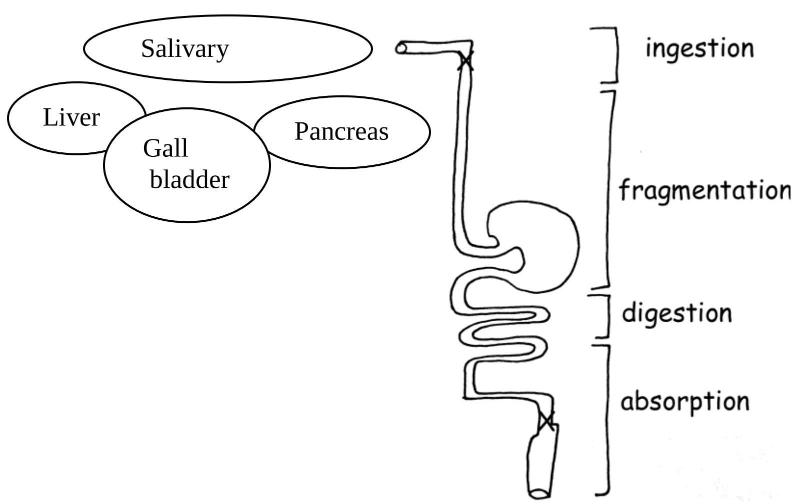

Figure 1. Functional regions of the gastrointestinal tract. X marks the sphincters under voluntary control.

The outside wall of the gastrointestinal tract has **two layers of smooth muscle** which are oriented perpendicular to each other (Fig 2). Constriction of the **innermost layer of muscle changes the diameter** of the tube. Constriction of the **outermost layer of muscle shortens the tube**.

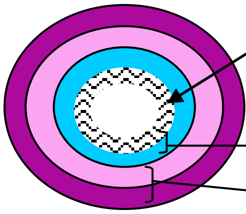

Figure 2. Layers of the gastrointestinal tract.

The lumen of the gastrointestinal tract is lined by a layer of cells (called epithelium) which differs in structure along the tract. At the two ends, **esophagus and anus, there is a "wear and tear"** non-secretory, non-absorptive epithelium (Fig 3). The **stomach has a secretory epithelium** and the **small intestines, absorptive epithelium**.

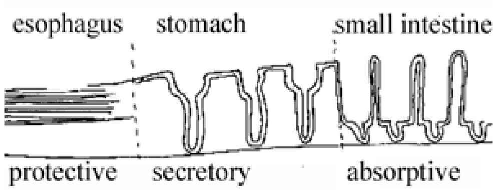

Figure 3. Changes in the gastrointestinal tract epithelium reflect function.

There are four accessory organs (salivary glands, liver, pancreas and gall bladder) (Fig 1). Secretions from the **salivary gland** are added to the oral cavity. Those from the **liver** are stored within the **gall bladder** and then released along with those from the **pancreas** into the duodenum (first portion of the small intestine).

INGESTION & FRAGMENTATION

Ingestion and fragmentation (chewing) of food occur within the oral cavity. Chewing reduces the size of the food particle and increases its surface area to facilitate attack by digestive enzymes. Chewing and later swallowing are aided by the secretion of **saliva** from **three salivary glands**. Enzymes in saliva initiate the breakdown of complex carbohydrates such as bread and cereals. The bolus of shredded food is then conveyed to the esophagus by the actions of the tongue during swallowing. Transit through the esophagus to the stomach is rapid.

ACID SECRETION & DIGESTION

The stomach can hold ~2 liters of food and fluid. It is divided into four regions, cardiac, fundic, antrum, and pyloric. The epithelium in all four regions secretes a protective barrier of mucus, a carbohydrate rich material that coats the surface of the lumen. The cells of the fundic region produce hydrochloric acid (HCl) into the lumen of the stomach. The cells of the antrum regulate the production of acid.

Digestion of dietary protein starts in the fundic region of the stomach. Here the epithelium lining the lumen contains 3 cell types: mucous secreting cells, chief cells and parietal cells. Their specific functions are as follows:

Mucous cells secrete mucus that protects the epithelium from acid.

Chief cells secrete pepsinogen, an inactive enzyme, which is converted to an active enzyme called **pepsin** by acid in the lumen of the stomach.

Parietal cells secrete intrinsic factor and hydrochloric acid (HCl). Intrinsic factor is a carrier required for the absorption of vitamin B12 by the ileum (distal region of the small intestine). Vitamin B12 is necessary for the formation of red blood cells. In the absence of intrinsic factor, vitamin B12 absorption is insufficient resulting in pernicious anemia. HCl is a strong acid which lowers the stomach contents to a pH of 2.0- 5.0.

SECRETION OF HYDROCHLORIC ACID BY PARIETAL CELLS

The production of hydrochloric acid (HCl) by the parietal cells requires the activity of the enzyme, **carbonic anhydrase.** In the presence of carbonic anhydrase, CO_2 and H_2O are converted to HCO_3^- and H^+.

$$CO_2 + H_2O \overset{\text{c.a.}}{=} H_2CO_3 = HCO_3^- + H^+$$

As shown in figure 4, the newly generated proton (H^+) is transported into the lumen of the stomach via the **H^+- K^+ ATPase (called the proton pump)**. Concurrently, HCO_3^- exits from the basal surface (blood side) of the parietal cell via the **HCO_3^- - Cl^- antiporter**.

The chloride ion (Cl^-) needed to form HCl, enters the parietal cell from the blood via the **HCO_3^- - Cl^- antiporter** and exits at the luminal side by the **Cl^- channel**. Once within the lumen of the stomach, Cl^- combines with H^+ to form **HCl**.

The luminal K^+ that is needed to maintain the activity of the proton pump **(H^+-K^+ ATPase)**, enters the parietal cells from the stomach lumen by the **H^+-K^+ ATPase** and is then recycled back into the lumen of the stomach by the **K^+ channel** (Fig 4).

Why is acid needed? The acidic pH in the stomach lumen is needed to convert pepsinogen (inactive pepsin) to pepsin (active enzyme) and to provide an optimal pH for pepsin action. Within the lumen of the stomach, muscle contractions mix the food particles with the HCl and the enzyme pepsin producing a semi-digested liquid called **chyme**. This starts the digestion of proteins. In addition, the HCl kills any bacteria that enter with the food.

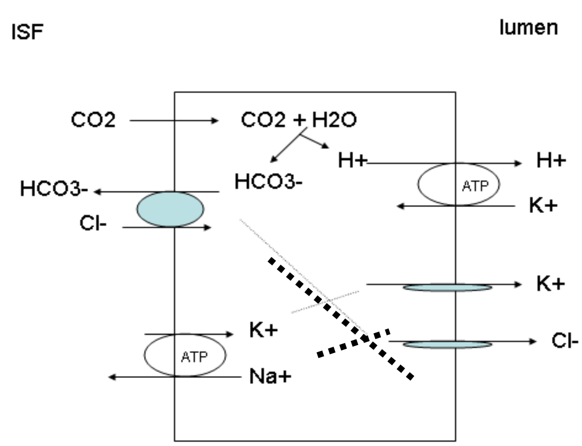

Figure 4. Mechanism of HCl secretion by parietal cells.

With entry of food into the lumen of the stomach, acid secretion increases and reaches a peak output by 90 minutes (Fig 5). Acid production subsequently falls as food leaves the stomach lumen to enter the small intestine. It takes ~ 4 hours to empty the stomach after a meal because only a few milliliters of acidic chyme exit to enter the proximal small intestine (duodenum) at any time.

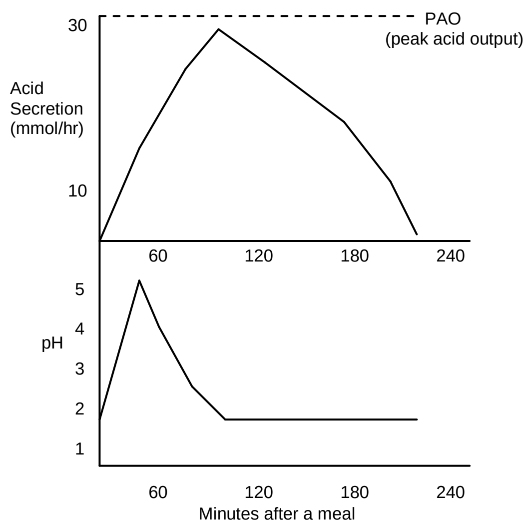

Figure 5. Secretion of gastric acid during fed and fasting states. Why does the pH initially rise then fall by 2 hours after a meal?

GENERAL CONCEPTS

1. The digestive system provides nutrients, water and solutes to the cells of the body from the external environment.
2. The digestive system is comprised of accessory glands and the gastrointestinal tract (tube) that coordinates four basic processes: fragmentation, secretion, digestion, and absorption.
3. The four regions of the gastrointestinal tract are specialized in structure and function and include: esophagus and anus (passive conduits), stomach (secretory) and intestines (absorptive).
4. The stomach produces acid from CO_2 and water. This reaction occurs in the parietal cells and is catalyzed by carbonic anhydrase. The acid secretion of the stomach starts the digestion of protein and provides a barrier against the entry of bacteria.

QUESTIONS

Case: A 23- year old male develops severe vomiting for 48 hours.

1. Will this change his acid-base status? If so, then how?
2. Will this alter his minute ventilation?

ANSWERS

1. Yes. Loss of protons in the vomit will lead to metabolic alkalosis.
2. Yes. Minute ventilation will decrease to retain CO_2.