MJC 4 (Physiology)
Physiology of Digestion

The digestive system

The digestive system includes the gastro-intestinal tract (mouth to anus) and the glandular organs. This system serves to transfer organic molecules, salts and water from the external environment to the body's internal environment. Most of the food taken into the mouth are large particles containing macromolecules such as polysaccharides and proteins. As such they cannot be absorbed by the intestinal wall. They must be dissolved and broken down into much smaller molecules. This process is named as digestion. Digestion is accomplished by substances called enzymes produced from the digestive glands. The enzymes are biocatalysts in the food breakdown process.

The process of digestion

Mouth

In the mouth, digestion starts with chewing. It breaks up large pieces of food into smaller particles that can be swallowed without choking. It is accomplished by teeth, tongue, jaws and saliva. Chewing is controlled by the somatic nerves to the skeletal muscles of the mouth and jaw. Rhythmic chewing motions are reflexly activated by the pressure of food against the gums, hard palate at the roof of the mouth and tongue.

Saliva: The saliva is secreted by three pairs of exocrine glands, namely: the parotid, the submandibular and the sublingual. The daily secretion of saliva ranges from 1000 to 1500 ml. It contains the organic substances amylase and mucin. The **salivary amylase** or **ptyalin** can act on starch. It converts cooked starch into the disaccharide, **maltose**. **Mucin** is a glycoprotein. It helps in the lubrication of food. The lubricated, swallowable form of food is called the **bolus**. The salivary secretion is controlled by reflex activities.

Swallowing: It is a complex reflex activity. It is controlled by the swallowing center in the medulla oblongata. During swallowing the soft palate is elevated, the larynx gets raised. The tongue forces the food back into the pharynx, the epiglottis closes the glottis and the food slowly passes into the oesophagus. The oesophageal phase begins with relaxation of the upper
oesophageal sphincter.

Oesophagus

In the oesophagus the food is moved towards the stomach by a progressive wave of muscle contractions that proceed downward to the stomach. Such waves of contraction in the muscle layer surrounding a tube is known as **peristaltic waves**. In the oesophagus one peristaltic wave takes about 9 seconds to reach the stomach. Due to peristaltic waves, swallowing can occur even while a person is upside down.

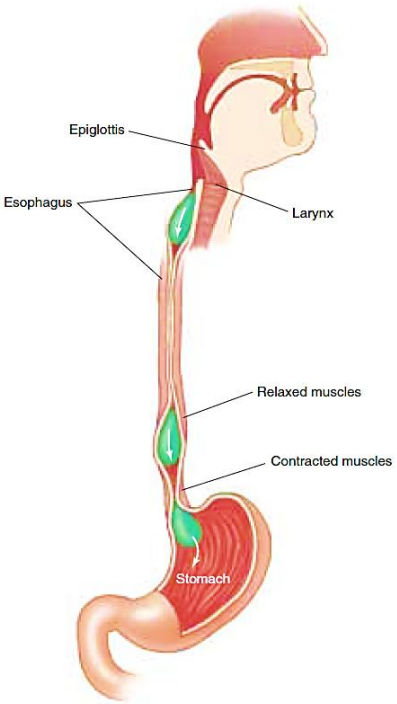

FIGURE 51.10
The esophagus and peristalsis. After food has entered the esophagus, rhythmic waves of muscular contraction, called peristalsis, move the food down to the stomach.

Stomach

It is a wide chamber, located below the diaphragm. The size and shape of the stomach depends on the food inside it. The stomach volume during feeding may increase upto 1.5 lit. Stomach's primary contractile action will produce peristaltic waves. Each wave begins in the body of the stomach and proceeds towards the pyloric region. The initial wave influences the muscles to close the **pyloric sphincter**, a ring of smooth muscles between the stomach and the duodenum. The inner wall of the stomach is lined with gastric glands. There are nearly 40 million glands engaged in producing gastric juice.

The stomach contains an extra layer of smooth muscle for churning food and mixing it with *gastric juice,* an acidic secretion of the tubular gastric glands of the mucosa. These exocrine glands contain two kinds of secretory cells: parietal cells, which secrete hydrochloric acid (HCl); and chief cells, which secrete pepsinogen, a weak protease (protein-digesting enzyme) that requires a very low pH to be active. This low pH is provided by the HCl. Activated pepsinogen molecules then cleave one another at specific sites, producing a much more active protease, pepsin. This process of secreting a relatively inactive enzyme that is then converted into a more active enzyme outside the cell prevents the chief cells from digesting themselves.

It should be noted that only proteins are partially digested in the stomach—there is no significant digestion of carbohydrates or fats.

The human stomach produces about 2 liters of HCl and other gastric secretions every day, creating a very acidic solution inside the stomach. The concentration of HCl in this solution is about 10 millimolar, corresponding to a pH of 2. Thus, gastric juice is about 250,000 times more acidic than blood, whose normal pH is 7.4. The low pH in the stomach helps denature food proteins, making them easier to digest, and keeps pepsin maximally active. Active pepsin hydrolyzes food proteins into shorter chains of polypeptides that are not fully digested until the mixture enters the small intestine. The mixture of partially digested food and gastric juice is called chyme.

Overproduction of gastric acid can occasionally eat a hole through the wall of the stomach. Such *gastric ulcers* are rare, however, because epithelial cells in the mucosa of the stomach are protected somewhat by a layer of alkaline mucus, and because those cells are rapidly replaced by cell division if they become damaged (gastric epithelial cells are replaced every 2 to 3 days). Over 90% of gastrointestinal ulcers are *duodenal ulcers.* In addition to producing HCl, the parietal cells of the stomach also secrete intrinsic factor, a polypeptide needed for the intestinal absorption of vitamin B12. Because this vitamin is required for the production of red blood cells, persons who lack sufficient intrinsic factor develop a type of anemia (low red blood cell count) called pernicious anemia.

The enzymes of the stomach are the **pepsin** and **rennin**. Pepsin is secreted in an inactive precursor form known as **pepsinogen**. The activity due to HCl converts pepsinogen into pepsin. Pepsin hydrolyses the proteins into short polypeptide chains and peptones. It is most effective in an acidic environment.

$$\text{Proteins} \xrightarrow{\text{pepsin}} \text{polypeptides} + \text{peptones}$$

Rennin acts on soluble milk protein caesinogen and converts it into insoluble casein. In the presence of calcium ions casein is precipitated as insoluble calcium-casein compound (curds). Repeated peristaltic waves in the stomach help to soften the food. The frequency of contraction is determined by the basic electrical rhythm and remains essentially constant. It is also aided by neural and hormonal influences. The food leaves the stomach in the form of chyme and enters the upper small intestine at periodic intervals.

Small Intestine

It is about 5-7 metres long. It is divided into three segments namely the initial short segment the **duodenum**, the **jejunum** and the longest segment the **ileum**. The food is propelled down into the duodenum due to peristaltic action of stomach wall. The pyloric sphincter located at the junction of stomach and duodenum regulates movement of chyme.

The villi and microvilli greatly increase the surface area of the small intestine; in humans, this surface area is 300 square meters! It is over this vast surface that the products of digestion are absorbed. The microvilli also participate in digestion because a number of digestive enzymes are embedded within the epithelial cells' plasma membranes, with their active sites exposed to the chyme. These brush border enzymes include those that hydrolyze the disaccharides lactose and sucrose, among others. Many adult humans lose the ability to produce the brush border enzyme *lactase* and therefore cannot digest lactose (milk sugar), a rather common condition called *lactose intolerance.* The brush border enzymes complete the digestive process that started with the action of the pancreatic enzymes released into the duodenum.

The food in the small intestine is mixed with three juices namely bile juice, pancreatic juice and intestinal juice.

Bile juice: It is a brownish green, alkaline secretion of the liver. It is stored in the gall bladder and poured into the duodenum via the bile duct. The bile contains water, mucus, inorganic salts, cholesterol and bile salts. The bile salts emulsify fats and help enzymes like lipase to act upon fats. During emulsification, the bile salts convert bigger fat particles into smaller fat globules.

Pancreatic juice: It is an alkaline fluid (pH 7 to 8). It is transported to the duodenum through the pancreatic duct. It contains water, mineral salts and a variety of enzymes like **trypsin**, **chymotrypsin** which are secreted in the form of inactive precursors **trypsinogen** and **chymotrypsinogen**. The precursors are activated by enterokinase of the intestinal juice, the amylytic enzyme **amylase**, the pancreatic **lipase** (steapesin), **carboxypeptidase** and **nuclease**. The enzyme trypsin hydrolyses proteins into polypeptides and peptones.

$$\text{Proteins} \xrightarrow{\text{trypsin}} \text{polypeptides} + \text{peptones}$$

Chymotrypsin hydrolyses peptide bonds associated with specific amino acids like phenylalanine, tyrosine or tryptophan. It results in large peptides.

$$\text{Proteins} \xrightarrow{\text{chymotrypsin}} \text{large peptides}$$

Carboxypeptidase is an exopeptidase. It attacks the peptide bonds at the carboxyl end of the polypeptide chain resulting in di-, tripeptides and amino acids.The pancreatic amylase converts starch into maltose. The lipase acts on emulsified fat (triglycerides) and hydrolyses them into free fatty acids and monoglycerides. Monoglycerides may be further hydrolysed to fatty acid and glycerol.

Intestinal juice (Succus entericus):

$$\text{Maltose} \xrightarrow{\text{maltase}} \text{glucose} + \text{glucose}$$

$$\text{Sucrose} \xrightarrow{\text{sucrase}} \text{glucose} + \text{fructose}$$

$$\text{Lactose} \xrightarrow{\text{lactase}} \text{glucose} + \text{galactose}$$

$$\text{Di, Tripeptides} \xrightarrow{\text{peptidase}} \text{aminoacids}$$

$$\text{Nucleotides} \xrightarrow{\text{nucleotidase}} \text{nucleoside} + \text{phosphoric acid}$$

$$\text{Nucleoside} \xrightarrow{\text{nucleosidase}} \text{nitorgenous base} + \text{sugar}$$

Absorption and assimilation

As a result of digestion, all macromolecules of food are converted into their corresponding monomeric units. Carbohydrates are broken into monosaccharides such as glucose and fructose. Proteins are hydrolysed into amino acids. Lipids get broken into glycerol and fatty acids. The simpler organic molecules along with minerals, vitamins and water enter into body fluids through the villi.

The villi are small microscopic finger-like projections. Each villus is an absorbing unit consisting of a lacteal duct in the middle surrounded by fine network of blood capillaries. While the fatty acids are absorbed by the lymph duct, other materials are absorbed either actively or passively by the capillaries of the villi.

From the lumen of the alimentary canal absorbed food materials are carried to the liver through hepatic portal vein. From the liver, materials are transported to all other regions of the body for utilisation. This conversion of food into energy and cellular organisation is called as assimilation.

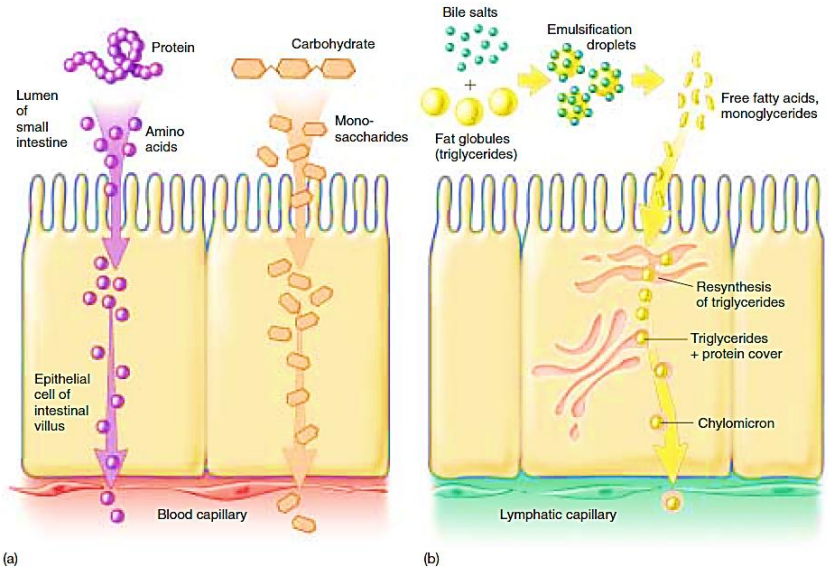

FIGURE 51.15
Absorption of the products of digestion. (*a*) Monosaccharides and amino acids are transported into blood capillaries. (*b*) Fatty acids and monoglycerides within the intestinal lumen are absorbed and converted within the intestinal epithelial cells into triglycerides. These are then coated with proteins to form tiny structures called chylomicrons, which enter lymphatic capillaries.

Table 51.1 Digestive Enzymes

Location	Enzymes	Substrates	Digestion Products
Salivary glands	Amylase	Starch, glycogen	Disaccharides
Stomach	Pepsin	Proteins	Short peptides
Small intestine	Peptidases	Short peptides	Amino acids
(brush border)	Nucleases	DNA, RNA	Sugars, nucleic acid bases
	Lactase, maltase, sucrase	Disaccharides	Monosaccharides
Pancreas	Lipase	Triglycerides	Fatty acids, glycerol
	Trypsin, chymotrypsin	Proteins	Peptides
	DNase	DNA	Nucleotides
	RNase	RNA	Nucleotides