DIGESTION

The process of digestion is a chemical reversal of condensation reactions. Condensation reactions were used to create large polymers—long chains of simple sugars, amino acids or nucleotides. They were also used to build triglycerides (fats). During digestion, water is added to these molecules to reverse the condensation reactions. This process is called hydrolysis. So, digestion is the hydrolysis of large bulk nutrient molecules to produce their component subunits. Before studying human digestion in detail, we begin by examining some representatives of other types of animals.

DIGESTION IN SOME REPRESENTATIVE ORGANISMS

Protozoa

Protozoa ingest food particles using phagocytosis to form food vacuoles. Each food vacuole will combine with a lysosome containing digestive enzymes and then digestion occurs. This is intracellular digestion because it takes place inside the cytoplasm of the cell. The hydrolysis reactions occur in the vacuole containing the food and the enzymes.

Filter feeders

Clams and other shellfish pump water over their gills. There are cilia on the gills that trap food particles, such as bacteria and plankton. The food particles are collected and ingested.

Coelenterates and flatworms

Coelenterates are animals that have a two-layer body structure with a central cavity. They have only one opening into the cavity. Digestive systems with one opening are known as incomplete. The opening is generally known as the mouth, a generic term implying the opening where the food enters. An example is a tiny aquatic animal known as the Hydra.

Flatworms such as Planaria similarly have an incomplete digestive tract. The food is digested in the body cavity. This constitutes extracellular digestion because the digestion occurs in the lumen of the cavity, not in the cytoplasm of the body cells. All higher organisms use extracellular digestion. The nutrients are absorbed directly by the body cells. Wastes are eliminated using the same body opening where the nutrient particles enter.
DIGESTIVE SYSTEM OF THE EARTHWORM

The digestive system of the earthworm has two openings. Thus, it is known as a complete digestive system. It is also an example of the “tube within a tube” design found in higher organisms. The digestive system consists of a series of chambers for mechanical breakdown of food, chemical digestion (hydrolysis) and absorption of nutrients.

**Mouth**

The earthworm takes food and soil particles into the body through the mouth. A sucking action is produced by the pharynx, a structure immediately behind the mouth. This sucking action facilitates ingestion of soil and food particles.

**Pharynx**

The pharynx contracts and sucks the food and soil particles into the mouth. It is a chamber that has thick muscular walls that give it the ability to contract.

**Esophagus**

The esophagus is a passageway to the crop. The food and soil particles pass from the mouth and pharynx through the esophagus to the crop.

**Crop**

The crop is a storage chamber where food awaits further processing. The next chamber it enters will be the gizzard.

**Gizzard**

The gizzard is a chamber with thick, muscular walls. It contracts and the food undergoes mechanical breakdown. “Breakdown” means that the soil particles help to grind and pulverize the food to make the food particles smaller. Smaller food particles have a greater surface area. This helps enzymatic activity because enzymes attack the food beginning at the surface of the food particles.

**Intestine**

The intestine is a long passageway where chemical (enzymatic) digestion takes place. Digestion products and water are absorbed at the end. Digestion in the earthworm is extracellular because the process takes place in the lumen of the intestine. Hydrolysis is used to reverse the dehydration synthesis reactions.
Anus

The *anus* is the other opening in the digestive system. The undigested food material and soil particles are excreted via the anus and returned to the soil. The earthworm serves to aerate the soil as a result of its activities.

THE HUMAN DIGESTIVE SYSTEM

Humans can digest only seven basic nutrients. No other nutrients can be digested. People eat all kinds of things but the only molecules that serve as nutrients for humans are the seven types listed in Table IX-1.

Table IX-1. Human nutrients that can be digested.

<table>
<thead>
<tr>
<th>Nutrient Molecule</th>
<th>Product(s) of Digestion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Starch</td>
<td>Maltose (a disaccharide that is further digested)</td>
</tr>
<tr>
<td>Maltose</td>
<td>2 Glucose molecules</td>
</tr>
<tr>
<td>Sucrose</td>
<td>Glucose and Fructose</td>
</tr>
<tr>
<td>Lactose</td>
<td>Glucose and Galactose</td>
</tr>
<tr>
<td>Proteins</td>
<td>Amino Acids</td>
</tr>
<tr>
<td>Fats</td>
<td>Glycerol and Fatty Acids</td>
</tr>
<tr>
<td>Nucleic Acids</td>
<td>Nucleotides</td>
</tr>
</tbody>
</table>

Upper portion of the digestive system

The upper portion of the human digestive system consists of the mouth, the salivary glands and the tongue. Food enters the mouth and is chewed to provide more surface area for digestion. Chemical digestion of *starch* begins in the mouth.

Mouth

The mouth contains four types of teeth. These are the *incisors*, the *canines*, the *premolars* and the *molars*. The teeth help to tear off and grind large masses of food into small, more easily digestible particles.

Tongue

The tongue can taste *sweet*, *sour*, *salty* and *bitter* sensations. It helps to roll the food into a ball called a *bolus* that is then ready for swallowing. Swallowing is a reflex caused by pressure on the back of the throat. The *epiglottis* prevents food from entering the trachea accidentally.
Salivary glands

The salivary glands make a secretion called saliva. Saliva contains an enzyme of the amylase type. Amylase enzymes digest starch. (Amyl is a term referring to starch.) A century ago, it was thought to be a good idea to give special names to enzymes. Salivary amylase is also called ptyalin. Scientists gave up the idea of using individual names when it became clear what a vast number (thousands) of enzymes there are. Salivary amylase requires neutral conditions, meaning a pH value of 7.

Esophagus

The esophagus is a muscular passageway to the stomach. Food is moved along the esophagus using waves of contraction called peristalsis. No digestive enzymes are produced in the esophagus.

Lower portion of the human digestive system

The lower portion of the human digestive system consists of the stomach, the small intestine and the large intestine. This is where food is chemically digested and absorbed.

There are other organs that are required but do not actually perform digestion. These are the liver, the gall bladder and the pancreas. They are part of the digestive system but food does not pass through them.

Stomach

Food from the esophagus is mixed with gastric juice in the stomach. Gastric juice is a stomach secretion ("gastric" means stomach) that contains digestive enzymes and hydrochloric acid (HCl). Muscles of the stomach contact and mix the food and gastric juice together. Large food pieces are made smaller by the mechanical action of the stomach. The result is chyme, a thick mixture of food and gastric juice.

The stomach is closed off by the cardiac sphincter at the top and the pyloric sphincter at the bottom. A sphincter is a ring of circular muscles that acts as a gateway. A list of human sphincters is found in Table IX-2.

The secretion of gastric juice is initiated by a hormone known as gastrin. A hormone is a substance that is secreted directly into the bloodstream of the body. When food enters the stomach, special detector cells secrete gastrin into the blood. The blood carries the hormone to all parts of the body. The only part of the body that responds to it (the target organ) is the stomach. The stomach responds to gastrin by secreting gastric juice and HCl. The HCl creates the proper pH conditions for the gastric enzymes. Stomach acid has a pH of approximately 1.6.
Table IX-2. Sphincters of the digestive system

<table>
<thead>
<tr>
<th>Sphincter</th>
<th>Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cardiac</td>
<td>Between the esophagus and the stomach</td>
</tr>
<tr>
<td>Pyloric</td>
<td>Between the stomach and small intestine</td>
</tr>
<tr>
<td>Ileocaecal</td>
<td>Between the small intestine and large intestine</td>
</tr>
<tr>
<td>Anal</td>
<td>Between the large intestine and the outside</td>
</tr>
</tbody>
</table>

Enzymes of the stomach

The stomach makes two enzymes called lipase and pepsin. Lipase is an enzyme that digests fats. Fat molecules are made of three fatty acids attached to a molecule of glycerol by condensation reactions. The action of lipase is to hydrolyze the bonds holding the fatty acids to the glycerol and release the components.

Pepsin digests proteins. Proteins are long polymers of amino acids that were joined together by condensation reactions. Pepsin digests proteins by hydrolyzing the bonds connecting the amino acids to each other. This takes a while so the effect of pepsin is to make long protein chains into shorter chains of amino acids called polypeptides. The completion of polypeptide digestion occurs in the small intestine.

Pepsin is produced by stomach cells in an inactive form called pepsinogen. The suffix “-ogen” implies beginning, that this inactive form is the beginning of the active enzyme. The inactive pepsinogen becomes activated once it enters the lumen of the stomach. The proper pH environment is provided by HCl. Stomach enzymes work best in strong acid conditions.

Gastric juice

Gastric juice contains the enzymes of the stomach. Its production is caused by a hormone known as gastrin. Gastrin is made by the stomach in response to the detection of food in the lumen of the stomach.

Enterogastrone

Enterogastrone is a hormone produced by the duodenum, which is the uppermost portion of the small intestine. This hormone regulates the amount of gastric juice that the stomach produces resulting from gastrin.

Duodenum

The duodenum is the uppermost 9-12" of the small intestine. The pH of the duodenum is 7.8, which is slightly alkaline. As the pH scale is logarithmic, this means
that there is approximately 1 million times more acid coming in from the stomach than the duodenum is comfortable with. The enzymes of the duodenum work best in slightly alkaline (weakly basic) conditions. The duodenum has villi that allow for some absorption to take place here.

The duodenum secretes two hormones that affect the pancreas. The first is secretin, which causes the pancreas to secrete sodium bicarbonate. The sodium bicarbonate neutralizes the excess stomach acid so that the duodenum can maintain the proper pH conditions it requires. The second hormone is pancreozymin, which causes the pancreas to secrete pancreatic juice. Pancreatic juice contains digestive enzymes in an inactive form.

Pancreas

Food does not pass through the pancreas. The pancreas produces digestive enzymes after a signal from the duodenum in the form of pancreozymin. The enzymes perform their digestion in the lumen of the small intestine. The pancreas is an exocrine gland whose secretions pass through a duct. A duct is a tube that acts as a conduit for fluids.

Enzymes of the pancreas

Trypsin and chymotrypsin digest protein in the small intestine. They are made by the pancreas in an inactive form (trypsinogen and chymotrypsinogen). Carboxypeptidase also digests proteins. Proteins start out as long chains of amino acids and become digested into medium length and shorter chains known as polypeptides or peptides.

Other pancreatic enzymes are lipase, amylase and nuclease. Lipase hydrolyzes fats and amylase hydrolyzes starch. Nuclease enzymes hydrolyze nucleic acids, DNA and RNA.

Liver

The liver is the largest organ in the body. It is located in the abdominal cavity, under the diaphragm, in the upper right corner under the rib cage. Food does not pass through the liver during digestion.

Functions of the liver

The functions of the liver include the following:

- Bile production
- Intermediary metabolic reactions
- Excretion of waste products from hemoglobin and protein metabolism
- Storage of glycogen, a glucose polymer used as a food reserve
Bile is a secretion that emulsifies fats. Emulsification makes the fat droplets smaller so that lipase enzymes have an easier time digesting them. The fat droplets become mechanically subdivided into smaller ones.

Intermediary metabolic reactions involve biochemical pathways that are used to make what the body needs. The liver has the ability to transform glucose into some of the amino acids that the body needs. The liver removes nutrient molecules from the blood after digestion and stores them for when the body needs them.

Urea is a waste product of protein digestion. Other waste products include creatinine and uric acid. These wastes are excreted by the liver into the blood stream. The kidneys remove them from the blood for final elimination in the urine. The liver also excretes cholesterol and hemoglobin breakdown products into the bile. These give bile its characteristic greenish color.

The liver is a food-storage organ. Most of the body's food reserves in the liver are in the form of a glucose polymer called glycogen. When necessary, the liver mobilizes glucose and sends it to the body cells to be used for energy production by cellular respiration.

Gall bladder

Bile is stored in the gall bladder. Bile is released by the gall bladder in response to the presence of cholecystokinin in the blood. Cholecystokinin is a hormone produced by the small intestine in response to the presence of food. Food does not pass through the gall bladder during digestion.

Small intestine

Digestion is completed in the small intestine. Intestinal juice is secreted by the intestine in response to the hormone enterocrinin. The small intestine (called “small” because it has the smaller diameter) has muscular walls and a large surface area for absorption due to the presence of villi. Villi are projections of the intestinal epithelium that resemble numerous fingers. They increase the surface area of the small intestinal lining for increased absorption. The surface of the intestinal lining is made of columnar epithelium. Material is moved along the intestine by peristalsis.

When digested food is absorbed, simple sugars, amino acids and nucleotides enter the capillaries inside the villi. Materials absorbed into the capillaries of the villi enter the blood stream and are taken to the liver. Digested fats result in glycerol and fatty acids. These are absorbed by the lacteals of the villi. A lacteal is a projection of the lymphatic system located inside each villus. Thus, the fatty acids and glycerol enter the lymphatic system.
The enzymes peptidase, lipase, maltase, sucrase and lactase are produced by the small intestine. The pancreatic enzymes are also active in the small intestine but are not produced there.

Appendix

The appendix is a vestigial structure attached to the caecum, which is the beginning, dead-end part of the large intestine. Vestigial means that the structure has no use in humans. It is a vestige, a left-over, from the evolutionary past. In some herbivores, such as rabbits, the appendix is large and well developed.

Large intestine (colon)

The remainder of the chyme enters the large (diameter) intestine through the ileocecal sphincter. The colon has a smooth lining like the mouth. Absorption of water and minerals takes place in the colon. People who have had the large intestine removed (thereby giving them ileostomy) have difficulty absorbing minerals, such as K (potassium) ions.

Undigested wastes are collected and stored in the rectum, the distal (furthest away from the entrance) portion of the colon. They are eliminated by passing through the anal sphincter.

Table IX-3. Hormones of the digestive system.

<table>
<thead>
<tr>
<th>Hormone</th>
<th>Source</th>
<th>Action</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gastrin</td>
<td>Lining of Stomach</td>
<td>Stimulates production of gastric juice by the stomach</td>
</tr>
<tr>
<td>Enteropeptin</td>
<td>Lining of Duodenum</td>
<td>Lessens gastric secretions and slows peristalsis in the stomach</td>
</tr>
<tr>
<td>Secretin</td>
<td>Lining of Duodenum</td>
<td>Stimulates pancreas to secrete sodium bicarbonate</td>
</tr>
<tr>
<td>Pancreozymin</td>
<td>Lining of Duodenum</td>
<td>Stimulates production of digestive enzymes by pancreas</td>
</tr>
<tr>
<td>Cholecystokinin</td>
<td>Lining of Intestine</td>
<td>Causes contraction of gall bladder and ejection of bile</td>
</tr>
<tr>
<td>Enterocin</td>
<td>Lining of Intestine</td>
<td>Causes secretion of intestinal juice</td>
</tr>
</tbody>
</table>

Table IX-4. Summary of chemical digestion

<table>
<thead>
<tr>
<th>Organ</th>
<th>Source of Enzyme</th>
<th>Enzyme</th>
<th>Substrate</th>
<th>Product</th>
<th>Special conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oral cavity</td>
<td>Salivary glands</td>
<td>Amylase</td>
<td>Starch</td>
<td>Maltose</td>
<td>Neutral</td>
</tr>
<tr>
<td>Stomach</td>
<td>Cells of stomach</td>
<td>Lipase</td>
<td>Fats</td>
<td>Glycerol, fatty acids</td>
<td>Acid, gastrin</td>
</tr>
<tr>
<td>Small intestine</td>
<td>Pancreas</td>
<td>Trypsin and chymotrypsin</td>
<td>Proteins and polypeptides</td>
<td>Amino acids</td>
<td>Alkaline; secretin and pancreozymin</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Amylase</td>
<td>Starch</td>
<td>Maltose</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Lipase</td>
<td>Lipids</td>
<td>Glycerol, fatty acids</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Carboxypeptidase</td>
<td>Peptides</td>
<td>Amino acids</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Nuclease</td>
<td>Nucleic acids</td>
<td>Nucleotides</td>
<td></td>
</tr>
<tr>
<td>Intestinal cells</td>
<td>Peptidase</td>
<td>Polypeptides</td>
<td>Amino acids</td>
<td>Bile salts</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Lipase</td>
<td>Lipids</td>
<td>Glycerol, fatty acids</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Maltase</td>
<td>Maltose</td>
<td>Glucose</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Sucrese</td>
<td>Sucrose</td>
<td>Glucose, fructose</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Lactase</td>
<td>Lactose</td>
<td>Glucose, galactose</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>