I. Digestive System
   A. Function
      1. Breaking down nutrients to their building blocks (amino acids, simple sugars, etc.) so they may penetrate the epithelial lining of the digestive tract.
   B. Four basic layers of the digestive tract
      1. The **mucosa** is the inner lining of the tract and is a mucous membrane consisting of multiple layers.
         a. The innermost layer is epithelial tissue and consists of either **stratified squamous** (mouth, pharynx, esophagus, anal canal) or **simple columnar** (stomach through the rectum).
         b. A layer of areolar connective tissue supports the epithelial layer.
         c. A thin layer of smooth muscle forms the outermost portion of the mucosa.
      2. The **submucosa** is the second layer of the tract and consists of areolar connective tissue.
         a. Contains many blood and lymphatic vessels to absorb the nutrients from the digestive tract.
         b. Contains glands to secrete digestive enzymes, mucous, etc.
         c. Will have both parasympathetic and sympathetic neuron processes to supply impulses to the glands.
            i. More parasympathetic stimulation increases the amount of glandular secretions.
            ii. More sympathetic stimulation decreases glandular secretions.
      3. The **muscularis** is the third layer of the tract.
         a. Consists of skeletal muscle within the mouth, pharynx and upper 1/3 of the esophagus to allow for the voluntary control over swallowing.
         b. The lower 2/3 of the esophagus through the anal canal contains 2 layers of smooth muscle (except for the stomach which has 3) allowing for wavelike muscular contractions known as **peristalsis**.
         c. This layer also contains both parasympathetic and sympathetic neuron processes to control the activity of the smooth muscle.
            i. More parasympathetic stimulation increases muscle motility.
            ii. More sympathetic stimulation decreases muscle motility.
      4. The **serosa** (**visceral peritoneum**)
         a. The outermost layer of the tract is the visceral portion of the serous membrane within the abdominal cavity known as the peritoneum.
         b. The parietal layer will line the inside of the abdominal cavity.
         c. The visceral peritoneum that wraps the small intestines also attaches to the posterior body wall. This creates layers of peritoneum known as **mesentery**.
            i. Contains blood and lymphatic vessels.
            ii. Stores fat.
   C. Mouth
      1. Chewing food is known as **mastication**.
         a. Acts to increase the surface area of food and mixes the food with saliva.
         b. The food is packed into a mass called a **bolus**.
      2. There are 3 pairs of salivary glands that release saliva into the mouth.

a. Saliva consists of 99.5% water; mucus for lubrication; bicarbonate to buffer acidic foods; **lysozyme** to kill bacteria; and **ptyalin** (**salivary amylase**) that initiates carbohydrate digestion.
b. The **parotid glands** are inferior and anterior to the ears.
    i. Secrete saliva high in ptyalin content.
c. The **submandibular glands** are in the floor of the mouth.
d. The **sublingual glands** are also in the floor of the mouth but anterior to the submandibular glands.
e. The glands are controlled by the autonomic nervous system.
    i. More parasympathetic stimulation increases the production of saliva.
    ii. More sympathetic stimulation decreases saliva production.

D. Pharynx
1. Swallowing (**deglutination**) moves food from the mouth into the **oropharynx**.
    a. Reflexes will occur that close other openings.
        i. The soft palate and uvula rise to close off the **nasopharynx**.
        ii. The **epiglottis** blocks the **trachea**.
2. Muscular contractions continue to move the food through the **laryngopharynx** and into the **esophagus**.

E. Esophagus
1. Once food enters the esophagus is it moved towards the stomach by muscular contractions known as peristalsis.
2. Gravity also helps.
3. Located at the end of the esophagus is the **lower esophageal (cardiac) sphincter** that controls the movement of food into the stomach.
    a. Reflexively relaxes by approaching peristaltic waves.
    b. Prevents regurgitation of food into the esophagus.
    c. **Heartburn (reflux esophagitis)** is a burning sensation that occurs when acid from the stomach enters the esophagus.
        i. Causes include increased pressure in the abdominal cavity due to strenuous exercise, belts, pregnancy, vomiting, obesity and overeating.

F. Stomach
1. Serves as a mixing and storage chamber.
2. Four regions of the stomach.
    a. The **cardia** is the region of the stomach around the cardiac sphincter.
    b. The **fundus** is the superior portion of the stomach.
    c. The **body** is the central portion.
    d. The **pylorus** is the most inferior region.
        i. At the end of the pyloric region is the **pyloric sphincter** connecting the stomach to the **duodenum** (the first portion of the small intestines).
3. Special modifications to the stomach wall.
    a. When the stomach is empty the mucosa is folded into wrinkles called **rugae**.
    b. There is an additional third layer of smooth muscle to reinforce the wall of the stomach and produce a churning action.
    c. The mucosal surface has **glandular gastric pits** which produce the digestive juices and mucus for the stomach. The cells within the gastric glands include:
        i. **Neck cells** that secrete mucus, used as a protective barrier.

ii. **Chief cells** secrete the inactive enzymes **pepsinogen** and **prorennin**
    (a) When **pepsinogen** encounters hydrochloric acid within the lumen of the stomach it is converted into **pepsin**, a protein digesting enzyme.
    (b) When **prorennin** encounters the hydrochloric acid within the lumen of the stomach it is converted into **rennin**, an enzyme that curdles milk to slow it's movement and allow for digestion.
        (i) Prorennin is primarily produced by the stomachs of children up to the age of two.
iii. **Parietal cells** produce **hydrochloric acid** and **intrinsic factor**.
    (a) **Hydrochloric acid** is important for converting pepsinogen and prorennin into active enzymes. The high acidity also kills microbes within the stomach.
    (b) **Intrinsic factor** is needed for the absorption of vitamin $B_{12}$. Vitamin $B_{12}$ is necessary for red blood cell production and inadequate levels can result in **pernicious anemia**.
iv. The secretions produced by the neck cells, chief cells and parietal cells are known collectively as **gastric juice**.
v. Within the pyloric region an additional glandular cell (**G cells**) produces the hormone **gastrin**.
    (a) **Gastrin** stimulates the other cells of the gastric glands to increase the production of gastric juices.

4. The control of stomach secretions and motility.
    a. The **cephalic phase** occurs at the sight, smell, taste or even thought of food.
        i. This initiates a parasympathetic reflex that stimulates the gastric glands to produce gastric juices and gastrin. Also increases stomach motility.
    b. The **gastric phase** occurs when the food actually enters the stomach.
        i. The mechanical contact with food and stretching of the stomach wall initiates a parasympathetic reflex that sends more impulses to the gastric glands, increasing the production of gastric juices and gastrin.
        ii. Also initiates muscular waves of the stomach wall to mix the food with the gastric juices producing a slushy liquid known as **chyme**.
        iii. These muscular waves push the chyme toward the pyloric sphincter and cause the sphincter to relax, allowing approximately a teaspoon of chyme to enter the duodenum.
    c. The **intestinal phase** occurs when the food enters the duodenum of the small intestines.
        i. As the acidic, fatty chyme enters the duodenum it stimulates endocrine cells within the mucosa of the intestines to release the hormones **cholecystokinin** and **secretin**.
            (a) **Cholecystokinin** circulates back to the stomach and inhibits gastric movements, slowing the movement of food from the stomach into the intestines.
            (b) **Secretin** also circulates back to the stomach and inhibits the production of gastric juices.
5. Absorption in the stomach.

a. Very little absorption occurs within the stomach because most materials are not broken down enough to get through the epithelial cells.
b. The stomach can absorb some water, ions, short-chain fatty acids and some fat-soluble substances (i.e. fat-soluble vitamins and alcohol).

6. **Ulcers** of the stomach
    a. 90% of stomach ulcers are caused by the bacterial **Helicobacter pylori** and can be treated with antibiotics.

G. Small intestines
1. This is where the majority of the digestion and absorption of nutrients occurs.
2. Is approximately 1 inch in diameter and is composed of 3 sections.
    a. The **duodenum** is the shortest part and attaches to the stomach.
        i. This portion receives bile from the liver and secretions from the pancreas.
    b. The **jejunum** is the middle portion.
    c. The **ileum** is the final portion and attaches onto the large intestine.
3. Special modifications of the intestinal wall.
    a. The mucosa of the small intestine contains circular folds known as **plicae circularis**.
        i. These cause the chyme to spiral as it moves down the intestine to allow more time for absorption.
    b. The mucosa also has finger-like projections known as **villi**.
        i. The villi help to increase the surface area of the mucosal layer.
        ii. Each villi contains a capillary network and a **lacteal** (lymphatic capillary) to pick up the nutrients from the epithelial cells.
    c. The simple columnar cells of the mucosa also have **microvilli** on their surface.
        i. These also help to increase surface area.
    d. The intestinal wall is also very glandular producing an alkaline mucous to buffer the acidic chyme, and many hormones.
4. Mechanical digestion of the small intestines.
    a. Along with peristalsis, the smooth muscle of the intestines produces a muscular movement known as **segmentation**.
        i. **Segmentation** produces an alternating contraction and relaxation of the smooth muscle, acting to knead the contents of the small intestine.
5. Chemical digestion in the small intestines.
    a. The digestion within the small intestines is a combined effort of intestinal enzymes, pancreatic juice and bile.
    b. The intestinal columnar cells produce brush border enzymes.
        i. Include amylases (digest carbohydrates), nucleases (digest nucleic acids), proteases (digest proteins) and enterokinase (an enzyme the actives the pancreatic enzyme trypsinogen).
    c. The pancreas
        i. The pancreas is composed of both exocrine and endocrine glandular cells (the endocrine portion will be discussed later).
        ii. The exocrine portion consists of **acinar** cells that produce the pancreatic enzymes and **duct cells** producing a bicarbonate rich fluid.
        iii. The pancreatic juice is composed of water, bicarbonate (which acts to buffer the acidic chyme so enzymes in the small intestine can work) and enzymes including:

(a) **trypsinogen** which is converted into the protein digesting **trypsin** after being activated by the brush border enzyme **enterokinase**.
(b) **amylases** to digest carbohydrates.
(c) **Lipases** to digest fats
(d) **Nucleases** to digest nucleic acids.

iv. The control of pancreatic secretions.
(a) The same parasympathetic reflexes initiated during the cephalic phase and the gastric phase also stimulate the acinar cells and duct cells to produce pancreatic juices.
(b) Cholecystokinin also stimulates the acinar cells to produce enzymes.
(c) Secretin stimulates the duct cells to produce the bicarbonate rich fluid.

d. The gallbladder
i. The gallbladder is a sac that can store 50 ml. of bile.

e. The liver
i. Composed of sections known as lobules.
ii. A lobule consists of specialized epithelial cells known as **hepatocytes** which produce bile
iii. Bile is composed of:
(a) Cholesterol
(b) Bicarbonate
(c) The bile pigment bilirubin from the breakdown of hemoglobin.
(d) Bile salts (sodium and potassium salts)
(i) Aid in **emulsifying** fats globules into fat droplets making it easier for the lipases to break down the triglycerides.

iv. The control of bile production and release.
(a) The same parasympathetic reflexes initiated during the cephalic phase and the gastric phase also stimulate the liver the increase bile production.
(b) In addition, cholecystokinen from the small intestine causes contraction of the wall of the gallbladder, squeezing the stored bile into the cystic duct which connects to the bile duct emptying into the duodenum.
(c) As these initial bile salts from the gallbladder emulsify fats they are slowly absorbed into the blood.
(d) These circulate back to the liver and act as a stimulus for more bile production by the liver.
(e) Secretin stimulates the production of bicarbonate by hepatic duct cells.

6. Absorption of nutrients in the small intestine.
a. Carbohydrates are broken into monosaccharides.
i. Glucose and galactose are actively transported into the epithelial cells while fructose is transported by facilitated diffusion.
ii. From the epithelial cells the monosaccharides are transported by facilitated diffusion into the capillaries within the villi.

b. Proteins are broken down into amino acids.
i. The absorption of amino acids is essentially the same as that of monosaccharides.

c. Lipids are broken down into monoglycerides and fatty acid chains.

i. Short chain fatty acids are absorbed by diffusion into the epithelial cells which also enter the capillaries within the villi.
ii. The monoglycerides, long chain fatty acids, cholesterol and fat soluble vitamins (A, D, E, K) are transported with the help of bile salts through the mucus lining the digestive tract in the form of micelles.
(a) Once the fats are through the mucus they diffuse into the epithelial cells.
(b) Once inside the cells the monoglycerides and fatty acids are recombined into triglycerides and covered in a layer of protein forming **chylomicrons**.
(c) The chylomicrons then exit the epithelial cell by exocytosis and enter the lacteal within the villi.

H. Large Intestine
1. Functions include:
   a. Completes absorption (primarily of water).
   b. Fermentation and putrefaction of wastes by microbes.
      i. Reduce the bulk of waste material.
      ii. The microbes produce vitamins K, $B_{12}$, thiamine and riboflavin for us.
   c. Formation of feces.
2. Modifications to the wall of the large intestine
   a. The longitudinal layer of muscle is arranged into three thick bands known as **teniae coli**.
   b. As the teniae coli pull on the wall of the large intestine it creates pouches along the length of the colon known as **haustra**.
3. Modifications to the wall of the anal canal.
   a. The mucosal layer is lined with stratified squamous epithelium.
   b. The mucosal layer is folded into **anal columns** containing an artery and a vein.
      i. The veins often varicose resulting in **hemorrhoids**.
   c. Has an **internal smooth muscle sphincter** and an **external skeletal muscle sphincter** that help regulate the elimination of feces during the defecation reflex.
4. Structure of the large intestine.
   a. The **appendix** is located where the ileum of the small intestine attaches to the large intestine.
   b. As the chyme enters the large intestine is travels superiorly through the **ascending colon**.
   c. It then travels across the abdomen in the **transverse colon**.
   d. The feces then travels inferiorly through the **descending colon**.
   e. The end of the descending colon curves as the **sigmoid colon**.
   f. From the sigmoid colon the feces enters the **rectum** which ends in the **anal canal**.
5. Mechanical movement within the large intestine.
   a. Peristaltic waves continue to help move the feces through the large intestine.
   b. In addition, the large intestine has **mass movements** which are large peristaltic waves beginning within the middle of the colon pushing the feces towards the rectum.
6. Defecation reflex
   a. Distention of the rectum initiates the parasympathetic defecation reflex.

b. Parasympathetic impulses stimulate contraction of the smooth muscle in the wall of the rectum pushing the feces towards the anal canal.
c. Parasympathetic impulses also inhibit the smooth muscle of the internal sphincter resulting in relaxation.
d. When the external skeletal muscle sphincter is relaxed the feces is expelled.

II. The use and hormonal control of the major nutrients.
A. The **absorption phase** occurs during the first 3 to 4 hours after eating.
1. The use of glucose.
a. Glucose is delivered to the liver by the hepatic portal vein.
i. The liver either uses the glucose or converts it to glycogen and/or fat for storage.
b. Excess glucose passes through the liver to the other tissues of the body.
i. Glucose will be the primary nutrient to supply energy for the body during the absorption period.
ii. Glucose can also be converted to fat and stored in the adipose tissue.
iii. Glucose can be stored as glycogen in skeletal muscle.
iv. Glucose can be converted to nonessential amino acids as needed.
2. The use of amino acids.
a. Amino acids are delivered to the liver by the hepatic portal vein.
i. The liver either uses the amino acids to build proteins or converts the amino acids into glucose to be stored as glycogen.
b. Excess amino acids pass through the liver to the other tissues of the body.
i. The amino acids can be used to build proteins.
ii. Can also be converted to fatty acids and stored as fat.
3. The use of fatty acids.
a. Fatty acids are delivered to adipose deposits and remain untouched during the first few hours after eating.
4. Hormonal control of nutrients during the absorption phase.
a. **Insulin** is the primary hormone to control the intake of nutrients during the absorption phase.
i. Insulin is produced by the **beta cells** of **the Islets of Langerhans of the pancreas** in response to **high** blood levels of glucose.
ii. The effects of insulin include:
(a) Increases the rate 15-20 times at which glucose is moved out of circulation and into body cells.
(b) Encourages the use of glucose as an energy source.
(c) Also increases the rate at which amino acids are moved into cells.
(d) Encourages the storage of fatty acids in the fat deposits.

B. The **postabsorption phase** occurs approximately 4 to 5 hours after eating (begins when the blood levels of nutrients fall below homeostatic levels).
1. There is a transition from glucose to fats as the primary energy source.
a. Fats are broken down into fatty acids and supply the energy needs of all active tissues other than the brain.
b. The brain continues to use glucose.

i. The glucose for the brain comes from the breakdown of glycogen stores in the liver and skeletal muscle (**glycogenolysis**) or the conversion of skeletal muscle protein into glucose (**gluconeogenesis**).

2. Hormonal control of nutrients during the postabsorption phase.
    a. Blood glucose levels have fallen so insulin is no longer being released.
    b. The low blood glucose stimulates the release of **glucagon** from the **alpha cells** of the **Islets of Langerhans of the pancreas**.
    c. The effects of glucagon include:
        i. Stimulates the breakdown of fats into fatty acids and glycerol (**lipolysis**) so they can be used as an energy store.
        ii. Encourages gluconeogenesis and glycogenolysis to increase blood glucose levels for the brain.

C. The **prolonged fast** phase occurs 6 or more hours after eating.
1. Fats are still the primary source of energy for all of the active tissues other than the brain.
2. In order to conserve muscle protein the brain begins using **ketone bodies**, derived from the excessive breakdown of fatty acids, as an energy source.
3. Hormonal control of nutrients during the prolonged fast phase.
    a. Very low blood sugar triggers the production of two more hormones.
        i. **Glucocorticoids** are secreted from the cortex of the **adrenal gland**.
        ii. The effects of glucocorticoids include:
            (a) Inhibits the synthesis of proteins to increase blood levels of amino acids.
            (b) Encourages gluconeogenesis to increase blood sugar levels.
            (c) Encourages lipolysis.
        iii. **Growth hormone** is secreted from the **anterior pituitary gland**.
        iv. The effects of growth hormone include:
            (a) Attempts to conserve muscle protein by encouraging the movement of amino acids into cells for the formation of proteins.
            (b) Encourages cells to decrease their use of carbohydrates and increase their use of fats in order to increase blood sugar levels.