Chapter 14
The Digestive System
Nutrition

- Foods are used as metabolic fuel (energy)
  - Foods are oxidized and transformed into ATP
  - $\text{ATP} = \text{Chemical energy the drives cellular activities}$

Energy value of food is measured in Calories (C)
Nutrients – required for growth, maintenance and repair

- Major nutrients
  - carbohydrates, fats, proteins AND water

- Minor nutrients –
  - Vitamins and minerals
Vitamins and Minerals

- **Vitamins** – mostly found in fruits and vegetables
  - Used as coenzymes
  - Fat soluble: Vitamin A, D, E and K
  - Water soluble: Vitamin B, C

- **Minerals** – foods rich in minerals = vegetables, legumes, milk and some meats
  - Important for enzyme activity
  - Iron (making hemoglobin), calcium (building bones, blood clotting)

- Vitamin and mineral deficiencies can cause severe disorders in the body
Stages of Food Processing

- Food must be processed to obtain macromolecules and nutrients
- The 4 main mechanisms of food processing are:
  - **Ingestion**: eating (taking in food)
  - **Digestion**: physical and chemical breakdown of food into the nutrient molecules
  - **Absorption**: movement of nutrients into the bloodstream
  - **Defecation**: elimination of indigestible waste
Food Processing (cont.)

- **Extracellular Digestion:**
  - In a gastrointestinal cavity in simple animals
    - Coiled, hollow tube
- **Intracellular Digestion:**
  - Occurs inside the cell, once the cell engulfs food particles
  - Is performed by the cell’s lysosomes
Alimentary canals are also called complete digestive tracts

“one way movement” of food: a specific opening for ingestion and another for elimination
  ◦ Makes for orderly progression of breakdown
  ◦ Allows for more than 1 meal to enter the tract a time
The organs and functions of that make up the human alimentary canal and accessory structures.
The Oral Cavity (Mouth) mucous membrane lined cavity

- Is bounded externally by lips and cheeks
  - **Vestibule**–the space between the lips, cheeks, & gums
- The tongue–composed of skeletal muscle
  - **Papillae**–rough projections on the tongue
    - Allow food handling
    - Contain sensory receptors (taste buds)
    - **Lingual frenulum**–fold of mucous membrane underside the tongue
      - Difficulty speaking if too short (“tongue–tied”)

- **Roof of the Mouth**
  - **Anterior hard palate**–maxilla and palatine bones
  - **Posterior soft palate**–muscle and glandular tissue
    - **Uvula**–finger–shaped projection
The Oral Cavity

- Incisors
- Soft palate
- Uvula
- Tonsil
- Tongue

Taste Buds

Map of Taste Receptors
- Bitter
- Sour
- Salt
- Sweet

- Accessory parotid gland
- Parotid duct
- Opening of submandibular (Wharton's) duct
- Sublingual gland
- Submandibular (Wharton's) gland
- Body of mandible
- Submandibular gland
The Oral Cavity (Mouth)

- **Teeth**—Begin the mechanical digestion by chewing food – increasing surface area.

- **Salivary glands**—produce saliva (begins carbohydrate breakdown)

- **Tonsils**—immune function
Salivary Glands (3 Pairs)

- **Parotid**—anterior and inferior to the ears
- **Send saliva to the mouth via ducts**
- **Sublingual**—underneath the tongue
- **Submandibular**—floor of the mouth, inside the surface of the lower jaw
  - Ducts for both open underneath the tongue
Oral Cavity (Mouth)

Functions:
- Mastication (chewing) of food
- Tongue mixes masticated food with saliva
- Tongue initiates swallowing
- Taste buds on the tongue allow for taste
Composition & Functions of Saliva

Mucus, water, bicarbonate

Functions

1. protects mouth while chewing
2. lubricates food for swallowing
3. helps prevent tooth decay
4. kills many bacteria before swallowing
5. Chemical digestion of carbohydrates by Salivary amylase (starch $\rightarrow$ maltose)
The Pharynx – passageway for food and air

- The connection between our oral cavity and the esophagus
  - Nasopharynx, Oropharynx, Laryngopharynx
- The windpipe (trachea) also is located anterior to the pharynx and the esophagus
- A flap of cartilage called the *epiglottis* closes the opening of the trachea when we swallow, which prevents things from entering the lungs or choking.

- **Swallowing – 2 phases (peristalsis)**
  - Voluntary
  - Reflex – once food is pushed into the oropharynx
3 parts of the pharynx

- Nasopharynx – respiratory function
- Oropharynx – respiratory and digestive function
  common pathway for food and air
- Laryngopharynx – respiratory and digestive function
The Swallowing Process

BUCCAL PHASE
- Hard palate
- Tongue
- Soft palate
- Epiglottis
- Trachea
- Esophagus

PHARYNGEAL PHASE

(a) 
(b) 
(c) 
(d)
The Swallowing Process

ESOPHAGEAL PHASE

Peristalsis

Esophagus
Diaphragm

Stomach
Thoracic cavity

Human Anatomy, 3rd edition
Prentice Hall, © 2001
Teeth

- 2 sets
  - **Deciduous** (20)
    - Ages 6 mo. – 2 ½ years
  - **Permanent** (32)
    - Ages 6 years – 25 years (**3<sup>rd</sup> molars**)

- **Held in sockets**

- **Gingiva** surrounds the base of the teeth
Deciduous Teeth

(d) The primary teeth

- Central incisors (7.5 mo)
- Lateral incisor (9 mo)
- Cuspid (18 mo)
- Primary 1st molar (14 mo)
- Primary 2nd molar (24 mo)
- Primary 1st molar (12 mo)
- Cuspid (16 mo)
- Lateral incisor (7 mo)
- Central incisors (6 mo)
Adult Teeth

(c) Adult teeth, upper and lower jaws
Structure of a Tooth

- **Crown**
  - Part you see above the gum

- **Root**
  - 1 – 3 projections embedded in socket

- **Neck**
  - Junction between crown and root
Composition of a Tooth

- **Dentin**
  - Primary substance in tooth
  - Encloses pulp cavity
    - In crown
    - Root canals – narrow extensions of pulp cavity

- **Enamel – covers crown**
  - Hardest substance in the body
  - Protects tooth from wear of chewing
  - Barrier against acids that dissolve dentin

- **Cementum – covers root**
- **Tooth decay**
- **Wisdom teeth**
The Esophagus (food pipe)

- Anatomy: ~10 inches long (pharynx to stomach
- Stratified squamous epithelium
- Rhythmic muscular contractions, known as *peristalsis* push the food in one direction...Down.
- No digestion occurs here.
Step 1:
Contraction of circular muscles behind bolus

Step 2:
Contraction of longitudinal muscles ahead of bolus

Step 3:
Contraction in circular muscle layer forces bolus forward

(a) Peristalsis

(b) Segmentation
The Esophagus cont...

- **Lower Esophageal Sphincter** (gastroesophageal) constriction between the esophagus and the stomach
  - Sphincters—muscles that encircle tubes
  - Relaxation—allows bolus to enter the stomach
  - Constriction—prevents acid backup from the stomach

- **Heartburn**—acid reflux from the stomach

- **Vomiting**—propelling of stomach contents by contraction of abdominal and stomach muscles
Layers of the Digestive Tract
(Deep → Superficial)

1. **Mucosa (mucous membrane layer):**
   - A layer of epithelium
   - Glandular cells (enzyme secretion)
   - Goblet cells (mucous secretion)

2. **Submucosa:**
   - Loose connective tissue with blood vessels, lymphatics, and nerves beneath it
   - Peyer’s patches—lymph nodules—immune function

3. **Muscularis (smooth muscle layer):**
   - Inner circular and outer longitudinal layer
   - Oblique—only in the stomach

4. **Serosa (serous membrane layer):**
   - Very thin outermost layer of squamous epi
   - Secretes serous fluid
   - Adventitia—only in the esophagus, loose CT
Figure 14.3 Basic structure of the alimentary canal wall.

- **Visceral peritoneum**
- **Intrinsic nerve plexuses**
  - Myenteric nerve plexus
  - Submucosal nerve plexus
- **Submucosal glands**
- **Mucosa**
  - Surface epithelium
  - Lamina propria
  - Muscle layer
- **Submucosa**
  - Longitudinal muscle layer
  - Circular muscle layer
- **Muscularis externa**
- **Serosa** (visceral peritoneum)
- **Mesentery**
- **Nerve Artery**
- **Vein**
- **Gland in mucosa**
- **Duct of gland outside alimentary canal**
- **Lumen**
- **Lymphoid tissue**
Layers of the Digestive Tract
Peritoneum (Serous membrane)

- Parietal peritoneum: lines the abdominal wall
- Visceral peritoneum: covers the organs
  - **Mesentary**: double layer of visceral peritoneum in between the organs
  - **Greater omentum**: hangs down anteriorly
    - Fat cushion for insulation
    - Contains macrophages
    - Contains infections from spreading
  - **Lesser omnetum**: between the stomach and the liver
External Anatomy of the Stomach

- Hepatoduodenal ligament
- Hepatogastric ligament
- Lesser omentum
- Lesser curvature
- Esophagus
- Cardia
- Diaphragm
- Liver
- Spleen
- Left gastroepiploic artery
- Splenic flexure of colon
- Greater curvature
- Greater omentum
- Gallbladder
- Duodenum
- Pylorus
- Right kidney
- Hepatic flexure of colon
- Right gastroepiploic artery

(a) Stomach, anterior view
Anatomy of the Stomach

- Esophagus
- Fundus
- Anterior surface
- Cardia
- Longitudinal muscle layer
- Circular muscle layer
- Lesser curvature (medial surface)
- Body
- Left gastroepiploic vessels
- Oblique muscle layer overlying mucosa
- Greater curvature (lateral surface)
- Rugae
- Pyloric canal
- Pyloric antrum
- Pyloric sphincter
- Duodenum

(a) Stomach, anterior view
The Stomach
The Stomach

- Performs 2 major functions: Storage and Digestion
- Can hold up to 4 liters (1 gallon) of food (entire meal)
- Creates *Gastric Juice*, which begins protein digestion.
- Stomach walls churn the food to further increase surface area and to mix the gastric juice in with the food.
The Stomach

- **4 Regions:**
  - **Cardiac**—near the heart, surrounds the lower esophageal sphincter
  - **Fundic**—superior expansion, temporarily holds food
  - **Body**—main region
  - **Pyloric**—funnel-shaped terminal end—leads to the pyloric sphincter

- **Rugae**—stomach folds with allow the diameter of the stomach to expand
Figure 14.4b Anatomy of the stomach.

- **Fundus**
- **Body**
- **Rugae of mucosa**

(b) **Pyloric sphincter**

**Pyloric antrum**
Smooth Muscle Layers of the Stomach

Three muscle layers:
• longitudinal
• circular
• oblique

Functions:
• move food along
• churn and mix food with gastric juices
• Break food down
Stomach mucosa

- Simple columnar epithelium
- Has millions of gastric pits leading to gastric glands
Stomach Glands and Functions

- 4 Cell types in gastric glands. Gastric juice is made from its 3 types of cells:
  - Mucus Cells
  - Chief Cells
  - Parietal Cells
- Enteroendocrine cells

Secrete mucus to line the stomach wall
Secrete Pepsinogen
Secrete HCl and Intrinsic factor * needed for absorption of Vitamin B$_{12}$
Secrete gastrin
Stomach (cont.)

- **Mucous cells:** produce mucus
  - Protects stomach from digesting itself
  - Stomach pH=2
  - **Ulcer**—open sore (most common cause *H. Pylori*)

- **Chief cells:** secrete pepsinogen (inactive enzyme)

- **Parietal cells:** produce HCL + Intrisic factor (IF)
  - HCl + Pepsinogen $\rightarrow$ Pepsin (active)
    - *Pepsin* chemically digests proteins into smaller proteins (polypeptides)
  - **IF** binds to VitB12 preventing pernicious anemia (failure of RBC development)
Stomach cont..

- **Enteroendocrine Cells**: produce gastrin
  - Gastrin (hormone) regulate stomach wall contractions and secretions

- The food (bolus) mixed with the stomach secretions is called *Chyme*.
  - *(Acidic) Chyme* is released into the small intestine in small amounts through the *Pyloric Sphincter*
  - *Alcohol and water* get absorbed in the stomach, but food does not
  - Gastric emptying takes 2–6 hours
Major Digestive organ

7–13 feet long

Nearly all digestion and nutrient absorption occurs here.

3 main sections:

- Duodenum
- Jejunum
- Ileum
Duodenum

- Attaches to the stomach
- Curves around pancreas

- The acid chyme from the stomach mixes with the digestive juices from the liver, pancreas, gall bladder and the small intestine walls.

- Most of the digestion (breakdown) of the chyme is completed by the time it reaches the end of the Duodenum
Jejunum and Ileum

- Remaining sections of the S.I.
- Majority of food molecule absorption
- Lined with finger-like projections called Villi.
- Villi are further lined themselves with Microvilli
Villi

- Mucosa–simple columnar epi
- Serve to increase the rate of absorption by vastly increasing the surface area.
- Each Villi has surrounding capillaries and a central lacteal
  - a small lymphatic vessel
Villi (cont.)

- The capillaries absorb simple sugars, which are transported to the liver through the *Hepatic Portal Vein*.

- Amino acids are also absorbed & transported through the body via the capillaries.

- Fats are absorbed through the lacteals and travel through the lymphatic system.
A Villus

- Goblet cell
- Columnar epithelial cell
- Nerve
- Lacteal
- Capillary network
- Lamina propria
- Arteriole
- Venule
- Lymphatic vessel

(c) Structure of an isolated villus
Large Intestine

- A.k.a. *Colon*.
- Larger in diameter
- Extends from ileocecal valve to anus
- Involved in water recovery from the digestive juices left behind.
- Houses beneficial Bacteria that produce several vitamins
The Large Intestine
Large Intestine (cont.)

- The useless end product of the digestive process is *feces*.
- Feces contains masses of bacteria, cellulose and undigested food materials.
- Feces is stored at the terminal portion of the L.I. called the *rectum*.
- Two rings of muscle called *Sphincters* control the elimination of feces from the body via the *anus*. 

Large Intestine (cont.)

- There are occasional interruptions in proper Large Intestine function:
  - *Constipation* occurs when peristalsis slows and most of the water is removed from the feces, which becomes impacted.
  
  - *Diarrhea* occurs when water is not reabsorbed, either due to bacterial infection or some other irritant.
Small Intestine and the Accessory Organs

- Accessory organs of the digestive system:
  - Teeth, tongue, salivary glands, liver, gallbladder, pancreas
- Accessory organs are essential to digestion, yet they are not actually part of the Alimentary Canal
- Three accessory organs associated with the small intestine:
  - Pancreas
  - Liver
  - Gall Bladder
Hormones

- **Gastrin** – produced by the enteroendocrine cells in the stomach when you eat a meal high in protein.
  - Causes stomach wall to contract and gastric juices to be secreted.

- **Secretin** – produced by cells of duodenum when it receives acidic chyme from stomach
  - Causes pancreas to release bicarbonate (strong base) into the duodenum (to raise the pH).

- **CCK** (cholecystokinin) – produced by cells of duodenum when it receives partially digested fats and protein from the stomach
  - Causes pancreas to release pancreatic juice into the duodenum (to complete breakdown of fat & protein)
Functions of the Liver

- Hepatocytes – liver cells produce **bile**
  - Composition
    - Water
    - Bile salts
    - Cholesterol
    - Pigments
      - **Bilirubin** – principal pigment.
      - **Jaundice** – caused by excessive amounts of bilirubin/blocked ducts – causes yellowing of skin/eyes.
  - Digestive function
    - Emulsification of fats – makes them more manageable for lipase to completely break them down.

- Stores carbohydrates as glycogen
- Filtering unit of the body
Liver Location and Overview

- Large & triangle shaped
- Right side of the body
- Below the diaphragm
- 4 lobes
The Liver – anterior

- Coronary ligament
- Left lobe
- Right lobe
- Falciform ligament
- Round ligament (ligamentum teres)
- Gallbladder

(c) Anterior (parietal) surface
The Liver – posterior

- Left lobe
- Caudate lobe
- Left hepatic vein
- Inferior vena cava
- Right lobe
- Coronary ligament
- Hepatic portal vein
- Hepatic artery
- Quadrat lobe
- Common bile duct
- Gallbladder
- Hilus (porta hepatis)

(d) Posterior (visceral) surface
Histology and Blood Supply of the Liver

(a) Lobar organization
Gall Bladder

- Stores and concentrates bile made by the liver.
- Contracts and squeezes bile into the Duodenum of the small intestine, as needed.
The Gallbladder – find those ducts again
1. Cystic duct from gall bladder

2. Hepatic ducts from Liver

These 2 ducts form the common bile duct that lead to the duodenum (pathway for bile)
Head: the broad end that fits into the C-shaped duodenum
Tail: the narrow end
Pancreatic duct: carries pancreatic enzymes to the duodenum
Opening of the duct: hepatopancreatic ampulla
The Pancreas—notice where it’s positioned

- The pancreatic duct is where the pancreatic juice leaves pancreas into the duodenum.
Pancreatic Cells

Acinus (Acini) – secrete pancreatic enzymes – trypsin, nuclease, lipase, amylase

Islet cells – secrete endocrine hormones (insulin and glucoagon to regulate blood sugar)
Pancreatic Secretions (Exocrine)

- **Digestive enzymes:** help with the chemical digestion of food in the small intestine

  - **Pancreatic Amylase:** disaccharides into monosaccharides
  - **Proteases & Trypsin:** small polypeptides into amino acids
  - **Pancreatic Lipase:** fat droplets (emulsified in bile salts) → glycerol & fatty acids
  - **Nuclease:** Nucleic acids into nucleotides
  - **Bicarbonate:** a base that neutralizes the highly acidic chyme

All of these tiny molecules will be absorbed into the capillaries & lacteal inside the villi

http://www.zerobio.com/secretin_flash.htm
Enzymes in summary:

- **Salivary Amylase** – made by salivary glands and breaks up carbs into disaccharides.
- **Pepsin** – made in stomach and breaks up proteins into small polypeptides.
- **Trypsin, Amylase, Nuclease, Lipase** – made in Pancreas and delivered to Small intestine.
  - **Trypsin** – breaks polypeptides into amino acids.
  - **Amylase** – breaks disaccharides into monosaccharides.
  - **Nuclease** – breaks nucleic acids into nucleotides.
  - **Lipase** – breaks emulsified fats into fatty acids and glycerol.
**Digestion of carbohydrates**

- **Foodstuff**: Starch and disaccharides
  - Oligosaccharides* and disaccharides
    - Lactose
    - Maltose
    - Sucrose
    - Galactose
    - Glucose
    - Fructose

- **Enzyme(s) and source**
  - Salivary amylase (Mouth)
  - Pancreatic amylase (Small intestine)

- **Site of action**
  - Small intestine

**Absorption of carbohydrates**

The monosaccharides glucose, galactose, and fructose enter the capillary blood in the villi and are transported to the liver via the hepatic portal vein.

*Oligosaccharides consist of a few linked monosaccharides.*
<table>
<thead>
<tr>
<th>Foodstuff</th>
<th>Enzyme(s) and source</th>
<th>Site of action</th>
</tr>
</thead>
<tbody>
<tr>
<td>Protein</td>
<td>Pepsin (stomach glands) in the presence of HCl</td>
<td>Stomach</td>
</tr>
<tr>
<td>Large polypeptides</td>
<td>Pancreatic enzymes (trypsin, chymotrypsin,</td>
<td>Small intestine</td>
</tr>
<tr>
<td></td>
<td>carboxypeptidase)</td>
<td></td>
</tr>
<tr>
<td>Small polypeptides, small peptides</td>
<td>Brush border enzymes (aminopeptidase, carboxypeptidase, and dipeptidase)</td>
<td>Small intestine</td>
</tr>
<tr>
<td>Amino acids (some dipeptides and tripeptides)</td>
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</tbody>
</table>

**Absorption of proteins**: Amino acids enter the capillary blood in the villi and are transported to the liver via the hepatic portal vein.
Digestion of fats

- Unemulsified fats
  - Emulsified by the detergent action of bile salts from the liver
  - Pancreatic lipase
  - Small intestine
- Monoglycerides and fatty acids
- Glycerol and fatty acids

Absorption of fats

Fatty acids and monoglycerides enter the lacteals of the villi and are transported to the systemic circulation via the lymph in the thoracic duct. (Glycerol and short-chain fatty acids are absorbed into the capillary blood in the villi and transported to the liver via the hepatic portal vein.)
Ingestion
- Food
- Pharynx
- Esophagus

Mechanical breakdown
- Chewing (mouth)
- Churning (stomach)
- Segmentation (small intestine)

Propulsion
- Swallowing (oropharynx)
- Peristalsis (esophagus, stomach, small intestine, large intestine)

Digestion

Absorption
- Lymph vessel
- Blood vessel
- Mainly H₂O

Defecation
- Feces
- Anus
Essential Nutrients

- Essential nutrients are minerals that are needed by the body, yet cannot be made by the organism.

- Missing out on one or more essential nutrient is known as *malnourished*.

- *Undernourishment* is caused by insufficient calories.
Essential Nutrient Deficiency Symptoms

- Vitamin and mineral deficiencies can cause severe disorders in the body

- Examples include: Kwashiorkor, Scurvy, Rickets, and Goiter.
Essential Nutrient Deficiency
Symptoms (cont.)

- Kwashiorkor

- Caused by inadequate Protein intake
- The protuberant abdomen is caused by the body’s inability to absorb fluids, due to depleted necessary blood proteins
Scurvy

Caused by Vitamin C deficiency.

Results in degeneration of blood vessels which causes spongy gums. Tooth loss is common in advanced stages.
Rickets

Caused by Vitamin D deficiency

Causes bone softening and deformity
Essential Nutrient Deficiency
Symptoms (cont.)

- Goiter – thyroid gland that has grown to an abnormally large size
- Iodine deficiency