Digestive System

- Ingestion: eating
- Secretion: water, acid, buffers, and enzymes help to break down food
- Mixing and propulsion: thoroughly mix with secretions and move food toward anus
- Digestion:
  - Mechanical: teeth cut and grind food, peristalsis moves food down GI tract
  - Chemical: enzymes act on food to break it down
Digestive Processes

- absorption: broken down food transports from lumen of GI tract into bloodstream, where it then is distributed throughout body
- defecation: elimination of undigested foods and bacteria
Layers of GI Tract

- mucosa: epithelium (protection and absorption), lamina propria (contains lymph tissue, among other things), and muscularis mucosae (smooth muscle that moves mucosa to ensure maximal contact between food and mucosa)
- submucosa: contains nerve plexus to control muscularis mucosae, lymph tissue
Layers of GI Tract

- muscularis:
  - two layers of muscle (circular and longitudinal)
    - skeletal muscle for voluntary swallowing and anal sphincter
    - smooth muscle everywhere else
  - also contains myenteric plexus, a nerve bundle that controls GI tract motility (peristalsis)
- serosa or adventitia (depending on location in body): connective tissue that surrounds GI tract

Peritoneum

- Liver
- Serosa
- Stomach
- Greater omentum
- Large intestine
- Small intestine
- Peritoneal peritoneum
- Peritoneal cavity
- Urinary bladder
- Rectum
- Diaphragm
- Lesser omentum
- Pancreas
- Duodenum
- Dorsal mesentery
- Visceral peritoneum
**Peritoneum**

- largest serous membrane (secretes slippery fluid) in body
- loosely holds viscera in place
- mesentary holds small intestine to wall
- greater omentum covers the colon and small intestine
- lesser omentum holds stomach up

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**Mouth**

- mechanical digestion involves mastication (chewing) of food into a soft bolus
- chemical digestion: salivary amylase initiates starch breakdown
Mouth

- tongue: much skeletal muscle for forming words, moving food around mouth
- salivary glands
  - parotid glands: watery liquid with salivary amylase (for starch digestion)
  - submandibular glands: similar to parotid secretion
  - sublingual glands: thick secretion (from mucous cells)
- Controlled by?

Salivary Glands
Teeth

- crown: portion above gumline
- root: below gumline
- dentin: makes up most of tooth, lots of calcium
- enamel: covers dentin on crown, very hard to resist wear and tear and to protect dentin from acid
- periodontal ligament: holds tooth in socket of bone
Teeth

- root canal therapy: clean out rotting root canal by removing entire pulp cavity contents and sealing
- incisors: cut food, as when you bite off a piece of food
- canines (cuspids): tear and shred food, found in meat-eaters
- molars: grind food
- adults have 32 teeth, children only 20 deciduous (baby) teeth because their jaw is too small for all 32

Deglutination

- voluntary stage: bolus is moved to oropharynx by activity of tongue, soft palate and uvula close off the nasopharynx to prevent bolus movement into nasal cavity
**Deglutination**

- pharyngeal (involuntary) stage:
  - bolus enters oropharynx
  - reflex involves medulla o brain to move larynx upward, epiglottis closes over it to seal larynx and trachea
  - vocal cords are also pulled together to prevent any possible movement of food through larynx

**Esophageal Peristalsis**

- Movement of food through esophagus
  - elevation of larynx causes upper esophageal sphincter to open, allowing bolus into esophagus
  - peristalsis
    - circular muscle contracts from above bolus, moving bolus down
    - the longitudinal muscle contracts shortens beneath the bolus to shorten the distance bolus must move
  - when bolus reaches the end of esophagus, the lower esophageal sphincter must open to allow passage into stomach
Esophageal Peristalsis

Stomach
- four areas: cardiac, fundus, body, and pylorus
**Stomach Functions**

- Secretions into lumen (gastric fluid)
  - Hydrochloric acid (HCl)
  - Mucus (protective)
  - Pepsinogen (inactive form of a protein digesting enzyme)
- Gastrin (hormone) is secreted into the bloodstream
- Mixing food with secretions into chyme
- Virtually no absorption occurs in stomach, except for some water and some drugs (like aspirin)

**Stomach Cells**

- mucous cell: secretes mucus to prevent acid from damaging stomach
- parietal cell: secretes HCl (allows conversion of pepsinogen to pepsin) and intrinsic factor (Vitamin B12 absorption for erythrocyte production)
Stomach Cells

- chief cell: secretes pepsinogen (pepsin breaks down protein in low pH) and gastric lipase (for fat digestion, but pH of stomach is too acidic for lipase to work well here)
- G cell (enteroendocrine cell): secretes gastrin (stimulates parietal and chief cells, increases stomach motility, constricts lower esophageal sphincter and relaxes pyloric sphincter)
Regulation of Gastric Activity

- the cephalic phase
  - cerebrum stimulates sensation of hunger, stimulates stomach cells and motility
- the gastric phase
  - stretch of stomach wall activates stretch receptors, activates stomach
- the intestinal phase
  - presence of acidic chyme, lipids inhibits stomach

**Key**
- Stimulation
- Inhibition
- Reduced or no effect
Chyme Mixing & Gastric Emptying

- A thick mixture of food and gastric fluid
- Mixed and moved by waves of stomach contractions (peristalsis)
- Chyme leaves stomach through pyloric sphincter in small amounts (few mls)

What about ulcers? Or GERD?

The gastric mucosal barrier made up of the following components enables the stomach to contain acid with injuring itself:

1. The luminal membranes of the gastric mucosal cells are impermeable to H⁺ so that HCl cannot penetrate into the cells.
2. The cells are joined by tight junctions that prevent HCl from penetrating between them.
3. A mucus coating over the gastric mucosa offers further protection.

= Passage prevented
Pancreas, Liver, and Gallbladder

- anatomical structures: common hepatic duct, cystic duct, common bile duct, pancreatic duct, hepatopancreatic ampulla, sphincter of Oddi

Pancreas

- In response to the acidity of chyme, the duodenum produces
  - Secretin: stimulates the pancreas to release sodium bicarbonate into the small intestine
  - CCK (cholecystokinin): stimulates the pancreas to release digestive enzymes into the small intestine
Pancreas

- pancreatic juice contains:
  - sodium bicarbonate to raise the pH to about 7.5
  - pancreatic lipase for triglyceride digestion
  - pancreatic amylase for starch digestion
  - trypsin, chymotrypsin, elastase, carboxypeptidase for protein digestion
    - these 4 are actually secreted in an inactive form, but are activated by the small intestinal brush border enzyme enterokinase
  - nucleases to digest DNA and RNA
Liver Functions

- carbohydrate metabolism
- lipid metabolism
- amino acid metabolism
- waste product removal
- some vitamin storage (A, D, E, K, B₁₂)
- iron storage
- break down drugs, hormones, antibodies, toxins

Bile

- Liver produces bile for emulsification of lipids (to increase the surface area for pancreatic lipase to digest fat)
- Gall bladder stores and concentrates bile
**Bile Production**

- Secretin production by duodenum causes sodium bicarbonate release by liver
- CCK results gall bladder contraction and release of bile

**Small Intestine**

- major site of digestion and absorption of nutrients
- made up of duodenum, jejunum, and ileum
Small Intestine

- mucosa is specialized with villi (singular: villus) containing special cells and lacteals

Small Intestine

- lacteal is a lymphatic capillary used here for fat transportation (as a chylomicron)
- goblet cells secrete mucus
- enteroendocrine cells secrete CCK, secretin, and GIP (gastric inhibitory polypeptide)
- paneth cell secretes lysozyme that regulate bacterial content of intestine
**Small Intestine**

- absorptive cells have microvilli that form the brush border
  - Absorption of many nutrients
  - Production of brush border enzymes
    - four enzymes for sugar digestion (alphadextrinase, maltase, sucrase, lactase)
    - two peptidases to break peptides into amino acids
    - nucleosidases to break down nucleotides

**Digestion in Small Intestine**

- mechanical digestion in small intestine consists of segmentation to mix food within the small intestine and peristalsis to move food along the intestine (regulated by the parasympathetic nervous system)
Digestion in Small Intestine

- chemical digestion is accomplished by the combined effects of pancreatic enzymes, bile, and brush border enzymes.

Absorption in Small Intestine

- sugars (mostly glucose, but also galactose and fructose) are carried across brush border by either secondary transport with sodium (also causes water to move in by osmosis) or facilitated diffusion (for fructose).
Absorption in Small Intestine

- sugars then move across basal surface of absorptive cell by facilitated diffusion into blood capillary of a villus

- amino acids cross brush border mostly by secondary active transport with sodium, then diffuse across basal surface
Absorption in Small Intestine

- Once bile has emulsified the lipid, pancreatic lipase breaks the triglycerides into monoglycerides and fatty acids.

- Bile salts then surround the monoglycerides and fatty acids to form small balls called micelles.

Micelles in the bile pass to the small intestine and pick up several types of dietary and emulsified lipids.
Absorption in Small Intestine

- the micelle then comes in contact with the brush border, and the monoglycerides and fatty acids simply diffuse across the brush border cell membrane
- once inside the absorptive cell, the monoglycerides and fatty acids reform as triglycerides
- the triglycerides are packaged by a protein coat with absorbed steroids and phospholipids
  - this is called a chylomicron
- the chylomicron is then secreted from the absorptive cell, where they then are picked up by a lacteal and transported in lymph to the left subclavian vein, where it joins the general circulation
Absorption in Small Intestine

- transport of lipids made in liver
  - VLDL (60% TG, 14% cholesterol) carries lipids from liver to adipose cells, where it stores much TG, leaving a LDL
  - LDL (10% TG, 45% cholesterol) transports cholesterol to most cells in body (“bad” chl)
  - HDL (5% TG, 20% cholesterol, 45% protein) carries excess lipids back to the liver (“good” chl)

Water Absorption

(Water in feces = ingested + secreted − absorbed)
**Large Intestine**

- very little digestion occurs (only some B vitamins and vitamin K)
  - accomplished by bacteria, not secreted enzymes
- some absorption of water in large intestine

- main purpose of large intestine is feces formation and storage until voluntary defecation
- peristalsis in large intestine is much slower than in small intestine, but does occur to help move food through colon
Large Intestine

- mass peristalsis also occurs, particularly during or immediately after a meal
  - powerful peristaltic wave from about the middle of the transverse colon to the rectum
  - pushes feces quickly toward the rectum, which initiates the defecation reflex (contraction of longitudinal rectal wall muscle to increase pressure)
  - voluntary contraction of diaphragm and abdominal muscles, together with voluntary relaxation of anal sphincter, allow defecation
  - in the absence of the voluntary actions, defecation in delayed

### Table 7.2 Major Enzymes of Digestion and What They Do

<table>
<thead>
<tr>
<th>Enzyme</th>
<th>Released by</th>
<th>Active In:</th>
<th>Breaks down:</th>
<th>Resulting Products</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>DIGESTING CARBOHYDRATES:</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Salivary amylase</td>
<td>Salivary glands</td>
<td>Mouth, stomach</td>
<td>Polysaccharides</td>
<td>Disaccharides, oligosaccharides</td>
</tr>
<tr>
<td>Pancreatic amylase</td>
<td>Pancreas</td>
<td>Small intestine</td>
<td>Polysaccharides</td>
<td>Disaccharides, monosaccharides</td>
</tr>
<tr>
<td>Disaccharidases</td>
<td></td>
<td>Small intestine</td>
<td>Disaccharides</td>
<td>MONOSACCHARIDES* (e.g., glucose)</td>
</tr>
<tr>
<td><strong>DIGESTING PROTEINS:</strong></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pepsin</td>
<td>Stomach lining</td>
<td>Stomach</td>
<td>Proteins</td>
<td>Protein fragments</td>
</tr>
<tr>
<td>Trypsin and chymotrypsin</td>
<td>Pancreas</td>
<td>Small intestine</td>
<td>Proteins</td>
<td>Protein fragments</td>
</tr>
<tr>
<td>Carboxypeptidase</td>
<td>Pancreas</td>
<td>Small intestine</td>
<td>Peptides</td>
<td>AMINO ACIDS*</td>
</tr>
<tr>
<td>Aminopeptidase</td>
<td>Intestinal lining</td>
<td>Small intestine</td>
<td>Peptides</td>
<td>AMINO ACIDS*</td>
</tr>
<tr>
<td><strong>DIGESTING FATS:</strong></td>
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<td></td>
<td></td>
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<td>Lipase</td>
<td>Pancreas</td>
<td>Small intestine</td>
<td>Triglycerides</td>
<td>FREE FATTY ACIDS, MONOGLYCERIDES*</td>
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<tr>
<td><strong>DIGESTING NUCLEIC ACIDS:</strong></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Pancreatic nucleases</td>
<td>Pancreas</td>
<td>Small intestine</td>
<td>DNA, RNA</td>
<td>NUCLEOTIDES*</td>
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<tr>
<td>Intestinal nucleases</td>
<td>Intestinal lining</td>
<td>Small intestine</td>
<td>Nucleotides</td>
<td>NUCLEOTIDE BASES, MONOSACCHARIDES*</td>
</tr>
</tbody>
</table>

*Products small enough to be absorbed into the internal environment.
Path of absorption

**Carbohydrate digestion**

Absorption: The monosaccharides glucose and fructose are absorbed via cotransport with sodium ions; fructose passes via facilitated diffusion. All monosaccharides enter the capillary blood in the villi and are transported to the liver via the hepatic portal vein.

- **Starch and disaccharides**
  - Salivary amylase
  - Pancreatic amylase
  - Site of action: Mouth, Small intestine

- **Oligosaccharides and disaccharides**
  - Lactose, Maltose, Sucrose
  - Brush border enzymes in small intestine (diastase, glucoamylase, isomaltase, maltase, and lactase)
  - Site of action: Small intestine

- **Glucose, Galactose, Fructose**

**Protein digestion**

Absorption: Amino acids are absorbed via cotransport with sodium ions; they enter the capillary blood in the villi and are transported to the liver via the hepatic portal vein.

- **Protein**
  - Pepsin (stomach glands) in the presence of HCl
  - Site of action: Stomach

- **Large polypeptides**
  - Pancreatic enzymes (trypsin, chymotrypsin, carboxypeptidase)
  - Site of action: Small intestine

- **Small polypeptides, small peptides**
  - Brush border enzymes (aminopeptidases, carboxypeptidases, and dipeptidases)
  - Site of action: Small intestine

- **Amino acids (some dipeptides and tripeptides)**

**Fat digestion**

Absorption: Fatty acids and monoglycerides enter the intestinal cells via diffusion. They are combined with proteins within the cells, and the resulting chylomicrons are excreted. They 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.)

- **Unemulsified fats**
  - Emulsified by the digestive action of bile salts derived from the liver
  - Site of action: Small intestine

- **Monoglycerides and fatty acids**
  - Pancreatic lipase
  - Site of action: Small intestine

**Nucleic acid digestion**

Absorption: Active transport via membrane carriers; absorbed into capillary blood in the villi and transported to the liver via the hepatic portal vein.

- **Nucleic acids**
  - Pancreatic ribonuclease and deoxyribonuclease
  - Site of action: Small intestine

- **Pentose sugars, N-containing bases, phosphate ions**
  - Brush border enzymes (nucleosidases and phosphatases)
  - Site of action: Small intestine
What is Malnutrition?

Population Distributions of Nutritional Status


UNICEF Conceptual Model of the Causation of Undernutrition, Modified To Include Its Consequences
Micronutrient Malnutrition

- Vitamin A deficiency
- Iron deficiency
- Iodine deficiency

Vitamin A Physiology

- Retinal vital for formation of rhodopsin
- Normal immune response (complex)
- Epithelial cell integrity (skin, digestive tract lining)
- Bone remodeling
- Sperm production
Vitamin A Deficiency

• Vision disturbances (from “night blindness” to xerophthalmia and blindness)
  • VAD is the leading cause of preventable blindness in children worldwide
• Increased risk of mortality from infectious disease
  • VAD increases severe illness and death from diarrhea, measles, malaria, etc.

Prevalence of VAD

West et al., 2002
Iron Physiology

- Creation of heme groups
  - Oxygen carrying capacity
- Creation of cytochromes and other enzymes
  - Also have heme groups
  - Cytochrome C plays role in electron transport

Iron Deficiency

- Symptoms related to reduced $O_2$ capacity
- Poor outcomes
  - Pregnancy (20% of maternal deaths)
  - Developmental delays (growth and cognitive)
  - Reduce work productivity
- Enormous prevalence: 3 billion people
Iron Deficiency

• Triad of causes: iron deficiency in diet, malaria, helminth infections

Iodine Physiology

• Iodine required for production of thyroid hormones in thyroid gland
  • Iodine attaches to tyrosine
  • Iodinated tyrosine couples to form $T_3$ and $T_4$
Iodine Deficiency

- Leading cause of preventable mental retardation in the world (cretinism)
- Poor pregnancy outcomes
- Goiter (hypertrophy of thyroid gland)
- Related to low iodine in soil for people who eat only local foods