Digestion, Absorption, and Transport

• Food is a mixture of nutrients
• Nutrients from food need to be released and transformed into units that the cells of the body can use
• Digestion is the process of breaking down foods into nutrients to prepare for absorption.
Challenges the Body Must Overcome

- Eating, drinking and breathing occur in the same anatomical area, how does the body keep breathing & swallowing from interfering with one another?
  - Swallowed food/fluid passes through the pharynx (a short tube shared by both the digestive and respiratory system. During swallowing, the epiglottis closes off the air passages so you don’t choke when you swallow.
- To reach the stomach, food must pass through the diaphragm, a dome of muscle that separated the upper half of the body cavity from the lower half.
Challenges the Body Must Overcome

- The materials in the digestive tract should be kept moving forward, slowly but steadily, at a pace that permits all reactions to reach completion.
- Food must be lubricated with liquids to move through the digestive system. The amount of fluids must be regulated to maintain the appropriate consistency to move smoothly along.
Challenges the Body Must Overcome

- When the digestive enzymes break food down they need it in a finely divided form, suspended in enough liquid so that every particle is accessible.
- Digestive enzymes are designed to break down carbohydrates, fat and protein. The walls of the GI tract, composed of living cells, are also made of carbohydrate, fat and protein. They need protection against the powerful digestive juices they secrete.
Challenges the Body Must Overcome

- After nutrients are absorbed, the system must excrete the remaining residue. Excreting all the water along with the solid residue, however, would be wasteful & messy.

- Once waste matter has reached the end of the digestive tract, it must be excreted, but it would be inconvenient and embarrassing if this function occurred continuously. Provision must be made for periodic, voluntary evacuation.
The Digestive System

- A series of hollow organs joined in a long, twisting tube that begins at the mouth and ends at the anus
- Inside this tube is a lining called the mucosa
  - The mucosa in the mouth, stomach & small intestine contains tiny glands that produce juices to help digest food

Adapted from:  http://www.nih.gov NIDDK (Your Digestive System and How it Works)
http://digestive.niddk.nih.gov/ddiseases/pubs/yrdd/
The Digestive System

- Two solid organs, the liver and the pancreas, produce digestive juices that reach the intestine through small tubes.
- Parts of other organ systems also play a major role, e.g., the nervous system & the circulatory system.

Adapted from: [http://www.nih.gov](http://www.nih.gov) NIDDK (Your Digestive System and How it Works)
The Digestive System

- Process of digestion begins in the **mouth**
  - **Teeth** crush/grind food into smaller pieces
  - Fluids from foods, beverages & **salivary glands** mix with chewed foods
    - Only particles in solution can react with **taste buds** on the **tongue**
    - Fluids make the process of swallowing easier
  - **Tongue** serves a couple of purposes
    - Allows you to taste foods
    - Helps move food around the mouth, thus facilitating chewing and swallowing
The Digestive System

- **Bolus** = portion of food swallowed at one time
- During swallowing, the bolus passes through the pharynx
  - Both the GI tract and respiratory tract share this short tube
  - To prevent choking during swallowing, the **epiglottis** closes off air passages in the pharynx
The Digestive System

- Once swallowed, the upper esophageal sphincter opens and the bolus enters the esophagus.
- The bolus slides down the esophagus passing through a hole in the diaphragm.
- The lower esophageal sphincter (LES) opens and the bolus enters the stomach.
  - The LES closes so that the bolus proceeds forward.
The Digestive System

- The *stomach* processes the bolus into a semi-liquid mass called *chyme*.
- Chyme is released through the *pyloric sphincter* into the *small intestine*.
  - The *pyloric sphincter* then closes behind the chyme.
- In the *small intestine*, an opening from the *common bile duct* is dripping fluids from two other organs.
  - Pancreas
  - Gallbladder
The Digestive System

- The chyme travels through the 3 segments of the small intestine
  - Duodenum
  - Jejunum
  - Ileum
- Chyme passes through the ileocecal valve into the large intestine (colon)
- The contents of the large intestine to the rectum & anal canal
  - water is reabsorbed throughout the colon, leaving a semi-solid mass
  - The strong muscles of the rectum & anal canal hold back the waste until it is time to defecate
The Digestive System

- **Peristalsis:**
  - wavelike muscular contractions of the GI tract that push its contents along

- **Stomach action**
  - Stomach has the thickest walls & strongest muscles of all of the GI tract organs
  - Circular, longitudinal & diagonal muscles churn food into semiliquid chyme
The Digestive System

- **Segmentation**
  - Rhythmic contraction of circular muscles of intestines
  - Mix chyme
  - Promote close contact with digestive juices & absorbing cells

- **Sphincter contractions**
  - Allow contents of GI tract to move at a controlled pace
  - Promote one-way flow of GI contents
  - Allow voluntary evacuation of waste products
The Digestive System

- Cells lining the digestive tract are replaced every 3-5 days
  - Because of this frequent turnover, the GI tract is very sensitive to changes in nutritional status
- Pancreas secretes enzymes in response to the amounts of carbohydrate, fat, & protein in the diet over the past several days
  - With a dramatic change in diet, there can be a day or two lag before the pancreas begins secreting the correct proportion enzymes, resulting in digestive upsets.

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The Secretions of Digestion

- Includes **digestive enzymes** that act as catalysts in hydrolysis reactions to break down foods into their constituent molecules
  - Carbohydrates to simple sugar units
  - Proteins to amino acids
  - Fats to fatty acids + glycerol
- **Saliva** from the salivary glands moistens foods
- Gastric juice from the gastric glands includes **hydrochloric acid**. Acid is needed to prepare proteins for digestion and also to enhance absorption of many minerals.
The Salivary Glands
Digestion

The Secretions of Digestion

- The goblet cells of the stomach wall secrete mucus to protect the walls of the stomach from the high acidity levels that are measured by pH units.

- **Pancreatic juice** contains intestinal enzymes (carbohydrase, lipase, protease) and bicarbonate (to neutralize the acidic chyme coming from the stomach).

- **Bile** is produced by the liver, stored in the gall bladder, and acts as an emulsifier to suspend fat in small droplets in the watery chyme.
pH of common substances:

14  Concentrated lye
13  Oven cleaner
12
11  Household ammonia
10
9   Baking soda
  Bile
  Pancreatic juice
  Blood
  Water
  Saliva
  Urine
9   Coffee
8   Orange juice
7   Vinegar
6   Lemon juice
5   Gastric juice
4   Water
3   Urine
2   Blood
1   Saliva
0   Pancreatic juice
  Bile
  Concentrated lye

Basic

pH neutral

Acidic
The Digestive Fate of a Sandwich

**MOUTH: CHEWING AND SWALLOWING, WITH LITTLE DIGESTION**

Carbohydrate digestion begins as the salivary enzyme starts to break down the starch from bread and peanut butter. Fiber covering on the sesame seeds is crushed by the teeth, which exposes the nutrients inside the seeds to the upcoming digestive enzymes.

**STOMACH: COLLECTING AND CHURNING, WITH SOME DIGESTION**

Carbohydrate digestion continues until the mashed sandwich has been mixed with the gastric juices; the stomach acid of the gastric juices inactivates the salivary enzyme, and carbohydrate digestion ceases. Proteins from the bread, seeds, and peanut butter begin to uncoil when they mix with the gastric acid, making them available to the gastric protease enzymes that begin to digest proteins. Fat from the peanut butter forms a separate layer on top of the watery mixture.

**SMALL INTESTINE: DIGESTING AND ABSORBING**

Sugars from the banana require so little digestion that they begin to traverse the intestinal cells immediately on contact. Starch digestion kicks up when the pancreas sends pancreatic enzymes to the small intestine via the pancreatic duct. Enzymes on the surfaces of the small intestinal cells complete the process of breaking down starch into small fragments that can be absorbed through the intestinal cell walls and into the hepatic portal vein. Fat from the peanut butter and seeds is emulsified with the watery digestive fluids by bile. Now the pancreatic and intestinal lipases can begin to break down the fat to smaller fragments that can be absorbed through the cells of the small intestinal wall and into the lymph. Protein digestion depends on the pancreatic and intestinal proteases. Small fragments of protein are liberated and absorbed through the cells of the small intestinal wall and into the hepatic portal vein. Vitamins and minerals are absorbed. Note: Sugars and starches are members of the carbohydrate family.

**LARGE INTESTINE: REABSORBING AND ELIMINATING**

Fluids and some minerals are absorbed. Some fibers from the seeds, whole-wheat bread, peanut butter, and banana are partly digested by the bacteria living there, and some of these products are absorbed. Most fibers pass through the large intestine and are excreted as feces; some fat, cholesterol, and minerals bind to fiber and are also excreted.
Intrinsic Factor

- Intrinsic factor is a glycoprotein secreted by the parietal cells of the gastric mucosa.
- Vitamin B₁₂ is bound to protein in food.
- The acidic environment of the stomach contents releases the food protein and allows B₁₂ to bind to a special binding protein plus the intrinsic factor.
- The B₁₂-binding protein-intrinsic factor complex passes into the small intestine where the binding protein is digested, leaving B₁₂-intrinsic factor.
- B₁₂ is then absorbed in the terminal ileum.
Intrinsic Factor

- Vitamin B₁₂ deficiency can occur (secondary to malabsorption) when
  - There is low stomach acid secretion & food-bound protein cannot be separated from B₁₂
    - Autoimmune disorder – pernicious anemia
    - Atrophic gastritis
    - Medications
  - There is damage to the terminal ileum
    - Crohn’s disease
    - Celiac disease
  - Partial or total gastrectomy; ileal resection
The Digestive System

- Both the vascular and lymphatic systems supply vessels to each villus in the digestive tract.
- Water-soluble nutrients and small particles of fat digestion are released directly into the circulatory system. From the GI tract, they are guided to the liver where their fate and destination will be determined.
The vascular system

1. Blood leaves the right side of the heart by way of the pulmonary artery.
2. Blood loses carbon dioxide and picks up oxygen in the lungs and returns to the left side of the heart by way of the pulmonary vein.
3. Blood leaves the left side of the heart by way of the aorta, the main artery that launches blood on its course through the body.
4. Blood may leave the aorta to go to the upper body and head; or Blood may leave the aorta to go to the lower body.
5. Blood may go to the digestive tract and then the liver; or Blood may go to the pelvis, kidneys, and legs.
6. Blood returns to the right side of the heart.
7. Lymph from most of the body’s organs, including the digestive system, enters the bloodstream near the heart.

Key:
- Arteries
- Capillaries
- Veins
- Lymph vessels

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The Digestive System

- Fat soluble vitamins and larger fats area assembled (with proteins) into *chylomicrons* and released into the lymphatic system.
- These *chylomicrons* move through the lymph, bypassing the liver at first, and later enter the bloodstream at a point near the heart.
The Liver

1. Vessels gather up nutrients and reabsorbed water and salts from all over the digestive tract.

   Not shown here: Parallel to these vessels (veins) are other vessels (arteries) that carry oxygen-rich blood from the heart to the intestines.

2. The vessels merge into the hepatic portal vein, which conducts all absorbed materials to the liver.

3. The hepatic artery brings a supply of freshly oxygenated blood (not loaded with nutrients) from the lungs to supply oxygen to the liver's own cells.

4. Capillaries branch all over the liver, making nutrients and oxygen available to all its cells and giving the cells access to blood from the digestive system.

5. The hepatic vein gathers up blood in the liver and returns it to the heart.

In contrast, nutrients absorbed into lymph do not go to the liver first. They go to the heart, which pumps them to all the body's cells. The cells remove the nutrients they need, and the liver then has to deal only with the remnants.
Gastrointestinal Bacteria

- GI bacteria can digest fiber and complex proteins producing short fragments of fat
  - Colon cells can use these fragments for energy
- GI bacteria can also produce several vitamins
  - Biotin
  - Folate
  - Vitamin B6
  - Vitamin B12
  - Vitamin K – a significant source of this vitamin
Gastrointestinal Bacteria

- A healthy GI tract has many different non-disease-causing bacteria known as flora or microflora.
- This healthy bacteria may prevent the overgrowth of pathogenic bacteria in the GI tract.
- **Probiotics** are bacteria found in the GI tract that can be beneficial to health. An example is the bacteria found in yogurt.
- **Prebiotics** are nondigestible substances in foods that stimulate growth or activity of resident bacteria within the large intestine.
Coordination & Regulation of Digestion & Absorption

- 2 intricate and sensitive systems coordinate all the digestive and absorptive processes:
  - Hormonal (endocrine) system
  - Nervous system
- Example: Gastrin is secreted by the stomach.
  - Food entering the stomach stimulates release of gastrin
  - Gastrin stimulates stomach glands to secrete components of hydrochloric acid
  - When pH of 1.5 is reached, the acid itself turns off the gastrin-producing cells (feedback mechanism)
Coordination & Regulation of Digestion & Absorption

- Example: Pyloric sphincter – sensitive to changes in pH
  - This ensures a slow release of acidic stomach contents and allows time for the pancreatic juices to be secreted to neutralize them.
    - Pyloric sphincter relaxes, allows acidic chyme to seep through from the stomach
    - Cells of pyloric muscle on the intestinal side sense acid, causing the sphincter to close tightly
    - Once the acidic chyme has been neutralized by pancreatic bicarbonate and juices surrounding the sphincter have become alkaline, the muscle relaxes again. This allows acidic chyme to seep in and starts the process again.
Example: Secretin is secreted by the duodenum.

- Presence of chyme stimulates cells of the duodenum to release the hormone secretin into the blood
- When secretin reaches the pancreas, it stimulates the release of bicarbonate-rich juices
Example: Fat in the intestine stimulates the intestinal wall to release the hormone cholecystokinin (CCK), which
- Targets the gall bladder and stimulates release of bile
- Stimulates release of pancreatic juices, bicarbonate & enzymes
- Slows GI motility for foods that take longer to be digested.
Digestion of Carbohydrates

• In the mouth, the salivary enzyme amylase begins to hydrolyze starch into short polysaccharides and maltose.

• In the stomach, acid continues to hydrolyze starch while fiber delays gastric emptying and provides a feeling of fullness (satiety).
Digestion of Carbohydrates

- In the small intestine, pancreatic amylase among other enzymes (maltase, sucrase, and lactase) hydrolyzes starches to disaccharides and monosaccharides.
- In the large intestine, fibers remain and attract water, soften stools and ferment.
Absorption of Carbohydrates

- Primarily takes place in the small intestine
- Glucose and galactose are absorbed by active transport.
- Fructose is absorbed by facilitated diffusion.
- Monosaccharides travel to liver via portal vein
- In the liver, fructose & galactose are converted to glucose
Digestion and Absorption of Carbohydrates

- Lactose Intolerance
  - Symptoms include bloating, abdominal discomfort, and diarrhea.
  - Causes include lactase deficiency due to a natural decrease that occurs with aging or damaged intestinal villi.
- Prevalence
  - Lowest in Scandinavians and northern Europeans
  - Highest in Southeast Asians and native North Americans
Digestion and Absorption of Carbohydrates

- Lactose Intolerance - Dietary Changes
  - Increase consumption of milk products gradually.
  - Mix dairy with other foods.
  - Spread dairy intake throughout the day.
  - Use of acidophilus milk, yogurt, and kefir (fermented products)
  - Use of enzymes
  - Individualization of diets
  - Must be careful that vitamin and mineral deficiencies do not develop

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Special arrangements are made in the digestion of lipids.
This is due to the hydrophobic nature of lipids.
Lipids tend to separate from the watery fluids of digestion.
Digestive enzymes are hydrophilic, or water loving.
Bile from the liver emulsifies lipids.
Enzymes are then able to break down lipids to monoglycerides and fatty acids.
Emulsification of Fat by Bile

In the stomach, the fat and watery GI juices tend to separate. The enzymes in the GI juices can't get at the fat.

When fat enters the small intestine, the gallbladder secretes bile. Bile has an affinity for both fat and water, so it can bring the fat into the water.

Bile's emulsifying action converts large fat globules into small droplets that repel each other.

After emulsification, more fat is exposed to the enzymes, making fat digestion more efficient.

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Enterohepatic circulation of bile

- In the liver, bile is made from cholesterol.
- In the gallbladder, bile is stored.
- In the small intestine, bile emulsifies fats.
- Bile reabsorbed into the blood.
- In the colon, bile that has been trapped by soluble fibers is lost in feces.
Absorption & Transport of Lipids

- Glycerol and short- and medium-chain fatty acids diffuse and are absorbed directly into the bloodstream.
- Monoglycerides and long-chain fatty acids combine with bile to form micelles.
Absorption of Fat

Large lipids such as monoglycerides and long-chain fatty acids combine with bile, forming micelles that are sufficiently water soluble to penetrate the watery solution that bathes the absorptive cells. There the lipid contents of the micelles diffuse into the cells.

Glycerol and small lipids such as short- and medium-chain fatty acids can move directly into the bloodstream.
Lipid transport is made possible by a group of vehicles known as lipoproteins.  
- Chylomicrons  
  - Largest of the lipoproteins  
  - Least dense  
  - Get smaller as triglyceride portion is removed by the cells
Transport of Lipids

- Lipid Transport
  - VLDL (Very-Low-Density Lipoproteins)
    - Composed primarily of triglycerides*
    - Made by the liver
    - Transport lipids to the tissues
    - Get smaller and more dense as triglyceride portion is removed
    - Remaining cholesterol-rich lipoprotein becomes a low-density lipoprotein (LDL)

*In clinical practice, a VLDL level is commonly known as a blood triglyceride level.
Transport of Lipids

- **Lipid Transport**
  - **LDL (Low-Density Lipoproteins)**
    - Composed primarily of cholesterol
    - Transport lipids to the tissues
    - Removed from circulation by the liver
  - **HDL (High-Density Lipoproteins)**
    - Made by the liver to transport cholesterol from the cells back to the liver
    - Composed primarily of protein
Sizes and composition of the Lipoproteins

This solar system of lipoproteins shows their relative sizes. Notice how large the fat-filled chylomicron is compared with the others and how the others get progressively smaller as their proportion of fat declines and protein increases.

A typical lipoprotein contains an interior of triglycerides and cholesterol surrounded by phospholipids. The phospholipids fatty acid “tails” point towards the interior, where the lipids are. Proteins near the outer ends of the phospholipids cover the structure. This arrangement of hydrophobic molecules on the inside and hydrophilic molecules on the outside allows lipids to travel through the watery fluids of the blood.

Chylomicrons contain so little protein and so much triglyceride that they are the lowest in density.

Very-low-density lipoproteins (VLDL) are half triglycerides, accounting for their very low density.

Low-density lipoproteins (LDL) are half cholesterol, accounting for their implication in heart disease.

High-density lipoproteins (HDL) are half protein, accounting for their high density.
Fat Malabsorption

- Fat - most frequently malabsorbed nutrient
  - Fat requires both digestive enzymes & bile for digestion
- Conditions that can cause fat malabsorption
  - Conditions that decrease secretion of pancreatic lipase, e.g., pancreatitis, cystic fibrosis
  - Conditions that reduce bile availability, e.g., severe liver disease
  - Conditions that damage intestinal mucosa
  - Conditions that cause rapid gastric emptying or rapid intestinal transit because they prevent normal mixing of dietary fat with lipase and bile

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Consequences of Fat Malabsorption

- Loss of
  - Energy (kcal)
  - Fat soluble vitamins
  - Essential fatty acids
  - Some minerals, e.g., calcium, magnesium, & zinc
    - Minerals form soaps with unabsorbed fatty acids & bile acids
  - Bone loss
    - Calcium deficiency, further aggravated by vitamin D deficiency (a fat-soluble vitamin)
- Increase risk of kidney stones (which are most often composed of calcium oxalate)
Consequences of Fat Malabsorption

FAT MALABSORPTION

- Loss of food energy
  - Weight loss and malnutrition
- Loss of essential fatty acids
  - Essential fatty acid deficiencies
- Loss of fat-soluble vitamins
- Loss of minerals
  - Vitamin deficiencies
  - Calcium and magnesium deficiencies
  - Increased absorption of oxalate
    - Increased risk of bone loss
    - Increased urinary excretion of oxalate
    - Increased risk of oxalate stone formation
Digestion and Absorption of Protein

- Stomach acid and enzymes facilitate the digestion of protein.
- It is first denatured, then broken down to polypeptides.
- The small intestine continues to break down protein into smaller peptides and amino acids so it can be absorbed.
Protein Absorption

- Used by intestinal cells for energy or synthesis of necessary compounds
- Transported to the liver
- Taking enzyme supplements or consuming predigested proteins is unnecessary for most people
  - Exceptions
    - Cystic fibrosis
    - Hypoallergenic formulas
Vitamins

- Vitamins are not generally changed in the digestive process, an exception might be food folate which is changed from a polyglutamate to a monoglutamate form in the small intestine.
- Water-soluble vitamins are absorbed and move directly into the blood.
- Fat-soluble vitamins first enter the lymph and then the blood.
  - Once in the blood some may travel freely
  - Other fat soluble vitamins require protein-carriers for transport
Minerals

- Minerals are not chemically changed during the digestive process. Substances consumed with minerals, however, may facilitate or inhibit their absorption.
- Some minerals are easily absorbed into the blood and are transported freely, e.g., potassium.
- Other minerals, e.g., calcium, are more like fat soluble vitamins – they must have carriers to be absorbed and transported.