The Stomach
*(Interactions Animation)*

**Lipid Digestion in the Stomach**

Lipid digestion - mouth and stomach
- Lingual and gastric lipases hydrolyze a small amount of triglycerides.

You must be connected to the internet to run this animation.
The Stomach

Food entering stomach disrupts homeostasis by:

- Increasing pH of gastric juice
- Distention (stretching) of stomach walls

**Receptors**

- Chemo-receptors and stretch receptors in stomach detect pH increase and distention

**Input**

- Nerve impulses

**Control center**

- Submucosal plexus

**Output**

- Nerve impulses (parasympathetic)

**Effectors**

- Parietal cells secrete HCl and smooth muscle in stomach wall contracts more vigorously
- Increase in acidity of stomach chyme; mixing of stomach contents; emptying of stomach

**Return to homeostasis**

- When response brings pH of gastric juice and distention of stomach walls back to normal (pre-eating status)
The Stomach

Although digestion is a major function of the stomach, its epithelial cells are impermeable to most materials, and very little absorption takes place.

Within 2 to 4 hours after eating a meal, the stomach has emptied its contents into the duodenum.

- Foods rich in carbohydrate spend the least time.
- High-protein foods remain somewhat longer.
- Emptying is slowest after a fat-laden meal containing large amounts of triglycerides.
The Stomach

At appropriate intervals, the stomach allows a small amount of chyme to pass through the pyloric sphincter and enter the **duodenum** to begin the intestinal phase of digestion.

- **Completion of digestion** is a collective effort of pancreatic juice, bile, and intestinal juice in the small intestine.
The Pancreas

Digestion and absorption in the small intestine depend heavily on secretions from the pancreas and gallbladder (liver).

- The **pancreas** is an oblong gland located posterior to the stomach in the retroperitoneal space.
  - It is connected to the duodenum by the hepatopancreatic ampulla and accessory ducts.
  - It secretes enzymes, which digest food in the small intestine, and sodium bicarbonate, which buffers the acidic pH of chyme.
The Pancreas
The Pancreas

About 99% of pancreatic acini (glandular clusters) participate in exocrine secretion – only 1% of the clusters, called pancreatic islets, form the endocrine portion of the gland (secreting the hormones glucagon, insulin, and somatostatin and pancreatic polypeptide).
The Pancreas

- About 1-1.5 liters of alkaline **pancreatic juice** is secreted into the duodenum each day. It creates the proper pH for the following digestive enzymes in the small intestine:
  - A starch digesting enzyme called **pancreatic amylase**
  - Several enzymes that cleave polypeptides into dipeptides and single amino acids: **trypsin**, **chymotrypsin**, **carboxypeptidase**, and **elastase**
  - **Pancreatic lipase**, the major triglyceride (fat) digesting enzyme in adults
Carbohydrate Digestion – The Pancreas

Carbohydrate digestion - pancreas and small intestine
- The pancreas secretes amylase into the duodenum.
- In the small intestine, bicarbonate ions from pancreatic juice neutralize gastric acid.

You must be connected to the internet to run this animation
The Pancreas
*(Interactions Animation)*

**Lipid Digestion - Bile Salts and Pancreatic Lipase**

- **Bile**
- **Gallbladder**
- **Duodenum**
- **Chyme**
- **Small intestine**

**Lipid digestion - small intestine**
- In the duodenum, triglycerides interact with bile salts and pancreatic juice.

You must be connected to the internet to run this animation
The liver is the body’s largest gland and second largest organ. It has 2 main lobes (right and left – divided by the falciform ligament) and is covered by visceral peritoneum.

- The liver is made up of repeating functional units called **liver lobules**.
The Liver and Gallbladder

Hepatocytes are the major functional cells of the liver. As the body’s “chemical factories”, their metabolic versatility is truly remarkable. Hepatocytes participate in a number of digestive and non-digestive functions.

- Important digestive functions include:
  - the synthesis, transformation, and storage of proteins, carbohydrates, and fats
  - detoxification, modification, and excretion of a variety of exogenous and endogenous substances
The Liver and Gallbladder

Non-digestive liver functions include:

- Phagocytosis of old or worn-out cells
- Making heparin (anticoagulant) and other plasma proteins (prothrombin, fibrinogen, and albumin)
- Modifying vitamin D to its active form

Human Albumin
Venous blood (from the hepatic portal vein) and arterial blood (from the hepatic artery) feed the lobule from the **triad** on its outer margin.

- The blood mixture percolates through endothelial-lined spaces called **sinusoids** (a specialized capillary) towards the **central vein**.
The Liver and Gallbladder

Path of blood in hepatic sinusoid

Microstructure of the liver lobule

- Oxygenated blood from hepatic artery
- Nutrient-rich, deoxygenated blood from hepatic portal vein
- Liver sinusoids
- Central vein
- Hepatic vein
- Inferior vena cava
- Right atrium of heart

Hepatocytes (liver cells)
Central vein of liver lobule
Sinusoid
The Liver and Gallbladder

- Fixed macrophages within the sinusoids called **Kupffer cells** destroy red cells, white cells, and bacteria in blood draining from the GI tract.

- An important function of lobule **hepatocytes** is to secrete bile, an excretory product that helps emulsify fats for the watery environment of small intestine digestive juices.
  - Hepatocytes secrete about 1 liter of bile per day.
The Liver and Gallbladder

Bile is an alkaline solution consisting of water, bile salts, cholesterol, and bile pigments. It is both an excretory product and a digestive secretion.

- Bile salts are used in the small intestine for the emulsification and absorption of lipids.
  - Without bile salts, most of the lipids in food would be passed out in feces, undigested.
- The dark pigment in bile is called bilirubin and comes from the catabolism of old red blood cells.
The Liver and Gallbladder

Bile secreted into the canaliculi (located between the hepatocytes) exits the liver in the **common hepatic duct**.

- This duct joins the **cystic duct** from the gallbladder to form the common bile duct (CBD).
The CBD works its way towards the duodenum and joins with the **pancreatic duct** to form the **hepatopancreatic ampulla** just proximal to the second part of the duodenum.

- The **duodenal papilla** ("nipple") pierces the intestinal mucosa to deliver its contents.
The Liver and Gallbladder

Between meals, the sphincter of the hepatopancreatic ampulla is closed – bile “backs-up” into the gall bladder where it is stored and concentrated up to ten-fold through the absorption of water and ions.
The Liver and Gallbladder

Under the influence of the hormone cholecystokinin (CCK), the gallbladder contracts and ejects stored bile.

Although not necessary for life, normal gall bladder function is highly desirable.

- After surgical removal of the gall bladder (called a cholecystectomy), a person would experience severe indigestion if they ate a large meal high in fat content.
The Liver and Gallbladder
(Interactions Animation)

Chemical Digestion – Bile

- Duodenum
- Common bile duct
- Bile

Digestive chemicals - bile
- Bile is produced by the liver.
- Bile consists mostly of bile salts (produced from cholesterol) and water.
- Primary function of bile is emulsification of fatty globules.

You must be connected to the internet to run this animation.
The Small Intestine

The small intestine is divided into 3 regions:

- The duodenum (10 in)
- The jejunum (8 ft)
- The ileum (12 ft)
  - If measured in a cadaver, the intestines are longer than if measured in a live person due to the loss of smooth muscle contraction.

In the small intestine, digestion continues, even while the process of absorption begins.
The Small Intestine

Mechanical digestion in the small intestine is a localized mixing contraction called segmentations.

- Segmentations is a type of peristalsis used to mix chyme and bring it in contact with the mucosa for absorption.
- It begins in the lower portion of the stomach and pushes food forward along a small stretch of small intestine.
  - It is governed by the myenteric plexus.
The Small Intestine

(Interactions Animation)

Segmentation Animation

Segmentation and migrating motility complexes
- Within a few hours, most of the stomach contents are in the duodenum.
- Distension of stretch receptors in the small intestine activates a reflex that stimulates segmentation, a mixing movement.

You must be connected to the internet to run this animation
Circular folds called the **plicae circulares** are permanent ridges of the mucosa and submucosa that encourage turbulent flow of chyme.
The Small Intestine

Villi are multicellular structures that can barely be seen by the naked eye. They form finger-like projections that are covered with a simple columnar epithelium.
Microvilli are microscopic folds in the apical surface of the plasma membrane on each simple columnar cell (about 200 million/mm$^2$).

The plicae circulares, villi, and microvilli all contribute to increase the surface area of the small intestine, allowing for maximum reabsorption of nutrients.
The Small Intestine

- The small intestinal mucosa contains many deep crevices lined with glandular epithelium (intestinal glands) that secrete intestinal juice. Its function is to complete the digestive process begun by pancreatic juice.
  - Trypsin exists in pancreatic juice in the inactive form trypsinogen - it and other enzymes are activated by intestinal juice.
The Small Intestine

Most of the enzymatic digestion in the small intestine occurs inside the epithelial cells or on their surfaces (rather than in the lumen of the tube) as intestinal juice comes in contact with the brush border of the villi.
The Small Intestine
*(Interactions Animation)*

**Digestion on the Brush Border**

- **Protein digestion - brush border enzymes**
  - End products of protein digestion:
    - Amino acids
    - Dipeptides
    - Tripeptides

---

You must be connected to the internet to run this animation
The Small Intestine
(Interactions Animation)

Before discussing the absorption of nutrients, the events of gastric and intestinal digestion are reviewed in this animation.

Hormonal Control of Digestive Activities

You must be connected to the internet to run this animation.
The Small Intestine

Intestinal absorption is the passage of digested nutrients into the blood or lymph: 90% of all intestinal absorption occurs in the small intestine.

- Proteins (amino acids), nucleic acids, and sugars (monosaccharides) are absorbed into blood capillaries by facilitated diffusion or active transport.
- Triglycerides (fats) aggregate into globules along with phospholipids and cholesterol and become coated with proteins. These large spherical masses are called chylomicrons.
The Small Intestine

Chylomicrons, too large to enter blood capillaries, enter specialized lymphatic vessels called lacteals and eventually drain into the superior vena cava and mix with blood.

- All dietary lipids are absorbed by simple diffusion.
Carbohydrate Absorption in the Small Intestine

- All end products of carbohydrate digestion (glucose, fructose, and galactose) are absorbed as monosaccharides.
- Carbohydrates are ultimately absorbed into capillaries of the villi.

You must be connected to the internet to run this animation.
The Small Intestine

(Interactions Animation)

Protein Absorption in the Small Intestine

- Protein absorption - transport mechanisms
  - The peptides are then hydrolyzed to single amino acids inside of the epithelial cells.
  - Amino acids diffuse out of the epithelial cells, through the interstitial fluid, and enter the blood capillaries of the villus.

You must be connected to the internet to run this animation
The Small Intestine
(Interactions Animation)

Nucleic Acid Absorption in the Small Intestine

- Absorption of nucleic acid mainly occurs in the duodenum and jejunum of the small intestine.
- At the intestinal villus, all nucleic acids are absorbed as:
  - Nitrogenous bases.
  - Pentose sugars.
  - Phosphate ions.

You must be connected to the internet to run this animation
The Small Intestine
*(Interactions Animation)*

**Lipid Absorption in the Small Intestine**

- Bile salts form micelles (tiny spheres), which ferry fatty acids and monoglycerides to epithelial cells.

You must be connected to the internet to run this animation.
The large intestine is about 5 feet in length. Starting at the ileocecal valve, the large intestine has 4 parts:

- The cecum
- The colon
  - ascending
  - transverse
  - descending
  - sigmoid
- The rectum
- The anal canal
The Large Intestine

- There are no circular folds or villi in the large intestine.
  - The mucosa is mostly an absorptive epithelium (mainly for water), and microvilli are plentiful.
  - Interspersed goblet cells produce mucous, but no digestive enzymes are secreted.

(c) Portion of wall of large intestine

Absorptive cell (absorbs water)
The Large Intestine

The large intestine is attached to the posterior abdominal wall by its **mesocolon** peritoneal membrane.

**Teniae coli** are 3 separate longitudinal ribbons of smooth muscle that run the length of the colon.

- Because the teniae coli is shorter than the intestine, the colon becomes sacculated into small pouches called **haustra** (giving it a segmented appearance).
  - As one haustrum distends, it stimulates muscles to contract, pushing the contents to the next haustrum.
The Large Intestine

Hanging inferior to the ileocecal valve is the cecum, a small pouch about 2.5 in long.

- Attached to the cecum is a 3 in coiled tube called the appendix.

The open end of the cecum merges with a long tube called the colon, with its various parts.

- Both the ascending and descending colon are retroperitoneal; the transverse and sigmoid colon are not.
The Large Intestine

The **rectum** is the last 8 in of the GI tract and lies anterior to the sacrum and coccyx.

- The terminal 1 in of the rectum is called the **anal canal**. The mucous membrane of the anal canal is arranged in longitudinal folds called anal columns that contain a network of arteries and veins.
- The opening of the anal canal to the exterior is called the **anus**.
The Large Intestine

TRANSVERSE COLON

Right colic (hepatic) flexure

ASCENDING COLON

Teniae coli

Ileocecal sphincter (valve)

CECUM

VERMIFORM APPENDIX

ILEUM

Mesoappendix

ILEUM

OMENTAL appendices

Haustra

SIGMOID COLON

RECTUM

ANAL CANAL

ANUS

(a) Anterior view of large intestine showing major regions
The Large Intestine

- Including the 2 liters we drink, about 9 liters of fluid enter the small intestine each day.
  - The small intestine absorbs about 8 liters; the remainder passes into the large intestine, where most of the rest of it is also absorbed.
The Large Intestine

Feces are the waste leftover after digesting and absorbing all the nutrients we can from eaten material. Though it is lower in energy than the food it came from, feces may still contain a large amount of energy, often 50% of that of the original food.

- The characteristic brown coloration comes from a combination of bile and bilirubin.
- The distinctive odor is due to bacterial action - both aerobic and anaerobic bacteria participate.
The Large Intestine

Though the human body consists of about 100 trillion cells, we carry about ten times as many microorganisms in the intestines. Bacteria make up most of the flora in the colon and about 60% of the dry mass of feces.

As these bacteria digest/ferment left-over food, they secrete beneficial chemicals such as vitamin K, biotin (a B vitamin), and some amino
The Large Intestine

- The **mechanical events** associated with defecation include localized haustral churning and peristalsis.
- Two autonomic nervous system reflexes that initiate strong bouts of mass peristalsis are the **gastroileal reflex** and the **gastrocolic reflex**.
  - Both reflexes occur with distension of the stomach.
The Large Intestine

- The **gastroileal reflex** causes relaxation of the ileocecal valve, intensifies peristalsis in the ileum, and forces any chyme into the cecum.

- The **gastrocolic reflex** intensifies strong peristaltic waves that begin at about the middle of the transverse colon and quickly drive the contents of the colon into the rectum.
  - This **mass peristalsis** takes place three or four times a day during or immediately after a meal, and may...
The Large Intestine

The defecation reflex is activated by stretch receptors stimulated by filling of the rectum.

- The events leading to defecation include:
  - Food in the stomach stimulates mass peristalsis.
  - Food moves through the intestine into the rectum.
  - Rectal pressoreceptors respond to distention and longitudinal muscles shorten the rectum.
  - ANS releases the internal anal sphincter and gives a conscious awareness of distention.
  - Release of external sphincter is under conscious control.
The Small Intestine
(Interactions Animation)

Mechanical Digestion in the Large Intestine

- **Gastroileal reflex**
  - The ileocecal valve is normally closed, so chyme cannot enter the large intestine.
  - The gastroileal reflex is triggered when food enters and distends the stomach.
  - Migrating motility complexes are intensified by this reflex, forcing chyme through the ileocecal valve into the cecum.

You must be connected to the internet to run this animation.
<table>
<thead>
<tr>
<th>ORGAN</th>
<th>FUNCTION(S)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tongue</td>
<td>Maneuvers food for mastication, shapes food into a bolus, maneuvers food for deglutition, detects sensations for taste, and initiates digestion of triglycerides.</td>
</tr>
<tr>
<td>Salivary glands</td>
<td>Saliva produced by these glands softens, moistens, and dissolves foods; cleanses mouth and teeth; initiates the digestion of starch.</td>
</tr>
<tr>
<td>Teeth</td>
<td>Cut, tear, and pulverize food to reduce solids to smaller particles for swallowing.</td>
</tr>
<tr>
<td>Pancreas</td>
<td>Pancreatic juice buffers acidic gastric juice in chyme, stops the action of pepsin from the stomach, creates the proper pH for digestion in the small intestine, and participates in the digestion of carbohydrates, proteins, triglycerides, and nucleic acids.</td>
</tr>
<tr>
<td>Liver</td>
<td>Produces bile, which is required for the emulsification and absorption of lipids in the small intestine.</td>
</tr>
<tr>
<td>Gallbladder</td>
<td>Stores and concentrates bile and releases it into the small intestine.</td>
</tr>
<tr>
<td>Mouth</td>
<td>See the functions of the tongue, salivary glands, and teeth, all of which are in the mouth. Additionally, the lips and cheeks keep food between the teeth during mastication, and buccal glands lining the mouth produce saliva.</td>
</tr>
<tr>
<td>Pharynx</td>
<td>Receives a bolus from the oral cavity and passes it into the esophagus.</td>
</tr>
<tr>
<td>Esophagus</td>
<td>Receives a bolus from the pharynx and moves it into the stomach; this requires relaxation of the upper esophageal sphincter and secretion of mucus.</td>
</tr>
<tr>
<td>Stomach</td>
<td>Mixing waves combine saliva, food, and gastric juice, which activates pepsin, initiates protein digestion, kills microbes in food, helps absorb vitamin $\text{B}_{12}$, contracts the lower esophageal sphincter, increases stomach motility, relaxes the pyloric sphincter, and moves chyme into the small intestine.</td>
</tr>
<tr>
<td>Small intestine</td>
<td>Segmentation mixes chyme with digestive juices; peristalsis propels chyme toward the ileocecal sphincter; digestive secretions from the small intestine, pancreas, and liver complete the digestion of carbohydrates, proteins, lipids, and nucleic acids; circular folds, villi, and microvilli help absorb about 90 percent of digested nutrients.</td>
</tr>
<tr>
<td>Large intestine</td>
<td>Haustral churning, peristalsis, and mass peristalsis drive the colonic contents into the rectum; bacteria produce some B vitamins and vitamin K; absorption of some water, ions, and vitamins occurs; defecation.</td>
</tr>
</tbody>
</table>
End of Chapter 24

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