Section Four: Chapter 20: Digestion, Nutrition and Metabolism

Digestion is the process of mechanically and enzymatically breaking down food into substances so that they can be absorbed into the bloodstream and assimilated into the body. The good food that we ingest contains three macronutrients that require various processes of digestion before they can be absorbed. They are carbohydrates, proteins and fats (lipids).

Nutrition: The process of taking in food and using it for growth, metabolism, and repair. Nutritional stages are ingestion, digestion, absorption, transport, assimilation, and excretion.

Figure 20.1 Shows an assortment plant based (left) and animal based (right) nutrients. Nutrients are essential compounds in food that the cells in the body require nutrients from food to provide the building blocks to maintain, repair and replace them, as well as the energy to perform bodily functions.

Overview

The function of the digestive system is to break down the foods you eat, release their nutrients, and absorb those nutrients into the body. All of the regions and organs makes a vital contribution to this process. The best way to understand this system is to see it as a tract, called the **alimentary** (nourishment) canal or the **gastrointestinal** (GI) tract that works in cooperation with **accessory organs** and **structures** to achieve all of the processes listed above that incorporate digestion

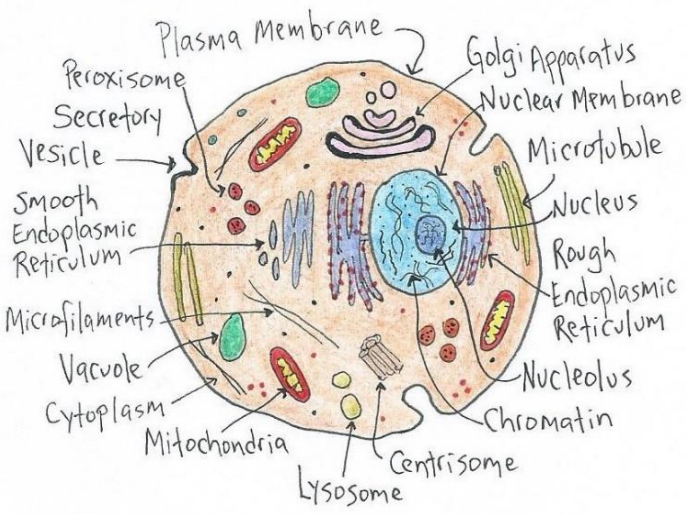


Figure 20.2 The cell is the unit of life. Each cell must attain adequate nutrients to ensure they can grow, maintain and repair themselves. There are about 200 different cell types, all require a healthy, non-toxic environment in order to survive and thrive.

The **science of nutrition** (from Latin nutrire a feeding, to nourish) is the study of food and the **nutrients** we need to **sustain life** and **reproduce**. It examines the way food nourishes the body and affects health. There are **six categories of nutrients** found in foods and in the body: ***carbohydrates, fats, proteins, vitamins, minerals, and water***. Foods also often contain non-nutrient compounds, such as **phytochemicals** or zoo-chemicals, non-digestible fiber, and other man-made additives. The entire digestive systems can be seen in an overview below in **Fig. 20.3**.

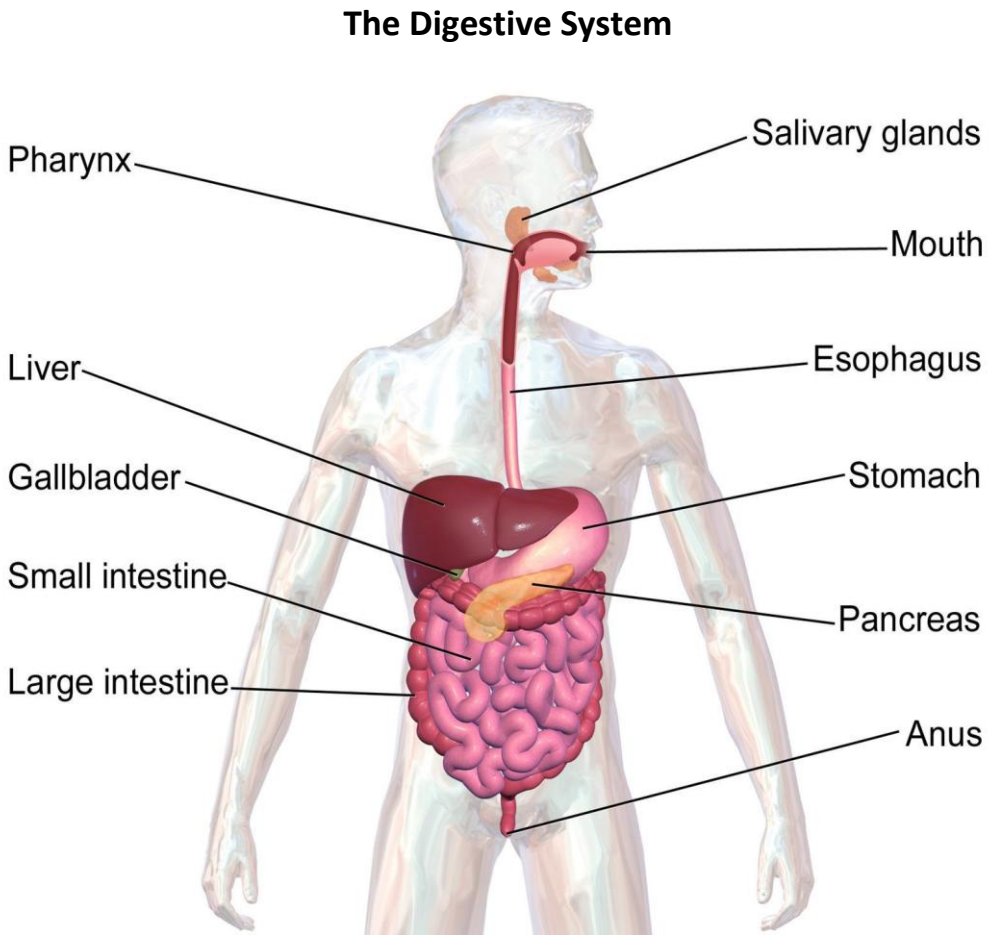


Figure 20.3 Shows the human digestive system, from where the ingestion of food starts at the mouth, through the gastrointestinal (G.I.) tract where nutrients are processed and absorbed, to the end where waste is eliminated.

What is Your View of Nutrition?

Our ability to wake up, to have calm rational thoughts, to communicate effectively, to have goals, to dream, to learn new things, to work, to do interesting things, to earn a living, and anything else we'd like to do, are dependent upon one factor - our health.

A meaningful way to view nutrition is that **Good Nutrition** translates into **Good Health**, and good health means you are **strong**, **happy** and **healthy** in a diverse multidimensional way that health incorporates. There are many facets contributing to a person's health and wellness. It may be possible that you could feel better than you currently do by a slight improvement in your nutrition. You may already feel great, but what if you could feel spectacular, rather than just great, would you want to give it a try?

The encouraging aspect of examining the link between nutrition and health is that there is an increasing amount of excellent information being made available. Many thoughtful and diligent people have raised great questions about firmly held 'beliefs' with regard to nutrition and health. This is especially true in the last 20 years, and as a consequence of these legitimate challenges to long-held erroneous beliefs regarding nutrition, astounding information is being revealed. ***Therefore, it is important to be honest and seek the truth about our health and how nutrition impacts it.***

The time is now, it is very important **not** remain silent about the things that matter (Dr. Martin Luther King Jr.), and have the courage to be able to listen to new or little known information and be able to think about it in an open way. As a consequence, it may be that you become better informed and change your opinions about nutrition - perhaps even change your behavior and your choices regarding nutrition in order for improved health and freedom.

Nutrition and Digestion

Let's first give and overview of how the body functions and the physiological processes involved in human nutrition related to digestions. The six phases of digestion and the brief overview of how the body extracts nutrients from the foods consumed are presented below.

1. **Ingestion** - To take substances into the body by the mouth for digestion.
2. **Digestion** - the process in the alimentary canal by which food is broken down physically by the action of the teeth, and chemically by the action of enzymes, and converted into a substance suitable for absorption and assimilation into the body.
3. **Absorption** - The movement of a substance, such as a liquid or solute, across a cell membrane.
4. **Transport** - The movement of ions or molecules across a cell membrane in the direction opposite that of diffusion, that is, from an area of lower concentration to one of higher concentration. Active **transport** requires the assistance of a type of protein called a carrier protein, using energy supplied by ATP.
5. **Assimilation** – The conversion of nutrients into a useable form (e.g. liquid or solid) that is incorporated into the tissues and organs following the processes of digestion. Also the chemical alteration of substances in the bloodstream by the liver or cellular secretions.
6. **Excretion** - Egestion is the act of excreting unusable or undigested material from the digestive tract of multicellular animals. Elimination broadly defines the mechanisms of waste disposal by a living system.

The GI Tract

The GI tract is a long tube, about 30 feet from one end to the other, with a starting point - the **mouth**, and an ending point - the **anus**. In between there is a variety of highly specialized regions of the tract for their particular role in the digestive process.

The GI tract from proximal (beginning) to distal (end) are:

Mouth, oropharynx, laryngopharynx, esophagus, stomach, small and large intestines, rectum, anal canal and anus.

The lining of the GI tract is a mucus membrane that functions both to protect the body and in specific regions to absorb nutrients. When food or liquids enter the canal, it is still considered to be outside of the body. Substances must be moved over the epithelial lined membrane via absorption to enter the body via the body stream.

Accessory Organs and Structures

All of the accessory organs and structures aid in the processing food and drinks and provide vital elements required for proper digestion to occur.

The Accessory Organs and Structures are:

- **Accessory Organs** include: the gallbladder, liver, and pancreas.
- **Accessory Structures** include: the teeth, the tongue, salivary glands, mucus glands, as well as gastric an intestinal glands.

Table 20.1 Shows the actions and end-products of the various compartments of the digestive tract.

Region of GI Tract	Secretion	Category of Food	Actions and End-Products
Mouth	Saliva (alkaline)	Carbohydrates	Starch → Maltose
Stomach	Gastric juice (acidic)	Proteins	Proteins → Peptides
Duodenum (Small Intestine)	Bile (alkaline)	Fats	Fats → Fat droplets
Duodenum (Small Intestine)	Pancreatic juices (alkaline)	Carbohydrates Fats Proteins	Starch → Maltose Fat droplets → Fatty acid, glycerol Peptides → Amino acids
Remainder of Small Intestine	Intestinal juices (alkaline)	Carbohydrates Proteins	Complex sugars → Simple sugar Peptides → Amino acids

The Human Digestive System

The entire human gastrointestinal (GI) tract is approximately 30 feet in length. The time it takes to go through all of the process (or phases) mentioned about will vary depending on the person, and the type and quantity of food ingested. Basically, the process of digestion is typically in the range of taking between 24 and 72 hours.

Digestive Processes

The processes of digestion include six activities: ingestion, propulsion, mechanical or physical digestion, chemical digestion, absorption, and defecation.

The first of these processes, **ingestion**, refers to the entry of food into the alimentary canal through the mouth. There, the food is chewed and mixed with saliva, which contains enzymes that begin breaking down the carbohydrates in the food plus some lipid digestion via lingual lipase. Chewing increases the surface area of the food and allows an appropriately sized bolus to be produced.

Food leaves the mouth when the tongue and pharyngeal muscles propel it into the esophagus. This act of swallowing, the last voluntary act until defecation, is an example of **propulsion**, which refers to the movement of food through the digestive tract. It includes both the voluntary process of swallowing and the involuntary process of peristalsis. **Peristalsis** consists of sequential, alternating waves of contraction and relaxation of alimentary wall smooth muscles, which act to propel food along (**Fig. 20.4**). These waves also play a role in mixing food with digestive juices. Peristalsis is so powerful that foods and liquids you swallow enter your stomach even if you are standing on your head.

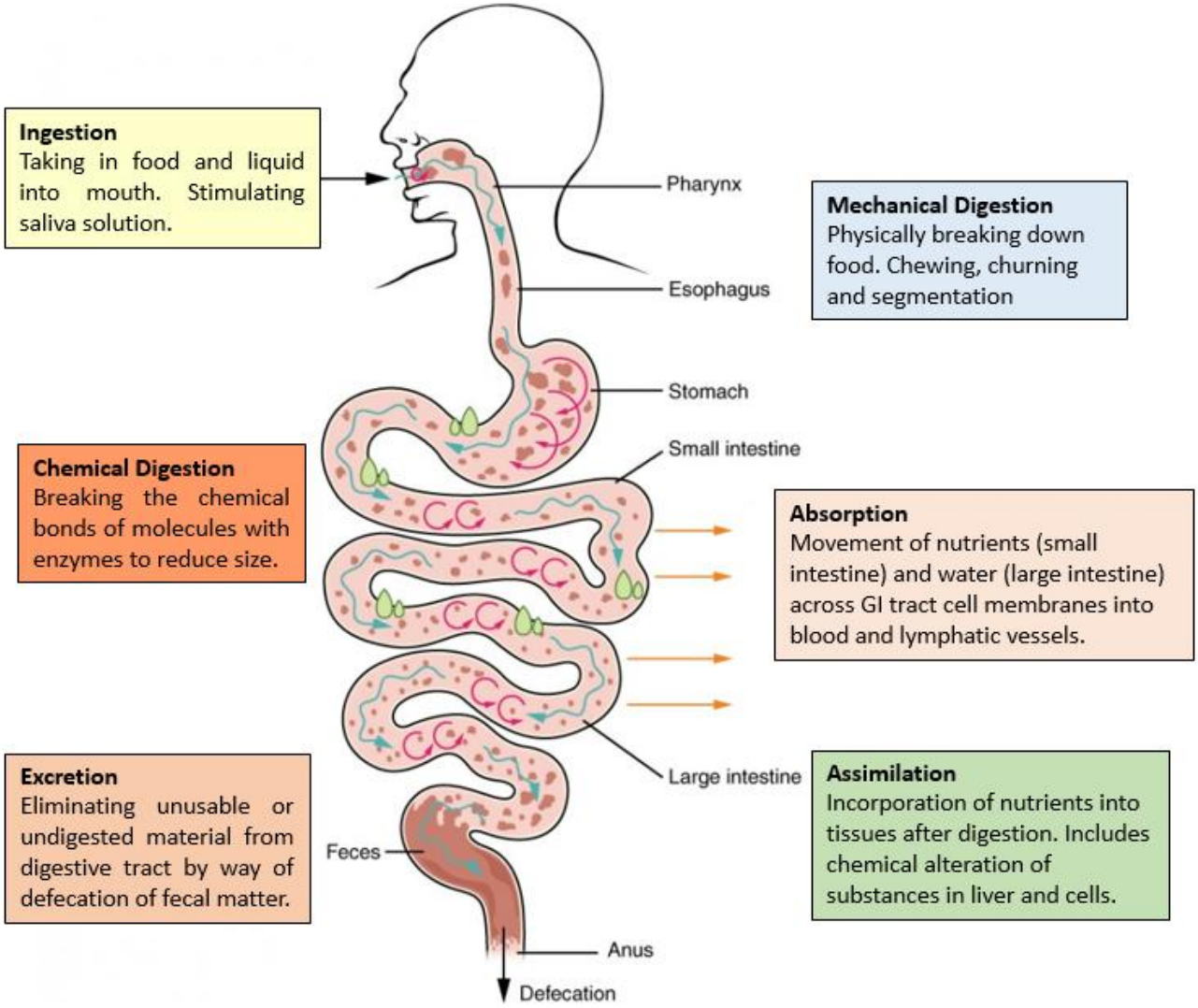


Figure 20.4 Shows the human digestive system, from where the ingestion of food starts at the mouth, through the gastrointestinal (G.I.) tract where nutrients are processed and absorbed, to the end where waste is eliminated.

Digestion includes both mechanical and chemical processes. **Mechanical digestion** is a purely physical process that does not change the chemical nature of the food. Instead, it makes the food smaller to increase both surface area and mobility. It includes **mastication**, or chewing, as well as tongue movements that help break food into smaller bits and mix food with saliva. Although there may be a tendency to think that mechanical digestion is limited to the first steps of the digestive process, it occurs after the food leaves the mouth, as well.

The mechanical churning of food in the stomach serves to further break it apart and expose more of its surface area to digestive juices, creating an acidic “soup” called **chyme**. **Segmentation**, which occurs mainly in the small intestine, consists of localized contractions of circular muscle of the muscularis layer of the alimentary canal. These contractions isolate small sections of the intestine, moving their contents back and forth while continuously subdividing, breaking up, and mixing the contents.

By moving food back and forth in the intestinal lumen, segmentation mixes food with digestive juices and facilitates absorption.

In **chemical digestion**, starting in the mouth, digestive secretions break down complex food molecules into their chemical building blocks (for example, proteins into separate amino acids). These secretions vary in composition, but typically contain water, various enzymes, acids, and salts. The process is completed in the small intestine.

Food that has been broken down is of no value to the body unless it enters the bloodstream and its nutrients are put to work. This occurs through the process of **absorption**, which takes place primarily within the small intestine. There, most nutrients are absorbed from the lumen of the alimentary canal into the bloodstream through the epithelial cells that make up the mucosa.

Lipids are absorbed into lacteals and are transported via the lymphatic vessels to the bloodstream (the subclavian veins near the heart). The details of these processes will be discussed later. In **defecation**, the final step in digestion, undigested materials are removed from the body as feces.

Neural Control via the ANS

The GI system is richly innervated by both **extrinsic** and **intrinsic** nerves. Extrinsic nerves are those that comprise the **autonomic nervous system** (ANS). Intrinsic nerves are those that comprise the **enteric nervous system** (ENS), a subdivision of the peripheral nervous system. The enteric nervous system relays information from the ANS and is also able to directly and independently regulate many GI functions.

Extrinsic Innervation (Autonomic Nervous System)

Extrinsic nerves provide reflexes, which coordinate activities at widely separated sites along the GI tract.

Parasympathetic division of the ANS: In general, the parasympathetic division stimulates GI functions.

- The parasympathetic neural supply for the gut comes from the *vagus and pelvic nerves.
- The vagus nerve innervates the esophagus, stomach, pancreas, and proximal colon.
- The pelvic nerves innervate the distal colon, rectum, and anus.
- Preganglionic parasympathetic fibers synapse with nerves of the intrinsic (enteric) nervous system (the submucosal and myenteric plexus).
- Fibers then project from cell bodies in the ganglia of these plexuses to secretory cells, endocrine cells, and smooth muscle cells in the GI system.

The Parasympathetic and Sympathetic Innervation of the GI tract

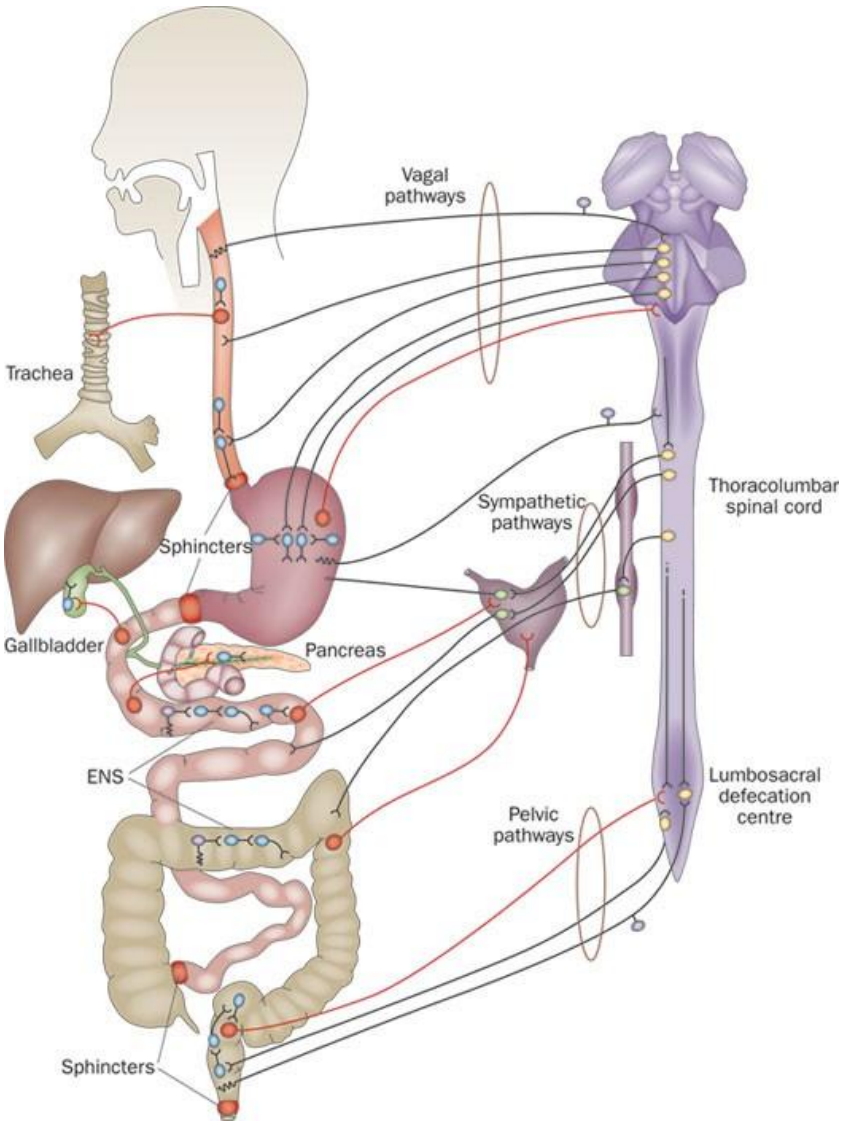


Figure 20.5 Shows the autonomic nervous system (ANS) control of the digestive system. It is the parasympathetic division of the ANS that presides over and stimulated the automated gastrointestinal processes, predominantly through the vagus nerve. Though the sympathetic division is also involved in critical reflex pathways, in general it acts to inhibit digestive activity such as secretions and tract motility.

Sympathetic division of the ANS: In general, the sympathetic division inhibits GI functions (see **Fig. 20.5**).

- Sympathetic preganglionic cholinergic nerves synapse in the prevertebral ganglia.
- Sympathetic postganglionic nerves innervate the GI tract from the celiac, superior mesenteric, and superior and inferior hypogastric plexus.
- Postganglionic sympathetic fibers synapse in the submucosal and myenteric plexus of the intrinsic nervous system.
- Some postganglionic fibers synapse directly with blood vessels and smooth muscle.
- Fibers then project from cell bodies in the ganglia of these plexus to secretory cells, endocrine cells, and smooth muscle in the GI tract.

***Vasovagal** reflexes have afferent and efferent components mediated by the vagus nerve.*

Intrinsic Innervation – The Enteric Nervous System

The enteric nervous system possesses all the elements necessary for short reflex regulation of GI functions, that is, modification of motility and secretory activity by afferent and efferent nerves entirely within the GI tract. It is able to do this without modulation from the extrinsic nervous system, with the exception of the proximal esophagus and external anal sphincter.

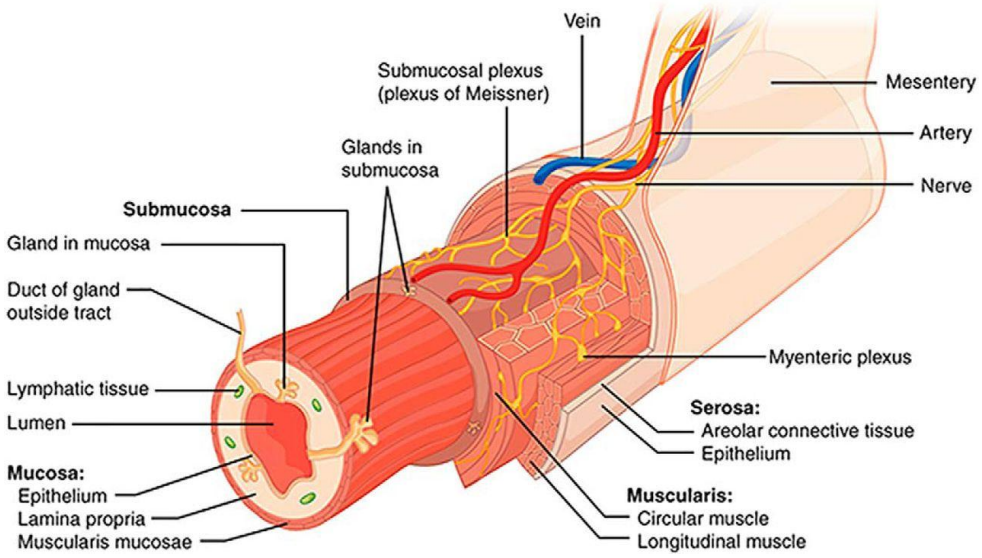


Figure 20.6 The entire GI tract has significant innervation by the enteric nervous system (ENS) which is found throughout the 4 layers of the tract, required for motility (submucosal plexus), secretions and hormonal relays.

Submucosal plexus (Meissner plexus)

- This is located in the submucosal layer between the mucosa and circular muscle in the wall of the GI tract.
- It principally controls GI secretions and blood flow.

Myenteric plexus (Auerbach plexus)

- This is located between the longitudinal and circular layers of smooth muscle in the wall of the GI tract.
- It principally controls the motility of GI smooth muscle.

Neural Controls via the Enteric Nervous System

The walls of the alimentary canal are embedded with nerve plexuses called the **enteric nervous system** (see **Fig. 20.6** above) that interact with the central nervous system and other nerve plexuses—either within the same digestive organ or in different ones. The tract contains a variety of sensors that assist in the regulation of digestive functions. These include **mechanoreceptors**, **chemoreceptors**, and **osmoreceptors**. These receptors sense whether food substances have been sufficiently broken down, the degree of liquid present, and the various types of nutrients in the food.

The triggering of these enteric receptors provokes various reflexes which enhance the digestion process. This includes sending signals in order to activate regions and glands that secrete **digestive juices** into the lumen, or it to stimulate of muscle layers within the GI tract and thereby activating **peristalsis** and **segmentation** that propel the food along the intestinal tract.

Reflexes in the Digestive System

There are short and long reflexes related to the digestive, and like any reflex these are rapid automated responses that assist in function. .

- **Short reflexes** are local and involve the resident **enteric nervous system** (ENS), which are able to act quickly and effectively. The enteric nervous system has been referred to at the 'brain of the gut'. It can react to a wide range of digestive movement and chemical changes. Short reflexes regulate activities in one area of the digestive tract and may coordinate local peristaltic movements and stimulate digestive secretions. For example, eating food that distends the stomach initiates short reflexes that cause cells in the stomach wall to increase their secretion of digestive juices. Also, the **gastro-ileal** reflex works with the **gastro-colic** reflex to stimulate the urge to defecate for elimination.

- **Long reflexes** involve a sensory neuron that sends external or internal digestive information to the **brain**, which is relatively speaking, far away. This type of reflex includes reactions or responses to food that can be emotion, or signal danger. These involve **extrinsic** (not enteric) nerve plexuses of the ANS and CNS that originate from stimuli from **outside** the digestive system. For example, the sight, smell, and taste of a food may initiate long reflexes, starting with sensory input to the medulla oblongata. The response to the signal is to stimulate cells in the stomach to begin secreting digestive juices in preparation for incoming food, this is called the **cephalic reflex**.

Hormonal Control in the Digestive System

The hormones of the GI tract are released from **endocrine cells** in the mucosa of certain regions of the GI system, particularly the **antrum of the stomach** and the **upper small intestine**.

The major hormones secreted by the GI system are **gastrin**, **secretin**, **glucagon-like peptide** 1 (GLP-1), **cholecystokinin**, and **glucose-dependent insulinotropic peptide** (GIP). The main digestive hormone of the stomach is **gastrin**, which is secreted in response to the presence of food. **Gastrin** stimulates the secretion of gastric acid by the parietal cells of the stomach mucosa.

Other GI hormones are produced and act upon the gut and its accessory organs. Hormones produced by the duodenum include **secretin**, which stimulates a watery secretion of bicarbonate by the pancreas; **cholecystokinin** (CCK), which stimulates the secretion of pancreatic enzymes and bile from the liver and release of bile from the gallbladder; and **gastric inhibitory peptide**, which inhibits gastric secretion and slows gastric emptying and motility.

These GI hormones are secreted by specialized epithelial cells, called endocrinocytes, located in the mucosal epithelium of the stomach and small intestine. These hormones then enter the bloodstream, through which they can reach their target organs.

Paracrine Control in the Digestive System

Paracrine substances are signaling molecules released by cells in the GI mucosa that diffuse through interstitial fluid to nearby target cells, where they exert their effects. The two key paracrine substances of the GI system are **histamine** and **somatostatin**.

The GI tract is a **25 to 30** feet long muscular tube.

The 5 Organs (Regions) of GI Tract:

- **Mouth** - taste, chewing, getting food into solution.
- **Esophagus** - bolus ready for transport down to stomach.
- **Stomach** - acidic chyme liquefies everything.
- **Small Intestine** - chemical breakdown and absorption.
- **Large Intestine** - water and ions absorption, compaction.

The Mouth

Both Mechanical and Chemical Digestion begin in the mouth. Chewing food thoroughly is a very important part of digestion. What do you think all those molars are for? The more time spent chewing adequately, the more nutrients will be absorbed. Mechanical digestion is chewing, grinding, squeezing (see **Fig. 20.7**). Chemical digestion is breaking down food via enzymatic reactions. The tongue contains taste buds on surface for 5 tastes: Sweet, sour, salt, bitter and umami (savory).

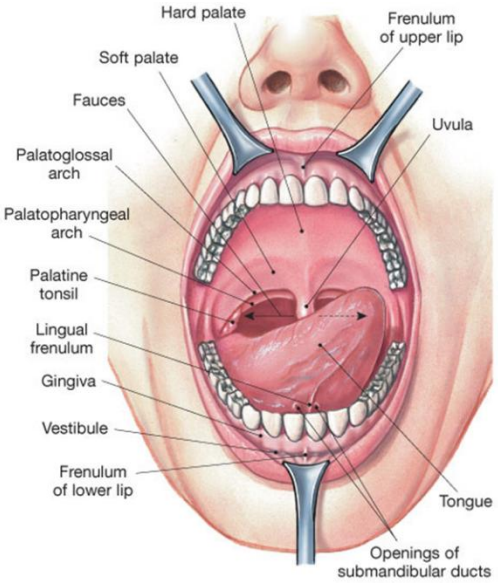
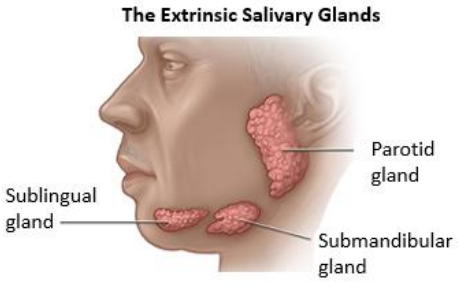


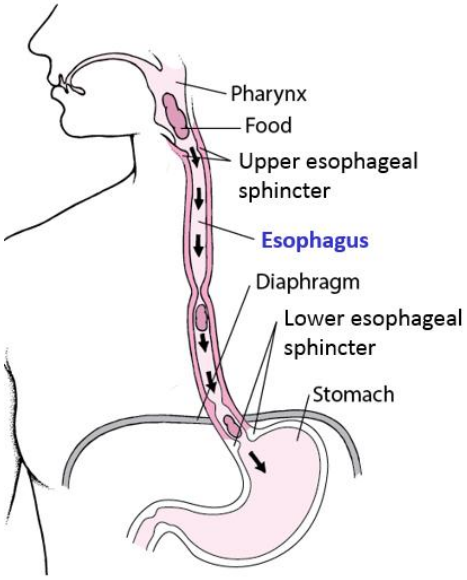
Figure 20.7 the oral cavity (mouth).

Saliva

Dissolves small food particles. Contains the enzyme lingual amylase, which begins to break down carbohydrate. Plus lysozymes (antibacterial). Lingual lipase in young, but in adults, no other chemical digestion of nutrients takes place in the mouth.



Salivary amylase is an enzyme secretion produced inside the mouth. It is present in an abundant amount in saliva. Chloride ions (Cl^-) are present in the enzymes and **act as activators** to activate the enzyme so that they can be put into action. Once adequately chewed and moistened, the tongue rolls food into a bolus and pushes into pharynx (throat) to be swallowed.



The Esophagus

It is the **muscular** esophagus that transports the bolus of food and fluids from the mouth to stomach. It is lined with tough **stratified squamous epithelium** for protection and has **mucus glands** along its length to help lubricate the bolus as it is propelled down toward the stomach. There are two sphincters in the esophagus: **1)** the **upper esophageal sphincter**, which allows the bolus of food to enter the esophagus from the mouth; and **2)** the **lower esophageal sphincter** (LES), which allows the bolus of food travelling down the esophagus to enter the stomach.

The Stomach and Gastric Secretion

The process of gastric secretion in the **stomach** the can be divided into three phases: **1) cephalic**, **2) gastric**, and **3) intestinal**. The secretions in the stomach are stimulated by the act of eating (**cephalic phase**) and the arrival of food in the stomach (**gastric phase**). And finally, the arrival of the food in the intestine also controls the gastric secretions of the stomach (**intestinal phase**).

The stomach has several key areas (**Fig. 20.8**) and is sufficiently complex. The secretion of gastric juice is controlled by both nerves and hormones. Stimuli in the brain, stomach, and small intestine activate or inhibit gastric juice production, hence the naming of the three phases cephalic, gastric, and intestinal). Importantly, once gastric secretion begins, all three phases can occur simultaneously.

The Cephalic Phase

The **cephalic phase** (reflex phase) of gastric secretion, occurs before food enters the stomach. The smell, taste, sight, or thought of food triggers this phase. This enhanced secretion is a conditioned reflex, meaning it occurs only if you like or want a particular food. Depression and loss of appetite can suppress the **cephalic reflex**.

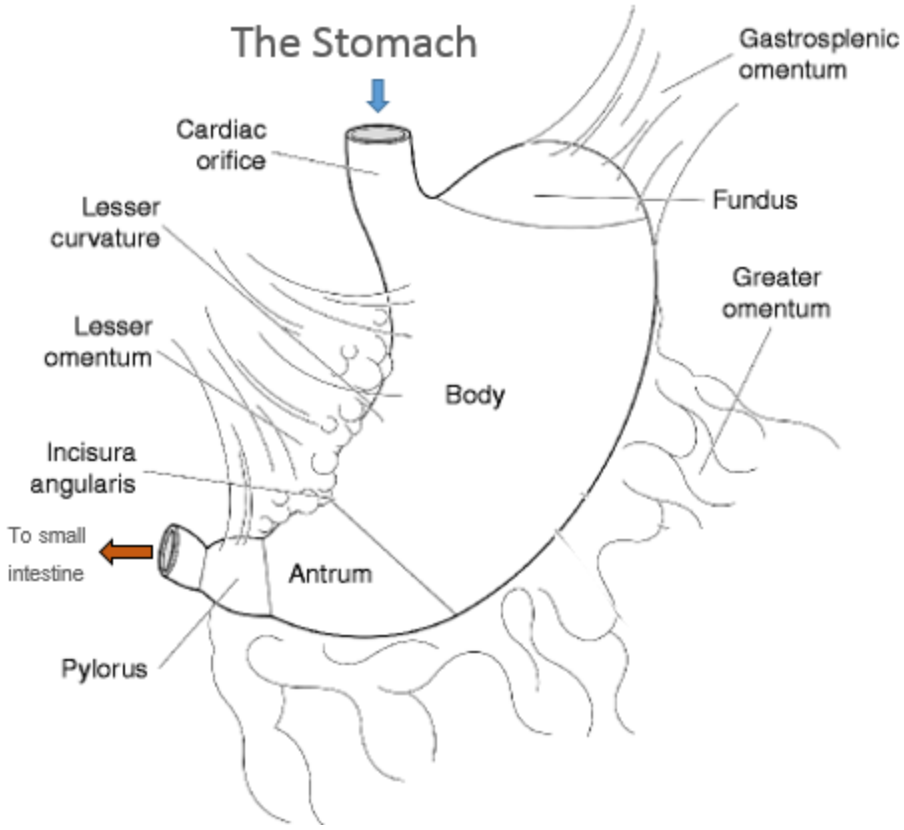


Figure 20.8 Lining the stomach the gastric mucosa has numerous openings called gastric pits that go into gastric glands which empty into the bottom of pits that have different cell types, including mucous cells and chief cells and parietal cells

The Gastric Phase

The **gastric phase** of secretion lasts 3 to 4 hours, and is set in motion by local neural and hormonal mechanisms triggered by the entry of food into the stomach. Once food arrives in the stomach, it stimulates **parasympathetic** neurons to release acetylcholine (ACh) inducing increased secretion of gastric juice. The commencement of digestive activity and rising pH stimulate the release of **gastrin** from

enteroendocrine G cells which stimulate parietal cells (see **Fig. 20.9** below) to increase their production of hydrochloric acid (HCl) to create the very acidic environment required for the cleavage and conversion of **pepsinogen** to **pepsin**, and start the digestion of proteins in the stomach.

The release of gastrin also activates vigorous smooth muscle contractions, facilitating the churning actions of the stomach. This starts the mixing process. Whenever pH levels in the stomach drop too low, cells lining the stomach react by suspending HCl secretion and increasing mucous secretions. It is a finely tuned process.

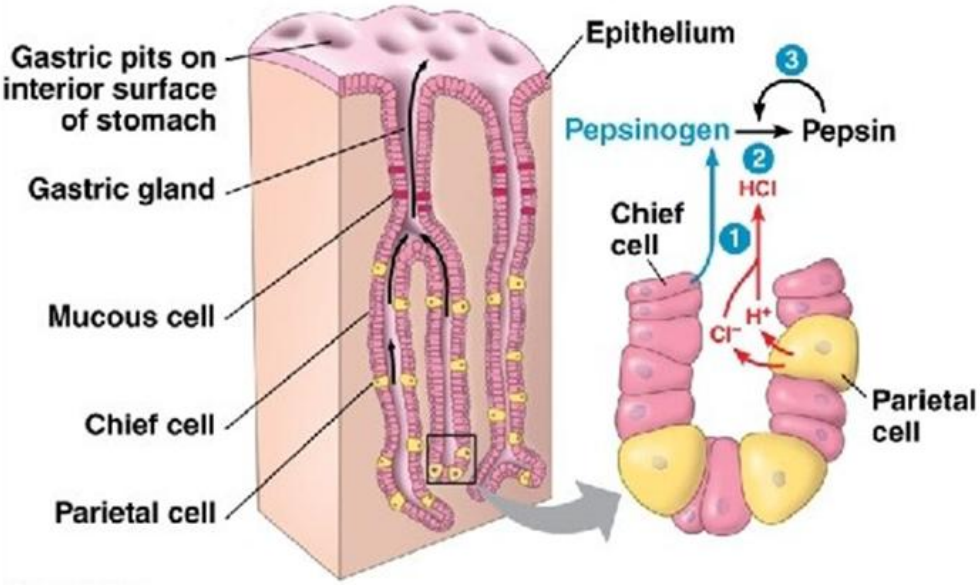


Figure 20.9 Lining the stomach the gastric mucosa has numerous openings called gastric pits that go into gastric glands which empty into the bottom of pits that have different cell types, including mucous cells and chief cells and parietal cells. These are the cells that are stimulated into action by food in the stomach to secrete pepsinogen and the HCl that cleaves it into the active pepsin to digest proteins.

The Intestinal Phase

The intestinal phase of gastric secretion has both excitatory and inhibitory elements. The duodenum has a major role in regulating the stomach and its emptying. When partially digested food fills the duodenum, intestinal mucosal cells release a hormone called intestinal (enteric) gastrin, which further excites gastric juice secretion. This stimulatory activity is brief, however, because when the intestine distends with chyme, the enterogastric reflex inhibits secretion. One of the effects of this reflex is to close the **pyloric sphincter**, which blocks additional chyme from entering the duodenum.

The Mucosal Barrier

The mucosa of the stomach is exposed to the highly corrosive acidity of gastric juice. Gastric enzymes that can digest protein can also digest the stomach itself. The stomach is protected from self-digestion from all of its powerful chemicals by the **mucosal barrier**. This barrier has a thick coating of bicarbonate-rich mucus which forms a physical barrier, and its **bicarbonate ions** neutralize acid. Secondly, the epithelial cells of the stomach's mucosa meet at **tight junctions**, which block gastric juice from penetrating the underlying tissue layers. Finally, **stem cells** located where gastric glands join the gastric pits quickly replace

damaged epithelial mucosal cells, when the epithelial cells are shed. In fact, the surface epithelium of the stomach is completely replaced every 3 to 6 days.

Mechanical Digestion of the Stomach
The stomach participates in virtually all the digestive activities (except ingestion and defecation). Within a few moments after food after enters the stomach, mixing waves begin to occur at intervals of approximately 20 seconds.

A **mixing wave** is a unique type of peristalsis that mixes and softens the food saturating it with gastric juices to create chyme. The initial mixing waves are moderate, but become more intense, starting at the body region of the stomach which is centrally located, and increasing in force as they reach the **pyloric region** at the distal end.

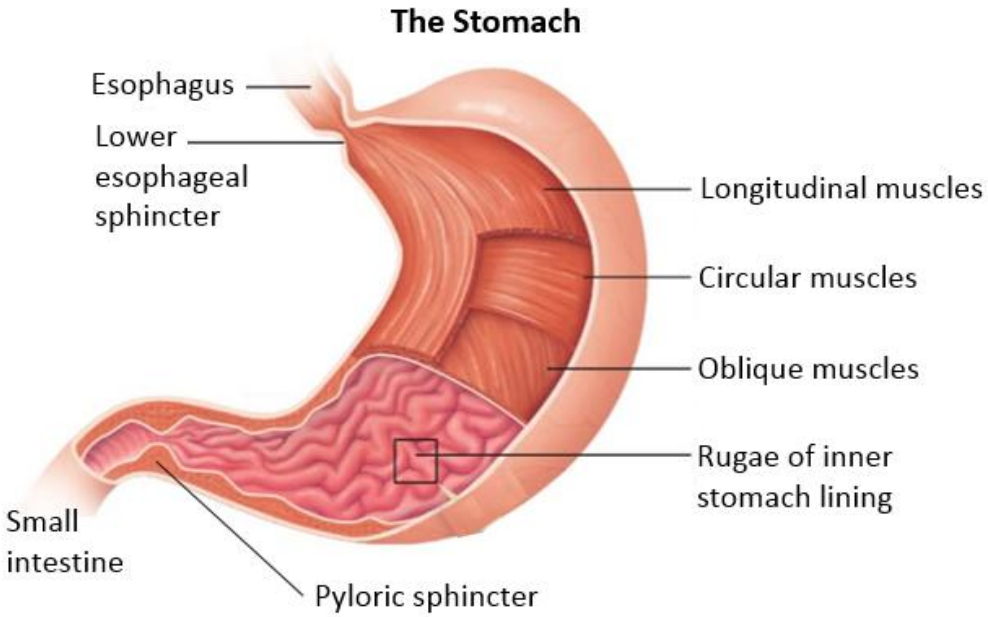


Figure 20.10 The three different muscular layers of the stomach enable for significant mixing of contents in this region of the gastrointestinal tract. Seen here are the three muscle layers from innermost to outermost; the oblique, the circular, and the longitudinal layers. There are also two important sphincters made from a thickening of the circular muscle layer which controls entrances and exits; they are the lower esophageal sphincter, connecting the esophagus to the stomach, and the pyloric sphincter, connecting the stomach to the small intestine.

Chemical (Enzymatic) Digestion
The **fundic region** of the stomach plays an important role in the storage of undigested food and gases released during the process of **chemical digestion** which requires **digestive enzymes**.

The digestive activities of **salivary amylase** from the oral cavity continue until mixing begins in the stomach and the **acidic chyme** inactivates salivary amylase. This same action activates **lingual lipase** also released in the mouth.

The lingual lipase breaks down triglycerides into free fatty acids, and mono- and diglycerides. The breakdown of protein begins in the stomach when the enzyme **pepsinogen** is cleaved into the active **pepsin** through the high levels of HCl. In infancy, the gastric glands also produce an enzyme **rennin** (with 2 n's, not to be confused with the renal enzyme renin), which facilitates the digestion of milk protein.

Gastric Emptying

The pylorus of the stomach holds around 30 mL (1 fluid ounce) of chyme and acts as a type of filter which permits only liquids and small food particles to pass through the **pyloric sphincter**, which is not fully closed but constricted enough to significantly regulate passage (see **Fig. 20.10** above). In a process called **gastric emptying**, rhythmic mixing waves force about 3 mL of chyme at a time through the pyloric sphincter and into the **duodenum**, which is the first region of the small intestine.

The release of too much chyme at one time would overwhelm the capacity of the small intestine to handle it, so this process is controlled. The rest of the chyme is pushed back into the body of the stomach, where it continues mixing. This process is repeated when the next mixing waves force more chyme into the duodenum.

Gastric emptying is regulated by both the stomach and the duodenum. The presence of chyme in the duodenum activates receptors that **inhibit gastric secretion**. This prevents additional chyme from being released by the stomach before the duodenum is ready to process it.

Another function of the stomach is the production of **intrinsic factor**. The intestinal absorption of **vitamin B_{12}** cannot occur without intrinsic factor. Vitamin B_{12}, as we have seen in the cardiovascular section, is necessary for the production of healthy mature red blood cells, and normal neurological functioning. If someone has must endure a total gastrectomy (stomach removal), at the very least they will need to receive vitamin B_{12} injections routinely.

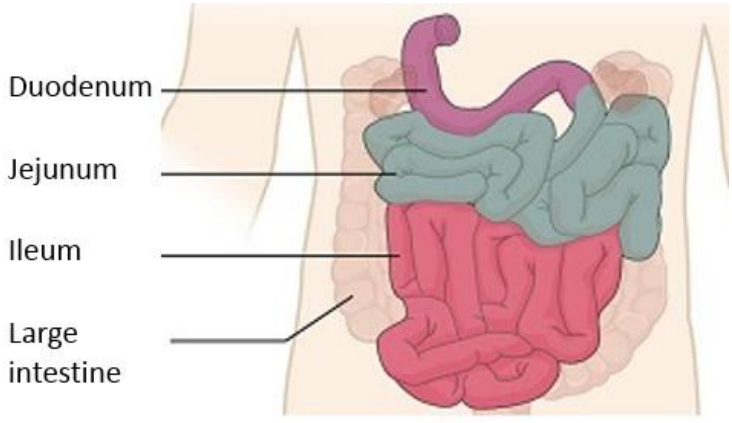
Amount of Time Food is in the Stomach

Typically, the contents of the stomach are completely emptied into the duodenum within **2 to 4 hours** after consumption of a meal, though this will differ with different types of food. Carbohydrate heavy foods empty fastest, followed by high-protein foods and foods, with high triglyceride (fat) content taking the longest amount of time to leave the stomach.

Food can stay in the stomach for 6 hours or longer if the duodenum is busy processing fatty chyme, because lipids must be emulsified first with bile to reduce the size of the lipid droplets, and the enzymes in the small intestine digest fats slowly. Even if it takes 8 hours, this time is still a fraction of the **24 to 72 hours** that full digestion often takes from start to finish.

The Small Intestine

The small intestine is the longest region of the GI tract, the length varying from 22 to 25 feet from start to end. It starts at pyloric end of the stomach which connects directly to the small intestine.



In anatomical order, the small intestine has three parts: **1)** the duodenum, **2)** the jejunum, and **3)** the ileum, see image below. The most distal portion (ileum) connects to the start (cecum) of the large intestine.

This segment of the alimentary canal is very important, because it serves both for both **mechanical** and **chemical digestion**, and **absorption**. The small intestine receives two

critical digestive fluids: **a)** **bile** from the liver (stored in the gallbladder), and **b)** **pancreatic juice** from the pancreas, both of which are introduced immediately in the duodenum.

After the enzymatic breakdown of food, the highly specialized lining of the small intestine absorbs many substances across its wall, such as glucose, amino acids, vitamins, lipids, minerals, water, etc. Any waste or undigested material is passed along to the large intestine.

The absorptive surface area of the small intestine is about 2,700 square feet, about the size of a tennis court. Note the complexity of the specialized structures in **Fig. 21.11 below**.

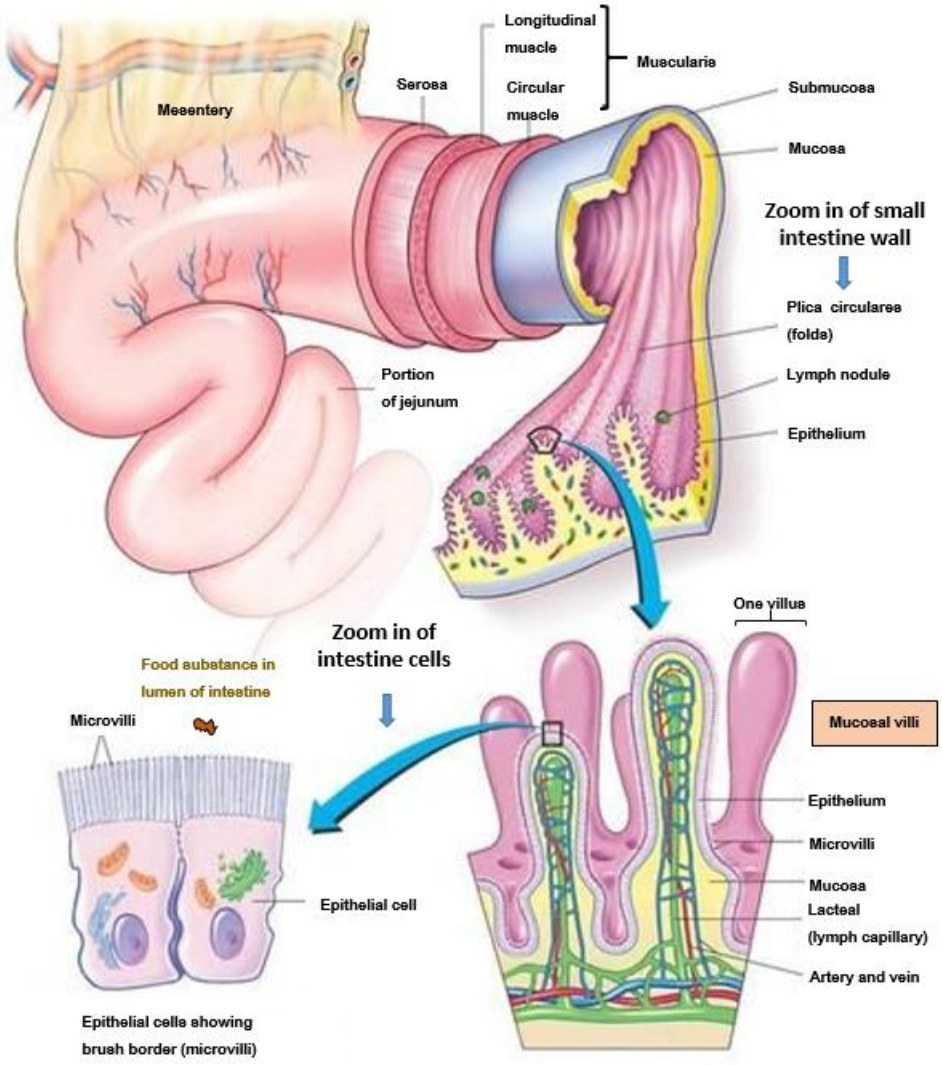


Figure 21.11 The small intestine is where mechanical and chemical digestions occur, and where the process of nutrient absorption occurs. The muscularis layer assists in peristalsis and propulsion of content along the 22 or so feet of this organ. The secretions involved in this region, including pancreatic juices which contain a myriad of digestive enzymes, all assist in chemical digestion. The brush border cells with microvilli greatly enhance surface area for effective nutrient absorption.

Mechanical Digestion in the Small Intestine

The actions of intestinal smooth muscles includes both **segmentation** and **peristalsis** (which are different to the peristaltic mixing seen in the stomach).

Segmentation in the small intestine combines the chyme with digestive juices and pushes food particles against the mucosa to be absorbed. The **duodenum** is where the most rapid segmentation occurs, at a speedy rate of about 12 times per minute. In the ileum, segmentations are only about eight times per minute. When most of the chyme has been absorbed, the small intestinal wall becomes less distended. At this point, the localized segmentation process is replaced by transport movements, to keep the material moving down the line.

The duodenal mucosa secretes the hormone **motilin**, which initiates peristalsis in the form of a **migrating motility complex**. These motility complexes, which start in the duodenum, push the chyme through a short section of the small intestine and then stop. The next contraction begins a little bit farther down than the first, forcing chyme a bit farther through the small intestine, then stops. These complexes move slowly down the small intestine, pushing chyme along its way, taking from **90** to **120** minutes to finally reach the end of the ileum. The process is repeated again, from the duodenum down the ileum.

There is a sphincter that controls the moment of material from the small intestine into the large intestine called the **ileocecal valve**. Typically it is in its closed or constricted state. However, whenever there is motility in the ileum, this sphincter dilates and allows the food residue to enter the first portion of the **large intestine**, which is the blind ended pouch is called the **cecum**.

The relaxation of the ileocecal sphincter is controlled by nerves and hormones. First, digestive activity in the stomach provokes the **gastroileal reflex**, which increases the force of ileal segmentation. Second, the stomach releases the hormone **gastrin**, which enhances ileal motility, thus relaxing the ileocecal sphincter. After chyme passes through, backward pressure helps close the sphincter, preventing retrograde flow of any material into the ileum. It takes from about 3 to 5 hours for all chyme to leave the small intestine.

Chemical Digestion in the Small Intestine

The digestion of proteins and carbohydrates, which partially occurs in the stomach, is completed in the small intestine with the aid of intestinal and **pancreatic juices**. Lipids arrive in the intestine largely undigested, so much of the focus here is on lipid digestion, which is facilitated by bile and the enzyme pancreatic lipase.

The intestinal juices combines with pancreatic juices to provide a liquid medium that facilitates **absorption**. The intestine is also where most **water** is absorbed, via **osmosis**. The small intestine's absorptive cells also synthesize digestive enzymes and then place them in the plasma membranes of the **microvilli**. This distinguishes the small intestine from the stomach; that is, enzymatic digestion occurs not only in the lumen, but also on the luminal surfaces of the mucosal cells!

In order to have optimal chemical digestion, the introduction of chyme from the stomach must be gradual and limited. In other words it is introduced in a very controlled way. The chyme entering the small intestine is usually a *hypertonic* solution, thus having too much of it enter at one time could result in water loss via osmosis from the blood into the intestinal lumen (one cause of 'watery stools' and diarrhea).

Water loss like this could cause low blood volume, enough to be life-threatening. Also, the highly acidic chyme from the stomach must be incrementally **neutralized** and **alkalized**, with the aid of **bile** and the **pancreatic juices**, both of which are alkaline. Therefore, the processes of digestion from the pylorus of the stomach to the duodenum of the small intestine can take some time.

The Large Intestine

The large intestine is only about 5 to 6 feet in length, so it is not nearly as long as the small intestine, but it is larger in breadth than the small intestine, having a diameter of about 3 inches, and therefore three times that of the small intestine. The **large intestine** has several parts and also contains the **colon** within it. From proximal (start) to distal (finish), the large intestine is: **a)** the **cecum** (that has the appendix attached to it), **b)** the **colon** (includes the ascending, transvers, descending and sigmoid), **c)** the **rectum**, and **d)** the **anal canal**. The **anus** is the opening at the end of the GI tract.

There may be partly digested food that moves into the cecum and the colon, and absorption of remaining nutrients can occur. Once the absorption of nutrients has been accomplished (mostly in the small intestine), the large intestine **absorbs water** and **minerals** from the undigested material and then **compacts** this in preparation for **elimination** from the body as **feces**. A simplistic representation of the large intestine can be seen in **Fig. 20.12** below.

Digestive Functions of the Large Intestine

The residue of chyme that originally came from the stomach, after going through the small intestine, then enters the large intestine. The contents of what was ingested contains **few nutrients except water** at this stage, which is reabsorbed as the residue traverses through the large intestine.

The length of time that contents spend in the large intestine is highly variable, it depends on the nature of the food and on the activity of the individual. Typically, movement through the system takes 12 to 24 hours, sometimes up to 36 hours.

Though it is commonly stated that the large intestine can be completely removed without significantly affecting digestive function, it is something to be avoided wherever possible. All structures in the body are totally necessary for an individual, even if the current science states a structure has limited and replaceable functions.

Nothing, no machine or drug treatment, can accomplish what a healthy organ does! In severe cases of inflammatory bowel disease, the large intestine can be removed by a procedure known as a **colectomy**. A new fecal pouch can be crafted from the small intestine and sutured to the anus, but if not, an ileostomy can be created by bringing the distal ileum through the abdominal wall, allowing the watery chyme to be collected in a bag-like adhesive appliance. That is not like having a healthy bowel.

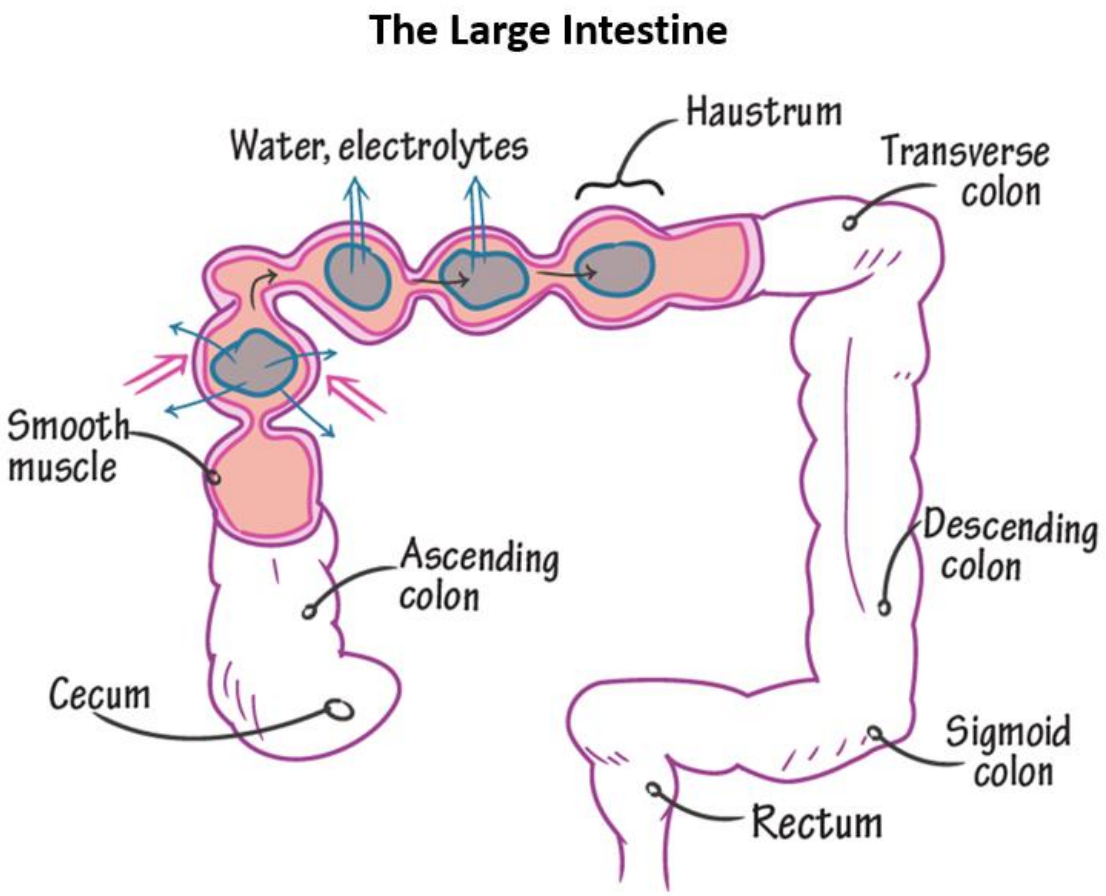


Figure 20.12 The large intestine is the final region of the alimentary canal and its primary functions are to absorb water and electrolytes, to produce and absorb vitamins, and to compact the excess waste material to form and propel feces toward the rectum for elimination from the body.

Mechanical Digestion in the Large Intestine

In the large intestine mechanical digestion begins when chyme moves from the ileum into the cecum, an activity regulated by the ileocecal sphincter. Right after you eat, peristalsis in the ileum forces chyme into the cecum. When the cecum is distended with chyme, contractions of the ileocecal sphincter strengthen. Once chyme enters the cecum, colon movements begin.

Mechanical digestion in the large intestine includes a combination of three types of movements. The presence of food residues in the colon stimulates a slow-moving **haustral contraction**. This type of movement involves slow segmentation, primarily in the **transverse** and **descending** colons. When a haustrum (plural haustra) is distended with chyme, its muscle contracts, pushing the residue into the next haustrum. These contractions occur about every 20 to 25 minutes, and each last about 1 minute. These movements also mix the food residue, which helps the large intestine absorb water.

Another type of movement in the large intestine is **peristalsis**, but this is slower than in the esophagus, stomach and small intestine. It likes to takes it time here. The last type of movement is a called a **mass movement**. These strong waves start midway through the transverse colon and quickly force the contents to the sigmoid colon and toward the rectum. Mass movements should usually occur three or four times per day, but that is not common on a standard (highly processed) diet.

Bacterial Flora

If bacteria are ingested by a person, the vast majority entering the alimentary canal are not dangerous at all as they are taken care of by lysozymes, hydrochloric acid (HCl), or protein-digesting enzymes. However, there are trillions of bacteria that happily live within the **large intestine** and are referred to as the **bacterial flora**.

The most abundant flora of the large intestine and feces are made up of *obligate anaerobes* such as **Bifidobacteria**, **Escherichia coli** (E. coli) and **Lactobacilli** (see **Fig. 20.13** below). There are than 700 species of bacteria that are **100% symbiotic with us**, again they cause no harm. In contrast to being harmful, they are beneficial bacterial, facilitating chemical digestion and absorption, some synthesize certain $\mathbf{B_5}$ (pantothenic acid) and $\mathbf{B_7}$ (biotin) vitamins, and **vitamin K.** Many are linked to increased cleansing responses and a much healthier large intestine, therefore a healthier body.

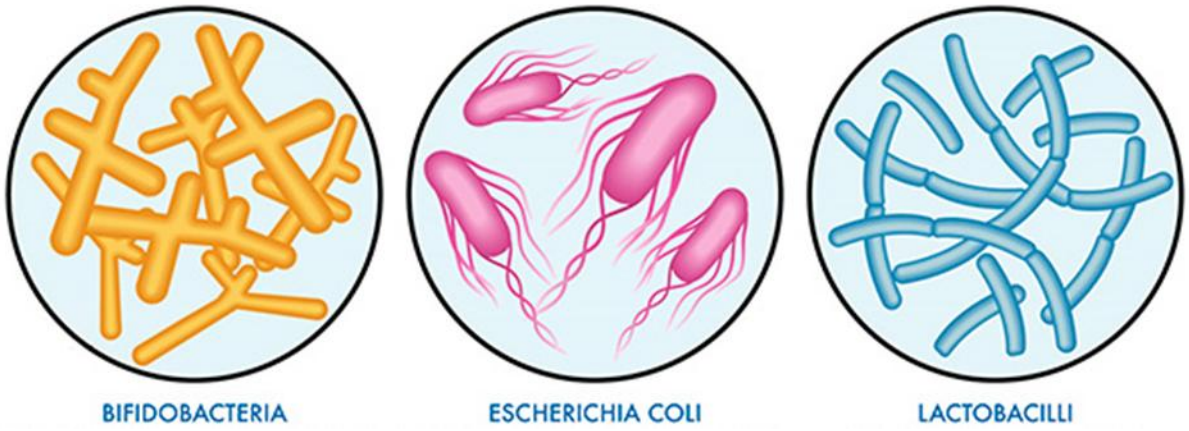


Figure 20.13 The obligate anaerobes Bifidobacteria, Escherichia coli (E. coli) and Lactobacilli that happily reside in your large intestine are shown above. There are many species of nonpathogenic bacteria that they are extremely beneficial to gut health, facilitating digestion and absorption, and synthesizing B and K vitamins.

The amazing structures that contribute to the **mucosal barrier** of the large intestine prevents these bacteria from crossing into the body. The peptidoglycan, a component of bacterial cell walls, activates the release of chemicals by the mucosa's epithelial cells, which draft protective cells, especially dendritic cells, into the mucosa. **Dendritic cells** open the tight junctions between epithelial cells and extend probes into the lumen to evaluate the microbial antigens, much like sticking your toes into a body of water to see what's going on in it, cautiously at first. The dendritic cells may then travel to neighboring lymphoid follicles in the mucosa where **T cells** inspect them for any irregularities. If a response is warranted, the lumen blocking infiltration can set off a far greater, widespread systematic reaction.

Chemical Digestion the Large Intestine

Although the glands of the large intestine secrete **mucus**, they do not secrete digestive enzymes. Therefore, chemical digestion in the large intestine occurs exclusively because of bacteria in the lumen of the colon. Thank you bacteria! Through the process of **saccharolytic fermentation** – this means the fermentation of dietary non-digestible carbohydrates into short chain fatty acids (SCFAs) by gut microbiota!

Note the elements of word; sacchro meaning saccharide and lytic meaning break! This is an awesome process because one of the most important elements of a healthy gut is having **sufficient fermentation occurring there**. It is the bacteria that break down some of the remaining carbohydrates.

The result of this process is the discharge of hydrogen, carbon dioxide, and methane **gases** that create flatus (gas) in the colon; **flatulence** is *excessive flatus*. Each day, up to 1500 mL of flatus is normally produced in the colon. More is produced when you eat foods such as beans, which are rich in otherwise indigestible sugars and complex carbohydrates like soluble dietary fiber. Even action in the stomach and small intestine influence the response of the large intestine. Distension of the stomach and the products of digestion breakdown in the small intestine provoke the **gastrocolic reflex** in the **colon**, which increases motility, including mass movements in the colon.

Absorption in the Large Intestine

The small intestine absorbs about 90 percent of the water you ingest (either as liquid or within solid food). The large intestine absorbs most of the remaining water, a process that converts the liquid chyme residue into semisolid **feces** or **stool**. Feces is composed of undigested food residues, unabsorbed digested substances, millions of bacteria, old epithelial cells from the GI mucosa, inorganic salts, and enough water to let it pass smoothly out of the body. Of every 500 mL (17 ounces) of food residue that enters the cecum each day, about 150 mL (5 ounces) become feces. Increased **fermented foods** and **dietary fiber** softens the stool and increases the power of colonic contractions, optimizing the activities of the colon.

Feces Formation and Defecation

Feces are eliminated through contractions of the rectal muscles. You help this process by a voluntary procedure called **Valsalva's maneuver**, in which you increase intra-abdominal pressure by contracting your diaphragm and abdominal wall muscles, and closing your glottis in the act – that means holding your breath! This is to help create greater pressure in the abdominal cavity to get that stuff out of you!

The process of **defecation** begins when what are called '**mass movements**' of the large intestine. As touched on briefly before, this action helps force feces from the distal regions of the **colon** toward the end of the line into the **rectum**. This movement causes a stretching of the rectal wall and provokes the **defecation reflex**! This results in the elimination of feces from the rectum via the anus and out of the body. Once this reflex begins, it is difficult although possible to stave off, but obviously it becomes more and more pressing!

Control of this defecation reflex is via the parasympathetic division of the ANS, mediated via the spinal cord. It requires the contraction of the **sigmoid colon** and the **rectum**, while relaxing the **internal anal sphincter**, and initially contracting the **external anal sphincter** as a means of preventing elimination until appropriate.

The movement of feces into the **anal canal** signals the brain and allows for the conscious choice of the voluntarily opening of the external anal sphincter and the commencement of the act of defecating, or to keeping it temporarily closed.

To delay defecation, a few seconds are required for the reflex contractions to stop and the rectal walls to relax. The next mass movement will trigger additional defecation reflexes until defecation is achieved.

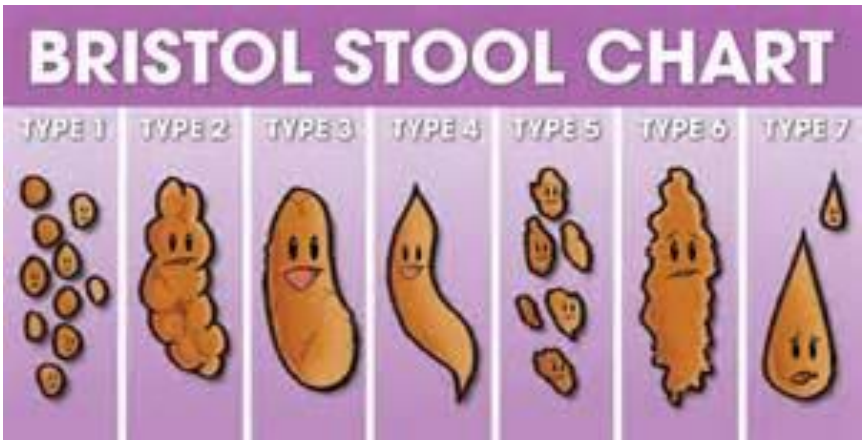
Bacteria in colon ferment some undigested and unabsorbed carbohydrates (**fibers**) into simpler compounds, which can lead to the production of methane gas (CH_4), CO_2, and H_2. Fermented fiber produces short-chain fatty acids. In the large intestine, **1 liter** of fluid material is gradually reduced to **200 grams** of brown fecal material. The intestinal matter passes through the large intestine in **12 to 70** hours, depending on the person's health, age, diet, and fiber intake.

Table 20.2 Shows the 7 types of stool in the Bristol stool scale, with a basic description.

7 Types of Stool	Basic Description	Possible Indications
Type 1	Separate hard lumps, like nuts (hard to pass)	Toxins, Very Constipated
Type 2	Sausage-shaped, but lumpy	Slightly Constipated
Type 3	Like a sausage but with cracks on its surface	Healthy
Type 4	Like a sausage or snake, smooth and soft	Healthy
Type 5	Soft blobs with clear cut edges (passed easily)	Lacking Fiber
Type 6	Fluffy pieces with ragged edges, a mushy stool	Inflammation
Type 7	Watery, no solid pieces, entirely liquid	Diarrhea Inflammation

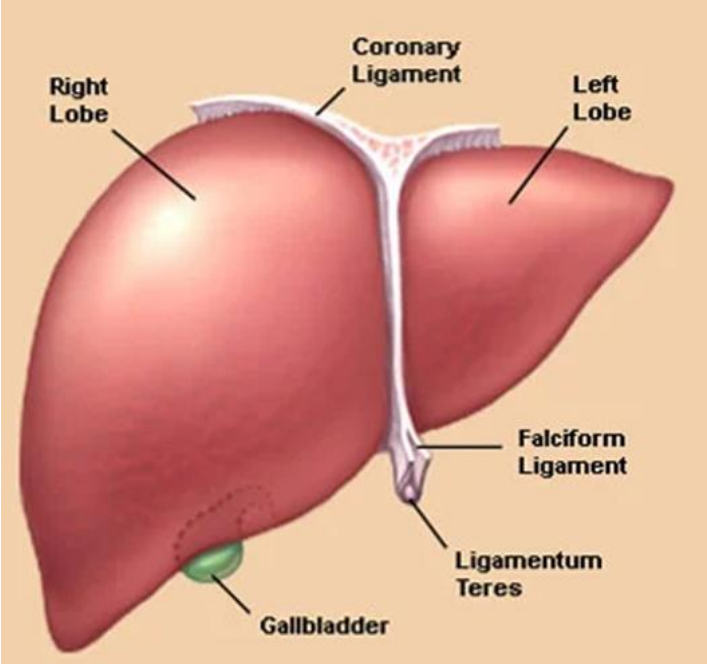
If defecation is delayed for an extended time, additional water is absorbed in the large intestine, **making the feces more condensed and firmer**, which potentially leads to **constipation**. In contrast, if the waste matter moves too quickly through the intestines, there will not be enough water absorption and **diarrhea** can result. The healthy number of bowel movements can vary greatly between individuals, ranging from two or three per day to three or four per week. Diet, health, toxins and stress levels are the major determinants of the frequency of bowel movements.

Note: When bile is metabolized by your gut bacteria, it makes **stercobilin** which accounts for the normal **brownish** color of feces. The condition of your stool is important! Be sure to take a look and make a determination about the state of your poo. Using the Bristol Stool Chart (right) is a handy way to make a quick assessment. Types 3 and 4 are the best for you!



The Liver

The liver is the largest internal organ in the body (**Fig. 20.14**), and is located on the right side of the abdominal cavity, immediately under the diaphragm in the right upper quadrant, and receives protection from the surrounding ribs. It usually weighs approximately three pounds. The size of the liver is proportional to the size of the person. No two livers are the same size, so there is no right or set size, though in general it can be about the size of a small football. In a healthy adult the texture of the liver should be soft yet firm, having a dark red-brown color.

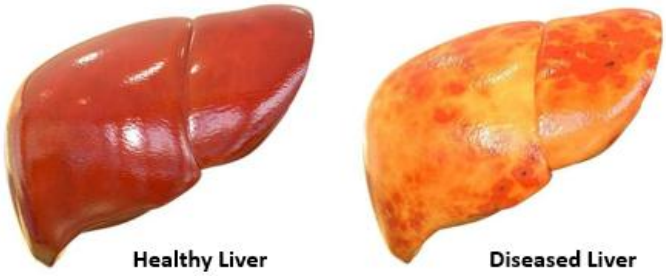


A **fatty liver** can arise from a poor diet and excess sugars, including **alcohol**. A hardened liver is a very unhealthy liver. **Cirrhosis** of the liver is a type of damage where healthy liver tissue is replaced by discolored hardened scar tissue (see images below).

The liver is one of the most important organs in the entire body. In addition to being an accessory digestive organ, it plays a number of pivotal roles in metabolism and regulation. The liver has four lobes, the large **right lobe**, the smaller **left lobe** (see **Fig. 20.14** at left) and the very small posteriorly located **quadrate lobe** (that looks a like a quad) and the **caudate lobe** (which is toward the 'tail').

Figure 20.14 The liver plays a vital role in regulating most chemical levels in the blood. It makes bile to emulsify ingested fats, as well as making the vast majority of plasma proteins for the blood. The liver metabolizes fats, proteins, and carbohydrates and stores glycogen, vitamins, and minerals. It continuously filters the blood of toxins, removing them or reducing their toxicity.

The **hepatic artery** and **hepatic portal vein** enter the liver at the **porta hepatis**, meaning gateway to the liver, along-side the **common hepatic duct**. The hepatic artery delivers oxygenated blood from the heart to the liver. The hepatic portal vein delivers partially deoxygenated blood containing nutrients absorbed from the small intestine and actually supplies more oxygen to the liver than do the much smaller hepatic arteries. Not only are nutrients absorbed here at the liver, but also drugs and toxins – the liver is **the great detoxifier of the body**, working to processes and reduce toxicity of whatever may be ingested. After processing the blood borne nutrients and toxins, the liver releases nutrients needed by other cells back into the blood, which drains into the central vein and then through the hepatic vein to the inferior vena cava.



With this **hepatic portal circulation**, all blood from the alimentary canal passes through, and is filtered and stabilized by the liver.

The hepatic sinusoids also contain star-shaped **Kupffer cells** which are resident phagocytes of the liver (also called reticuloendothelial cells). These remove dead red and white blood cells, bacteria, and other foreign material that enter the sinusoids. The **portal triad** is a distinctive arrangement around the perimeter of hepatic lobules, consisting of three structures: a **bile duct**, a **hepatic artery** branch, and a **hepatic portal vein** branch.

Bile

We know that lipids are hydrophobic and most do not dissolve in water, therefore, before they can be digested in the watery environment of the small intestine, they must be made easier to digest. This is accomplished with **bile**. Reminder; bile does not digest (chemically breakdown) lipids, what it does is surround large lipid droplets and separates them into smaller lipid droplets, a process called **emulsification**. The **hepatocytes** of the **liver** produce about **800** to **1,000 ml** (27 to 34 fluid ounces) of bile each day. Whoa, that's a lot of bile. It is a yellow-brown or yellow-green **alkaline** solution (pH 7.6 to 8.6), and a mixture of water, bile salts, bile pigments, phospholipids (such as lecithin), electrolytes, cholesterol, and triglycerides.

The hepatocytes secrete bile into canaliculi, which are small canals, leading to the common bile duct. The bile is then directed into the gallbladder where it is stored and concentrated. The production of bile increases if **lipid rich** chyme enters the duodenum, and it stimulates release of the hormone **secretin** in the gut. Between meals, bile is produced but conserved. The **hepatopancreatic sphincter** constricts and closes which shunts bile into the **gallbladder**, for more storage.

The bile components that are most critical to emulsification are the **bile salts** and **phospholipids**. The hydrophobic region of the phospholipid interacts with the large lipid molecules, whereas the hydrophilic region interacts with the watery chyme in the intestine. This results in the large lipid globules being pulled apart into many **smaller lipid fragments** of about 1 μm in diameter. This dramatically increases the surface area available for lipid-digesting enzyme activity.

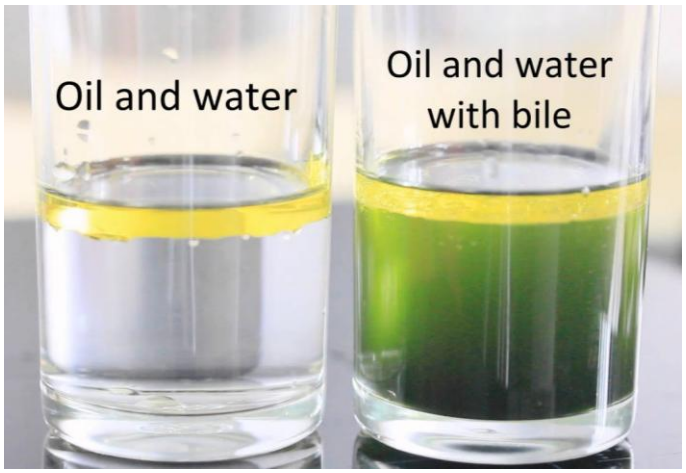


Figure 20.15 On the left is a glass with oil and water and on the right is a glass with oil, water and bile, which creates an interface for the lipid molecules to become emulsified within a watery solution. If you look carefully you can see the smaller lipid droplets within the green of the bile solution.

Bile salts act as emulsifying agents in the same way that soap works on fats mixed with water (see **Fig. 20.15** below). They are also important for the absorption of digested lipids. While most constituents of bile are eliminated in feces, bile salts are efficiently recycled via the **hepatic portal system** back to the

liver by the **enterohepatic circulation**. Once bile salts reach the ileum they are absorbed and returned to the liver in the hepatic portal blood. Yay! The hepatocytes then excrete the bile salts into newly formed bile. Thus, this precious resource is exquisitely recycled.

The main pigment in bile is called **bilirubin**, which is a waste product created during the culling of old or damaged red blood cells from the circulation in the spleen. The breakdown products of this process include proteins, iron, and the toxic bilirubin, which transported to the great 'detoxifier, the liver via the splenic vein of the hepatic portal system. The liver really is the great sorter and detoxifier, and the proteins and iron delivered to the liver are recycled. The bilirubin is expertly excreted and incorporated in the bile.

It is the bilirubin which accounts for the **green** color of bile. As bile is squirted into the gut, intestinal bacteria transform the bilirubin into **stercobilin**, which is responsible for the characteristic **brown** pigment that gives color to the **stool** to be eliminated.

The Gallbladder

The gallbladder is 8–10 cm (about 3–4 in) long and is nested in a shallow area on the posterior aspect of the right lobe of the liver. This muscular sac **stores**, **concentrates**, and when stimulated, **propels** the bile into the duodenum via the common bile duct. It is divided into three regions. The fundus is the widest portion and tapers medially into the body, which in turn narrows to become the neck (see **Fig 20.16** below). The neck angles slightly as it approaches the hepatic duct. The cystic duct is 1–2 cm long (less than 1 inch) and turns inferiorly as it bridges the neck and hepatic duct.

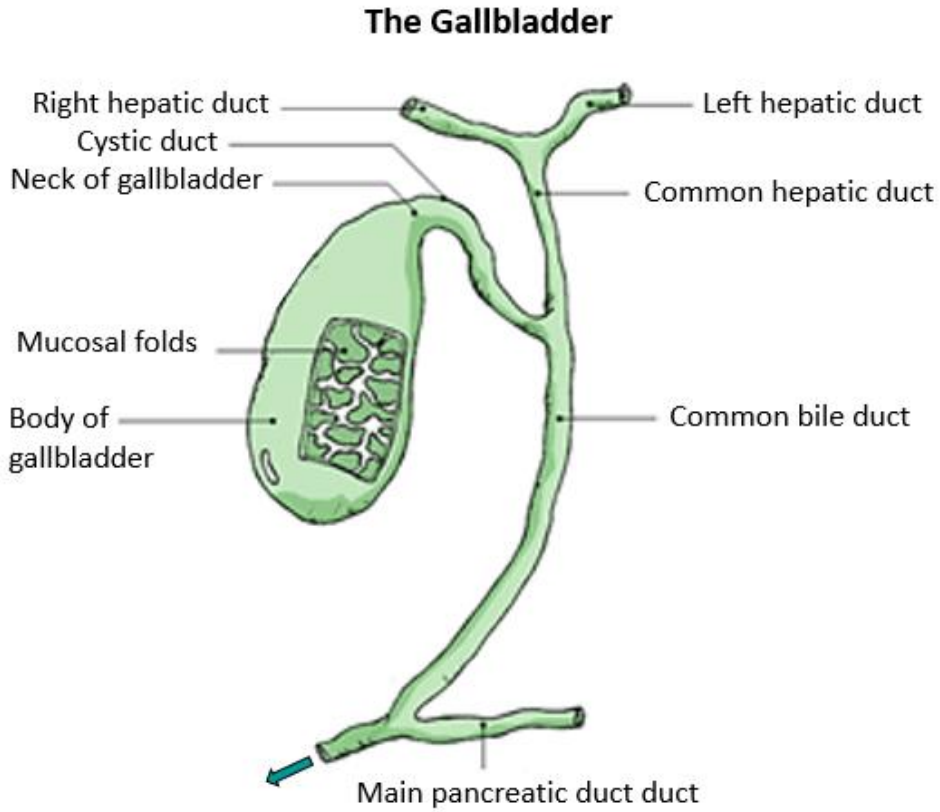


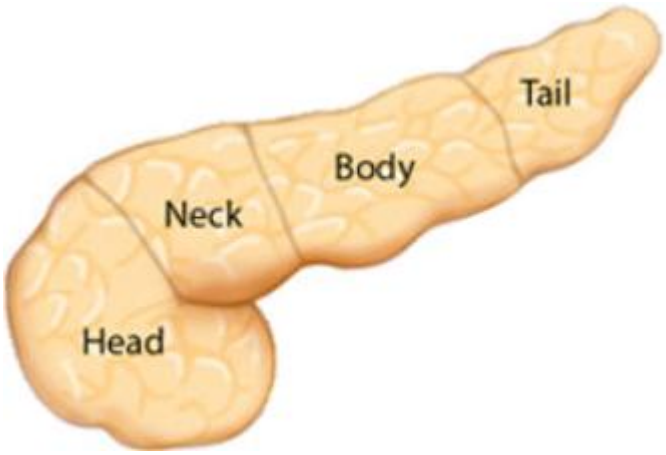
Figure 20.16 The gallbladder does not make bile but it receives it from the liver and acts to store and concentrate the bile. The contraction of the muscular layer of the body and the ducts of the gallbladder promotes the release of bile when stimulated by the ingestion of lipid rich (fatty) foods.

The simple columnar epithelium of the gallbladder mucosa is organized in **rugae**, similar to those of the stomach. There is no submucosa in the gallbladder wall. The wall's middle, muscular coat is made of smooth muscle fibers. When these fibers contract, the gallbladder's contents are ejected through the **cystic duct** and into the bile duct.

Visceral peritoneum reflected from the liver capsule holds the gallbladder against the liver and forms the outer coat of the gallbladder. The gallbladder's mucosa absorbs water and ions from bile, concentrating it by up to **10 times**.

The Pancreas

The glandular **pancreas** sits inconspicuously behind the stomach, with its head comfortably snuggled into the "c-shaped" curvature of the **duodenum** of the small intestine. In its digestive role, the pancreas has a very important role with the duodenum. The body of the pancreas extends laterally about 6 inches (15 cm) with the tapered tail ending in the hilum of the spleen (see **Fig. 20.17** below). It is a mixed gland, both an exocrine gland (secreting digestive enzymes) and an endocrine gland (releasing hormones such as insulin and glucagon into the blood).



The exocrine portion of the pancreas is created by structures called **pancreatic acini** (singular acinus), meaning 'round' and these structures make up the bulk of the pancreas. The acinar cells synthesizes store and secretes the digestive enzymes called **pancreatic juice**. Under normal physiological conditions, digestive enzymes are activated only once they have reached the duodenum. The acini secrete their contents into tiny ducts that merge to form the **main pancreatic duct** and the smaller **accessory pancreatic duct**.

The main pancreatic duct fuses with the common bile duct, delivering bile from the gallbladder and liver, immediately prior to entering the duodenum via the **greater duodenal papilla**. This entrance is controlled by the **hepatopancreatic sphincter** (sphincter of Oddi), which regulates the release of pancreatic juice and bile into the small intestine. The **accessory pancreatic duct** delivers only pancreatic juices to the duodenum via the lesser duodenal papilla which is proximal (superior) to, but smaller than, the greater duodenal papilla (see **Fig. 20.17** below).

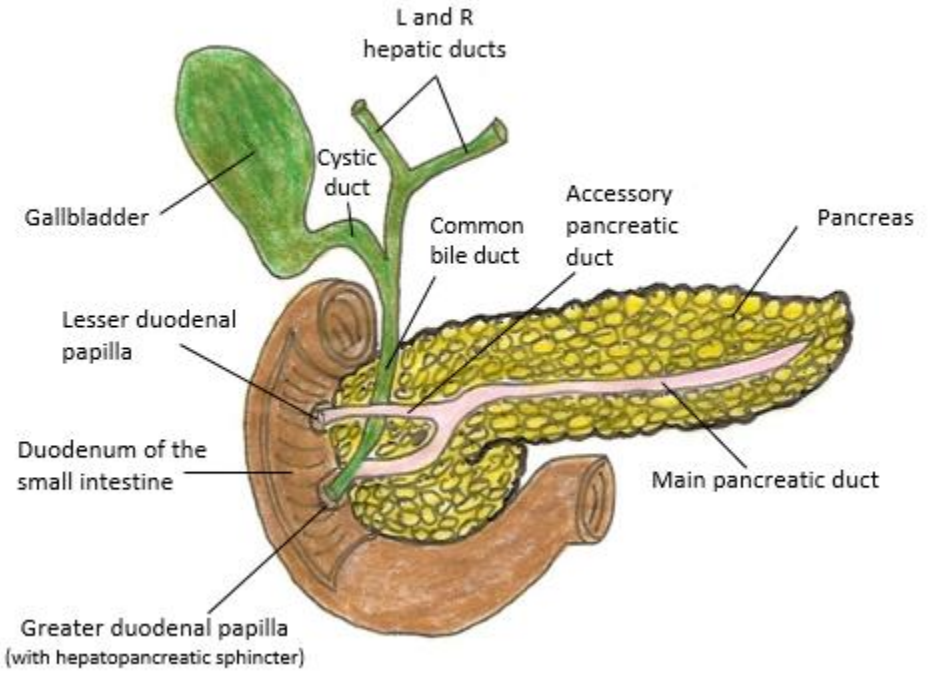


Figure 20.17 The pancreas shown above is vital to both the digestive and endocrine systems. In the digestive system its role is to release pancreatic juice into the duodenum, which contains digestive enzymes that chemically breaks down large macromolecules (polymers) into smaller monomers to facilitate absorption.

Scattered through the sea of exocrine acini are little 'islands' of endocrine cells, they are called **pancreatic islets** (or the islets of Langerhans). These contain different groups of cells that make pancreatic hormones, such as the two polypeptide hormones insulin and glucagon that regulate blood glucose (*see endocrine section*) and also makes the hormone **somatostatin**, which regulates and slows growth.

in the small intestine. Pancreatic enzymes are active in the digestion of sugars, proteins, and fats.

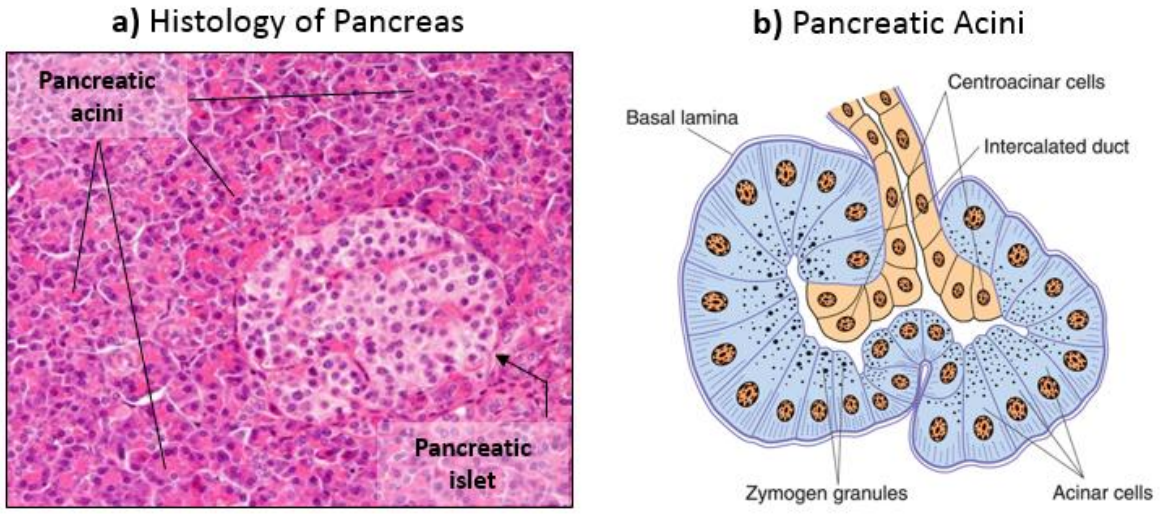


Figure 20.18 The histology of the pancreas is shown in **a)** where far more pancreatic acini are present under the microscope that the pancreatic islets. The drawing in **b)** shows the basic functional arrangement of the acini in the pancreas. The acinar cells have zymogen granules located at the apical end which are specialized storage organelles in acinar for sorting, packaging and regulating the secretion of digestive enzymes.

Pancreatic Juice

The pancreas produces over a liter of pancreatic juice each day. The histology of pancreatic tissue is shown in **Fig. 20.18** above. Unlike bile, it is clear and composed mostly of water along with some salts, sodium bicarbonate, and several digestive enzymes. Sodium bicarbonate is responsible for the slight alkalinity of pancreatic juice (pH 7.1 to 8.2), which serves to buffer the acidic gastric juice in chyme, inactivate pepsin from the stomach, and create an optimal environment for the activity of pH-sensitive digestive enzymes

Proteolytic Enzyme Activation

The pancreas produces digesting enzymes that are in their inactive forms. The enzymes are activated once they arrive in the duodenum, otherwise they would digest the pancreas. The process involves **proteolytic activation**, recall from the enzyme section at the beginning of the text, that this means the enzyme is cut and shortened in terms of the length of its polypeptide chain, and as a consequence becomes activated. In most instances it will follow the "-ogen" naming system, wherein when the enzymes is cleaved and activate, it sheds the -**ogen** from its name to denote activation. Other enzyme (or hormone) activations can involve a **pro-** and **pre-** name prefixes (at the beginning of the word) being cleaved of to denote at the activation.

Examples of these name changes from inactive to active are seen when the intestinal brush border enzyme **enteropeptidase** in the duodenum cleaves off the 'ogen' of **trypsinogen**, creating the active **trypsin**, which in turn changes the pancreatic enzymes **procarboxypeptidase** and **chymotrypsinogen** into their active forms, **carboxypeptidase** and **chymotrypsin**. The enzymes that digest starch (amylase), fat (lipase), and nucleic acids (nuclease) are secreted in their active forms, since they do not attack the pancreas as do the protein-digesting enzymes.

Pancreatic Secretion

In terms of the regulation of pancreatic digestive secretions, this is mainly achieved by certain hormones and by the innervation of the **parasympathetic** division of the ANS. The entry of **acidic** chyme from the stomach into the duodenum stimulates the release of **secretin**, and this stimulates the pancreas (and liver) to respond with their **alkaline** secretion. The acini duct cells release bicarbonate (HCO_3^-) which helps to neutralize the acid (H^+) rich influx from the stomach, and the bile made by the liver (stored in the gallbladder) is also alkaline and contributes to elevating the pH of the duodenum. This is an example of compartmentalization of the digestive track by changing the pH of the soundings. As we know, enzymes have an **optimal pH** that influences their activity, and radical changes in pH can quickly turn down the activity of some enzymes, and turn up activity of others. Therefore, changes in pH are very effect at controlling enzyme activity.

When there are proteins and fats present in the duodenum, it stimulates the secretion of the hormone **cholecystokinin** (CCK), which stimulates the pancreatic acini to secrete their digestive enzymes within the pancreatic juice and also enhances the activity of **secretin**. Cholecystokinin is released from endocrine cells of the upper small intestine, specifically in response to amino acids and fatty acids in the chyme. Not only does it stimulates pancreatic secretions, but also triggers gallbladder contraction, the regulation of gastric emptying, and the induction of feelings of satiety or fullness. The parasympathetic regulation occurs mainly during the cephalic and gastric phases of gastric secretion, when **vagal** stimulation prompts the secretion of pancreatic juice.

A notably important role of the pancreatic secretions is in helping to maintain **stable pH** of the blood as it enters and leaves the digestive system. Most often the pancreas secretes just enough of the **bicarbonate**

(HCO_3^-) to counterbalance the amount of hydrochloric acid (HCl) produced in the stomach. The liberated hydrogen ions (H^+) enter the blood when bicarbonate is secreted by the pancreas. Thus, the acidic blood draining from the pancreas **neutralizes** the alkaline blood draining from the stomach, maintaining the pH of the venous blood that flows to the liver.

The Genetic Component of Nutrition

a) Human Genetic Variation

The variations in the human genome means that often people deal with foods differently. For instance, some people are **lactose intolerant** because they may lack the gene responsible for making the enzyme **lactase**, which breaks down the disaccharide lactose into the two monosaccharides **glucose** and **galactose**. Others may be sensitive to dairy because they are allergic the protein **casein** that is found in milk. Another common emerging allergy is to **gluten**, which is found in many grains.

> *An **allergy** is when the body experiences an inappropriate exaggerated inflammatory response to a harmless substance; that is, it over-reacts to something that is not really dangerous.* This is why some people need to avoid traditional dairy food, because they respond poorly to them, not because dairy is bad for the body.

An important question to ask is why have allergic reactions shown a relatively sudden and dramatic increase over the last 20 years? Good question. It's likely to be related to toxins introduced into our bodies from pesticides, genetically modified organisms (GMO's), artificial preservatives and additives, toxins from vaccine injections, air pollutants, water impurities, etc. All of these can promote super-sensitivity of our detoxification cells, that are then triggered into a type of hyper-alert state and this causes exaggerated inflammatory responses within our bodies. The food item isn't bad because people are allergic to it.

b) Epigenetics

A valuable concept to keep in mind is that we are **not** 'doomed by your genes' to anything, including bad health. Incredibly important scientific studies have been carried out in the field of **Epigenetics** – the study of cell trait variations caused by **external** or **environmental** factors that can turn genes on and off and affect how cells read gene and also possibly change your DNA sequence. Below is a summary of the published work by Waterland, R. A. & Jirtle, J. L. Transposable elements: targets for early nutritional effects on epigenetic gene regulation. *Molecular and Cell Biology*, **23,** 5293 - 5300, (2003).

The Agouti Mice Experiment

The Agouti mice are adorable little animals that have yellow coats, display obesity, diabetes and cardiovascular disease, similar to animals missing leptin. **Leptin** is a hormone released by fat cells (adipocytes) after eating that signal satiation or the feeling of being full, thus triggering cessation of eating.

In the Agouti mice, their condition is due to a naturally occurring ***genetic mutation*** that blocks the function of the gene that produces *alpha melanocyte stimulating hormone* (**α-MSH**). Phenotypic (physical) changes result in the appearance of the Agouti mouse. It appears that when these rodents have a deficiency in methyl groups residing at specific DNA gene locations, it causes these 'deleterious' genes to more likely by expressed.

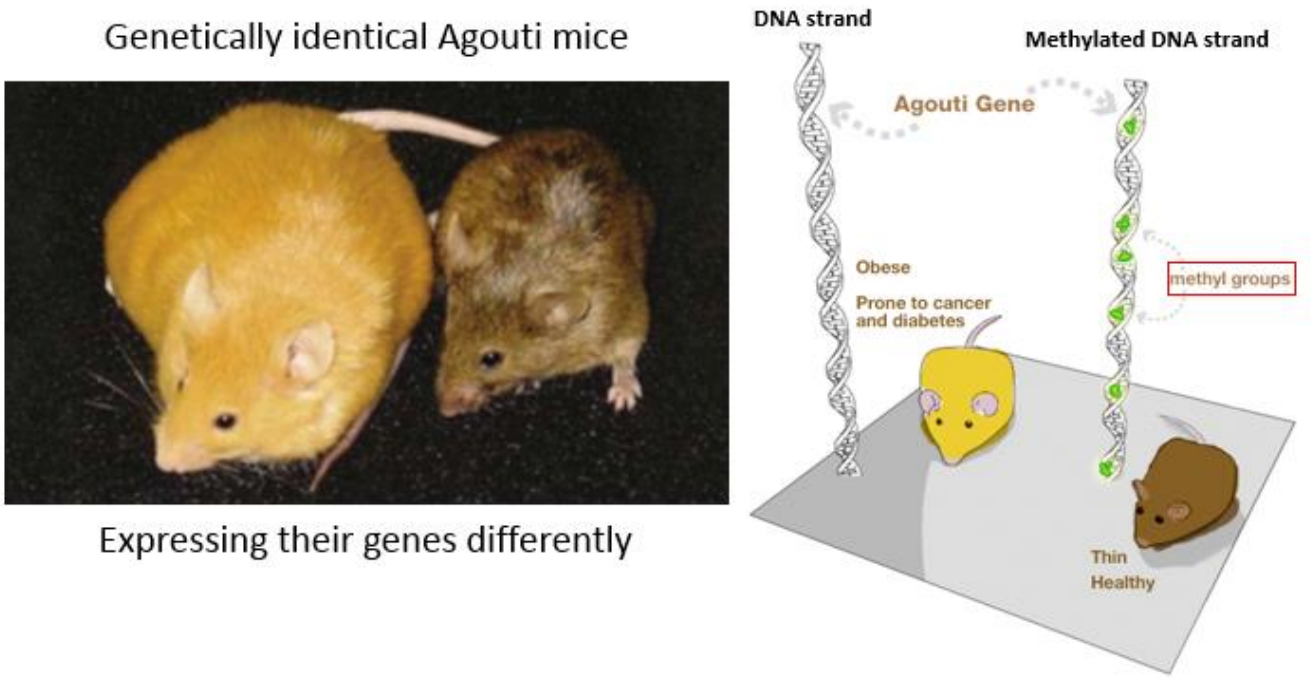


Figure 20.19 The photograph at left of the genetically identical Agouti mice shows they are expressing genes differently. The diet of the mother of the large yellow mouse on the left was fed the normal lab mouse food diet, while the diet of mother of the smaller brown mouse was supplemented with choline, folic acid, betaine and vitamin B_{12} (*Photo Randy L. Jirtle, PhD.)* To the right, the same genetic Agouti mice are shown with the difference in their phenotype (physical appearance) proposed to be due to the DNA hypo-methylation (obese **yellow** mouse) and adequate DNA methylation (thin **brown** mouse). It appears that a severe methyl donor deficiency induces gene-specific changes in these rodents.

All mammals have a gene identified as and called the *agouti gene*. When a mouse's *agouti gene* is completely un-methylated, its coat is **yellow** and it is **obese** and prone **diabetes**, **cardiovascular disease** and **cancer**. By the way, do these disorders sound familiar? Here is what the researchers tested:

The effect of diet on gene expression. The researches fed pregnant yellow agouti mice a **methyl-rich diet**, providing "methyl donors" to the mice which yielded protective measures to gene expression. As a result, most of the pups born were brown and stayed healthy for life. Such that adequate DNA methylation prevented the expression of deleterious gene mutations. It was established that when the *agouti* gene is methylated (as it is in normal mice), the coat color is brown and the mouse has a low disease risk. The fat yellow mice and skinny brown mice are **genetically identical**, it is the **phenotype** or the physical expression of the gene that has been altered. The fat yellow mice are different because they have an epigenetic "mutation" that is ***expressed*** - due to lack of methyl donors (good nutrition) in their diet. These results show that the environment in the womb influences adult health. In other words, our health is not only determined by what we eat, but also what our parents ate. Particularly important is the mother's diet, as it helps to shape the **epigenome** of her offspring.

Toxic Chemicals in our Food Supply can Alter our Genes

Chemicals that enter our bodies can also affect the epigenome. You may be aware of **Bisphenol A** (**BPA**). It is a compound used to make ***polycarbonate plastic***. It is in many consumer products, including *water bottles* and *tin cans*. Controversial reports questioning the safety of BPA came out in 2008, prompting some manufacturers to stop using the chemical. In the laboratory, ***BPA appears to reduced methylation***

of the agouti gene. Darn it! After we worked so hard to eat good food and keep it methylated. In the strain of mice studied, yellow mothers gave birth to pups with a range of coat colors from yellow to brown. When mothers were fed BPA, their babies were more likely to be yellow and obese - like the one shown in **Fig. 20.19** above. However, when mothers were fed BPA along with methyl-rich foods, the offspring were more likely to be brown and healthy - like the one on the right. ***The maternal nutrient supplementation had counteracted the negative effects of exposure***. YAY!

If a pregnant mother's diet can affect the child's epigenetic outcome, can dad's diet also do the same? Quite possibly, according to scientists who delved into the well-kept, historical records of annual harvests from a small Swedish community. These records showed that food availability between the ages of nine and twelve for the paternal grandfather affected the lifespan of his grandchildren. But not in the way you might think. It was a shortage of food for the grandfather that was associated with extended lifespan of his grandchildren.

Food abundance, on the other hand, was associated with a **greatly shortened lifespan of the grandchildren**. Interesting huh? There is a lot of emerging evidence to suggest that in times of food scarcity the body makes protective chemicals, like *resveratrol*, that enhance cell longevity. In the Swedish community, early death was the result of either diabetes mellitus or heart disease. Perhaps during this critical period of development for the grandfather, epigenetic mechanisms "capture" nutritional information about the environment to pass on to the next generation?

Trees Practice Epigenetic Too

Another example of changing gene expression, but this time in trees, occurs if the Holly tree (Ilex aquifolium) finds its leaves are being nibbled by deer. This triggers a sequence of events that switches on genes to make the leaves spiky when they regrow. On taller Holly trees, the upper leaves (which are out of reach of the deer) have smooth edges, while the lower leaves are prickly, see the two leaves in **Fig. 20.20** at left.

Nutraceuticals are defined as foodstuffs which provide health benefits in addition to their basic nutritional value. These may include fortified foods as well as dietary supplements that can be sold in capsules, tablets or powders. The idea behind the use of nutraceuticals is that certain organic extracts can have positive benefits on both the body and mind. From cancer to vertigo, claims are abundant of nutraceuticals' effectiveness in combating or altogether curing a long list of ailments.

Figure 20.20. Shows the changes in the morphology of leaves of the Holly tree that occur when the tree is under predation. They are genetically changes from the smooth easy to eat leaf (left), to the convoluted spiky and difficult to each prickly leaf (right). Same tree different environment and circumstances.

What you eat can alter your DNA and how it is Expressed

Research suggests that the nutrients we eat attach to regulatory proteins that bind to DNA or to the cell surface, thereby increasing or decreasing gene expression (see the **agouti mice experiments**). They serves as a great example of the huge benefits that adding some very basic nutrients to your diet can have on your physical, mental and spiritual wellbeing. It will be shown again and again that what you eat has a

significant impact on your life. The area of research that studies the relationships among gene expression, nutrition, and health is called ***nutritional genomics***.

The Scientific Method

Sound research, whether nutritional or otherwise, begins with the **scientific method**, which is the process of *objectively* establishing facts through *testing* and *experimentation*. It is very important for people to understanding the related terms and methodologies, such what a **hypothesis** is, what a **valid control** is, observational versus experimental or laboratory research, and the process of peer-reviewed journals.

Different types of experiments can be run to confirm or negate a hypothesis. **Observational** research in nutritional studies can evaluate groups of people to determine a relationship with a certain health outcome. **Epidemiological** research involves looking at an entire population of people to examine a certain health outcome. **Experimental** research involves at least two groups of subjects: the experimental group (receives a treatment) and a valid control group (doesn't receive a treatment or any other confounding action).

The concepts of **control groups**, **placebos**, **nocebos**, and **double-blind** studies are part of experimental research. Many hypotheses fail along the way in scientific research, but each finding presents new, valuable questions to researchers. Only when multiple affirming research studies have been conducted is a consensus reached about nutrition or any advice. Also, nothing in science is ever "settled".

Introduction to the Scientific Method and its Application to Nutritional Research

Basic scientific knowledge about nutrition does change and develop, and should not be viewed in a rigid or fixed way. If you have the opportunity to delve further into scientific research in nutrition, you may be surprised at the lack of rigor and 'purity' of the scientific method applied to some of the most famous research that is still influencing public policy to this day.

As clear as the above information is about the fundamentals of the scientific method, the important part to remember is that ***it must be followed in good faith*** in order to glean anything legitimate from it!

"Let Truth be the Authority rather than Authority be the Truth"

It is not necessarily valid that the advice from ***authoritative health groups*** such as the American Heart Association (AHA), American Medical Association (AMA), Cancer Foundations and others, is wholly accurate and can be unquestioningly trusted. After all, it's been the powerful and influential organizations such as these that have been actively promoting a low fat diet to the American public as a healthy way to avoid heart disease for about 60 years now. The glaring problem is that this heavily promoted dietary change has only resulted in more heart disease, not less! This is where the ability to question authoritative entities remains so vital to our health, physically, mentally and spiritually.

There are numerous articles on the website that examine health myths, like the horrible falsehood that margarine is better for human health than butter. Please read 'Margarine vs Butter' if you'd like some well researched facts about how margarine is actually made. I dare you to go within 10 feet of it after you find out. As a population, the U.S. is more obese and have more nutritionally related diseases than ever. Cardiovascular disease has continued to skyrocket and there is still no cure for cancer. I wonder why?

The Famous Study by Dr. Ancel Keys Linking Saturated Fats to Heart Disease

As evidence that we should uphold the practice of applying the scientific method appropriately, and we should continue to ask valid questions, let us consider the famous Dr. Ancel Keys study that supposedly 'demonstrated' a link between eating saturated fats and developing heart disease. It truly deserves a closer look. The landmark "Seven Countries" study was published in 1958, and is **one of the most-cited studies in all of medical science**. More recently, it has been more thoroughly scrutinized and the inescapable realization is that it appears this study was never really a valid, vetted scientific study at all. **Never**. It has been openly criticized (though not widely exposed) for a very long time now, but only somewhat recently has it been meticulously examined in the book entitled "The Big Fat Surprise: Why Butter, Meat and Cheese Belong in a Healthy Diet" (2014) By Nina Teicholz.

Although this is not the place to go into the **significant shortcomings** of the original study (and 'shortcoming's is a generous word), the key is that by *omission* and *manipulation*, very poor and inaccurate conclusions were drawn and accepted as valid. The powerful and famous physiologist Dr. Keys could never be questioned. It was settled because they all said so. The notion that animal fats cause heart disease is one of the pillars of the Diet-Heart hypothesis. It helped to convince the USDA, the AHA, the AMA, doctors, nutritionists, media health writers, your parents, etc., that saturated fat clogs our arteries and kills us, so we all need to be on low-fat diets, even kids. All of that despite there being **no legitimate scientific evidence to support this contention**. None. Not then, not now. This study has left a lasting scar and serves as a reminder to those who are aware or as a notice to anyone who does not understand that science is never settled.

The only settled aspect is that science is always political. Therefore, it then becomes our task, our duty to question everything and to deliberately look for any information that contradicts any belief we may have so that we can robustly challenge it. If an idea or a belief cannot survive a healthy challenge, then why should it be worth keeping? Into the dustbin of bad ideas it goes.

The Silent Culprits – Refined Sugar and Fructose

Fairly recently Dr. Robert Lustig has presented some excellent work regarding the harmful effects of excess **fructose** in the diet, especially with regard to young children. His work has made a clear connection between the shift in the American diet from being one high in natural fats, to one with significant reductions in fat - noting the catastrophic effect this seems to have had on the health of people in this country. He has suggested that the main reason for this decline in health is that not only were **good fats removed from the diet**, but they were subsequently replaced with refined carbohydrates, **replaced with refined sugar**, especially **fructose**. Thus, something good was taken out and replaced with something very harmful. Interestingly, the excessive addition of sugar was, in part, to make up for the blandness of the low fat food!

Good natural fats are very tasty, not only does the body need them, but eating fats triggers satiation! This replacement of healthy fats with fructose is not compatible with the way our bodies processes energy, especially how out liver functions. For over 60 years now Americans have been told to eat less fat if they wanted to be healthier. But again as we know, that dietary change has not produced the consequence of better health. Instead, this misinformation and 'confusion' about the roles fats and sugars in human health have made it very difficult for many people in this country to get quality nutrients and to maintain good health. How is it possible that this is not clear to everyone by now?

Real Salt is Healthy

It is very likely that most of the same 'health' institutions hold faithfully to the standard conventions in nutrition, **even when they are known to be wrong**. For example let's briefly examine the claim or tenant that **decreasing salt consumption** in the diet is good for your health. This is another monumentally devastating **untruth** in nutrition. Salt is not bad for you nor should it be avoided. Firstly, let's be clear: **Salt** is different from the *isolated Sodium Chloride* (NaCl) found in conventional 'table salt', which is comprised of, you guessed it, Sodium and Chloride.

Real salt, like Celtic Sea Salt, not only contains the major minerals that your body needs, like **Sodium**, **Potassium**, **Phosphorus** and **Calcium**, but it also supplies varying degrees of necessary **trace minerals**, about 80 of them, all of which are also crucial for good health. These include some of the following: *Magnesium, Manganese, Boron, Copper, Silicon, and Iron. Nickel, Bromide***,** *Sulfur, Iodine, Cobalt and even Platinum.*

If it were stated that massive amounts of isolated sodium chloride may not be good for your health, yes, that may sound reasonable. Still, show us the valid repeatable studies (with appropriate controls) that support this claim. The assertion that reducing all of the other minerals just listed is anything remotely like a beneficial strategy to one's health makes no sense at all. That practice is actually literally bad for you, it's called **mineral deficiency** and is shockingly common in this country.

In addition, the Journal of the American Medical Association published a meta-analysis of 56 clinical trials done since 1980 in people with normal blood pressure, and found that extreme salt reduction had **little effect on lowering blood pressure**. This means that the vast majority of studies quietly found that restricting salt intake did nothing to help high blood pressure.

In another study, the investigators found that the less salt people ate, **the more likely they were to die of heart disease**. And another study shows that eating less salt increases triglycerides and hormones in the blood, which increases blood pressure and heart attack risk. All of this is to demonstrate that if you take a little time and effort to find the facts it is clearly acknowledged in the scientific literature that most of the "health advice" is surprisingly bad for your health.

Ban Bad Drinks!

There has been some movement towards logical and accurate approaches to improving health, for example, the desire for many to **decrease the consumption sugary drinks**. The outcome of this might be to create public policy to deal with health, such as creating a "soda tax" to dissuade people from consuming that bad drink, especially children. Or an all-out "ban" on them. Please note that alcohol is very expensive and yet this does not deter people from consuming it. It is also 'banned' from the grips of teenagers, but again that has had little success in reducing its consumption by this group. Just as injecting heroine is illegal and therefore "banned", it may surprise some to know that there are still plenty of people who use heroine. These people will risk jail time for the reward of getting their fix. Therefore, even stiff laws will not prevent people from making poor choices. It is your choice, so be as informed as possible.

In conclusion, public policy or legislative laws do not necessarily change people's behavior. **What is much more powerful is for any individual to be as informed as possible about the true nature of the world they live in**. Carefully examine the world around you. Then, despite a law 'protecting' anyone from drinking something, a person will already be well informed enough to know the truth and be able to decide for themselves. For example, if a person wants to drink raw milk (but it is banned), they should be able to

do so. It is likely that the person is informed and knowledgeable enough to know that it is not harmful. Also, the cows must be very healthy if there is no need to super-boil the milk to kill all the pathogens in it! A person may also might decide not to eat the cheaply priced, excessively available and heavily refined foods that consist mostly of corn, soy, sugar, canola oil and wheat, even though it is perfectly legal to do so. Many legal items are known to be deleterious and they are also aggressively promoted.

The key is, everyone needs to be responsible and make the choices of what to do or what not to do for themselves. Chances are, some people will decide not to consume these readily available items because they understand they are nutritionally empty and harmful. Thus, no laws about foods, one way of the other, are required when adults are responsible for their own actions.

Review Questions for Chapter 20: Digestion and Nutrition

1. Which of these organs is **not** considered an accessory digestive structure?
- **a)** mouth
- **b)** salivary glands
- **c)** pancreas
- **d)** liver

2. Which of these ingredients in saliva is responsible for activating **salivary amylase**?
- **a)** mucus
- **b)** phosphate ions
- **c)** chloride ions
- **d)** urea
- **e)** hydrogen ions

3. Which of these processes occurs in the mouth?
- **a)** ingestion
- **b)** mechanical digestion
- **c)** chemical digestion
- **d)** a and b
- **e)** all of the above

4. Pancreatic juice _____.
- **a)** deactivates bile
- **b)** is secreted by pancreatic islet cells
- **c)** buffers chyme
- **d)** is released into the cystic duct
- **e)** is delivered to the pylorus

5. Which of the following stimuli can activate sensors in the walls of digestive organs?
- **a)** breakdown products of digestion
- **b)** distension
- **c)** pH of chyme
- **d)** all of the above

6. Which of these statements about reflexes in the GI tract is **false**?

a) Short reflexes are provoked by nerves near the GI tract.
b) Short reflexes are mediated by the enteric nervous system.
c) Long reflexes can be provoked by stimuli originating outside the GI tract.
d) Smelling food before eating it can initiate long reflexes.
e) Food that distends the stomach initiates long reflexes.

7. During gastric emptying, chyme is released into the duodenum through the _____.

a) pyloric sphincter
b) esophageal hiatus
c) pyloric antrum
d) pyloric canal
e) lower esophageal sphincter

8. Parietal cells secrete _____.

a) gastrin
b) hydrochloric acid
c) pepsin
d) pepsinogen
e) chloride ions

9. In which part of the alimentary canal does most digestion occur?

a) stomach
b) proximal small intestine
c) distal small intestine
d) ascending colon
e) transverse colon

10. Which of these statements about bile is **true**?

a) About 500 mL is secreted daily.
b) Its main function is the denaturation of proteins.
c) It is synthesized in the gallbladder.
d) Bile salts are exquisitely recycled.
e) It acts to digest fats.

Answers in Appendix B