9.5

Digestion in the Small and Large Intestines

Do some foods keep you feeling full for a long time? Do you ever feel that after eating certain foods, you are hungry again in a short time? Some foods stay in the stomach longer than others and keep you feeling full. Other foods move quickly from the stomach to the small intestine. Carbohydrates, proteins, and lipids are digested in the small intestine with the help of hormones and enzymes. About 3 h to 5 h are required to process the contents of a meal in the small intestine, where nutrients from digested food are absorbed into the body.

Mini **Investigation**

Explore Surface Area

Skills: Observing, Analyzing, Communicating

SKILLS HANDBOOK A2.1, A6.2

Many biological processes occur on, or through, the surfaces of cells and tissues. The amount of available surface area determines how efficiently these processes occur. The digestive system (as well as other organ systems) requires large surface areas in order to function efficiently. In this activity, you will examine a model that increases surface area in a limited space.

Equipment and Materials: 10 cm × 10 cm piece of corrugated cardboard (**Figure 1**); ruler

Figure 1 Corrugated cardboard

1. Measure and record the length and width of the top layer of the piece of corrugated cardboard. Use your measurements to calculate the area of the top layer.
2. Calculate the surface area of the piece of cardboard. Ignore the thickness of the cardboard.
3. Separate the three layers of the cardboard, taking care not to tear the layers.
4. Flatten the folded (corrugated) middle layer. Measure and record its dimensions, and calculate its total surface area.

A. What is the difference between the surface area you calculated in Step 2 and the surface area you calculated in Step 4? What accounts for this difference in area? T/I

B. By what percentage is the surface area of the middle layer greater than the surface area of the cardboard in Step 2 (before it was separated)? T/I

C. Suggest at least one method of further increasing the surface area within the same space as the original piece of cardboard. Illustrate your suggestions with a simple sketch. T/I C A

LEARNING **TIP**

Surface Area
Surface area is the sum of the exposed area of an object. For example, the surface area of a piece of paper would be the sum of the areas of the front and back of the paper.

The Structure of the Small Intestine

Most digestion and absorption of nutrients takes place in the small intestine. The small intestine is a long tube that is only about 2.5 cm in diameter. Although narrow, this section of the GI tract can be up to 7 m in length. In comparison, the large intestine can be up to 7.6 cm in diameter but is only about 1.5 m in length. Lipids and carbohydrates, as well as any remaining proteins, are digested in the small intestine.

The small intestine is made up of three sections: the duodenum, the jejunum, and the ileum (**Figure 2**). The duodenum is the first 25 cm to 30 cm of the small intestine and is where most enzymes are added and digestion in the small intestine begins. In the jejunum, digestion continues and some nutrients are absorbed. However, the majority of nutrients are absorbed in the ileum, the last section of the small intestine. There is no clear division between the jejunum and the ileum, but they can be distinguished by the shapes of the cells in the epithelium.

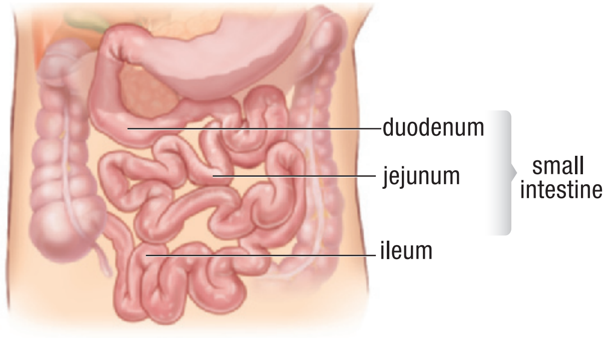

Figure 2 The three segments of the small intestine

The inner surface of the small intestine is adapted to provide the maximum surface area for efficient nutrient absorption. The inner layer of the small intestine is folded into ridges and has many small finger-like projections called **villi** (singular: villus) which produce an estimated tenfold increase in surface area. To further increase the surface area available for absorption, each of the epithelial cells that make up the villi has even smaller, microscopic projections of the cell membrane called **microvilli** (singular: microvillus) (**Figure 3**). The combined effect of the villi and microvilli is estimated to increase the surface area by a factor of 500. Within each villus is a network of tiny blood vessels called capillaries. Capillaries are part of the circulatory system, which you will learn more about in Chapter 11. All nutrients, except digested fats, enter the bloodstream through the capillaries. Digested fats are transported through small vessels called **lacteals**. The digested fats are transported into the lymphatic system, and from there into the bloodstream.

villus a small, finger-like projection of the small intestine mucosa

microvillus a microscopic projection of the cell membrane of certain types of epithelial cells; greatly increases the surface area of the cell

lacteal a lymphatic vessel within a villus, through which digested fats enter the circulatory system

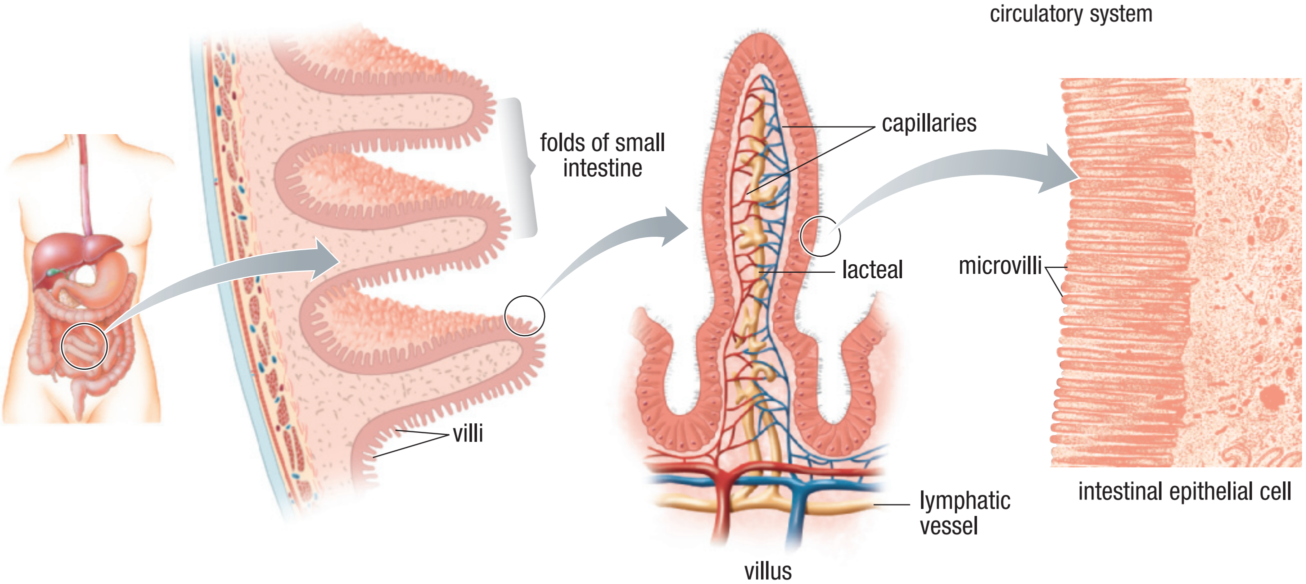

Figure 3 The villi and microvilli greatly increase the surface area available for absorption of nutrients.

Chemical Digestion in the Small Intestine

The pyloric sphincter controls the passage of food from the stomach into the small intestine. When the food in the stomach has been mixed with gastric juice and the proteins are partially digested, the pyloric sphincter periodically relaxes to release small portions of chyme into the duodenum (**Figure 4**). This slow and steady release of chyme into the small intestine prevents overloading and allows time for thorough digestion.

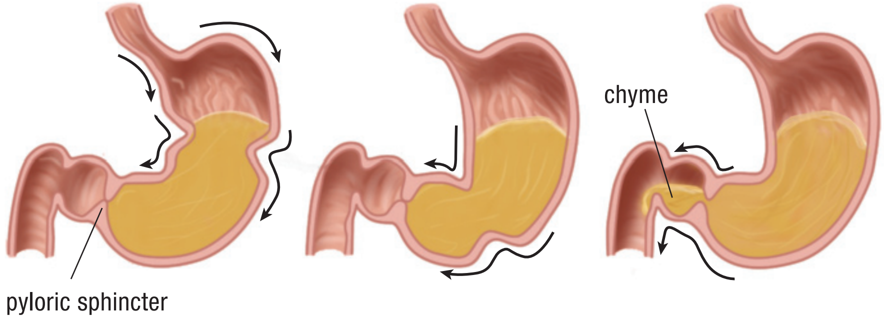

Figure 4 The pyloric sphincter controls the movement of the chyme from the stomach to the duodenum.

Most of the enzymes required for digestion are added in the duodenum. This digestion requires input from the pancreas, liver, and gall bladder.

Investigation 9.5.1

Factors Affecting the Digestion of Starch (page 426)
Consider what you have read about lipid, carbohydrate, and protein digestion. At the end of this section, you can complete Investigation 9.5.1.

In this controlled experiment you will identify factors that affect the digestion of starch. You will conduct an experiment to determine how digestion is affected by these factors.

The Role of the Pancreas in Digestion

The pancreas is a long, flat gland nestled between the stomach and the duodenum. The pancreas has a dual role. It secretes enzymes that are critical to the digestive process, and it also secretes hormones that regulate the absorption and storage of glucose from the blood. (This second function of the pancreas will be addressed in Chapter 11.)

The digestion of carbohydrates that began in the mouth continues in the duodenum. The enzyme amylase, found in saliva, is also secreted by the pancreas. This amylase continues the digestion of starch that was started in the saliva.

When fat-rich chyme enters the duodenum, a hormone called cholecystokinin (CCK) is secreted by special cells in the mucosa of the duodenum and released into the bloodstream. This hormone signals the pancreas to secrete a variety of substances, including ones that control the pH of the intestine and enzymes that are needed for lipid, carbohydrate, and protein digestion. These secretions enter the duodenum through the pancreatic duct (**Figure 5**). CCK also signals the stomach to slow down the speed of digestion so that the small intestine can effectively digest the fats.

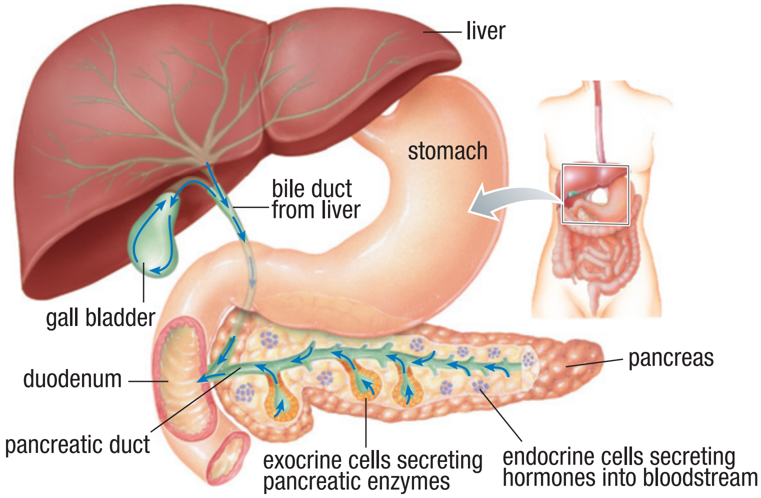

Figure 5 The digestive enzymes, hormones, bile, and other substances secreted by the liver and pancreas enter the duodenum.

The chyme that enters the small intestine has a low pH of about 2.5. When the acidic chyme enters the small intestine, a chemical called prosecretin that is present in the epithelial cells of the small intestine is converted into its active form, secretin. **Secretin** is a hormone that stimulates the liver to make more bile and encourages the pancreas to secrete lipid and protein enzymes. However, its primary function is to stimulate the pancreas to release bicarbonate ions (HCO_3^-) to neutralize the acidic chyme and raise the pH from about pH 2.5 to pH 9.0. Pepsin is inactivated in the basic pH conditions since it requires an acid environment to be activated. Thus, secretin protects the small intestine from stomach acids. Secretin also acts as a digestive rate regulator and prevents more food from entering the duodenum from the stomach until the current batch is digested.

Since pepsin is active only in acidic conditions, the action of pepsin is discontinued in the small intestine. However, protein digestion is carried on by other enzymes. The pancreas releases trypsinogen, which is an inactive form of a protein-digesting enzyme called **trypsin**. The trypsinogen travels from the pancreas to the duodenum. Once it reaches the duodenum, an enzyme called **enterokinase** converts it into active trypsin. Trypsin continues the work begun by pepsin in the stomach, further breaking down any partially digested proteins that remain. Other protein-digesting enzymes help break the short protein chains into single amino acid molecules. **Figure 6** shows the breakdown of proteins in the small intestine.

secretin a hormone secreted by the duodenum that stimulates pancreatic and bile secretions

trypsin a protein-digesting enzyme produced from trypsinogen

enterokinase an enzyme of the small intestine that converts inactive trypsinogen into trypsin

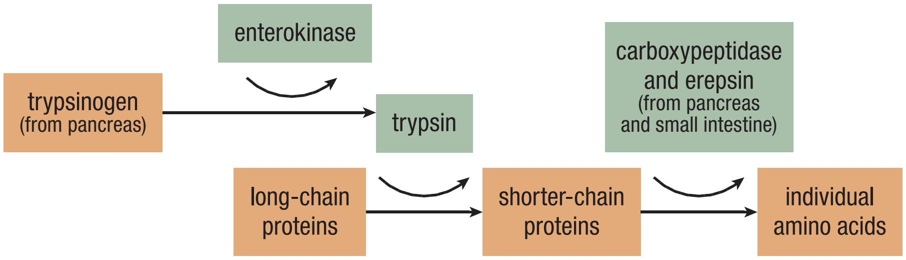

Figure 6 The breakdown of proteins into amino acids occurs in the small intestine.

Mini Investigation

Chemical Reactions with Fruit Juice!

Skills: Controlling Variables, Performing, Observing, Analyzing

SKILLS HANDBOOK A1.2, A2.1

Many foods contain chemicals that can break down other foods in a way that is similar to the action of chemicals in the digestive system. In this activity you will test a number of fruits for evidence that they contain these "digestive chemicals."

Equipment and Materials: 6 test tubes; dissolved gelatin; juices of fresh fruits (apple, orange, kiwi, pineapple, papaya)

1. Number the test tubes 1 to 6.
2. Add 5 mL of water to test tube 1.
3. Add 5 mL of a different juice to each of test tubes 2 to 6. Record which juice has been added to each test tube.
4. Add 10 mL of dissolved gelatin to each of the test tubes and swirl or shake gently to mix the contents.
5. Place the test tubes in the refrigerator and leave overnight.
6. Prepare a table in which to record your observations.
7. Observe the contents of each test tube and describe any changes that have occurred. Record your observations in the table.

A. What is the control in this activity? T/I A

B. What evidence is there that a reaction has occurred in the test tubes? In which test tubes has the reaction occurred? T/I A

C. Based on your observations, which of the fruit juices contain chemicals that can break down other foods? T/I A

D. Gelatin is made of protein. Based on your current knowledge, propose an explanation for your observations. T/I A

E. How does this investigation relate to the functioning of the digestive system? K/U T/I A

F. Since gelatin and muscle meat are both made of protein, suggest a practical application for the fruit juices that contain the "digestive chemicals." T/I A

lipase an enzyme that digests lipids

Lipids are also digested in the small intestine. Fats that enter the duodenum are subjected to the action of **lipases**, a group of enzymes secreted by the pancreas that break down lipids. Lipases break the lipid chains into shorter chains and into individual fatty acid molecules. However, fats in chyme are present as large globules. Lipases cannot penetrate beyond the surface of the fat globules, so for lipases to efficiently digest lipids, the liver and its secretions must become involved.

The Liver and Gall Bladder

bile a substance that emulsifies fats for faster breakdown by lipases; produced by the liver

The liver is the largest internal organ of the body, located just underneath the diaphragm (refer back to Figure 5, page 414). The liver performs a number of important functions. In its digestive function, it is considered a gland because it produces and secretes bile. **Bile** emulsifies fats, breaking them into tiny droplets called micelles. Once the large fat globules are broken down into micelles, the lipases have a much greater surface area on which to act, and the rate of lipid digestion increases.

Bile is continuously produced in the liver, but it is stored in the gall bladder until food enters the duodenum. Lipids entering the duodenum stimulate the gall bladder to contract, which causes bile to be squeezed out from the gall bladder into the duodenum through the bile duct.

All blood travelling through the capillary beds of the intestines goes directly to the liver before returning to the heart. The liver begins the removal and breakdown of toxins, such as alcohol, that have been absorbed by the digestive system. The liver is also involved in producing and storing various nutrients including glycogen and fat-soluble vitamins. Due to its varied functions, there are many diseases and disorders that are associated with a malfunctioning liver, including various forms of hepatitis, jaundice, and cancer.

Absorption in the Small Intestine

Once proteins, carbohydrates, and lipids are broken down, they are absorbed in the jejunum and ileum. Vitamins, minerals, and water are also absorbed in the small intestine. The structure of the small intestine plays a very important role in absorption. Both the villi and microvilli increase the surface area for absorption of nutrients. Nutrients pass through these cells, into the bloodstream, where they are then transported by capillaries to the tissues of the body. There are several different mechanisms for absorption in the small intestine. These mechanisms can be categorized as either passive transport or active transport.

Passive Transport

passive transport the movement of materials across a cell membrane without any expenditure of the cell's energy

Passive transport is the movement of materials across a cell membrane without the use of energy from the cell. This includes (simple) diffusion, osmosis, and facilitated diffusion.

concentration gradient the difference in the number of molecules or ions of a substance in a given volume between adjoining areas

Due to their constant, random motion, particles in a gas or liquid state will spread out until all the particles are evenly distributed. This process is referred to as diffusion. Diffusion will follow the **concentration gradient**, from an area of higher concentration to an area of lower concentration (**Figure 7(a)**, next page). Many nutrients enter the cells lining the small intestine by simple diffusion. For example, small amino acids can diffuse directly into the bloodstream.

Osmosis is the diffusion of water molecules across a selectively permeable membrane, from an area of higher concentration (of water molecules) to an area of lower concentration. Some of the water content in food is absorbed by osmosis in the stomach and small intestine during digestion.

Another type of diffusion that plays a role in digestion is facilitated diffusion. **Facilitated diffusion** is the diffusion of molecules across a membrane through transport proteins. The transport proteins are embedded in the cell membrane and help, or facilitate, diffusion (**Figure 7(b)**). Transport proteins physically bind to molecules on one side of the membrane and release them on the other side. Each transport protein has a unique size and shape that allows only certain substances to pass through. Transport proteins act as gateways that increase the rate of diffusion of specific nutrient molecules. For example, during digestion, carbohydrates are broken down into disaccharides and monosaccharides. Many of these carbohydrates are transported into the cells lining the small intestine by facilitated diffusion.

facilitated diffusion the diffusion of molecules across a cell membrane via a transport protein

Active Transport

In **active transport**, materials are moved across a cell membrane, from an area of lower concentration to an area of higher concentration, using energy provided by the cell. As in facilitated diffusion, special transport proteins embedded in the cell membrane actively move materials through the membrane (**Figure 7(c)**). Unlike facilitated diffusion, this movement across the cell membrane requires energy from the cell. Active transport is used to transport molecules that are too large to diffuse through the cell membrane on their own, as well as to transport molecules (or ions) that have a strong and uneven electrical charge that prevents diffusion across the membrane.

active transport the transportation of materials through a cell membrane using energy from the cell

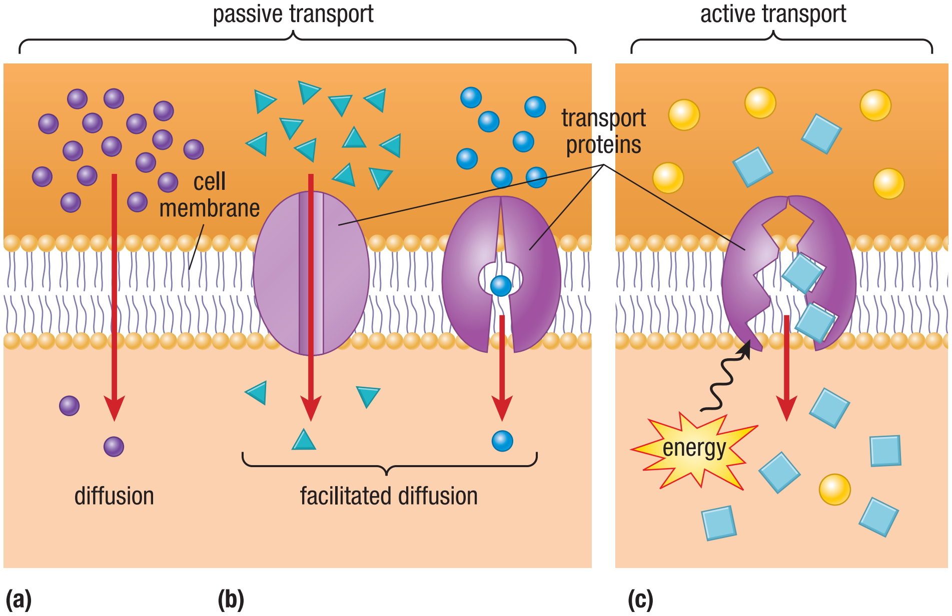

Figure 7 (a) In diffusion, substances move across the cell membrane from an area of higher concentration to an area of lower concentration. (b) In facilitated diffusion, transport proteins speed up the movement of molecules that already move across the cell membrane. (c) In active transport, energy is required to move molecules through transport proteins across the membrane. Only certain types of molecules can pass through the transport proteins.

Absorption of Nutrients in Capillary Networks

Whether transported by diffusion, osmosis, facilitated diffusion, or active transport, all nutrients make their way through the mucosa of the small intestine and into the capillary networks in the villi. These capillary networks carry nutrients through the bloodstream to the rest of the body. The lacteals, which are small vessels of the lymphatic system, carry dietary fats through the lymphatic system, eventually reaching the bloodstream. Nutrients are transported from the bloodstream into the body cells by means of passive or active transport.

The Structure and Function of the Large Intestine

The diameter of the large intestine, rather than the length, gives it its name. The large intestine is approximately 1.5 m in length but is two to three times larger in diameter than the small intestine, about 7.6 cm. The large intestine consists of the cecum, colon, rectum, and anus, or external opening (**Figure 8**).

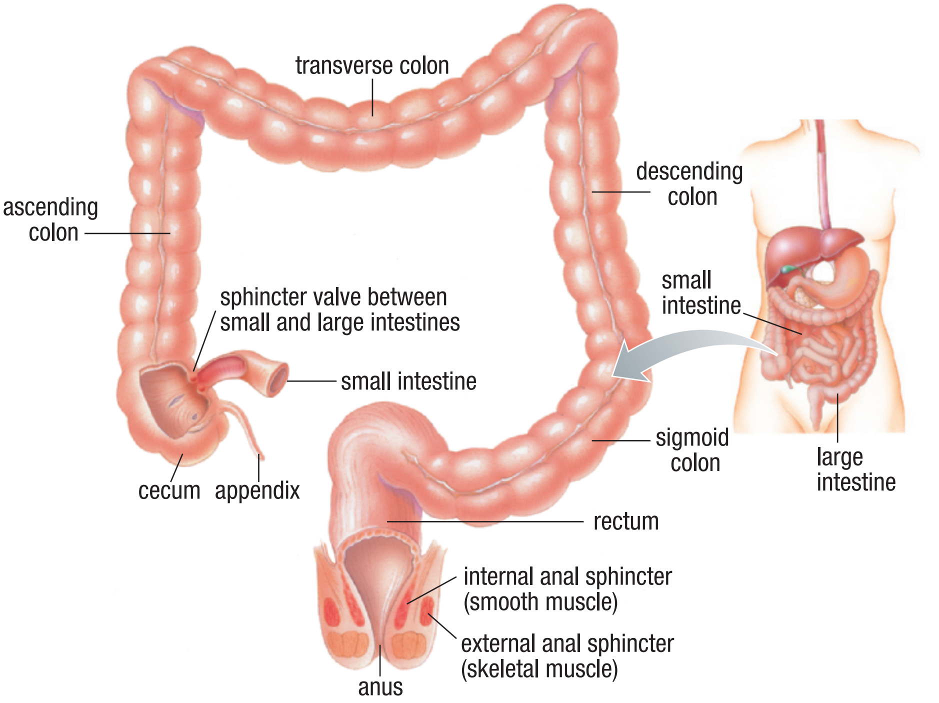

Figure 8 Digestion and most nutrient absorption are complete when food reaches the large intestine. Waste materials are collected here and are evacuated from the body through the anus.

cecum a blind pouch at the upper end of the large intestine

colon the longest part of the large intestine

rectum the lower 20 cm of the large intestine, generally referred to as the lower bowel, where feces are stored

anus the opening at the lower end of the large intestine through which digestive wastes are eliminated from the body

The small intestine does not simply continue on and become the large intestine. The small intestine joins the large intestine a few centimetres from the end. The short upper end of the large intestine creates a blind pouch called the **cecum**, a sort of dead end that receives the processed material from the small intestine. A small finger-like projection from the cecum is called the appendix. The appendix does not serve any digestive function in modern humans but may have had a digestive function in its evolutionary past.

The **colon** is the longest part of the large intestine and has four segments: the ascending colon, the transverse colon, the descending colon, and the sigmoid colon. The **rectum** is the last 20 cm of the large intestine. The rectum holds the waste products of digestion until they are eliminated through the external opening, the **anus**.

Digestion is complete and most of the nutrients have been absorbed by the time the digested material reaches the large intestine. However, there is still a significant quantity of undigested and indigestible material, such as cellulose, that cannot be broken down by humans. As this matter passes through the colon, most of the water is absorbed through the process of osmosis. Approximately 20 L of fluids pass through the large intestine daily, and most of this is absorbed back into the body. This fluid comes from the water ingested in the diet and from saliva, mucus, gastric juices, and other digestive fluids that are secreted as food moves through the GI tract. Vitamins B and K and sodium, Na^+, and chloride, Cl^-, ions are also absorbed. It may take 4 h to 72 h for the undigested material to pass through the large intestine, depending on the types and volume of food eaten.

There are more than 500 species of bacteria that normally inhabit the large intestine. Some of these species of bacteria are important partners in human nutrition. The most common species of bacteria in the human large intestine is *Escherichia coli*, or *E. coli*. These bacteria exist in the intestine in a mutually beneficial relationship. The bacteria live in a suitable environment and have access to a plentiful food supply. In return, they produce essential substances such as vitamin K and some B vitamins. Another byproduct of bacterial action is gas—a mixture of carbon dioxide, methane, and hydrogen sulphide. The amount of gas produced is affected by the types of food that are eaten. Most of the gas is absorbed in the intestine, but some may escape through the anus as flatulence.

Although these bacteria are needed, they can create serious or even fatal problems if they enter and reproduce in the stomach or small intestine. These problems will be explored in Section 9.6.

Egestion

The indigestible components of food, such as cellulose and other fibres, are important in the diet. They provide bulk and help maintain a full feeling for a longer time. This can reduce overeating and help maintain a healthy weight. Fibre also helps retain some water in the large intestine, which is important in **egestion**, the elimination of digestive wastes.

egestion the removal of waste food materials from the body

The absorption of water in the large intestine changes the liquid material in the colon into a soft solid called **feces**. If too much water is absorbed back into the bloodstream, the feces become firmer and constipation may be the result. If too little water is absorbed, watery feces, or diarrhea, may result, and this can lead to dehydration. The problem of diarrhea will be discussed in Section 9.6.

feces the undigested material that is eliminated as waste from the body

Nerves in the wall of the large intestine detect the movement of feces into the rectum. This initiates the defecation reflex, which causes the urge to have a bowel movement. While this is a reflex, there is some degree of control. The anus is surrounded by two sphincter muscles (Figure 8, page 418). The internal anal sphincter is a smooth muscle and therefore under involuntary control. The external anal sphincter is a skeletal muscle and under voluntary control. Feces are eliminated through the anus when both sphincters are relaxed.

Endoscopy: Looking Inside the Body

endoscopy any medical procedure that uses an endoscope to look inside the body

Historically, the only way to directly examine the digestive system was to perform surgery. Medical scientists and technologists have developed alternative methods of seeing inside the human body that are much safer and less traumatic for patients.

The endoscope is a tool that is designed to look inside the body. It consists of a narrow tube that is fitted with a light source, a lens, and a camera to obtain images (**Figure 9**). An endoscope has one or more openings through which tools can be inserted. This tube can be inserted through a natural opening in the body such as the mouth or anus, or through a small incision into the body cavity. The procedure that uses an endoscope to look inside the body is referred to as **endoscopy**.

Figure 9 The flexible endoscope is a long tube that varies in diameter, depending on the area of the body to be explored. It includes a light source and a lens and camera to capture images.

Endoscopes can also be used to perform some medical procedures. Endoscopes are designed with remotely operated tools that can be inserted through the tube. For example, samples of tissue are often required for detailed examination under a microscope. The process of removing a tissue sample is called a biopsy. If a biopsy of the intestine is needed, a biopsy tool at the end of a cable is inserted through the endoscope tube and a tiny sample of the intestinal lining is removed.

Many surgeries can also be completed using endoscopes. For example, the removal of a diseased gall bladder is one of the most common surgical procedures that use endoscopes. Compared to open surgery, the procedure is less painful, has a shorter recovery period, requires a shorter hospital stay, and is more cost effective. About 98 % of all gall bladder removals are now done using endoscopes.

Figure 10 A capsule endoscope

UNIT TASK BOOKMARK

Consider what you have learned about the structure and function of the human digestive system. How can this information help you in the Unit Task when you create a plan for a healthy diet?

The Capsule Endoscope

Although the traditional endoscope is a remarkable tool, it cannot be used to examine the entire length of the small intestine. The latest technology in gastrointestinal endoscopy is the capsule endoscope. Advances in miniature and wireless technology have enabled technologists to create a camera small enough to fit inside a capsule that can be swallowed (**Figure 10**). The capsule passes through the digestive tract, taking thousands of pictures that are transmitted wirelessly to a receiver.

There is tremendous potential for future advancements in capsule endoscopy. The capsules could be equipped with sensors, such as pH and temperature sensors, and might even be able to deliver drugs to specific targets within the digestive tract.

9.5 Summary

- Most digestion takes place in the duodenum and the jejunum of the small intestine. Enzymes, hormones, and bile from the pancreas and the liver are secreted into the bloodstream or directly into the duodenum.
- The mucosa of the small intestine consists of villi and microvilli, which greatly increase the surface area for absorption.
- Absorption of nutrients occurs in the jejunum and ileum in the small intestine. Water, sodium, and chlorine ions, and some vitamins, are absorbed in the colon in the large intestine.
- Passive transport is the movement of materials across a cell membrane without the expenditure of energy by the cell. Passive transport includes diffusion, facilitated diffusion, and osmosis.
- Active transport uses the cell's own energy to move materials into or out of the cell.
- Indigestible material, such as cellulose, and other waste products are collected in the rectum and egested as feces through the anus.

9.5 Questions

1. Name the sections of the small intestine. Briefly describe the digestive processes that occur in each. K/U
2. (a) Describe the inside surface of the small intestine and explain the reason for this structure.
   (b) How does the structure of the small intestine relate to the Mini Investigation at the beginning of this section? K/U A
3. Explain the process that releases bile into the duodenum. K/U
4. Gallstones often develop in the gall bladder when minerals in the bile form into small pebble-like structures. This often requires the removal of the gall bladder. K/U T/I C A
   (a) What is the function of the gall bladder?
   (b) What might be the consequences of having your gall bladder removed?
   (c) Use the Internet and other sources to research how you might need to adjust your diet following gall bladder removal. Write a report of your findings.
5. Create a graphic organizer to summarize the physical and chemical digestion of the three groups of nutrients. K/U C
6. Name two hormones and two enzymes that are involved in digestion, and explain their roles. K/U
7. (a) Describe the processes involved in the breakdown of proteins into individual amino acids.
   (b) Why is it necessary to reduce large protein molecules to single amino acids? K/U A
8. How does facilitated diffusion differ from simple diffusion and osmosis? K/U
9. Use a graphic organizer to compare the roles of the small and large intestines in digestion. K/U C
10. Ontario has implemented a colorectal cancer screening program. Use the Internet and other sources to find information about this program. T/I A
    (a) Describe the program and its goals.
    (b) What criteria are used to identify individuals who should have a colonoscopy?
    (c) Evaluate the use of colonoscopies in diagnosing and/or treating diseases such as colitis and colon cancer.
11. Unlike in humans, the cecum in some mammals is functional. Use the Internet and sources to research the structure and function of the cecum in rabbits. Write a brief report of your findings. T/I A

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