

The Anatomy and Physiology of the Digestive System

CHAPTER 1

INTRODUCTION

The digestive system is also known as the gastrointestinal system or the alimentary canal. A comprehensive understanding of the anatomy and physiology of the digestive system is fundamental to the education and clinical practice of healthcare students. The digestive system is a highly specialised and dynamic network responsible for the ingestion, digestion, absorption and assimilation of nutrients, as well as the elimination of waste products. Its function is vital not only for maintaining nutritional homeostasis but also for supporting the body's immune defences, metabolic processes and overall health.

This chapter offers an examination of the structure and function of the digestive tract and its associated organs. It will begin by exploring the organisation of the alimentary canal, from the oral cavity, pharynx and oesophagus, through to the stomach, small intestine and large intestine, before discussing the accessory organs, including the liver, gallbladder and pancreas. Each anatomical region will be discussed in relation to its specialised physiological role, highlighting the intricate coordination required for the effective processing of food substances.

An understanding of these mechanisms is critical for appreciating how the digestive system responds to varying physiological demands and how dysfunction can contribute to a range of pathological conditions.

In clinical practice, recognising the normal anatomy and physiology of the digestive system provides the foundation for identifying deviations indicative of disease or dysfunction. A thorough grasp of these principles enhances clinical reasoning, informs patient assessment and underpins safe, evidence-based care across a range of healthcare settings.

Through the study of this chapter, readers will not only gain essential knowledge of the digestive system's structure and function but also develop the ability to apply this knowledge in clinical scenarios, supporting the provision of holistic, person-centred care.

ROLE AND FUNCTION OF THE DIGESTIVE SYSTEM

The activity of the digestive system can be classified into five fundamental processes, each integral to the overall function of nutrient acquisition and waste elimination.

INGESTION

This is the active process by which food is introduced into the oral cavity. It represents the initial stage of digestion, whereby food is voluntarily placed into the mouth to commence mechanical and enzymatic processing.

PROPULSION

Propulsion encompasses the movement of food through the gastrointestinal tract. It begins with the voluntary act of swallowing (deglutition) and is followed by peristalsis, which is an involuntary, coordinated series of muscular contractions that systematically advances food through the digestive system.

DIGESTION

Digestion refers to the breakdown of food into its constituent nutrients, facilitating absorption. This occurs through two interrelated mechanisms:

- Mechanical digestion, involving physical processes such as mastication (chewing) and the churning and segmentation movements within the stomach and intestines, which increase the surface area of food particles.
- Chemical digestion, involving the enzymatic degradation of complex macromolecules (proteins, carbohydrates and lipids) into absorbable monomers (these are the small molecules that are produced by digestion that the body can absorb and use) through the action of digestive secretions that are produced by the salivary glands, stomach, pancreas, liver and intestines.

ABSORPTION

Absorption is the transfer of the end products of digestion across the epithelial lining of the gastrointestinal tract into the circulatory and lymphatic systems. The majority of absorption occurs within the small intestine, where nutrients such as monosaccharides, amino acids, fatty acids, vitamins and minerals are taken up for distribution and use by body tissues.

ELIMINATION

The final process, elimination or defaecation, is where indigestible food residues and waste products of metabolism are expelled from the body in the form of faeces. This process primarily occurs in the large intestine, where water is reabsorbed and the remaining material is compacted and stored until excretion.

HOW THE DIGESTIVE SYSTEM IS ORGANISED

The digestive system is organised into two principal components:

- The primary digestive organs
- The accessory digestive organs

The primary structures comprise the continuous, hollow muscular tube known as the gastrointestinal tract, which is responsible for the ingestion, propulsion, digestion, absorption and elimination of food substances. The gastrointestinal tract includes the following:

- Mouth
- Pharynx

- Oesophagus
- Stomach
- Small intestine
- Large intestine
- Rectum and anus

Figure 1.1 provides details of the digestive system.

Each segment of the tract is anatomically and functionally specialised to perform specific roles; for example, the stomach has a role to play as a reservoir for food; it also initiates protein digestion, while the small intestine is the primary site for the digestion of enzymes and nutrient absorption.

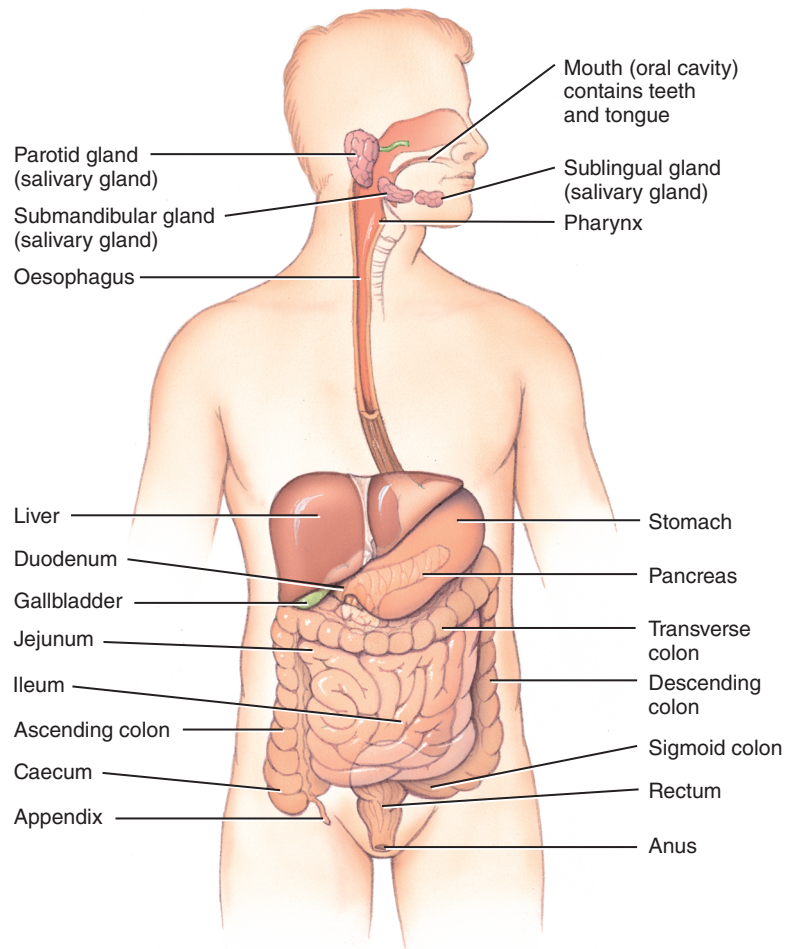


FIGURE 1.1 The digestive system. *Source:* Tortora and Derrickson (2009). With permission of John Wiley & Sons.

In parallel, there are several accessory organs that support and enhance the digestive process without being part of the alimentary canal itself. These accessory organs include the following:

- Salivary glands
- Liver
- Gallbladder
- Pancreas

The salivary glands secrete saliva containing enzymes such as amylase, which begin the chemical breakdown of carbohydrates in the oral cavity. The liver synthesises bile, a substance that is crucial for the emulsification and absorption of dietary fats, while the gallbladder stores and concentrates bile, releasing it into the duodenum in response to hormonal signals. The pancreas has a dual role; it produces both digestive enzymes (such as proteases, lipases and amylases) and bicarbonate ions, which neutralise the acidic chyme entering the small intestine from the stomach. Collectively, the primary and accessory components of the digestive system work in a highly coordinated manner to ensure the efficient processing of ingested nutrients, the maintenance of internal homeostasis and the elimination of metabolic waste products.

THE MOUTH

The process of digestion begins as food enters the mouth (also known as the oral cavity). This initial stage involves the ingestion of food, which then mixes with saliva to facilitate further breakdown. The oral cavity is composed of various structures, as shown in Figure 1.2, which illustrates an anterior view of the mouth. The lips and cheeks are made up of muscle and connective tissue, and they play a critical role in the mechanical manipulation of food. These structures help move the food, now combined with saliva, around the mouth, initiating the mechanical process of digestion.

The teeth further contribute to mechanical digestion through grinding and tearing food, a process that is known as mastication. The act of chewing, combined with the mixing of food with saliva, enhances the breakdown of food particles, preparing them for chemical digestion. Given that the oral cavity may be exposed to extreme temperatures, for example, very hot or cold food, as well as rough food particles, it is lined with a protective layer of mucus-secreting, stratified squamous epithelial cells. This epithelial layer serves as a barrier, offering protection against abrasion, thermal damage and the wear and tear associated with regular food processing.

In addition to their role in facilitating the mechanical movement of food during digestion, the lips and cheeks are integral to several other functions, including the production of speech and the expression of emotions. The lips, composed of both muscular and connective tissue, are essential for articulating sounds and forming words. They also contribute to non-verbal communication by enabling various facial expressions that convey emotions. Similarly, the cheeks, which are also made up of muscle and connective tissue, assist in the modulation of airflow during speech, as well as in the movement of food within the oral cavity. Together, these structures play a multifaceted role in both the digestive and communicative processes, highlighting their importance beyond simple mechanical digestion.

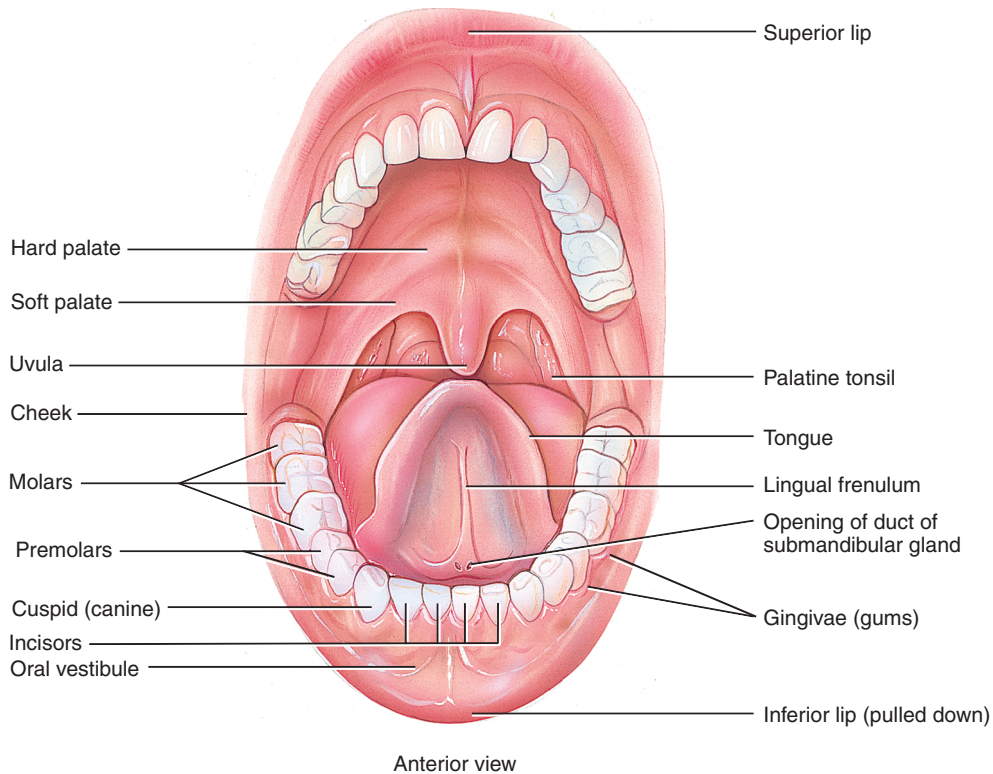


FIGURE 1.2 An anterior view of the mouth. *Source:* Tortora and Derrickson (2009). With permission of John Wiley & Sons.

TONGUE

The tongue is a large, voluntary muscular organ that occupies a significant portion of the oral cavity. It is firmly anchored at its posterior end to the hyoid bone and at its inferior surface by the lingual frenulum, a small fold of tissue (see Figure 1.3).

The superior surface of the tongue is covered by stratified squamous epithelium, which provides a resilient layer that protects the tongue from mechanical abrasion during mastication and other oral activities. This surface is also populated by numerous small projections known as papillae, which contain the taste buds (see Figure 1.3). These specialised structures house the nerve endings responsible for detecting taste, playing a central role in the sensory experience of food and influencing food preferences (McErlean 2025). In addition to its role in taste, the tongue serves various other critical functions. These include swallowing (deglutition), which helps propel food towards the throat, manipulating food within the oral cavity during mastication and articulating speech sounds. The tongue's versatility highlights its essential role not only in digestion but also in communication.

PALATE

The palate forms the roof of the oral cavity and is anatomically divided into two sections: the hard palate and the soft palate. The hard palate, located anteriorly, is a bony structure

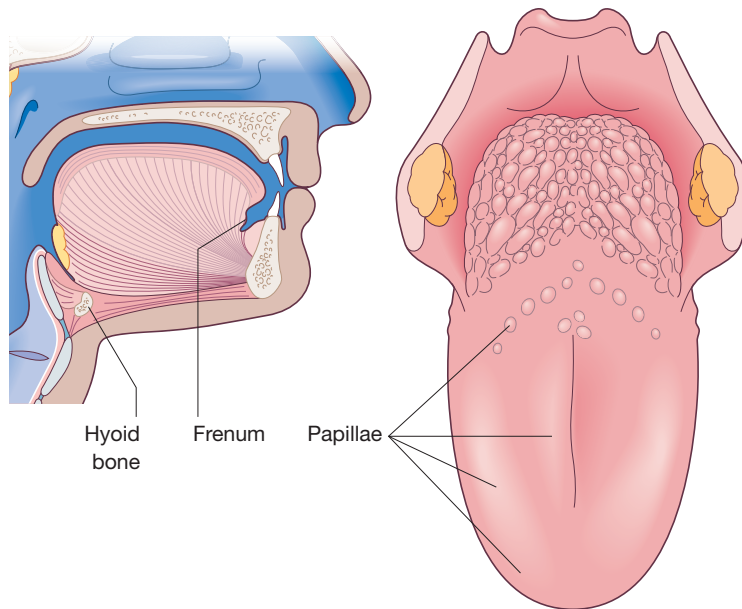


FIGURE 1.3 Tongue, hyoid bone and frenum. *Source:* Tortora and Derrickson (2009). With permission of John Wiley & Sons.

that provides a firm surface against which food is pressed during chewing. In contrast, the soft palate, located posteriorly, is a flexible structure composed of skeletal muscle and connective tissue. The soft palate plays a crucial role in the act of swallowing by elevating to close off the nasopharynx, preventing food and liquids from entering the nasal passages. On either side of the soft palate are the palatine tonsils, which are lymphoid tissues involved in immune defence. The uvula, a small conical projection from the centre of the soft palate, assists in both speech and preventing food from entering the nasopharynx during swallowing.

TEETH

Temporary teeth, also known as deciduous or milk teeth, typically begin to emerge around the age of six months. A complete set of 20 deciduous teeth is generally present by the age of two or three, and these are gradually replaced by permanent teeth starting around the age of six. In adulthood, individuals typically have 32 permanent teeth, divided evenly between the maxillary arch (upper jaw) and the mandibular arch (lower jaw), with 16 teeth in each arch. These permanent teeth are essential for the mechanical digestion of food, as they assist in chewing, grinding and tearing food into smaller particles, facilitating the process of digestion. Figure 1.4 outlines deciduous and permanent dentition.

SALIVARY GLANDS

There are three pairs of salivary glands (see Figure 1.5). The parotid glands are the largest and are situated anterior to the ears. Saliva from these glands is secreted into the oral cavity near the level of the second upper molar tooth. The submandibular glands are located beneath the

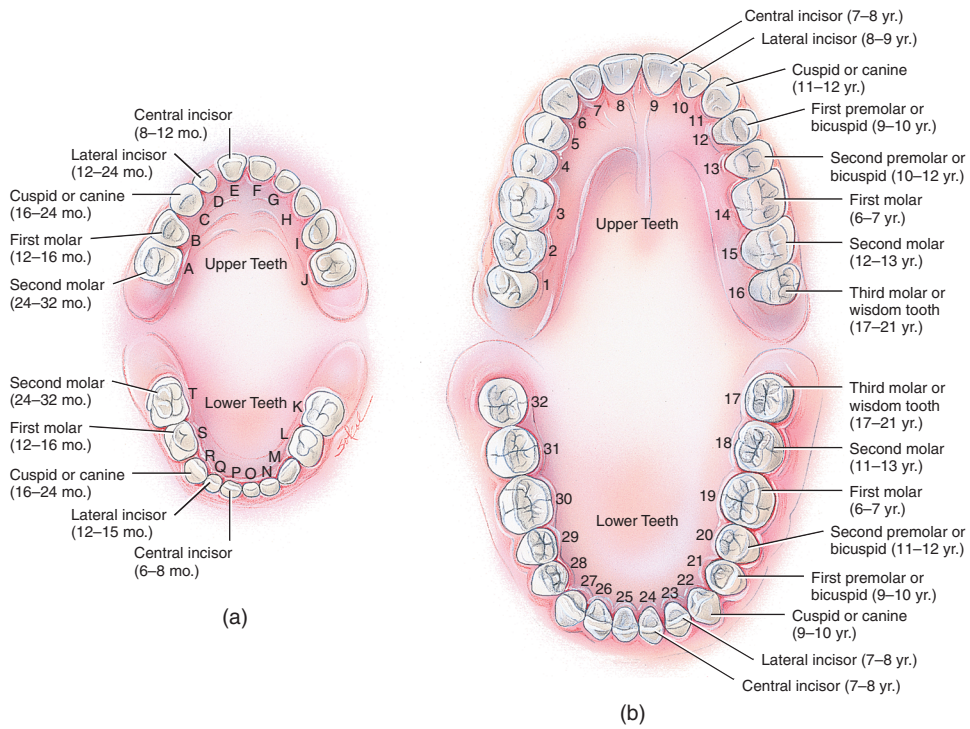


FIGURE 1.4 Teeth: (a) deciduous (primary) dentition and (b) permanent (secondary) dentition. *Source:* Tortora and Derrickson (2009). With permission of John Wiley & Sons.

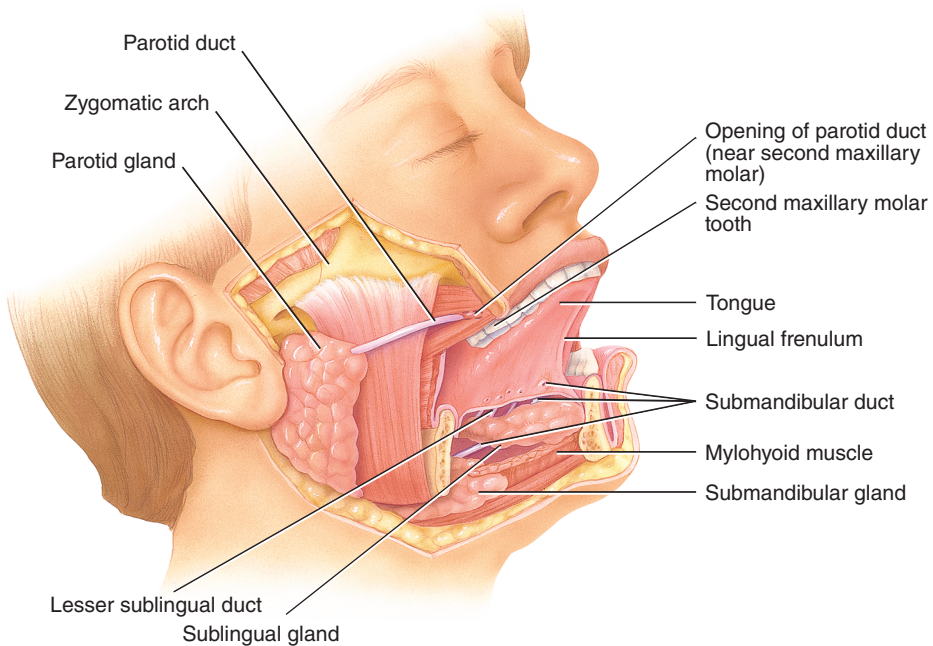


FIGURE 1.5 Salivary glands. *Source:* Peate and Evans (2020). With permission of John Wiley & Sons.

jaw on either side of the face, with saliva entering the oral cavity near the lingual frenulum of the tongue. The sublingual glands, the smallest of the three, are situated in the floor of the mouth.

Although saliva is constantly secreted to maintain moisture in the oral cavity, the parasympathetic fibres that innervate the salivary glands stimulate an increase in saliva production in response to sensory cues such as the sight, smell or taste of food. In contrast, the sympathetic fibres reduce saliva secretion.

In a healthy individual, approximately 1–1.5 L of saliva is produced daily (Colbert et al. 2020). Saliva is composed of:

- Water
- Salivary amylase
- Mucus
- Mineral salts
- Lysozyme
- Immunoglobulins
- Blood clotting factors

Saliva serves a number of essential functions, including the following:

- Salivary amylase is a digestive enzyme that initiates the breakdown of starch (a complex carbohydrate) into smaller sugar molecules, primarily maltose (a disaccharide).
- The fluid nature of saliva helps moisten and lubricate food entering the mouth, facilitating the manipulation and holding of food within the oral cavity and assisting in forming a bolus for swallowing.
- Continuous saliva secretion helps to cleanse the oral cavity and maintain moisture, reducing the risk of oral mucosal infections and the formation of mouth ulcers.
- As an entry point for pathogens, the oral cavity is vulnerable to infection. Lysozyme, a key component of saliva, has antibacterial properties, while immunoglobulins and blood clotting factors contribute to the prevention of infection.
- Taste perception is dependent on the moisture of food. Saliva plays an essential role in moistening food, enabling the activation of taste receptors for the detection of flavours.

PHARYNX

The pharynx is formed of three parts:

- Oropharynx
- Nasopharynx
- Laryngopharynx

The nasopharynx is seen as a structure of the respiratory system. The oropharynx and the laryngopharynx are passages for food and also respiratory gases (see Figure 1.6). The epiglottis

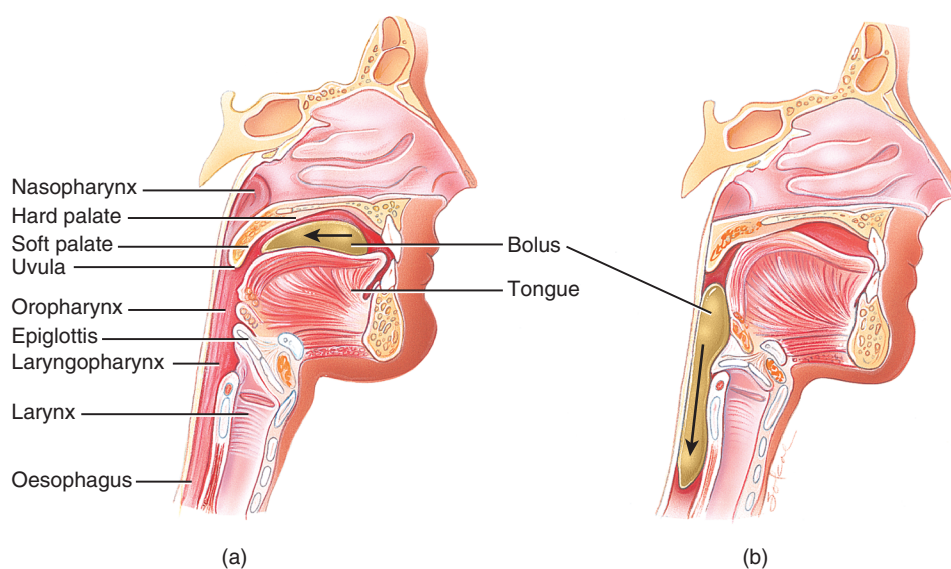


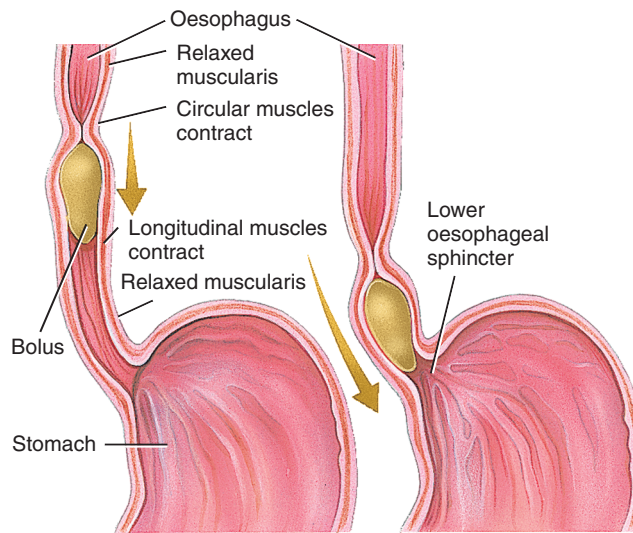
FIGURE 1.6 (a) The position of structures before swallowing and (b) During the pharyngeal stage of swallowing. *Source:* Tortora and Derrickson (2009). With permission of John Wiley & Sons.

is responsible for closing the entrance to the larynx during swallowing and this essential action prevents food from entering the larynx and obstructing the respiratory passages.

SWALLOWING (DEGLUTITION)

Once food has been thoroughly chewed and formed into a bolus, it is ready to be swallowed. The process of swallowing occurs in three distinct phases:

1. **The voluntary phase:** This initial phase involves the action of voluntary muscles within the oral cavity, which manipulate the food bolus and move it into the oropharynx. The tongue presses against the roof of the mouth (the palate), which prevents the bolus from being pushed forward and ensures it moves towards the back of the mouth for the next phase.
2. **The pharyngeal phase:** This phase is triggered reflexively when the food bolus enters the oropharynx. The swallowing reflex is coordinated by the swallowing centre located in the medulla oblongata of the brainstem. This triggers a motor response causing the pharyngeal muscles to contract. Simultaneously, the soft palate elevates to seal off the nasopharynx, preventing food from entering the nasal passages. The larynx rises, and it moves forward, allowing the epiglottis to cover the entrance to the larynx and prevent food from entering the airway or respiratory passages.
3. **The oesophageal phase:** When the bolus has passed through the pharynx, it enters the oesophagus. The oesophageal muscles contract in a coordinated manner to propel the bolus down the length of the oesophagus and into the stomach. This series of muscular contractions is known as peristalsis, which ensures that the bolus moves efficiently and in a controlled manner (see Figure 1.7).



Anterior view of frontal sections of peristalsis in oesophagus

FIGURE 1.7 Oesophageal peristalsis. *Source:* Tortora and Derrickson (2009). With permission of John Wiley & Sons.

OESOPHAGUS

After food has exited the oropharynx, it passes into the oesophagus, a muscular tube that extends from the laryngopharynx to the stomach. Measuring approximately 25 cm in length, the oesophagus is located in the thoracic cavity, running posterior to the trachea (Moini 2019). The primary function of the oesophagus is to transport food and liquids from the mouth to the stomach.

The inner lining of the oesophagus, known as the mucosa, secretes a thick layer of mucus that serves two essential purposes: it lubricates the food bolus, facilitating its smooth passage and acts as a protective barrier, shielding the oesophageal walls from the friction and potential abrasion caused by the food bolus as it moves towards the stomach.

Two important muscular structures regulate the movement of substances through the oesophagus:

1. The upper oesophageal sphincter, located at the junction of the pharynx and oesophagus, controls the entry of substances into the oesophagus from the oral cavity, preventing the backflow of food.
2. The lower oesophageal sphincter (also known as the cardiac sphincter), is situated at the junction of the oesophagus and stomach, controls the passage of food from the oesophagus into the stomach and prevents gastroesophageal reflux.

The muscle layer of the oesophagus is unique compared to other parts of the digestive tract. The superior portion of the oesophagus is composed of skeletal (voluntary) muscle, which allows for voluntary control during the initial stages of swallowing. As the oesophagus descends towards the stomach, the muscle transitions into smooth (involuntary) muscle, facilitating the automatic, rhythmic contractions required for peristalsis, the wave-like motion that moves food towards the stomach.

It is important to note that breathing and swallowing cannot occur simultaneously, as the body prioritises protecting the airway during swallowing by temporarily closing off the airway, a reflex that prevents food from entering the respiratory passages.

FEATURES OF THE DIGESTIVE SYSTEM

Throughout most of the digestive tract, from the oesophagus to the anus, the wall is composed of four main layers (tunics): the mucosa, submucosa, muscularis externa and an outer covering that is either serosa or adventitia, depending on location (see Figure 1.8). These layers work in coordination to facilitate the digestive process and ensure the efficient movement of food and digestive materials. Each layer has a specific structure and function that contributes to the overall function of the digestive system.

The mucosa is the innermost layer of the digestive tract, directly in contact with the products of digestion. It consists of three components: the mucous epithelium, which secretes mucus and digestive fluids (e.g. saliva, gastric juice) to protect the digestive system from wear; in the small intestine, it also facilitates nutrient absorption. Beneath this is the lamina propria, a layer of loose connective tissue that supports blood vessels and lymphatic tissue. The outermost layer of the mucosa, the muscularis mucosae, is a thin smooth muscle layer that aids in forming structures such as gastric pits and microvilli.

The submucosa is a thick connective tissue layer containing blood and lymph vessels, glands and Meissner's plexus, which stimulates glandular secretion.

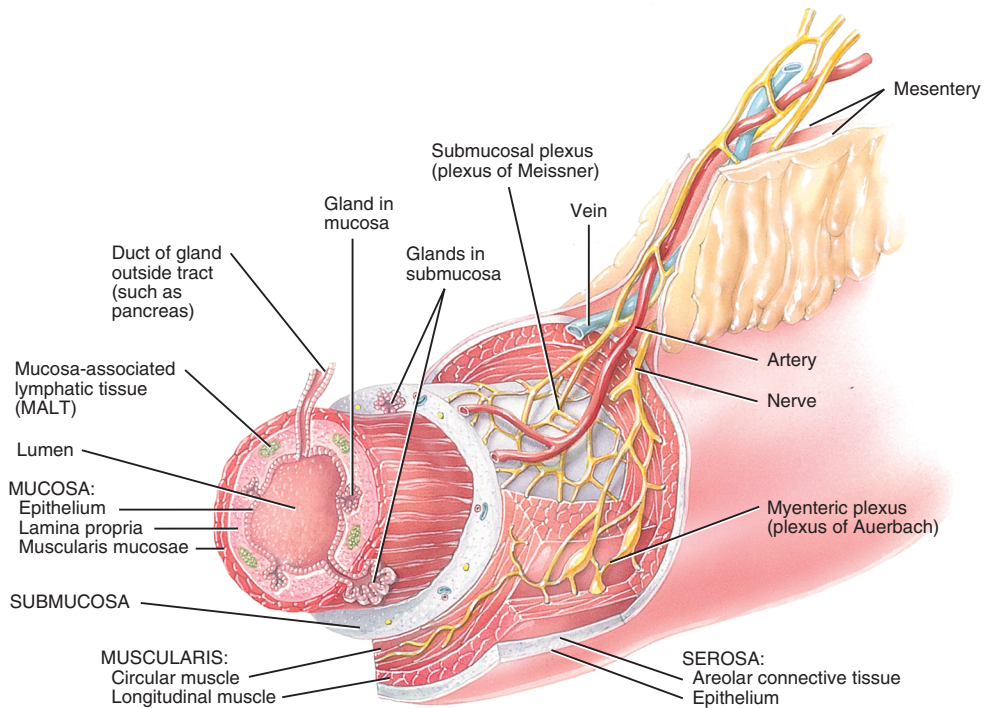


FIGURE 1.8 Structure of the digestive tract. *Source:* Tortora and Derrickson (2009). With permission of John Wiley & Sons.

The muscularis consists of two smooth muscle layers: an inner circular layer and an outer longitudinal layer. In the stomach, an additional third layer of muscle exists, while the upper oesophagus contains skeletal muscle. Blood vessels, lymphatic vessels and the myenteric plexus (a network of nerves) lie between these muscle layers. These muscles enable peristalsis, the wave-like contractions that propel food through the digestive tract and aid in mechanical digestion.

The outermost layer, the serosa (or adventitia), is predominantly found in the abdominal and pelvic cavities. The peritoneum, a closed sac, serves as the serosa in these regions. The visceral peritoneum covers abdominal organs, while the parietal peritoneum lines the abdominal wall. A small amount of serous fluid lies between these layers, facilitating organ movement. The peritoneum, rich in blood supply and lymphatic vessels, acts as a protective barrier and helps isolate infections to prevent damage to surrounding structures.

THE STOMACH

The stomach is located in the abdominal cavity; it is found between the oesophagus (superiorly) and the duodenum of the small intestine (inferiorly). It is divided into distinct regions (see Figure 1.9). Entry into the stomach from the oesophagus is regulated by the lower oesophageal sphincter, also known as the cardiac sphincter. This opens into the cardiac region (cardia).

Above this area is the fundus, a dome-shaped section at the uppermost part of the stomach. The body of the stomach lies between the lesser and greater curvatures and constitutes the largest portion. As the stomach narrows, it forms the pyloric region, which leads into the pyloric canal. Exit from the stomach into the small intestine is controlled by the pyloric sphincter. Once food has been mixed and partially digested, it is referred to as chyme.

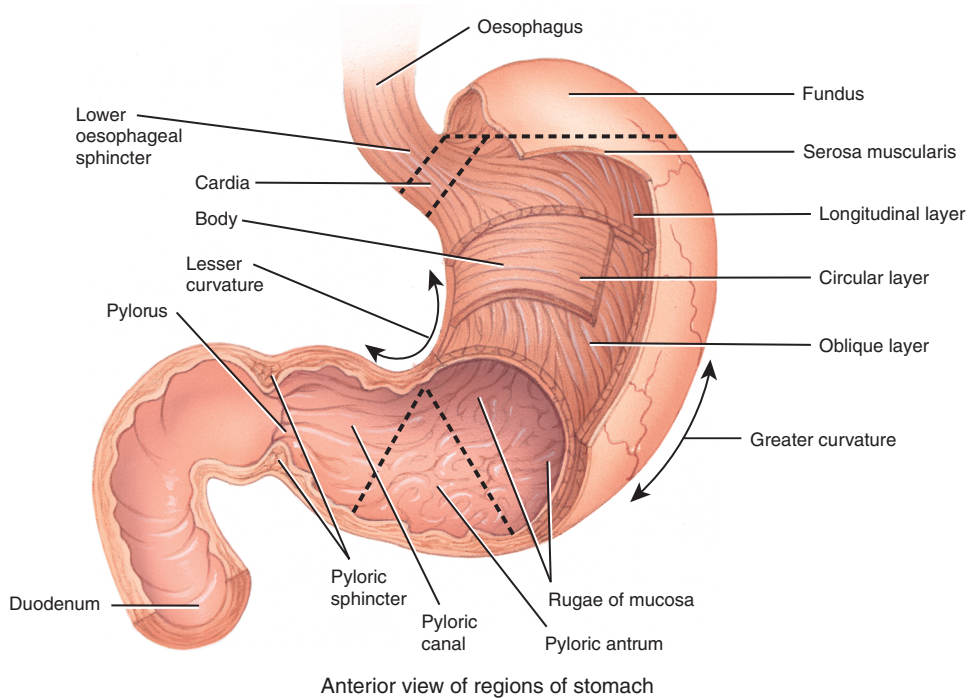


FIGURE 1.9 The stomach. *Source:* Tortora and Derrickson (2009). With permission of John Wiley & Sons.

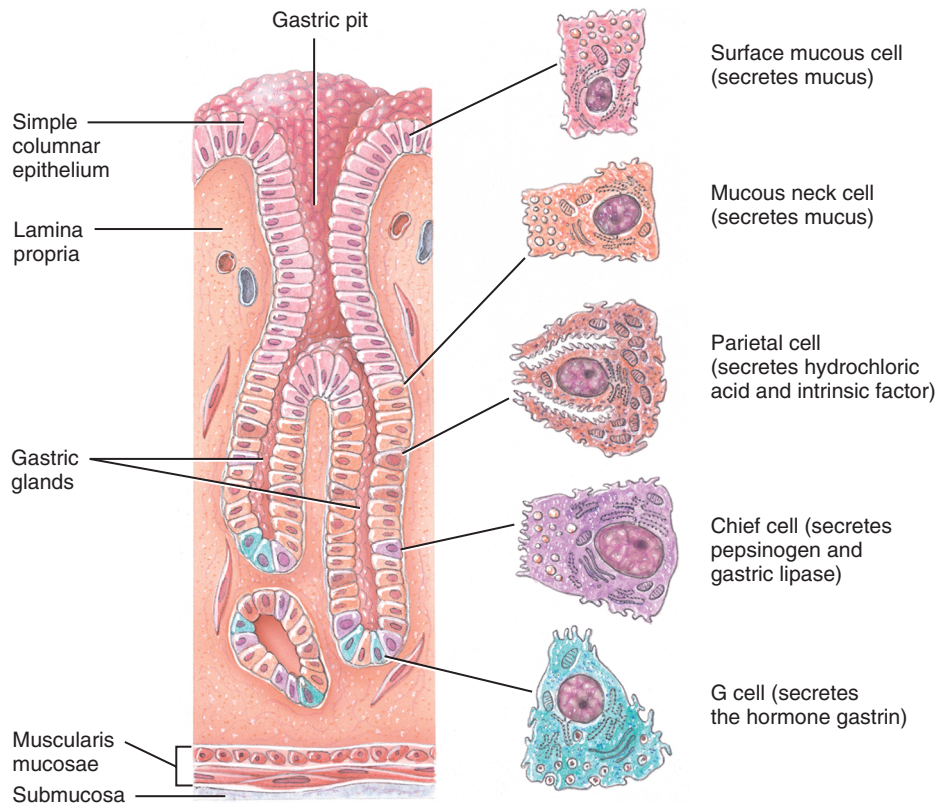


FIGURE 1.10 Gastric glands and cells. *Source:* Tortora and Derrickson (2009). With permission of John Wiley & Sons.

The stomach receives arterial blood supply from branches of the coeliac artery, while venous blood drains via the hepatic portal vein. It is innervated by parasympathetic fibres from the vagus nerve, stimulating both gastric motility and secretion of gastric juices. Sympathetic fibres arising from the coeliac plexus act to inhibit gastric activity.

Structurally, the stomach shares the same four basic layers as the rest of the gastrointestinal tract but with important differences. The muscularis layer contains three layers of smooth muscle, longitudinal, circular and oblique fibres, providing additional strength to aid the vigorous churning and mechanical digestion of food, as well as supporting peristalsis.

The mucosa of the stomach is unique. When the stomach is empty, its mucosal lining folds into ridges called rugae, which flatten out as the stomach fills. A very full stomach can hold up to 4 L of content, whereas an empty stomach contains only about 50 mL (Tortora and Derrickson 2023). The size and shape of the stomach vary depending on the individual and the quantity of ingested food.

Embedded within the mucosa are numerous gastric glands, responsible for secreting the components of gastric juice (see Figure 1.10):

- Surface mucous cells secrete thick, bicarbonate-rich mucus that coats and protects the stomach lining from the corrosive effects of gastric acid. These cells have a high turnover rate, rapidly replacing any damaged cells.

- Mucous neck cells produce a thinner mucus distinct from the surface mucus.
- Parietal cells release hydrochloric acid (HCl), creating a highly acidic environment (pH 1–3) necessary for protein denaturation and microbial defence. They also produce intrinsic factor, essential for the absorption of vitamin B12 in the small intestine, vital for erythrocyte (red blood cell) production.
- Chief cells secrete pepsinogen, an inactive precursor that, in the presence of HCl, is converted into pepsin, an enzyme critical for protein digestion.
- Enteroendocrine cells, including G cells, produce hormones such as gastrin, which regulates gastric motility and secretion.

This complex mixture of secretions, water and mineral salts is known collectively as gastric juice, with approximately 2 L produced each day (Welsh et al. 2021).

PHASES OF GASTRIC SECRETION

Gastric juice secretion is tightly regulated through three overlapping phases (see Figure 1.11):

- Cephalic phase: This phase is stimulated by the sight, smell, thought or taste of food, triggering parasympathetic stimulation and gastric secretions even before food reaches the stomach.
- Gastric phase: Begins when food enters the stomach, stimulating gastrin release, which enhances gastric juice production. As the pH of the stomach contents drops below 2, gastrin secretion is inhibited.
- Intestinal phase: Commences as chyme enters the duodenum, prompting the release of secretin and cholecystokinin (CCK). These hormones slow gastric activity, regulating the movement of chyme into the small intestine.

The speed of gastric emptying depends on the size and type of meal. Liquids pass quickly through the stomach, while solids require more extensive mixing. Typically, most meals empty from the stomach within four hours.

FUNCTIONS OF THE STOMACH

The stomach carries out several key functions:

- Acts as a temporary storage site for ingested food.
- Secretes mucus to protect the stomach lining from self-digestion.
- Undertakes mechanical digestion through vigorous muscular churning.
- Contributes to chemical digestion by mixing food with hydrochloric acid, helping to destroy pathogens and denature proteins.
- Converts the food bolus into chyme.
- Produces intrinsic factor, essential for vitamin B12 absorption.

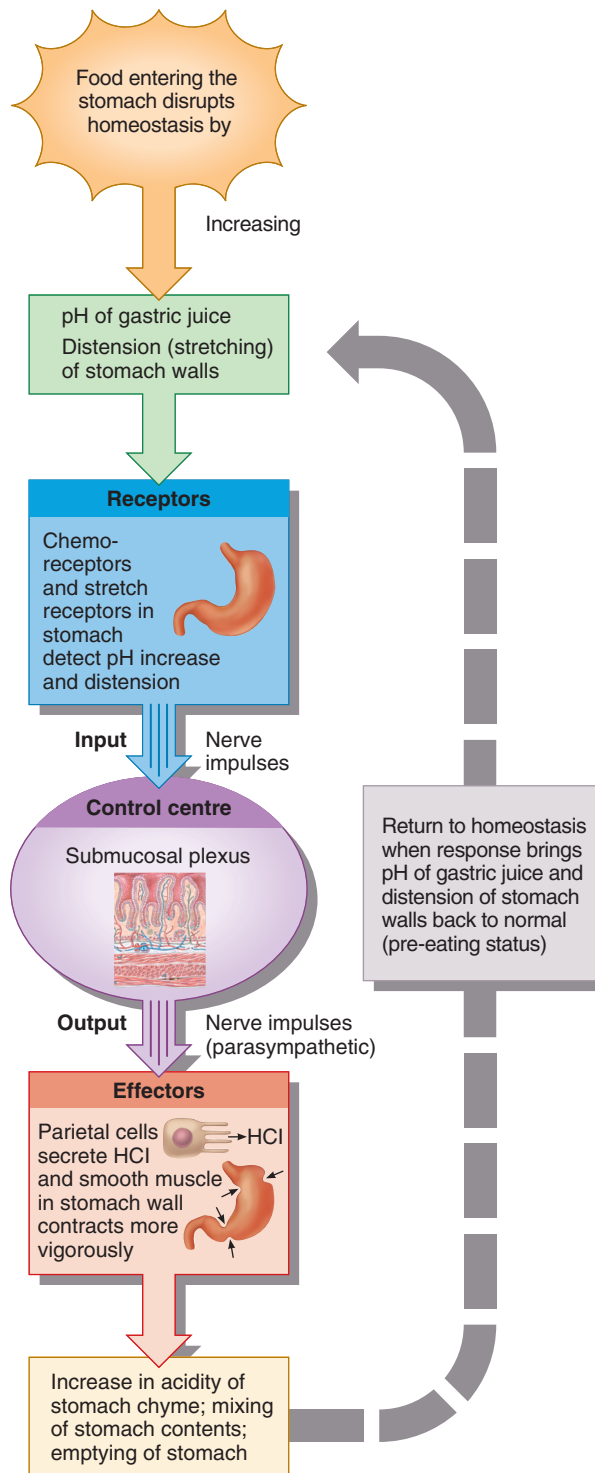


FIGURE 1.11 Phases of gastric juice secretion. *Source:* Tortora and Derrickson (2009). With permission of John Wiley & Sons.

THE SMALL INTESTINE

The small intestine is approximately 6 m long and is the site where mechanical and chemical digestion continue, alongside the absorption of nutrients. It is divided into three sections (see Figure 1.12):

1. Duodenum: About 20–25 cm long and the first part of the small intestine.
2. Jejunum: Roughly 2.5 m in length and forms the middle section.
3. Ileum: Approximately 3.5 m long and joins the large intestine at the ileocaecal valve, which prevents the backward flow of intestinal contents.

The small intestine is richly innervated by both parasympathetic and sympathetic nerves. Arterial blood is supplied by the superior mesenteric artery, and nutrient-rich venous blood drains via the superior mesenteric vein into the hepatic portal vein, heading towards the liver.

Cells of the small intestine (see Figure 1.13):

- Absorptive cells: Produce digestive enzymes and absorb nutrients.
- Goblet cells: Secrete mucus to protect the intestinal lining from mechanical damage and acidic chyme.
- Enteroendocrine cells: Release hormones such as secretin and CCK to regulate digestive secretions.
- Paneth cells: Secrete lysozyme to defend against pathogens, supported by Peyer's patches (aggregated lymphatic tissue).

DIGESTIVE PROCESSES IN THE SMALL INTESTINE

Chyme enters the small intestine and remains for three to six hours, when digestion and absorption take place. Smooth muscle activity promotes two types of mechanical digestion:

- Segmentation: Localised contractions mix chyme with digestive secretions.
- Peristalsis: Propels chyme along the intestinal tract.

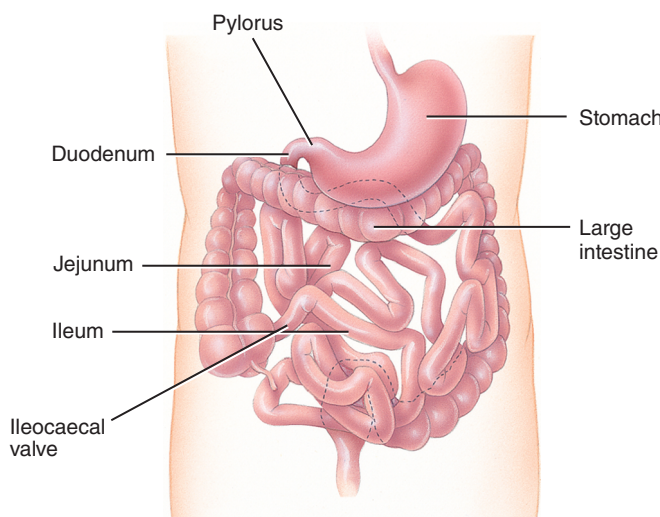
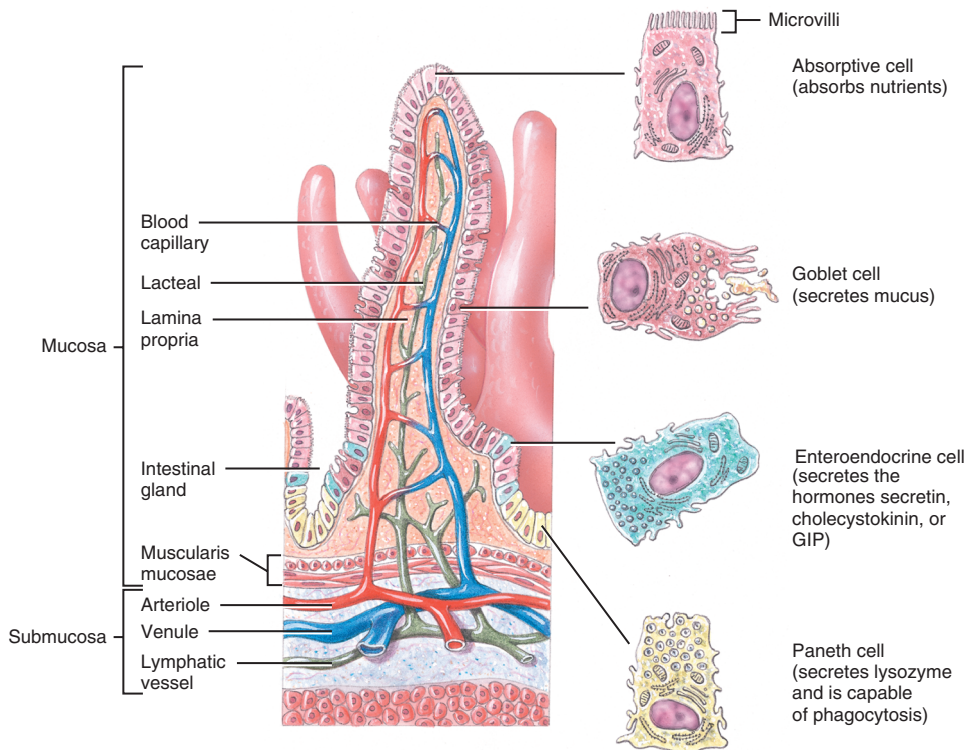


FIGURE 1.12 The small intestine. *Source:* Tortora and Derrickson (2009). With permission of John Wiley & Sons.



Enlarged villus showing lacteal, capillaries, intestinal glands and cell types

FIGURE 1.13 The cells within the villi of the small intestine. *Source:* Tortora and Derrickson (2009). With permission of John Wiley & Sons.

Chemical digestion completes the breakdown of the carbohydrates, fats and proteins. Pancreatic juice from the pancreas, bile from the gallbladder and intestinal juice contribute to this.

- Carbohydrates not broken down in the mouth are digested by pancreatic amylase.
- Fats are emulsified by bile, then broken down into fatty acids and glycerol by lipase.
- Proteins, initially denatured by stomach acid, are further broken down by trypsin, chymotrypsin and carboxypeptidase into peptides and amino acids.

The small intestine produces 1–2 L of intestinal juice daily. This alkaline secretion (pH 7.4–8.4), arising from the crypts of Lieberkühn, neutralises the acidic chyme, protects the mucosa and provides an environment suitable for enzyme action.

ADAPTATIONS FOR ABSORPTION

The small intestine is highly specialised to maximise absorption:

- Plicae circulares: Permanent circular folds slow the passage of chyme, increasing contact time for absorption.

- Villi: Finger-like projections lined with absorptive cells and containing a blood capillary network and a central lacteal for nutrient transport.
- Microvilli: Fine extensions on the villi form the brush border, massively increasing surface area. The brush border also produces enzymes such as lactase, maltase, sucrase and peptidases for final digestion.

Nutrient absorption occurs either by diffusion or active transport into blood capillaries or lacteals, depending on the molecule.

FUNCTIONS OF THE SMALL INTESTINE

- Secretes mucus to protect the mucosa from acidic chyme.
- Produces intestinal and pancreatic juices to neutralise chyme and enable enzyme function.
- Receives bile for fat emulsification.
- Completes chemical digestion of carbohydrates, proteins and fats.
- Performs mechanical digestion (segmentation and peristalsis) to enhance mixing and absorption.
- Provides an extensive surface area for efficient absorption.
- Absorbs the majority of nutrients, electrolytes and water.

THE PANCREAS

The pancreas is a glandular organ located in the abdomen, with both exocrine (digestive) and endocrine (hormonal) functions. It lies in close proximity to major blood vessels, including the aorta and inferior vena cava, which run behind the head of the pancreas.

Measuring approximately 12–15 cm in length and about 2.5 cm in thickness, the pancreas is positioned across the back of the abdomen, behind the stomach (Knight et al. 2024). The head of the pancreas lies on the right side of the abdomen and is connected to the duodenum, the first part of the small intestine, via the pancreatic duct. The narrow end, known as the tail, extends towards the left side of the body (see Figure 1.14).

The pancreas releases digestive juices through exocrine cells into small ducts, which merge to form larger ducts. Pancreatic juice consists of:

- Water
- Mineral salts
- Pancreatic amylase, which completes the digestion of carbohydrates
- Lipase, used in the digestion of fat
- Trypsinogen, chymotrypsinogen and procarboxypeptidase, which are released in an inactive form to protect the digestive system structures from the protein-digesting enzymes that they become – once they enter the duodenum – they are activated by enterokinase from intestinal juice and become trypsin, chymotrypsin and carboxypeptidase, respectively, and are then used in the digestion of protein

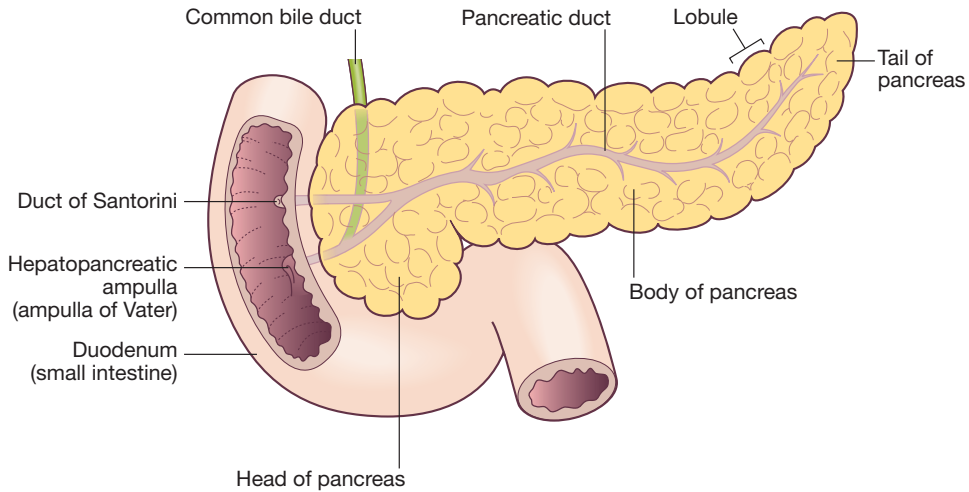


FIGURE 1.14 The pancreas. *Source:* Peate and Evans (2020). With permission of John Wiley & Sons.

The main duct, known as the duct of Wirsung, usually joins the common bile duct and enters the duodenum through an expanded channel called the hepatopancreatic ampulla.

Most individuals also have a secondary (minor or accessory) duct, which exits through a smaller opening called the minor papilla, located approximately 2 cm above and slightly to the right of the main papilla. In cases where the main papilla does not function properly, the minor papilla can serve as the primary drainage route for pancreatic secretions.

The pancreas also has an important endocrine role. Specialised cells within the islets of Langerhans produce the hormones insulin and glucagon, which are essential for regulating carbohydrate metabolism. In summary, the exocrine function of the pancreas is to secrete pancreatic juice into the duodenum. The actions of pancreatic juice lead to the further breakdown of carbohydrate, fat and protein.

THE LIVER AND PRODUCTION OF BILE

The liver is the body's largest gland, weighing between 1 and 2 kg. Located beneath the diaphragm and partly protected by the ribs, it spans the right hypochondriac, epigastric and part of the left hypochondriac regions. The right lobe is the largest of its four lobes. The portal fissure on its posterior surface allows the entry and exit of blood vessels, lymphatics, bile ducts and nerves. See Figure 1.15 for the liver, gallbladder and pancreas.

The liver is made up of hexagonal lobules containing hepatocytes, supported by Kupffer cells, which remove foreign particles and old blood cells. Each corner of a hepatic lobule contains a portal triad: a branch of the hepatic artery (carrying oxygenated blood), a branch of the hepatic portal vein (bringing nutrient-rich blood) and a bile duct (see Figure 1.16).

Blood drains through liver sinusoids into central veins, then flows into the hepatic vein and the inferior vena cava. Meanwhile, bile produced by hepatocytes drains into bile canaliculi, then into bile ducts and exits the liver via the common hepatic duct towards the duodenum.

The liver produces up to 1 L of alkaline, yellow-green bile daily, composed of bile salts (e.g. bilirubin), cholesterol, fat-soluble hormones, fats, mineral salts and mucus. Bile emulsifies fats, aiding lipase in fat digestion. Bile is stored and concentrated in the gallbladder.

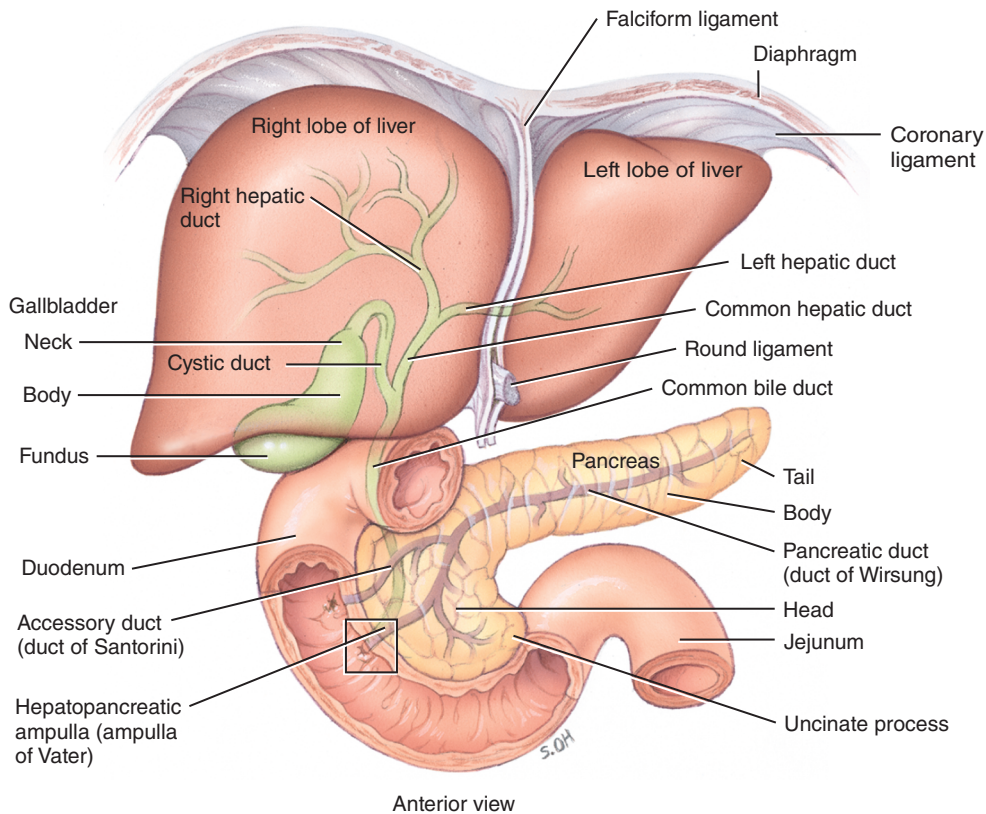


FIGURE 1.15 Liver, gallbladder and pancreas. *Source:* Tortora and Derrickson (2009). With permission of John Wiley & Sons.

THE FUNCTIONS OF THE LIVER

Beyond bile production and nutrient metabolism, the liver detoxifies harmful substances, recycles red blood cells, deactivates hormones, produces clotting factors, stores nutrients, synthesises vitamin A and generates heat.

THE GALLBLADDER

The gallbladder is a small, green, muscular organ; it is located behind the liver. The gallbladder serves as a bile reservoir, concentrating bile by absorbing water. Its mucosa, similar to the rugae in the stomach, has folds that allow it to expand and store varying amounts of bile. When the gallbladder contracts, bile is released into the cystic duct, then flows through the common bile duct into the duodenum via the hepatopancreatic ampulla.

Gallbladder contraction is triggered by the hormone CCK, which is released from the small intestine in response to fatty chyme. CCK not only stimulates the release of pancreatic juice but also causes the relaxation of the hepatopancreatic sphincter, allowing both bile and pancreatic juice to enter the duodenum. See Figure 1.17 for bile production and secretion.

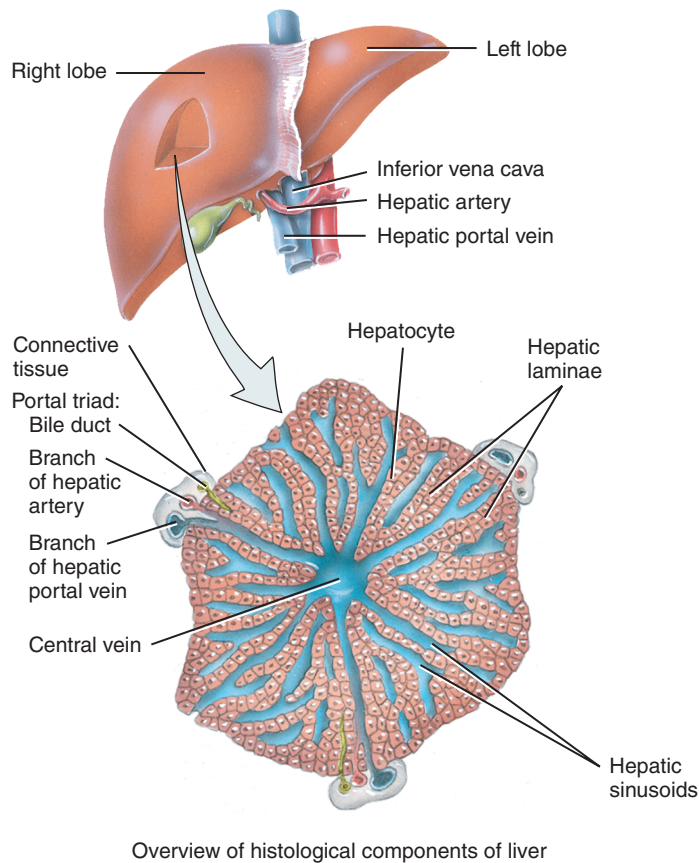


FIGURE 1.16 Liver lobule. *Source:* Tortora and Derrickson (2009). With permission of John Wiley & Sons.

THE LARGE INTESTINE

The large intestine receives the contents of the small intestine, which moves through it slowly via segmentation. This process allows for the final stages of digestion and absorption. The entry to the large intestine is controlled by the ileocaecal sphincter, which opens in response to increased stomach activity and the hormone gastrin. Once the food residue enters the large intestine, it cannot flow back into the ileum (see Figure 1.18).

The large intestine is approximately 1.5 m long and 7 cm in diameter. It begins at the ileocaecal valve and ends at the anus. The food residue enters the caecum and moves through the ascending colon, transverse colon and descending colon, eventually passing out of the body via the rectum, anal canal and anus. The caecum is a sac-like structure leading into the large intestine. The vermiform appendix is a narrow, tube-like extension of the caecum that plays a role in immunity.

Faecal expulsion from the anus is controlled by two sphincter muscles: the internal anal sphincter (smooth muscle, controlled by the parasympathetic nervous system) and the external anal sphincter (skeletal muscle, under voluntary control).

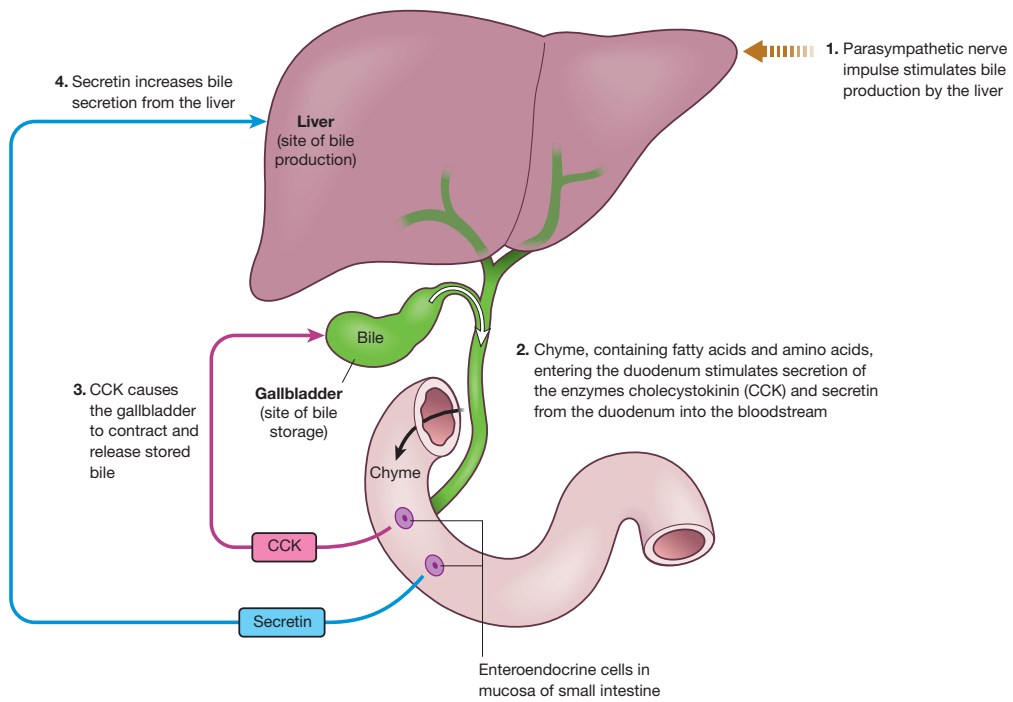


FIGURE 1.17 Bile production and secretion. *Source:* Peate (2022). With permission of John Wiley & Sons.

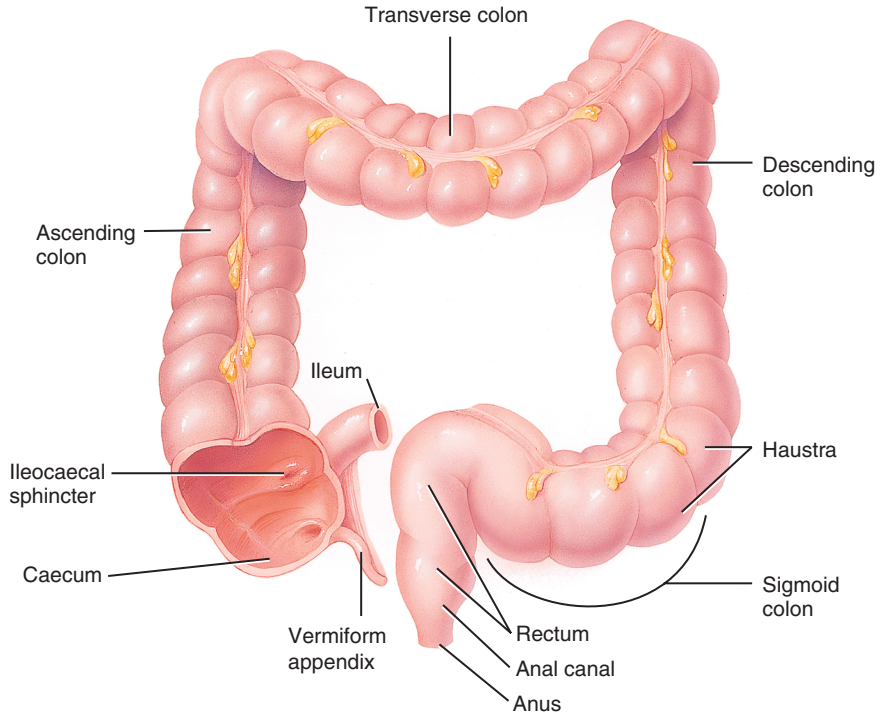


FIGURE 1.18 The large intestine. *Source:* Tortora and Derrickson (2009). With permission of John Wiley & Sons.

The mucosa of the large intestine contains many goblet cells that secrete mucus, facilitating the passage of faeces and protecting the intestinal walls. The epithelium changes from simple columnar to stratified squamous epithelium at the anal canal, and anal sinuses secrete mucus, protecting against abrasion during defaecation.

The longitudinal muscle layer forms bands called taeniae coli. These create the large intestine's characteristic gathered appearance, with sac-like structures known as haustra.

When food residue enters the caecum, it is fluid and nutrient-poor. The primary function of the large intestine is to absorb water and convert the residue into semi-solid faeces, along with absorbing some vitamins, minerals, electrolytes and drugs. It typically takes 24–48 hours for food residue to pass through the large intestine, with 500 mL entering daily and about 150 mL exiting as faeces.

As faeces enter the rectum, the stretching triggers the defaecation reflex. Voluntary control of this reflex is acquired between ages two and three years. The external anal sphincter can be consciously controlled, allowing defaecation to occur when appropriate. Contraction of the abdominal muscles and diaphragm (the Valsalva manoeuvre) increases intra-abdominal pressure and assists with defaecation. If defaecation is not appropriate, the urge can be postponed until the next mass movement through the large intestine.

Faeces are a brown, semi-solid substance consisting of fibre, stercobilin (from bilirubin breakdown), water, fatty acids, shed epithelial cells and microbes. Stercobilin gives faeces its brown colour. Diarrhoea occurs when faeces pass too quickly through the large intestine, preventing adequate water absorption, while constipation happens when residue remains too long, causing excessive water absorption.

DIGESTIVE TRACT HORMONES

Hormones play a crucial role in regulating the activity of the digestive system, coordinating various processes such as secretion, motility and digestion. These hormones are produced by specialised cells within the gastrointestinal tract and act on different parts of the digestive system to ensure its effective functioning. A summary of these hormones and their specific functions is outlined in Table 1.1.

Each digestive hormone is involved in a specific aspect of digestion. For instance, some hormones stimulate the release of digestive enzymes and bile, while others regulate the movement of food through the digestive tract. These hormonal signals are crucial for ensuring that digestion occurs efficiently and at the right time.

Additionally, digestive hormones help regulate the secretion of gastric acid, control appetite and maintain fluid balance within the digestive system. The interplay of these

Table 1.1 Digestive tract hormones

Hormone	Origin	Target	Action	Stimulus
Gastrin	Stomach	Stomach	Stimulates gastric gland secretion of hydrochloric acid, promotes gastric emptying	Presence of protein in the stomach

(Continued)

Table 1.1 (Continued)

Hormone	Origin	Target	Action	Stimulus
Secretin	Duodenum	Stomach	Inhibits gastric gland secretion, reduces gastric motility	Acidic and fatty chyme in the duodenum
		Pancreas	Increases pancreatic juice secretion	
		Liver	Stimulates bile secretion	
Cholecystokinin	Duodenum	Pancreas	Stimulates pancreatic juice secretion	Presence of chyme in the duodenum
		Gallbladder	Stimulates contraction of the gallbladder	
		Hepatopancreatic sphincter	Relaxes, allowing entry into the duodenum	

Source: Adapted from Colbert et al. (2021) and Mc Erlean (2025).

hormones allows the body to respond appropriately to the ingestion of food, supporting effective nutrient breakdown, absorption and waste elimination.

NUTRITION, CHEMICAL DIGESTION AND METABOLISM

Up until now, this chapter has focused on the digestive tract's role in processing the food ingested, breaking it down into its basic components for absorption and use by the body's cells. This section explores the concept of nutrition and the vital role that a balanced diet plays in maintaining health.

An adequate intake of nutrients is fundamental to overall health. Beyond its physical benefits, nutrition significantly contributes to social and psychological well-being. Poor nutritional management, however, can lead to a variety of physical and psychological disorders. As such, it is crucial to understand the role of different nutrients in the body, as an imbalance, whether through deficiencies or excess, can result in various health issues.

NUTRIENT GROUPS

An adequate intake of nutrients is essential for optimal health, as well as for social and psychological well-being. When mismanaged, nutrition can contribute to both physical and psychological conditions. Understanding the role of nutrients in the body is vital, as an imbalance – whether through deficiency or excess – can lead to various health issues.

NUTRIENT BREAKDOWN

Macronutrients: Carbohydrates, proteins and fats are required in large quantities and provide the bulk of the body's energy needs.

Micronutrients: Vitamins and minerals are needed in smaller amounts, but are crucial for maintaining health and facilitating essential bodily functions.

Water

Water is essential for digestion and various metabolic processes. It aids in the production of digestive juices and supports the breakdown of food molecules through hydrolysis, which is the addition of water to break chemical bonds.

Carbohydrates

Carbohydrates include monosaccharides, disaccharides and polysaccharides, with the majority of dietary carbohydrates sourced from plants, though lactose in milk is another form. Carbohydrates are composed of carbon, hydrogen and oxygen and include both complex forms, such as starch and glycogen and simple forms, including sucrose and glucose.

After digestion, carbohydrates are broken down into glucose, fructose and galactose, with fructose and galactose converted to glucose by the liver. Glucose is the main energy source for cells and is used in the process of glycolysis to produce ATP, the body's energy currency. Insufficient carbohydrate intake leads to the breakdown of fats and proteins in a process called gluconeogenesis to supply the body with glucose. Excess glucose is stored as glycogen or converted into fat for storage.

Fats

Fats, sourced from dairy, meat and plant oils, contain carbon, hydrogen and oxygen in a different combination than carbohydrates. When fat enters the small intestine, bile emulsifies it and pancreatic lipase further breaks it down into fatty acids and glycerol. Some fatty acids are absorbed into the lymphatic system and others directly into the bloodstream. Fat is used for energy, stored in adipose tissue and is necessary for absorbing fat-soluble vitamins. Excessive dietary fat can lead to obesity and cardiovascular diseases, while insufficient fat intake can cause poor growth and skin issues.

Proteins

Proteins are derived from animal and plant sources, including meat, eggs, milk and legumes. Proteins are broken down into amino acids, which are absorbed through the villi of the small intestine. Amino acids are essential for tissue structure, repair and enzyme and hormone production. Protein can also be used for energy when necessary. The liver converts excess amino acids into carbohydrate or fat for storage as adipose tissue. Excessive protein intake can lead to obesity. A deficiency could result in muscle wasting and oedema.

Vitamins

Vitamins are organic compounds needed in small amounts to maintain health. While some vitamins can be synthesised by the body, such as vitamin D from sunlight and vitamin K by intestinal bacteria, others must be obtained from the diet. Vitamins act as coenzymes that enable enzymes to function effectively. Fat-soluble vitamins (A, D, E, K) are stored in the body, which can become toxic if accumulated. Water-soluble vitamins (B-complex and C) are not stored; excess amounts are excreted in the urine.

Minerals

Minerals are inorganic compounds that are needed in small quantities for various bodily functions. They contribute to structural strength (e.g. calcium in bones) and help maintain osmotic pressure (e.g. sodium). Some minerals are required in moderate amounts, such as calcium and magnesium, while others are needed in trace amounts, such as cobalt and copper.

Each nutrient group requires specific digestive processes to be broken down into smaller molecules that the body can absorb and use. The digestive system enables the breakdown of large food molecules into smaller, absorbable units such as glucose, fatty acids, amino acids, vitamins and minerals. These nutrients are then absorbed into the bloodstream through the walls of the small intestine, transported to the liver for further processing and finally used by the body's cells for energy, growth, repair and other essential functions. Therefore, the digestive system plays a central role in converting food into the nutrients that the body needs to maintain health.

CONCLUSION

A comprehensive understanding of the anatomy and physiology of the digestive system is fundamental to the safe and effective delivery of digestive system-related clinical skills. Exploring the structural organisation of the gastrointestinal tract and its associated organs, as well as the coordinated physiological processes that enable ingestion, digestion, absorption and elimination. This chapter has emphasised the central role of the digestive system in maintaining overall health and homeostasis.

As the subsequent chapters examine the clinical skills associated with digestive assessment and intervention, the introductory principles outlined here will support those who offer people care and support to perform procedures with a deeper understanding of the underlying anatomy and physiology. This integration of scientific knowledge with practical competence underpins safe, skilled and compassionate practice in digestive healthcare.

GLOSSARY OF TERMS

Absorption: The process by which nutrients from digested food pass through the walls of the intestines into the bloodstream or lymphatic system.

Amylase: An enzyme that breaks down starches into sugars, found in saliva and pancreatic fluid.

Anus: The opening at the end of the digestive tract through which faeces are excreted.

Bile: A digestive fluid produced by the liver and stored in the gallbladder, which helps emulsify fats.

Bile salt: Substances found in bile that help to emulsify fats, aiding in digestion and absorption.

Calcium: A mineral important for the formation of bone and teeth, muscle function and nerve transmission.

Carbohydrate: A major macronutrient found in foods such as bread, pasta and fruits that the body breaks down into glucose for energy.

Cholecystokinin (CCK): A hormone that stimulates the release of digestive enzymes from the pancreas and bile from the gallbladder.

Chyme: The semi-liquid mixture of food and digestive juices that moves from the stomach into the small intestine.

Colon: The large intestine, responsible for absorbing water and electrolytes and forming faeces.

Diarrhoea: A condition characterised by frequent, loose, watery stools, often caused by infection or digestive disorders.

Digestive enzymes: Proteins that break down large food molecules into smaller, absorbable components (e.g. amylase, lipase, proteases).

Duodenum: The first section of the small intestine, where most chemical digestion occurs.

Enzyme: A protein that accelerates the breakdown of food into smaller molecules for absorption.

Exocrine: Referring to glands that secrete substances through ducts to an external surface (e.g. digestive enzymes from the pancreas).

Faeces: The waste products of digestion that are excreted from the body via the anus.

Fatty acids: The building blocks of lipids that provide energy and are important for cell structure.

Gallbladder: A small organ that stores bile produced by the liver and releases it into the small intestine to aid in fat digestion.

Gastric juice: The acidic digestive fluid secreted by the stomach, containing hydrochloric acid and digestive enzymes.

Gastrin: A hormone produced by the stomach that stimulates the secretion of gastric juices.

Hepatic portal vein: The blood vessel that carries nutrients absorbed from the small intestine to the liver for processing.

Ileocaecal valve: The valve between the small intestine and the large intestine that prevents backflow of material from the colon.

Insulin: A hormone produced by the pancreas that helps regulate blood glucose levels by promoting the uptake of glucose into cells.

Jejunum: The middle portion of the small intestine, where the majority of nutrient absorption occurs.

Kupffer cells: Specialised macrophages located in the liver that help to filter and remove pathogens, debris and old red blood cells from the blood.

Lactase: An enzyme that breaks down lactose, the sugar found in milk, into glucose and galactose.

Lipase: An enzyme that breaks down fats into fatty acids and glycerol.

Liver: The organ that produces bile, stores glycogen and processes nutrients absorbed by the intestines.

Mesentery: A fold of tissue that attaches the intestines to the abdominal wall and provides blood vessels to the intestines.

Mucosa: The innermost lining of the digestive tract, which secretes mucus to protect and lubricate the digestive surfaces.

Oesophagus: The tube that transports food from the mouth to the stomach.

Pancreas: An organ that produces digestive enzymes and hormones like insulin, playing a crucial role in both digestion and blood glucose regulation.

Pepsin: A digestive enzyme found in the stomach that breaks down proteins into peptides.

Peristalsis: The wave-like muscular contractions that move food through the digestive tract.

Protease: An enzyme that breaks down proteins into amino acids.

Rectum: The final section of the large intestine, where faeces are stored before excretion.

Rugae: The folds in the stomach lining that allow for expansion when food is ingested.

Salivary amylase: An enzyme in saliva that starts the digestion of carbohydrates in the mouth.

Small intestine: The part of the digestive tract where most digestion and nutrient absorption occur. It is made up of the duodenum, jejunum and ileum.

Sphincter: A ring-like muscle that controls the passage of food through various parts of the digestive tract (e.g. lower oesophageal sphincter, pyloric sphincter).

Stomach: The organ that stores food and begins the process of protein digestion through gastric juices and enzymes like pepsin.

Taeniae coli: Longitudinal muscle bands in the colon that cause the organ to form pouches called haustra.

Trypsin: A protease enzyme produced by the pancreas that continues the digestion of proteins in the small intestine

Ulcer: A sore or break in the lining of the digestive tract, often caused by excessive acid production or infection.

Villi: Tiny finger-like projections in the small intestine that increase the surface area for nutrient absorption.

Water-soluble vitamins: Vitamins that dissolve in water and are not stored in the body, including the B-vitamins and vitamin C.

MULTIPLE CHOICE QUESTIONS

1. Which part of the digestive system is primarily responsible for nutrient absorption?
 - a) Stomach
 - b) Small intestine
 - c) Large intestine
 - d) Oesophagus
2. The majority of digestion and nutrient absorption takes place in which section of the small intestine?
 - a) Jejunum
 - b) Duodenum
 - c) Ileum
 - d) Caecum
3. The enzyme pepsin is secreted by which part of the digestive system?
 - a) Small intestine
 - b) Pancreas
 - c) Stomach
 - d) Liver

4. The bile is produced by which organ?
 - a) Gallbladder
 - b) Pancreas
 - c) Small intestine
 - d) Liver
5. What is the function of the villi in the small intestine?
 - a) Absorb water
 - b) Increase surface area for nutrient absorption
 - c) Secrete digestive enzymes
 - d) Store bile
6. The ileocaecal valve regulates the flow of material between the:
 - a) Stomach and small intestine
 - b) Small and large intestine
 - c) Rectum and anus
 - d) Liver and gallbladder
7. What is the primary function of the large intestine?
 - a) Nutrient absorption
 - b) Water absorption
 - c) Digestion of proteins
 - d) Digestion of fats
8. The enzyme amylase is responsible for the digestion of:
 - a) Proteins
 - b) Carbohydrates
 - c) Fats
 - d) Nucleic acids
9. Which type of cell in the liver helps in filtering blood and removing pathogens and debris?
 - a) Hepatocytes
 - b) Kupffer cells
 - c) Epithelial cells
 - d) Enterocytes
10. Which part of the digestive tract is responsible for the mechanical breakdown of food?
 - a) Small intestine
 - b) Oesophagus
 - c) Stomach
 - d) Large intestine

REFERENCES

- Colbert, B., Ankney, J., Lee, K. et al. (2020). *Anatomy and Physiology for Nursing and Healthcare Professionals*, 2e. London: Pearson.
- McErlean, L. (2025). The digestive system (Chapter 11). In: *Fundamentals of Anatomy and Physiology*, 4e (ed. I. Peate and S. Evans). Oxford: Wiley.
- Knight, J., Nigam, Y., and Cutter, J. (2024). *Understanding Anatomy and Physiology in Nursing*, 2e. London: Learning Matters.
- Moini, J. (2019). *Anatomy and Physiology for Health Professionals*. Burlington: Jones and Bartlett.

- Peate, I. (2022). *Anatomy and Physiology for Nursing and Healthcare Students at a Glance*, 2e. Wiley-Blackwell.
- Peate, I. and Evans, S. (eds.) (2020). *Fundamentals of Anatomy and Physiology: For Nursing and Healthcare Students*, 3e. Wiley-Blackwell.
- Tortora, G. and Derrickson, B. (2023). *Tortora's Principles of Anatomy and Physiology*, 16e. New York: Wiley.
- Tortora, G.J. and Derrickson, B.H. (2009). *Principles of Anatomy and Physiology*, 12e. Wiley.
- Welsh, C.J. (2021). *Hole's Essentials of Human Anatomy and Physiology*, 14e. New York: McGraw-Hill.