Anatomy and Physiology

CHAPTER 1

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1.1 INTRODUCTION

From the moment food enters the body to the point of nutrient absorption and waste elimination, the gastrointestinal (GI) tract provides a number of functions and processes to ensure the body receives the energy and building blocks it needs. Beginning at the mouth and culminating at the anus, the GI tract encompasses a series of specialised organs, each with a unique role in digestion. We will follow the movement of food through the GI tract, its transformation into nutrients and waste via mechanical and enzymatic breakdown, and the intricate balance maintained by gut microbiota.

Through a comprehensive exploration of the GI tract's anatomy and physiology, this chapter aims to provide readers with a deeper understanding of this essential system. By appreciating its complexity, we can better grasp the ways in which the human body transforms food into life-sustaining energy and nutrients, before finally removing the waste products from digestion.

1.2 OVERVIEW OF THE DIGESTIVE SYSTEM

The digestive system is composed of the GI tract (alimentary canal) and the accessory organs of digestion (Ogobuiro et al., 2025). These accessory organs include the salivary glands, liver and gallbladder, and the pancreas. The teeth and tongue are also involved here, as the process of digestion begins with ingestion and mastication (chewing) of food. The alimentary canal is a continuous tube extending from the mouth to the anus and is composed of the mouth, pharynx, oesophagus, stomach, small intestine (duodenum, jejunum and ileum) and the large intestine (caecum, appendix, colon, rectum and anal canal). The GI tract is approximately 5–7 m in length, allowing for individual differences.

The digestive process consists of the transformation and chemical breakdown of food by enzymes into carbohydrates, fats and proteins, which can be absorbed by the body (Tuhin, 2025). Digestive processes involve the breakdown of food into simple, soluble molecules that can be absorbed into the blood for transport to cells. In addition to carbohydrates, proteins and fats, the body also requires nucleic acids, vitamins, minerals and fibre to properly function, repair damage and grow.

The digestive process can be subdivided into a number of functions:

- **Ingestion** of food into the GI tract, usually via the mouth.
- **Mechanical chewing** (mastication), mixing and manipulation of solid food in the mouth, by the tongue and teeth.
- **Propulsion** of ingested food through swallowing and peristalsis. Peristalsis involves the alternating contraction and relaxation of smooth muscle to aid with the mixing of digesting food and secretions, and to move them towards the anus for excretion.

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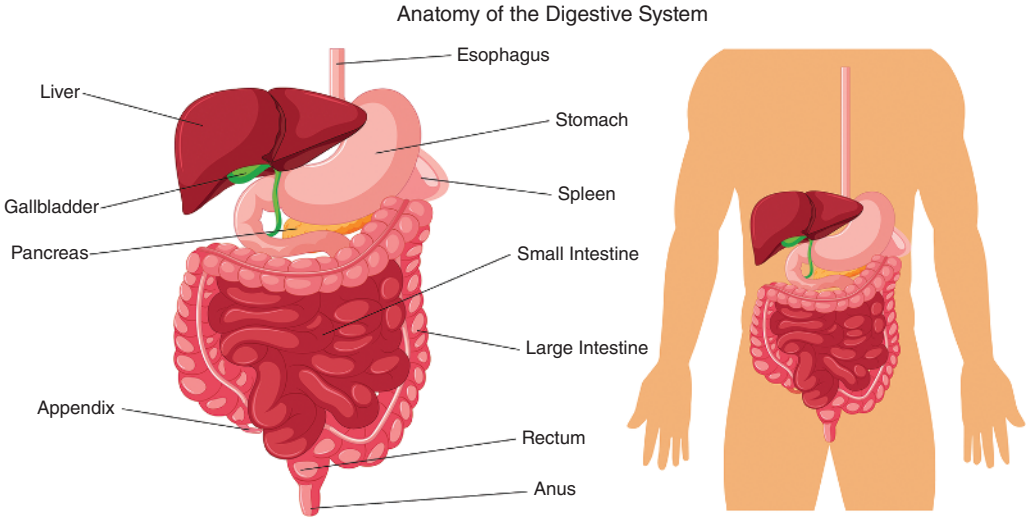
- **Digestion** through chemical and catabolic breakdown of food from complex molecules into smaller molecules that can be absorbed in the small intestine. This disassembly of molecular chains releases chemical energy which is stored as adenosine triphosphate (ATP) and heat. Heat generated helps maintain body core temperature. Digestion begins in the mouth with the chewing of food by the teeth and secretion of salivary amylase, which begins the digestion and breakdown of starch (carbohydrate).
- **Secretion** of water, acids, enzymes and buffers (bicarbonate ions) by the digestive tract and accessory organs. The GI tract introduces approximately 7 L of secretions into the lumen of the tract on a daily basis.
- **Absorption** and movement of nutrients from the GI tract into the blood stream and lymph capillaries for further circulation to cells throughout the body.
- **Excretion** (elimination or defecation) of compacted, indigestible waste (faeces).

The organs of the GI tract require a blood supply and drainage to enable normal function and distribution of absorbed nutrients from the digestive process. Oxygenated blood supply comes from the oesophageal, gastric, coeliac, hepatic and superior mesenteric arteries. Venous drainage enters the hepatic portal vein, leading to the liver, where further processing occurs before blood from the hepatic vein enters general circulation.



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1.3 BASIC CELL STRUCTURE OF THE GI TRACT

The wall of the GI tract from the lower oesophagus to the anal canal has the same basic, four-layered arrangement of tissues. The four histologic layers of the GI tract from the lumen outwards are the mucosa, submucosa, muscularis propria (externa) external and serosa/adventitia (Mayer, 2011).

1.3.1 MUCOSA

The mucosa or inner lining of the GI tract is a mucous membrane that consists of:

- Epithelium
- Lamina propria
- Muscularis mucosa

1.3.2 EPITHELIUM

The epithelium is a single layer of cells that forms a tissue barrier to prevent the entry of pathogens and toxins. It also absorbs nutrients, ions, and water.

The epithelium in the mouth, pharynx, oesophagus and anal canal is mainly stratified squamous epithelium that serves a protective function. Epithelium lining the stomach and intestines is simple columnar or glandular epithelium, which has the functions of secretion of mucus and enzymes that protect the mucosa and aid digestion, and absorption of nutrients. Simple columnar epithelium is tightly grouped to prevent leakage between cells. Epithelial cells are replaced every 5–7 days with new cells and old cells sloughing off into waste products of digestion.

The mucosa at the epithelium layer is in direct contact with the contents of the GI tract. The epithelium is highly folded to allow expansion after ingestion of food and to increase its surface area for absorption. In the small intestine, the mucosa forms villi, which are tiny hair-like structures containing blood vessels. Villi increase the surface area of the small intestine and help with the absorption of nutrients. Within the folds of the epithelium are tubular exocrine glands that secrete mucus, electrolytes, water and digestive enzymes into the lumen of the GI tract. It also houses endocrine glands, which release GI hormones such as cholecystokinin (CCK).

The lamina propria is a connective tissue layer that supports the epithelium. Within the lamina propria are blood and lymphatic vessels that transport absorbed nutrients to the tissues of the body. In addition to supporting the epithelial layer, the lamina propria binds it to the muscularis mucosa. Within the lamina propria are the majority of the cells of the mucosa-associated lymphatic tissue (MALT). MALT is present throughout the GI tract and can be found in the tonsils, small intestine, appendix and large intestine (Smith et al., 2020). MALT are prominent lymphatic nodules containing immune system cells that protect against disease. MALT constitutes approximately 50% of the body's total immunity and is responsible for approximately 70% of antibody production. The lamina propria is infiltrated with lymphocytes and lymph nodules that are collectively known as the gut-associated lymphoid tissue (GALT). GALT is part of the larger MALT. Put simply, GALT is MALT within the GI tract. It protects the GI tract wall from its resident bacterial flora and any ingested pathogens.

The muscularis mucosa is a thin layer of smooth muscle that forms the border between the mucosa and the submucosa. It is the deepest layer of the mucosa and is composed of elastic fibres oriented in different directions (outer longitudinal and inner circular layer) to maintain a constant state of agitation which helps movement of mucus from within the crypts formed by folds. The muscularis mucosa varies in thickness throughout the GI tract from 3 to 10 cells thick. It provides constant motion in the GI tract and helps the mucosa to stretch and contract, and aids the villi in movement and absorption of intestinal contents. The thin layer of muscle in the stomach and small intestine creates the many folds that increase surface area and aid digestion and absorption.

1.3.3 SUBMUCOSA

The submucosa is a connective tissue layer containing collagen and elastic fibres, which binds the mucosa to the muscularis. Within it are larger blood vessels and lymphatic vessels. The submucosal (Meissner) plexus is found in this layer (Anatomy.co.uk, 2025a). Meissener's plexus is a network of neurons that control the circular and longitudinal smooth muscles of the muscularis. They are largely responsible for controlling frequency and strength of contraction of the muscularis, and therefore GI tract motility. These neurons are also responsible for regulating the secretions from digestive glands.

1.3.4 MUSCULARIS EXTERNA

The muscularis externa in the mouth, pharynx and upper oesophagus comprises skeletal muscle or striated muscle cells that aid voluntary swallowing. This same muscle type is found within the anal canal to help with voluntary control of defecation. In the rest of the GI tract, the muscularis externa comprises two smooth muscle layers: an inner circular and an outer longitudinal muscular layer. Between these two layers is where the myenteric (Auerbach) plexus is found. This plexus is a group of ganglia (cluster of nerve cells) that run throughout the GI tract and innervate its multiple layers of smooth muscle (Shahrestani and Das, 2025). The coordinated involuntary contraction of the muscular layers via the myenteric plexus controls peristalsis which mixes food with digestive secretions and moves it along the GI tract. At various points along the GI tract are sphincters, or thickened rings of muscle, which act as valves, preventing back flow of partially digested and digested contents, thus allowing time for further digestion and absorption. The stomach contains a third muscular layer, the inner oblique, which helps with the churning of stomach contents during digestion.

1.3.5 SEROSA AND ADVENTITIA

The serosa or adventitia is the layer of the GI tract that is furthest from the lumen. If this layer is attached to surrounding tissue, it is known as adventitia. The oesophagus does not have a serosa but has a single layer of connective tissue (adventitia). Likewise, the muscularis externa of the oral cavity, pharynx and rectum have no serosa but instead are surrounded by a dense network of collagen fibres, known as adventitia, that attaches these parts of the GI tract to adjacent structures.

When this layer is adjacent to peritoneal cavity, it is called serosa. The serosa is a smooth membrane comprising a thin layer of connective tissue and a thin layer of cells that secrete serous fluid to lubricate internal structures. This lubricating fluid aids in reducing friction during movement. Serosa is connective tissue that has a surface composed of simple squamous epithelial cells (mesothelium) (Anatomy.co.uk, 2025b). The serosa is also known as visceral peritoneum, while parietal peritoneum lines the inner surfaces of the body cavity. Where visceral and parietal peritoneum are connected by sheets of serous membrane, these are known as mesenteries. Mesenteries provide a structure for blood vessels, nerves and lymphatic vessels of the digestive tract to pass through. They also offer stability to attached organs and prevent the tangling of the intestines.

The serosa covers intraperitoneal organs, while the adventitia covers retroperitoneal organs and functions to hold structures together instead of reducing friction between them.

1.4 MOUTH AND PHARYNX

The mouth forms the entrance to the digestive system. The enzymes in saliva play a role in the digestive process and the motion of swallowing, which transports the food towards the stomach. The mouth is composed of a number of parts:

- The lips
- The cheeks
- The palate
- The teeth
- Salivary glands
- The tongue
- The pharynx

The space between the inner aspect of the lips, cheeks and teeth is known as the vestibule. The space behind the teeth where food is mixed with saliva and formed into a bolus before swallowing is the oral cavity, or oral cavity proper.

1.4.1 THE LIPS

The lips form the border to the opening of the mouth. The lips consist of orbicular muscle (Orbicularis Oris) covered by skin on the outside and covered by mucous membrane on the inside. Orbicularis Oris is a complex circular muscle that is innervated by the facial nerve (CN VII), allowing the lips to close, which is important for mastication and formation of a sealed tube to aid swallowing. The lips derive their blood supply from the facial artery, the maxillary artery and the superficial temporal artery. A labial frenulum attaches the lips to the upper and lower gums (gingiva) at the midline of the maxilla.

1.4.2 THE CHEEKS

The sides of the mouth are formed by the cheek muscles of which the buccinator and masseter muscles are most important for aiding digestion through mastication. The buccinator muscle compresses food against the buccal mucosa during mastication. The masseter muscle elevates and protrudes the mandible during mastication. The masseter muscle and the region anterior to the ear contain the parotid gland that produces digestive enzymes.

1.4.3 THE PALATE

The palate forms the roof of the mouth. It is composed of hard palate (anterior) and soft palate (posterior). Its role in digestion is to aid mastication, formation of a food bolus and swallowing with the help of the tongue. The maxilla and palatine bones form the hard palate. The soft palate is muscular and joins the hard palate posteriorly before curving downwards to join the pharynx. The superior aspect of the palate forms the floor of the nasal cavities while the inferior aspect of the palate forms the roof of the oral cavity. The soft palate is comprised of muscle fibres covered by a mucus membrane of which three muscles have a functional role in swallowing (Helwany and Rathee, 2025). The levator veli palatini muscle elevates the soft palate completely blocking off the airway and nasal passages preventing food from entering the respiratory tract. Breathing ceases briefly during swallowing because the elevated soft palate closes off the airway. The palatoglossus muscle pulls the soft palate towards the tongue and initiates the act of swallowing. The tensor veli palatini muscle tenses the soft palate during swallowing, preventing the entry of food into the nasopharynx.

1.4.4 THE TEETH

Teeth arise in the alveolar bone of the mandible and maxilla. Children are born with no visible teeth. By the age of two, a set of teeth will have developed, which are usually lost by the age of 12–13 when 32 permanent teeth replace them. Teeth have a vascular and nerve supply in the centre of the tooth, commonly known as pulp. Nerve supply is via the trigeminal nerve (CN III). Surrounding the pulp is the hard dentine layer, and surrounding the dentine layer is a very hard layer of enamel.

The shape of the tooth determines the function of the tooth.

- Incisors are flat and sharp for cutting through tough foods.
- Canine teeth have sharp pointed edges for gripping and tearing food.
- Premolars and molars have flatter surfaces that allow crushing and grinding.

1.4.5 SALIVARY GLANDS

While there are many small glands lining the mouth, there are three main pairs of salivary glands. The parotid salivary glands are below and in front of the ear beneath the zygomatic arch. Saliva from the parotid gland empties into the vestibule via a duct at the second upper molar tooth. The parotid glands produce approximately 10% of the saliva when not eating; however, they can produce up to 25% of the total saliva volume when stimulated by eating.

The sublingual salivary glands are located beneath the mucous membrane on the floor of the mouth beneath the tongue. They are situated superior to the submandibular salivary glands. Ducts from sublingual glands open into the mouth on both sides of the lingual frenulum, which is the band of tissue anchoring the tongue to the floor of the mouth, stabilising it. The sublingual gland contributes approximately 5% of saliva in the oral cavity (Armstrong and Turturro, 2013). The submandibular salivary glands lie on each side of the floor of the mouth along the inner aspect of the mandible. Ducts from these glands empty into the floor of the mouth on each side of the lingual frenulum. The submandibular gland produces the most saliva (approximately 70%) in the unstimulated state (Grewal et al., 2025).

Salivation (secretion of saliva) is under autonomic control i.e. the part of the peripheral nervous system that regulates involuntary physiologic processes including digestion.

Saliva is composed of >99% water and <1% solutes including sodium, potassium, chloride, bicarbonate and phosphate. It also contains salivary amylase, an enzyme that starts the digestion of carbohydrates. The chemical digestion of carbohydrates involves the breaking down of long chains of glucose (starch) into maltose, which is a disaccharide composed of two glucose molecules. Disaccharides are further broken down to monosaccharides in the small intestine. Salivary lipase is also present in saliva and begins the breakdown of fats in the mouth. However, as salivary lipase is most efficient at a pH of 4, it works best in the more acidic environment of the stomach. Digestion of fats in the mouth is quite limited. Salivary amylase and salivary lipase are summarised in Table 1.1. saliva is essential for chewing and the formation of a food bolus for swallowing. It also dissolves some chemicals in food that enable the taste buds to taste food, which in turn enhances the secretion of more saliva to aid chewing, formation of a food bolus and swallowing. Saliva has the additional property of preventing infection through the presence and action of antibacterial enzymes such as lysozyme and immunoglobulins (IgA), which help maintain a healthy mouth.

1.4.6 THE TONGUE

It is composed of two types of voluntary muscle, **extrinsic** muscles, which are connected to the bones in the skull and **intrinsic** muscles, which are responsible for adjusting the shape and orientation of the tongue. The extrinsic muscles move food around the mouth, enabling chewing and shaping of food, before moving it to the back of the throat for swallowing (Rathee and Jain, 2025). There are four types of paired intrinsic muscles:

- Superior longitudinal
- Inferior longitudinal

Table 1.1 Enzymes Produced by Salivary Glands

Enzyme	Produced	Action
Salivary amylase	Mouth (salivary glands)	Begins process of carbohydrate/starch digestion into disaccharides
Salivary lipase	Mouth (salivary glands)	Begins digestion of fats by breaking them down into fatty acids and glycerol

- Transverse
- Vertical

The intrinsic tongue muscles operate independently, or in combination with each other, which is an important feature as it helps shape the food into a bolus before swallowing.

The tongue is anchored posteriorly to the hyoid bone, and the lingual frenulum, a thin flap of tissue, connects it to the floor of the mouth limiting its movement. The tongue is innervated by the hypoglossal cranial nerve (CN XII), which controls movement. Sensory fibres travel in the glossopharyngeal cranial nerve (CN IX) and in the facial nerve (CN VII). These nerves, along with the vagus nerve (CN X), innervate the taste buds. It also takes part in the oral phase of swallowing by moving it posteriorly to propel the food bolus towards the oesophagus, triggering the swallowing reflex.

The tongue also commences the digestion of fats in the mouth through the secretion of lingual lipase from lingual glands (von Ebner's glands) in the lamina propria of the tongue. Lingual lipase becomes activated in the acidic environment of the stomach, and therefore digestion of fats in the mouth is minimal. Lipase works mainly after swallowing and acts on dietary triglycerides to convert them into simpler fatty acids and diglycerides.

The tongue is covered with a squamous epithelium, which is continuous with the rest of the oral mucosa. Its surface has a rough texture caused by tiny extensions called papillae, some of which contain taste buds. They also help maintain contact with food, gripping it and mixing it with saliva. There are three main types of papillae:

- Fungiform (mushroom-shaped) papillae are mainly located around the tip and edges of the tongue. There are more fungiform papillae than vallate.
- Circumvallate or vallate papillae are the largest. They are visible and form an inverted V at the posterior of the tongue. There are approximately 8–10 of these.
- Filiform papillae are the smallest and most numerous, situated mainly at the anterior of the tongue (Informed Health, 2006).

1.4.7 PHARYNX

The pharynx is a common passageway for food, water and air. It consists of three parts:

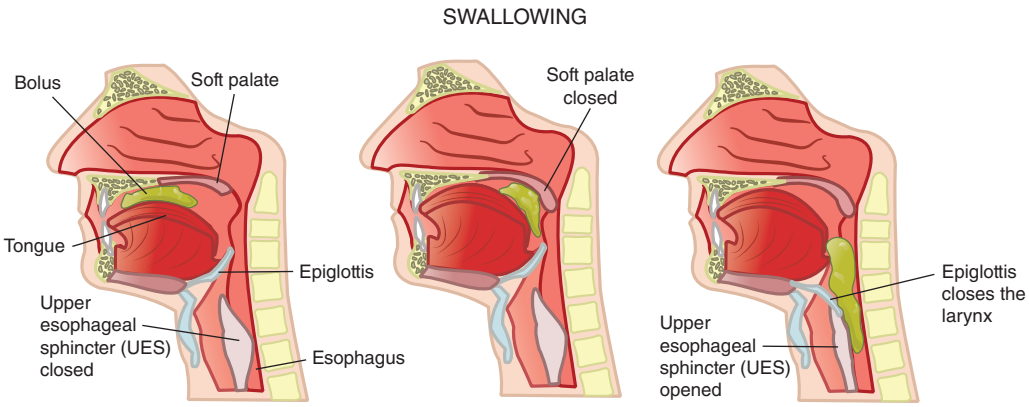
- Nasopharynx
- Oropharynx
- Laryngopharynx

The oropharynx and laryngopharynx are part of the digestive tract as they form part of the passageway for food and water transit as well as air, while the nasopharynx is part of the respiratory system. The walls of the pharynx consist of three layers. It is lined with same squamous epithelium as the rest of the oral cavity. This squamous epithelium is continuous with the mouth and the oesophagus, providing a protective lining against the swallowing of rough food boluses (mechanical abrasion), chemical erosion and pathogenic attack. The middle layer is connective tissue containing blood vessels, lymph vessels and nerves, while the outer layer is formed of involuntary muscles used in swallowing. The pharynx is surrounded by three sets of voluntary muscle that overlap each other and form the superior, middle and inferior constrictors. The circular muscle of the upper oesophagus is continuous with the inferior constrictor.

The propulsion by the tongue of a food bolus into the oropharynx initiates the process of swallowing. The bolus is propelled by the elevation and retraction of the tongue against the palate. During the swallowing process, the passages to the nasal and respiratory areas are blocked

to prevent the passage of food and water. The food bolus is propelled through the pharynx by peristalsis of the superior constrictor muscles. Peristalsis progresses through the middle and inferior constrictor muscles of the pharynx, while relaxation of the upper oesophageal sphincter allows propulsion of the bolus into the oesophagus. The entire process takes approximately one second, it is initially under voluntary control; however, once initiated it becomes an involuntary process coordinated by the swallowing centre of the brain.

The medulla oblongata region of the brain controls the process of swallowing. The voluntary movement of a food bolus towards the pharynx triggers impulses in the primary nerves involved including trigeminal (CN V), glossopharyngeal (CN IX), vagus (CN X) and hypoglossal (CN XII), the ansa cervicalis and the recurrent laryngeal nerves. Pharyngeal sensation occurs mainly via glossopharyngeal (CN IX). The upper oesophagus is innervated by the vagus nerve (CN X), while the splanchnic plexus and vagus nerve innervate the lower oesophagus (Malone and Arya, 2025).



1.5 THE OESOPHAGUS

The oesophagus is the muscular channel, beginning at the distal end of the pharynx and ending at the superior aspect of the stomach, along which the food bolus descends to the stomach from the mouth. It does not secrete digestive enzymes and does not absorb digested food molecules. The oesophagus is approximately 25 cm long and 2 cm in diameter. It is composed of skeletal muscle in the upper third, smooth muscle in the lower third, with the middle section being a combination of both muscle types. It lies posterior to the trachea. It passes through the mediastinum in the thoracic cavity, enters the peritoneal cavity through the diaphragm through the oesophageal hiatus, before emptying its contents into the stomach at the cardia via the lower oesophageal sphincter. The oesophagus has two sphincters: the upper oesophageal sphincter controls the passage of food into the oesophagus from the pharynx and prevents aspiration of oesophageal contents back into the pharynx or trachea; the lower oesophageal sphincter controls the passage of food from the oesophagus into the stomach. The sphincters relax and dilate in order to allow passage of the food bolus from the pharynx into the oesophagus, and the oesophagus into the stomach. This is especially important with the lower oesophageal sphincter in order to prevent back flow of acidic gastric contents into the oesophagus. Where the oesophagus enters the stomach at the cardia, it curves upwards, which helps reduce the back flow, or regurgitation, of acidic gastric contents into the oesophagus.

The oesophagus is lined with stratified squamous epithelium that is able to resist the harsh environment of the oesophagus such as ingested chemicals, hot and cold swallowed food and liquid, and abrasive contents in a food bolus. Mucous glands lubricate the lumen of the oesophagus forming a protective layer of mucous and preventing swallowed material from sticking to

the walls of the oesophagus during passage to the stomach. The superficial layer of the oesophagus, the adventitia, is a connective tissue of the oesophagus that merges with the connective tissue of the surrounding structures through which it passes. The adventitia attaches the oesophagus to these surrounding structures.

1.5.1 BLOOD SUPPLY OF THE OESOPHAGUS

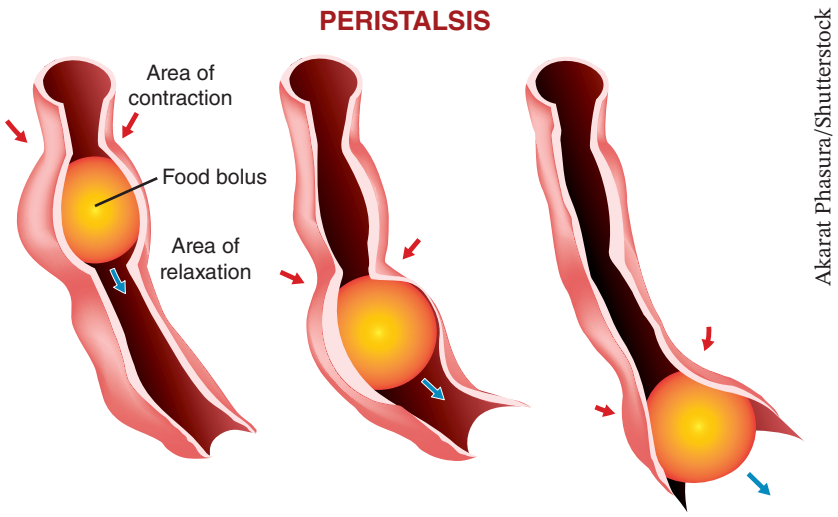
Blood supply of the oesophagus can be divided into its thoracic and abdominal sections, which receive and return blood supply by different vessels. The thoracic oesophagus receives its arterial supply from branches of the thoracic aorta and the inferior thyroid artery. Venous drainage of the thoracic oesophagus is via branches of the azygous veins and the inferior thyroid vein into the systemic circulation. The abdominal oesophagus is supplied by the left gastric branch of the coeliac artery and left inferior phrenic artery. The abdominal oesophagus has venous drainage via two routes, to the portal circulation via the left gastric vein, and to the systemic circulation via the azygous vein.

1.5.2 INNERVATION OF THE OESOPHAGUS

The oesophagus is under the involuntary control of the autonomic nervous system. A branch of the vagus nerve (the recurrent laryngeal nerve) supplies the parasympathetic component of the cervical oesophagus, while the sympathetic fibres stem from the cervical sympathetic trunk. The vagus nerve runs alongside the oesophagus and directly innervates the oesophagus. Innervation here is also via intrinsic nerves in the myenteric (Auerbach) nerve plexus located between the longitudinal and circular muscle layers, and by the submucosal plexus (Keshav, 2012).

The oesophageal plexus is an autonomic network of nerves surrounding the oesophagus that innervates the thoracic oesophagus. The parasympathetic component of the oesophageal plexus originates from the vagus nerve, while the sympathetic fibres stem from the sympathetic trunk, which runs along the neck.

Parasympathetic innervation of the abdominal oesophagus arises from the thoracic oesophageal nervous plexus, while its sympathetic component originates from the fifth to twelfth thoracic spinal nerves (T5–T12). The parasympathetic and sympathetic branches control the tone of the oesophageal sphincters, relaxation of the muscles of the oesophagus and peristalsis along the oesophagus.



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1.5.3 LYMPH DRAINAGE OF THE OESOPHAGUS

Lymph channels and lymph nodes provide the oesophagus with lymphatic drainage. The channels begin in the endothelial layer and collect into larger lymph channels running the length of the oesophagus. These channels then merge in different areas to enter into regional lymph nodes (Chaudhry and Bordoni, 2025).

1.6 THE STOMACH

The stomach is located in the left side of the abdominal cavity under the **diaphragm**. The stomach is 'J' shaped and is approximately 25 cm long. Diameter is variable along its length and is dependent on how much food it contains at any time. Its capacity is approximately 1.5 L due to its ability to expand or decrease in diameter. **Rugae**, deep folds in the mucosa, which allow for stretch, aid the ability to increase and decrease. The stomach has a number of functions when it receives food, including:

- Temporary storage for food from the oesophagus.
- Secretion of gastric acid and enzymes, which are mixed with the food to start chemical digestion.
- Regulates the rate at which **chyme** (partially digested food) enters the small intestine.
- Absorbs a small amount of water – absorbs alcohol.

On average it takes between 4 and 6 hours for the stomach to empty after a meal. Liquids and carbohydrates pass through in around four hours, proteins take longer and fats may take up to six hours. The digestion of carbohydrates (starch) and fats (triglycerides) commences in the mouth and continues in the stomach, while the digestion of proteins commences in the stomach.

The stomach is divided into a number of regions. Located near the heart is the cardiac region or cardia. This area surrounds the lower oesophageal sphincter. The fundus is lateral and superior to the cardia and is where food is stored when it initially enters the stomach. The body is the middle section and is the largest section. The lower region of the stomach is called the antrum. It contains the pylorus and is funnel-shaped towards the pyloric sphincter, or outlet to the duodenum and small intestine. The majority of digestion in the stomach is performed in the pyloric region. The pyloric sphincter determines the volume of chyme that can pass out of the stomach.

When the stomach is empty, the pyloric sphincter is relaxed and open. It contracts and closes when food enters the stomach to allow time for digestion. As muscle layers around the stomach expand and contract in different directions, they cause a churning effect, mixing food with gastric acid and enzymes which are secreted from gastric glands in the columnar epithelial layer of the stomach lining. The churning action also moves the food by peristalsis towards the pyloric sphincter. The churning of the stomach and mixing with gastric juices ensures both physical and chemical digestion.

Gastric juice is the term used for the combination of water, hydrochloric acid (HCl), pepsinogen and mucus. Approximately 1.5–2 L of gastric juice is produced daily by gastric glands, of which there are approximately 35 million. Gastrin is also produced mainly in the antrum area of the stomach. Vagal nerve fibres from the brain, communicating with the digestive system, trigger gastrin release. The vagal nerves pass information to the stomach that food has been consumed. This triggers gastric glands containing G-cells (gastrin cells) to secrete gastrin. Gastrin stimulates the secretion of HCl, which in turn activates pepsin. Gastrin secretion ceases when the stomach empties. Pepsinogen is secreted by chief cells and is the inactive

Table 1.2 Gastric Cell Types – Their Secretion and Function

Cell type	Secretion	Function
Chief cells	Pepsinogen	Begin protein digestion
Parietal cells	HCl	Break down connective tissue in meat. Activate pepsinogen. Kill pathogens
Mucous cells	Alkaline mucous	Protect stomach lining
Endocrine cells	Gastrin	Stimulate gastric gland secretion
Parietal (oxyntic) cells	Intrinsic factor	Absorption of vitamin B12

precursor to pepsin, which is the stomach's main digestive enzyme. HCl is secreted by parietal cells, which are found in the fundus, body and antrum. Parietal cells also secrete intrinsic factor and gastroferrin, which are required in the absorption of vitamin B12 and iron. Chief cells and parietal cells complement each other as HCl promotes the conversion of pepsinogen to pepsin, which then helps to break down proteins by severing the bonds between amino acids, reducing them to smaller amino acid chains. Pepsinogen relies on the interaction with HCl to convert it to pepsin. HCl does not directly digest food but breaks down the connective tissue in meat. It is a strong acid with a pH of 1.5–2. The highly acidic environment is also useful in killing pathogens that have been ingested. The digestive action of salivary amylase on carbohydrates is reduced in the stomach as the acidic environment deactivates salivary amylase. Of note, children also release rennin in the stomach to help with the digestion of milk protein.

The stomach itself needs protection from HCl and relies on mucous secreted from mucous cells (**goblet cells** and **neck cells**). A breakdown of cell type, secretion and function can be seen in Table 1.2. Secreted mucous forms a lining (1–3 mm thick) on the stomach, which protects it from the erosive effects of HCl and also from friction injury to the stomach wall as it lubricates stomach contents during the churning motion. This protective mucous layer can be broken down by substances including NSAIDS, alcohol and Aspirin. **Intrinsic factor** is also secreted in the stomach by specialised parietal cells called **oxyntic cells** and is needed for the absorption of vitamin B12, which is essential for the development of red blood cells and the normal functioning of the nervous system.

The secretion of gastric juices occurs over three phases:

- Cephalic phase
- Gastric phase
- Intestinal phase

Once gastric secretion has commenced, all three phases may be occurring simultaneously. During the cephalic phase, sight or thought of food or stimulation of the taste or smell receptors stimulates secretory activity in the stomach through the parasympathetic nervous system. Ghrelin (the hunger hormone) is a peptide hormone produced in the pancreas and released from the stomach wall when the stomach is empty. It sends a signal to the hypothalamus stimulating the excitatory primary neurons, and therefore stimulates appetite. The cerebral cortex, hypothalamus and medulla oblongata activate the facial (CN VII) and glossopharyngeal (CN IX) nerves to stimulate salivary glands to secret saliva. They also activate the vagus nerve to trigger increased secretory activity of gastric glands in the stomach to secrete gastric juice and prepare the stomach to receive food. The cephalic phase is responsible for approximately 30% of gastric secretion. When the stomach is full or satiety has been achieved, ghrelin release is inhibited and hunger is reduced.

When food arrives in the stomach, the gastric phase commences. This is the longest phase and may last three hours or more while acid and enzymes continue to breakdown food. Stretch receptors and chemoreceptors in the pylorus and duodenum are activated prompting G-cells in gastric pits to release gastrin into the circulating blood that supplies the stomach. Gastrin then activates parietal cells into secreting HCl and chief cells into secreting pepsinogen. HCl activates pepsinogen by converting it to pepsin, a potent protease that breaks up proteins into peptides. These smaller peptides are ready to be further broken down into amino acids by the action of further enzymes in the small intestine. The pH of the stomach drops and digestive activity increases. During this time, the churning motion of the stomach mixes and lubricates the gastric contents, aiding digestion and forming a thick, soupy substance called chyme. As digestion continues, the churning and peristaltic motion of the stomach moves the chyme towards the pylorus, which allows small amounts of chyme (approximately 3 mL at a time) through to the duodenum via the pyloric sphincter with each contraction. This phase accounts for approximately 60% of gastric secretions. Secretions of gastrin reduce when the acidity level of the pyloric region drops to around pH 1.5.

The third and final phase is the intestinal phase. This is a mainly inhibitory phase as it slows down gastric activity to allow the small intestine time to secrete further juices for digestion, digest chyme further and absorb the products of digestion. During this phase, the hormones secretin, gastric inhibitory peptide (GIP) and CCK are released in the duodenum and jejunum as chyme enters the small intestine. These hormones are secreted by endocrine cells in the intestinal mucosa with the purpose of inhibiting gastric emptying and gastric juice secretion, allowing small volumes of chyme to enter the small intestine and mix with bile and pancreatic juice, changing the acidity level to prevent harm to the small intestine. This phase is responsible for approximately 10% of gastric juice secretion.

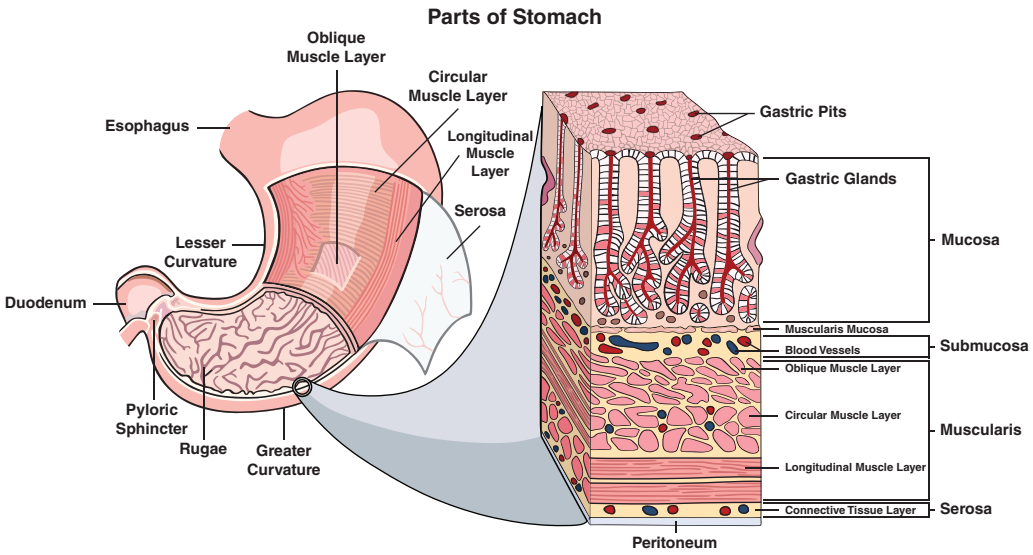
1.6.1 INNERVATION OF THE STOMACH

Nervous stimulation of the stomach is via the parasympathetic nervous system, specifically the vagus nerve. Once the vagus nerve is stimulated, the stomach increases its churning action and secretion from gastric glands increases. Sympathetic innervation is via the splanchnic nerve.

1.6.2 BLOOD SUPPLY TO THE STOMACH

The stomach receives its arterial blood supply via the left gastric artery (stemming from the coeliac artery), the right gastric artery and the gastroomental artery (branching into gastroepiploic arteries). Venous drainage is via left and right gastric veins, short gastric veins and left and right gastroomental veins. These then drain into the portal vein.

The stomach is primarily a vessel for storage and breaking down of ingested food to a more liquid state (chyme) and propelling it via the pyloric sphincter into the duodenum for further digestion and absorption in the small intestine. The stomach's regulatory function is to limit the volume of chyme that enters the duodenum with each contraction, enabling time for further digestion and absorption in the small intestine. The stomach has the ability to absorb a small amount of nutrients, though its cellular structure, impermeability and thick mucous layer restrict any great volume of absorption. Further, the soupy chyme mixture is not broken down sufficiently in the stomach to permit absorption of carbohydrate, lipid and protein molecules. These actions occur mainly in the small intestine with the help of further digestive juices introduced by the pancreas, liver and gallbladder (**accessory organs** of digestion).



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1.7 THE PANCREAS

The pancreas is a complex organ with critical roles in digestion and metabolism. It is a gland measuring approximately 15 cm in length and is 3–6 cm wide (variable width throughout). The pancreas is located in the abdominal cavity and is primarily responsible for synthesizing and secreting digestive enzymes and hormones that regulate metabolism.

Its tissue has a lobular structure, composed of acini (clusters of exocrine cells) and islets (clusters of endocrine cells). It plays an essential role in both the digestive and endocrine systems.

The walls of acini are made up from secretory cells, which drain into tiny ducts. These tiny ducts merge to form small pancreatic ducts, which in turn drain into the main pancreatic duct, which extends along the length of the pancreas. The main pancreatic duct merges with the common bile duct (CBD) at the hepatopancreatic ampula and opens into the duodenum via the ampulla of Vater, which is controlled by the sphincter of Oddi. A smaller accessory duct drains the superior part of the head, opening separately into the duodenum. Columnar epithelial cells that line the pancreatic ducts produce a bicarbonate secretion, making the pancreatic juice alkaline, which is essential for neutralising the acidic chyme entering the duodenum and activating digestive enzymes.

The pancreas is a retroperitoneal organ, meaning it lies behind the peritoneum. It has a unique structure, playing both exocrine and endocrine roles, and it is divided into several parts:

Head: The broadest part of the pancreas, the head lies within the curve of the duodenum, the first part of the small intestine. The head of the pancreas is connected to the duodenum by connective tissue. The CBD runs through the head, allowing for the secretion of bile into the small intestine. The uncinate process is a projection from the lower part of the head and extends medially to lie beneath the body of the pancreas. It lies posterior to the superior mesenteric vessels.

Neck: This narrow section connects the head to the body of the pancreas. It overlies the superior mesenteric blood vessels, which form a groove in its posterior aspect. It serves as a transitional area and is relatively short.

Body: The central part of the pancreas, the body, extends towards the left side of the abdomen lying behind the stomach and to the left of the superior mesenteric vessels. This is where the majority of the pancreatic tissue is located, containing clusters of cells that perform both endocrine and exocrine functions.

Tail: The left end of the pancreas, the tail, extends across the epigastrium towards the spleen. This section is involved in the production of certain hormones and is the only part of the pancreas that is intraperitoneal.

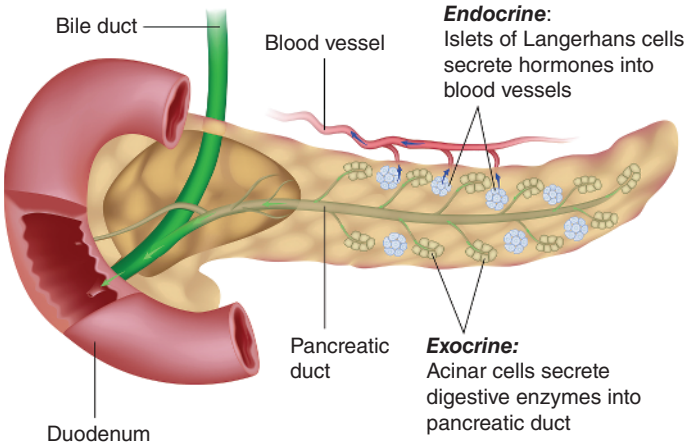
The pancreas consists of two main types of cells:

Exocrine cells: These cells make up approximately 80% of pancreatic mass. The majority of the pancreas is arranged into lobules formed from functional units called acini. Acinar cells have a triangular cross section and are arranged in a spherical pattern, with their apical (pointed) surface towards the centre. Acinar cells are specialised for secretion and secrete pancreatic enzymes and fluid from the apical surface into the ducts, which merge and drain into the main pancreatic duct. These cells produce digestive enzymes, such as amylase (breaks down carbohydrates), lipase (breaks down fats) and proteases (break down proteins). These enzymes are secreted into the pancreatic duct, which opens into to the duodenum. The pancreas secretes approximately 1.5 L of alkaline bicarbonate-rich fluid daily, which act as buffers to neutralise stomach acid creating optimal conditions for pancreatic enzymes to continue the digestive process.

Endocrine cells: Scattered throughout the pancreas are the islets of Langerhans, which contain different types of hormone-producing cells:

- **Alpha cells:** Produce glucagon, which raises blood glucose levels.
- **Beta cells:** Produce insulin, which lowers blood glucose levels.
- **Delta cells:** Produce somatostatin, which regulates the endocrine system and inhibits the secretion of other hormones.

Unlike the exocrine cells of the pancreas, which secrete into ducts, the endocrine cells secrete directly into the bloodstream via a network of capillaries.



1.7.1 PHYSIOLOGY OF THE PANCREAS

As stated earlier, the pancreas has dual functions: exocrine and endocrine. The exocrine function of the pancreas involves the production and secretion of digestive enzymes. The acinar cells secrete digestive enzymes in inactive forms (pro-enzymes or zymogens) to prevent self-digestion. For example, trypsinogen is an inactive form of trypsin.

Pancreatic enzymes include:

- Trypsinogen
- Chymotrypsinogen
- Procarboxypeptidase A and B
- Pro-elastase
- Phospholipase A
- Pancreatic lipase
- Pancreatic amylase
- Ribonuclease
- Deoxyribonuclease

When food enters the duodenum, the enzyme **enteropeptidase** activates trypsinogen to trypsin. Trypsin then activates other zymogens.

Pancreatic lipase is the most active lipase in the GI tract. As with salivary and gastric lipase, pancreatic lipase acts on fats, breaking down triglyceride fats into fatty acids and glycerol. Bile salts break down or emulsify larger fat particles, allowing pancreatic lipase to work more effectively. To aid the work of pancreatic lipase, the pancreas also secretes the protein co-enzyme colipase, which works with pancreatic lipase to breakdown fats in the small intestine.

Pancreatic amylase takes over the digestion of carbohydrates, which was stopped by the acid environment of the stomach. Initial carbohydrate digestion began with salivary amylase in the mouth but stopped due to the high stomach pH. Pancreatic amylase continues carbohydrate digestion in the small intestine by breaking down the bonds between glucose molecules in polysaccharides and breaking down starch into maltose, a disaccharide. Like salivary amylase, pancreatic amylase does not work well in an acid environment, preferring a neutral to alkaline environment to work effectively.

Protein digestion starts in the stomach, where pepsin acts to break down the peptide bonds of larger molecules, breaking down proteins into smaller amino acid chains known as polypeptides. The next stage of protein digestion takes place in the small intestine and relies on pancreatic proteases including Trypsin, Chymotrypsin, Carboxypeptidase and Elastase. Trypsin is the major protease present in pancreatic juice. It is initially secreted as trypsinogen, an inactive pro-enzyme (zymogen), so as to avoid autodigestion and damage to the pancreatic acini and ducts. Trypsinogen is converted to trypsin in the duodenum by the enzyme enteropeptidase (enterokinase), which is produced by the mucosal cells of the duodenum and jejunum. Trypsin then catalyses the activation of the other pancreatic zymogens into their active forms: chymotrypsin, carboxypeptidase and elastase.

Carboxypeptidase catalyses the removal of single amino acids from the ends of protein and polypeptide molecules, gradually reducing their length. Trypsin, chymotrypsin and elastase attack the peptide bonds in the central portions of proteins and polypeptides. This results in the generation of smaller chains of amino acids called peptides, which are then digested in the jejunum and ileum by intestinal peptidase.

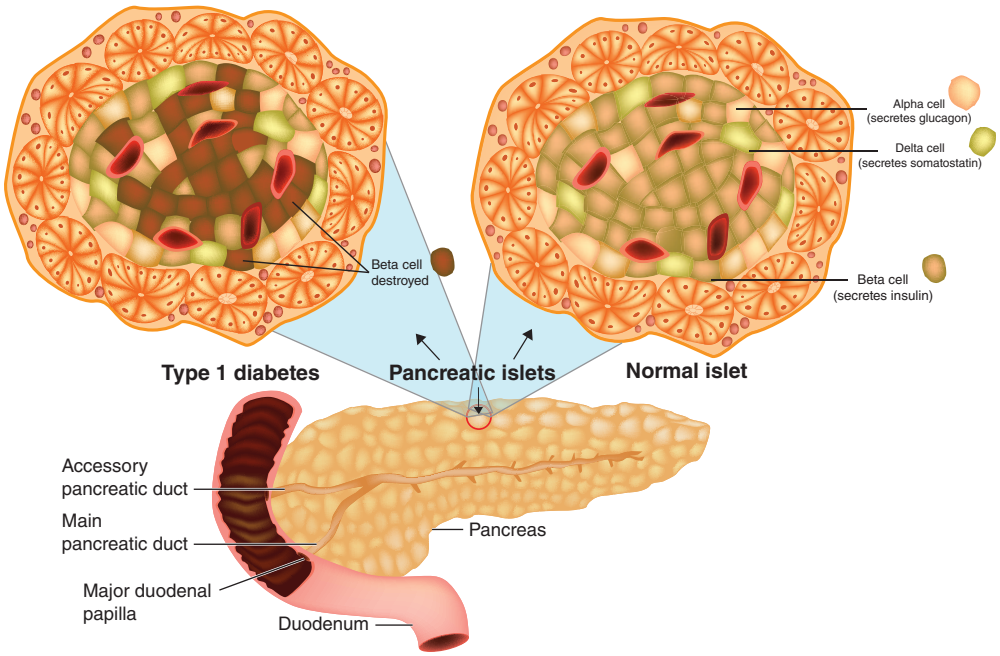
Pancreatic juices contain enzymes that break down DNA and RNA in ingested food into their building blocks or nucleotides. These enzymes are the pancreatic nucleases DNase and RNase. This allows for the recycling of nucleotides and their subsequent use as building blocks for DNA synthesis and for RNA during the process of transcription and protein synthesis.

In addition to enzymes, the pancreas secretes bicarbonate to neutralize the acidic chyme from the stomach, creating an optimal pH for enzyme activity. Neutralisation of stomach acid also plays a protective role for the rest of the GI tract as it prevents autodigestion and chemical damage. Pancreatic secretion of digestive enzymes is stimulated by the hormone CCK, released in the duodenum by the intestinal mucosa in response to fatty acids and amino acids.

The endocrine function involves the regulation of blood glucose levels through the secretion of hormones:

- Insulin, produced by beta cells, facilitates the uptake of glucose by cells, and promoting its conversion to glycogen in the liver and muscle for storage.
- Glucagon, released by alpha cells, raises blood glucose levels by promoting glycogenolysis (breakdown of glycogen) and gluconeogenesis (production of glucose from non-carbohydrate sources) in the liver.
- Somatostatin, produced by delta cells, inhibits the release of both insulin and glucagon, playing a role in regulating the endocrine functions of the pancreas.
- Pancreatic polypeptide is a hormone released by PP cells in the islets and is thought to regulate both the exocrine and endocrine activities of the pancreas.

The secretion of pancreatic hormones is tightly regulated by blood glucose levels. High blood glucose levels stimulate insulin release, while low levels promote glucagon secretion. This feedback mechanism helps maintain homeostasis. In addition, neural and hormonal signals coordinate pancreatic secretion with digestion. For example, the sight or smell of food can trigger pancreatic enzyme secretion even before food enters the stomach.



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1.7.2 PANCREATIC BLOOD SUPPLY

The pancreas receives its blood supply primarily from the **pancreaticoduodenal** arteries, which branch from the **coeliac** trunk and **superior mesenteric** artery (SMA). Venous blood drains into the **hepatic portal** vein, which carries blood to the liver.

The pancreas is highly vascularized with blood from several major arteries. From the coeliac trunk, the **splenic** artery runs along the posterior surface of the pancreas towards the tail. The **dorsal pancreatic** artery and the **greater pancreatic** artery branch off the splenic artery to deliver blood supply to other parts of the pancreas. These arteries travel largely on posterior surfaces of the pancreas while a branch of the dorsal artery runs laterally along the inferior edge of the body of the pancreas.

Also originating with the coeliac trunk and the **gastroduodenal** artery, the **superior pancreaticoduodena**l artery serves the head of the pancreas. It divides into **anterior** and **posterior superior pancreaticoduodenal** arteries to serve anterior and posterior regions respectively.

The **inferior pancreaticoduodenal** artery, a branch of the SMA, also serves the head of the pancreas. It too divides into anterior and posterior branches, which run along the uncinate process towards the head and typically anastomose with the superior pancreaticoduodenal arterial branches.

The pancreas drains blood into the portal circulation. Blood from the body and tail typically drains through small veins into the splenic vein. Blood from the neck drains directly into the portal vein.

Blood from the posterior head drains into the portal vein directly. From the anterior superior portion of the head, blood drains into the anterior superior pancreaticoduodenal vein, which merges with either the right gastric or right gastroepiploic vein, and from there to the superior mesenteric vein (SMV). Inferior portions of the head and the uncinate process may drain through inferior pancreaticoduodenal veins into the SMV (Standring, 2016).

1.7.3 PANCREATIC INNERVATION

Innervation of the pancreas includes the autonomic nervous system (sympathetic and parasympathetic), extrinsic sensory innervation (visceral afferents) and enteric efferent innervation. The parasympathetic system, primarily through the vagus nerve, stimulates pancreatic secretion, while the sympathetic system inhibits these processes.

The vagus nerve (CN X) provides parasympathetic innervation to the pancreas with postganglionic parasympathetic neurons. Parasympathetic innervation is associated with glandular secretion. Sympathetic innervation is derived from the sympathetic chain or the aortic plexus. These efferents are supplied by postganglionic neurons from the coeliac plexus. Preganglionic sympathetic fibres originate in the T6–T12 spinal cord levels and travel in the thoracic splanchnic nerves (Standring, 2016). Sympathetic innervation is associated primarily with vascular tone.

Visceral afferent nerves from the pancreas travel back to the CNS along the thoracic splanchnic nerves carrying pain sensation, or via the vagus nerve carrying other sensory information. The enteric system from the stomach and duodenum sends efferent fibres to the pancreas (Standring, 2016).

1.7.4 PANCREATIC LYMPHATIC DRAINAGE

Lymphatic drainage from the pancreas largely parallels the arterial supply. Lymph from the tail and body drains through nodes along the splenic artery towards coeliac and preaortic nodes. Lymph from the head, neck and uncinate process drain via pancreaticoduodenal nodes and hepatic nodes associated with the pancreaticoduodenal and hepatic arteries.

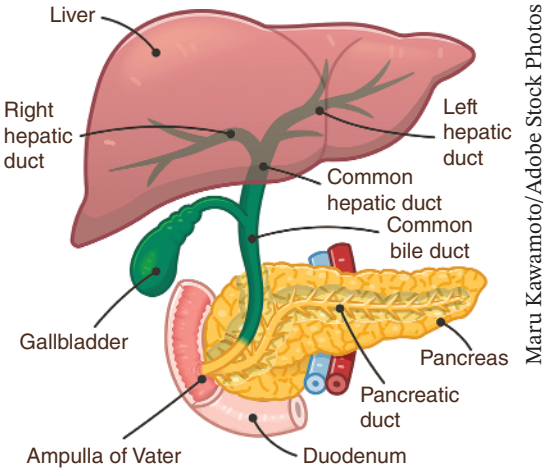
1.8 THE LIVER

The liver is the largest organ in the body and is located in the right hypochondriac region of the abdomen beneath the diaphragm, protected by the ribs. It is bordered on the left by the stomach and spleen, on the right by the gallbladder and the right kidney and on the anterior side by the diaphragm. The liver has a distinct wedge-like or triangular shape. It is divided by the falciform ligament into two main lobes: the right lobe, which is significantly larger, and the left lobe, which is smaller and located closer to the midline. There are two further accessory lobes that arise from the right lobe, which are located on the visceral surface of liver. The **Caudate lobe** is located on the upper aspect of the visceral surface. The **Quadrate lobe** is located on the lower aspect of the visceral surface. It lies between the gallbladder and a fossa produced by the ligamentum teres (a remnant of the foetal umbilical vein). The falciform ligament is a fold of peritoneum that attaches the liver to the anterior abdominal wall and the diaphragm. It is a thin, triangular structure that extends from the anterior surface of the liver to the under surface of the diaphragm and the linea alba (a fibrous line running down the centre of the abdomen, separating the rectus abdominis muscles) of the anterior abdominal wall. The falciform ligament divides the liver into right and left lobes and contains the ligamentum teres hepatis (round ligament of the liver), which is a remnant of the umbilical vein from foetal development. A fibrous layer, known as Glisson's capsule, covers the liver.

The Couinaud classification of liver anatomy divides the liver into eight functionally independent segments with each segment containing its own portal triad, bile duct and vascular structure (Smithius et al, 2006) Using the Couinaud classification, these segments are:

- Caudate lobe (Segment I)
- Left superior lateral segment (Segment II)
- Left inferior lateral segment (Segment III)
- Left medial segment (Segment IV – divided into Segments IVa and IVb)
- Right inferior anterior segment (Segment V)
- Right inferior posterior segment (Segment VI)
- Right superior posterior segment (Segment VII)
- Right superior anterior segment (Segment VIII)

In the centre of each segment there is a branch of the portal vein, hepatic artery and bile duct. In the periphery of each segment there is vascular outflow through the hepatic veins. The numbering of the segments is in a clockwise manner. Segment I (the caudate lobe) is located posteriorly and cannot be seen from a frontal view.



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1.8.1 VASCULAR SUPPLY

The liver receives blood from two main sources, the hepatic artery and the portal vein. The hepatic artery is a branch of the coeliac trunk of the abdominal aorta that supplies oxygen-rich blood to the liver. The hepatic artery accounts for about 25% of the blood flow to the liver. The portal vein is formed by the union of superior mesenteric and splenic veins on the posterior aspect of the neck of the liver (Mitra and Metcalf, 2009). This vein carries nutrient-rich blood from the GI tract and spleen to the liver, making up about 75% of the liver's blood supply. The portal vein is crucial because it delivers substances absorbed from the intestines, including toxins, drugs and nutrients, allowing the liver to process and detoxify these substances.

The liver also produces bile, which plays a major role in digestion, specifically the emulsification of fats. Bile is an aqueous solution produced and secreted by the liver consisting mainly of bile salts, phospholipids, cholesterol, conjugated bilirubin, electrolytes and water (Hundt et al., 2025). Bile is produced by hepatocytes, the functional cells of the liver. It travels from hepatocytes via bile canaliculi (tiny bile channels) before merging with a network of bile ducts that converge into the common hepatic duct. The liver can produce between 400 and 800 mL of bile per day. From the liver, bile either flows into the gallbladder for storage or into the duodenum via the CBD to assist in digestion. Bile is released into the duodenum in response to the presence of CCK. Through emulsification, bile acids break down lipid droplets into smaller droplets, increasing the surface area for digestive enzymes to continue digestion. Bile salts also allow the products of lipid digestion to be transported as micelles, spherical aggregates of fatty acids and cholesterol that aid in lipid absorption across the intestinal lining. Without bile salts, the fat-soluble vitamins (A, D, E, K) cannot be absorbed (Hundt et al., 2025).

The lobes of the liver are made up of functional units called lobules, which are hexagonal in shape and formed by cells known as hepatocytes. Hepatocytes are involved in a wide variety of metabolic processes, including the synthesis of proteins like albumin and clotting factors, detoxification of harmful substances and the storage and release of glucose as glycogen. Hepatocytes are specialized epithelial cells responsible for most of the liver's functions. These cells are arranged in plates or cords that radiate out from a central vein. In between columns of hepatocytes are sinusoids which are specialized, leaky capillaries. Hepatocytes are bathed in blood within the sinusoids. Sinusoids allow for easy exchange of substances between the blood and the hepatocytes. These blood vessels are lined with endothelial cells, and in the spaces between endothelial cells are Kupffer cells – macrophages that make up 80–90% of all macrophages in the human body (Basit et al., 2025). Kupffer cells play an important role in immune defence by filtering bacteria, dead cells and other pathogens from the blood e.g. inhibiting the growth of viral infections in the liver, particularly Hepatitis B and C infections. The blood flows through the network of sinusoids before being collected by central veins and ultimately returned to the inferior vena cava for circulation back to the heart.

The liver's physiological functions are many, ranging from metabolic regulation to detoxification and storage. The following are some of the liver's primary roles.

1.8.2 METABOLISM OF NUTRIENTS

- **Carbohydrate metabolism:** The liver plays a central role in regulating blood glucose levels. It can store glucose in the form of glycogen through glycogenesis and release glucose through glycogenolysis when blood glucose levels drop. Additionally, the liver can synthesize glucose from non-carbohydrate sources via gluconeogenesis.
- **Fat metabolism:** The liver is involved in both the synthesis and breakdown of fats. It produces lipoproteins, such as low-density lipoprotein (LDL) and high-density lipoprotein (HDL), which are involved in transporting lipids throughout the body. The liver also synthesizes cholesterol, which is vital for cell membrane structure and hormone production.

- **Protein metabolism:** The liver synthesizes many proteins essential for bodily function, including albumin (the most abundant protein in plasma) and clotting factors (e.g. fibrinogen, prothrombin). It also helps break down amino acids and convert them into other molecules or remove nitrogen from amino acids, which is excreted as urea in the urine.
- **Detoxification:** The liver is a major detoxification organ, processing substances that are potentially harmful to the body. It filters out toxins from the blood, including alcohol, drugs and metabolic waste products. Some drugs are largely inactivated by the liver through 'first pass metabolism', where they are absorbed after ingestion, travel in blood to the liver and are metabolised to a therapeutic level that is greatly reduced and may no longer have the desired therapeutic effect. Hepatocytes use enzymes like cytochrome P450 to metabolize these substances into more water-soluble compounds, making them easier to excrete through urine or bile. For instance, ammonia, a byproduct of protein metabolism, is converted into urea, which is then excreted by the kidneys.
- **Glycogen Storage:** The liver stores glucose in the form of glycogen, which can be quickly mobilized during periods of fasting or exercise to maintain blood glucose levels.
- **Vitamin and mineral storage:** The liver stores vitamins and minerals, including vitamin A, vitamin D, vitamin B12 and iron, which can be released into the bloodstream when needed.

1.8.3 BILE PRODUCTION AND DIGESTION

The liver produces bile, a digestive fluid that is essential for the emulsification and absorption of fats in the small intestine. Bile contains bile salts, which aid in breaking down large fat molecules into smaller ones, making them easier to digest by enzymes. The liver continuously produces bile, which may be stored in the gallbladder and concentrated it until it is needed during digestion.

1.8.4 IMMUNE FUNCTION

The liver has an important role in immune function through the actions of its resident Kupffer cells. These cells act as part of the **reticuloendothelial system** and help to filter out pathogens and dead cells from the blood. Additionally, the liver produces proteins that are involved in the body's **acute-phase immune response** to infection or injury.

The liver is a multifaceted organ that is integral to a wide range of physiological processes necessary for survival. It plays a vital role in metabolism, detoxification, bile production, protein synthesis and immune defence.

1.9 THE GALLBLADDER

The gallbladder is a small, intraperitoneal, pear-shaped organ located beneath the liver, playing a critical role in the digestive system. Its primary function is to store and concentrate bile, a fluid produced by the liver that aids in the digestion and absorption of fats. It is situated in the right upper quadrant of the abdomen (right hypochondriac region), nestled in a small depression on the liver's inferior surface. It is approximately 7–10 cm long and can hold approximately 30–50 mL of bile. There are four main structural parts of the gallbladder:

- **Fundus:** The rounded, distal part of the gallbladder that projects out from the liver.
- **Body:** The main, central part of the gallbladder, where bile is stored. It connects the fundus to the neck.

- **Neck:** The narrowest part of the gallbladder, leading into the cystic duct. The cystic duct connects the gallbladder to the CBD, which carries bile to the duodenum. It contains a mucosal fold, known as Hartmann's Pouch, which is a common location for gallstones to become lodged, causing cholestasis.
- **Cystic duct:** This duct transports bile between the gallbladder and the CBD. The cystic duct merges with the common hepatic duct from the liver to form the CBD, which empties bile into the small intestine.

The gallbladder is composed of three distinct layers:

- **Mucosa:** The innermost layer, lined with simple columnar epithelial cells that absorb water and concentrate bile. The luminal surface of the gallbladder is folded into rugae and has a honeycomb appearance. When the gallbladder becomes distended the rugae will smooth out and disappear. There is no submucosal layer in the gallbladder.
- **Muscularis:** This is a layer of smooth muscle that contracts to expel bile into the cystic duct when needed. These muscle fibres possess CCK receptors that respond to CCK released from cells of the duodenum in response to the presence of fats and proteins in the intestines. This results in concentrated bile from the gallbladder being pumped into the cystic duct and transported to the duodenum via the CBD.
- **Serosa:** The outer layer, which provides structural support.

1.9.1 GALLBLADDER BLOOD SUPPLY

The blood supply to the gallbladder primarily comes from the cystic artery, a branch of the right hepatic artery. Anatomical variants of this supply are not uncommon and have implications for surgery such as cholecystectomy. Venous drainage occurs via the cystic vein, which drains into the portal vein.

1.9.2 GALLBLADDER INNERVATION

The gallbladder is innervated by the autonomic nervous system. The vagus nerve (parasympathetic) stimulates gallbladder contraction, while sympathetic fibres of the coeliac plexus inhibit its activity. This neural control helps coordinate gallbladder function with digestion.

1.9.3 GALLBLADDER LYMPH DRAINAGE

Cystic lymph nodes are situated at the gallbladder neck. These nodes subsequently drain into the hepatic lymph nodes and then the coeliac lymph nodes.

The primary functions of the gallbladder are bile storage, concentration and secretion. Bile is produced by the liver and contains bile salts, bilirubin, cholesterol and electrolytes. The gallbladder stores bile between meals and when it is not needed for digestion, it is concentrated by the gallbladder through the absorption of water and electrolytes, resulting in a potent solution that effectively emulsifies fats. When food enters the duodenum, particularly fatty foods, it stimulates the release of the hormone CCK from the intestinal mucosa. CCK then stimulates the smooth muscle in the gallbladder, causing it to contract and expel concentrated bile through the cystic duct into the CBD and subsequently into the duodenum. CCK also relaxes the sphincter of Oddi, a muscular valve at the entrance of the duodenum, allowing bile to flow freely into the small intestine.

The presence of bile in the duodenum facilitates the digestion and absorption of dietary fats. Bile salts emulsify fats, increasing their surface area for enzymatic action by pancreatic lipase. Additionally, bile salts help form micelles (a spherical aggregation of molecules), which transport fatty acids and monoglycerides to the intestinal epithelial cells for absorption.

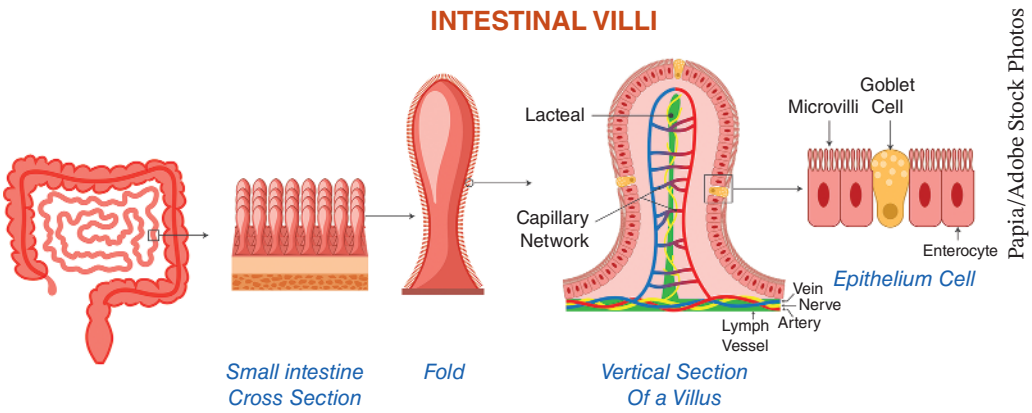
The gallbladder's functions are finely regulated by hormonal and neural mechanisms. The primary hormone involved is CCK, which responds to fatty acids and amino acids in the duodenum. Other hormones, such as secretin, can stimulate bile production by the liver and increase the bicarbonate content of bile, enhancing its alkalinity in response to the presence of acid in the duodenum. Neural regulation through the vagus nerve provides a rapid response to the presence of food, coordinating the gallbladder's contraction with the digestive process.

1.10 THE SMALL INTESTINE

The small intestine is the longest part of the digestive system and has a number of physiological functions including:

- Digestion
- Nutrient absorption
- Water absorption
- Waste excretion
- Immune function
- Hormone production
- Motility

The secretory and absorptive functions of the small intestine require a rich blood supply and drainage system. The small intestine is approximately 2.5 cm in diameter and 5.5–6 m (20 feet) long and is comprised of three parts: the duodenum, jejunum and ileum. The jejunum and ileum are more mobile than the duodenum because they are attached to a suspensory mesentery. The small intestine starts at the pyloroduodenal junction, where the pylorus meets the duodenum, and it ends at the ileocaecal junction, where the terminal ileum meets the caecum. The mucosa of the small intestine has a large surface area to enable absorption of nutrients from digested food. The surface area is greatly increased through the circular folding (plicae circulares) of the small intestine and the many villi and microvilli that line the surface throughout the length of the small intestine. Enterocytes are columnar epithelial cells that are bound to their neighbouring cells at 'tight junctions'. Their cell membrane possesses numerous microvilli (estimated at 3000–7000 per cell in the small intestine and fewer in the large intestine). These microvilli greatly increase the surface area enabling absorption of nutrients (Granger et al., 1985). The presence of microvilli on the enterocytes creates the appearance of a brush border. Food travels through the digestive tract through the process of peristalsis and segmentation. Peristalsis slows down in the small intestine to allow for segmentation to mix chyme with digestive juices in order to break it down further to allow absorption. Segmentation is the process where smooth muscle in the small intestines contract, moving food backwards and forwards in a churning motion, mixing it with digestive juices and breaking it down further to enable absorption. Segmentation occurs at a greater rate in the duodenum (12 times/minute), slowing in the ileum (8 times/minute). Peristalsis then increases again in the large intestine.



1.10.1 DUODENUM

The first part of the small intestine is the duodenum, starting at the pylorus of the stomach and ending at the **duodenojejunal flexure**. It curves around the head of the pancreas. The duodenum is roughly C-shaped and is the shortest (25–30 cm), widest and least mobile part of the small intestine. It is retroperitoneal and does not have a mesentery, which makes it immobile (Mahadevan, 2020). Although it is a short anatomical structure, it comprises four regions:

- Superior region (D1) – this short segment of approximately 2–3 cm is also known as the duodenal bulb. It is a continuation of the pyloric sphincter and is attached to the liver by the hepatoduodenal ligament.
- Descending region (D2) – extends downwards from the superior duodenal flexure into the abdominal cavity. Midway down this segment is the major duodenal papilla, or ampulla of Vater, where secretions from the gallbladder and pancreas merge at the hepatopancreatic ampulla and enter the duodenum. The duodenal papilla is surrounded by a ring of smooth muscle, the hepatopancreatic sphincter, or sphincter of Oddi, which regulates the release of bile and pancreatic juices into the duodenum to continue the work of digestion.
- Horizontal/transverse region (D3) – this is the longest section of the duodenum at approximately 10 cm. It commences at the inferior duodenal flexure, passing the vena cava, abdominal aorta and vertebral column anteriorly.
- Ascending region (D4) – passes superiorly until it reaches the inferior border of the body of the pancreas. It then curves anteriorly and terminates at the duodenojejunal flexure, where it joins the jejunum. The duodenojejunal flexure is surrounded by a peritoneal fold containing muscle fibres known as the ligament of Treitz, which is the suspensory muscle of the duodenum (Radiopaedia, 2024).

The walls of the duodenum comprise the same layers as the rest of the intestinal wall (from the lumen outwards):

- Mucosal layer with epithelial lining
- Muscularis mucosae
- Submucosa including Brunner's glands
- Circular muscle layer
- Longitudinal muscle layer
- Adventitia or serosa

The mucosa has a simple columnar epithelium that is invaginated to form the crypts of Lieberkühn and evaginated to form finger-like projections called villi (Amerongen, 2018). The submucosa and mucosa of the small intestine are thrown into circular folds, the plicae circulares (valves of Kerkring), and while they are present in the duodenum, they are most prominent in the jejunum. These are permanent folds that do not disappear when the lumen is full, and together with mucosal villi they increase the surface area and slow the passage of chyme through the small intestine, increasing time for digestion and absorption. Each villus has an arteriole, a venule and a lymphatic channel called a lacteal supply. This allows for enhanced intestinal absorption of nutrients.

The surface of each columnar epithelial cell has tiny projections called microvilli, which form the brush border where digestive enzymes work. The microvilli play an important role in the digestion and absorption of intestinal contents by increasing the surface area for absorption. They also secrete the enzymes disaccharidase and peptidase that hydrolyse disaccharides and polypeptides to monosaccharides and dipeptides to amino acids. The epithelial cells are sloughed off and replaced every four to seven days, providing a source of endogenous protein.

When chyme is released into the duodenum via the pyloric sphincter, the increased level of acidity stimulates the release of hormones including, secretin, CCK, gastric inhibitory polypeptide (GIP) and vasoactive intestinal peptide (VIP). These hormones play an important role in neutralising acidity, protecting the small intestine, inhibiting gastric emptying, prompting release of bile and regulating pancreatic juice (see Table 1.3).

The main function of the duodenum is continued chemical digestion of semi-digested food (chyme) received from the stomach. The absorptive function of the small intestine is mainly performed in the jejunum and ileum, where there is a more dense population of longer villi. Digestive juices are received into the duodenum from the liver, gallbladder and pancreas when CCK signals the sphincter of Oddi to open. The duodenal mucosa contains many mucus producing goblet cells and Brunner's glands that secrete an alkaline fluid containing mucin and bicarbonate ions, which protect the mucosa from the acidic stomach contents entering the duodenum. This mucus has the dual function of protecting the duodenum from autodigestion and lubricating the duodenum to allow the passage of chyme.

Table 1.3 Hormone Secretion in the Duodenum

Hormone	Secreted by	Action
Cholecystokinin (CCK)	Duodenum, jejunum	• Inhibits gastric emptying • Stimulates gallbladder contraction • Stimulate release of pancreatic enzymes • Relaxes Sphincter of Oddi allowing pancreatic juices and bile to enter duodenum • Controls of satiety (Inducing/reducing)
Secretin	Duodenum, jejunum	• Stimulates secretion of bicarbonate from pancreas to neutralise chyme • Inhibits gastrin and gastric acid secretion
Gastric inhibitory peptide (GIP)	Duodenum, jejunum	• Reduces gastric acid secretion • Reduces intestinal motility • Stimulates insulin release
Vasoactive intestinal peptide (VIP)	Enteric nerves	• Increases water and electrolyte secretion from pancreas and gut • Releases smooth muscle in the gut

1.10.2 JEJUNUM

The jejunum continues directly from the duodenum at the duodenojejunal flexure and continues to the ileum, where there is no clearly defined border. It measures approximately 2.5–3 m long. The jejunum and the ileum are the main absorptive sections of the small intestine. Unlike the duodenum, the jejunum does not have Brunner's glands, and unlike the ileum, the jejunum does not have Peyer's patches. Like the duodenum and ileum, villi, microvilli and plicae circulares are present, though the villi are longer in the jejunum at approximately 1–1.6 mm in length compared to approximately 0.5 mm in the duodenum, and there are slight anatomical differences between these structures in the jejunum and the ileum. Longer villi in the jejunum increase the surface area for absorption and allow for fatty acids and glycerol to be absorbed into lacteals in the villi, and glucose and amino acids to be absorbed into venules in the villi. The main functions of the jejunum are as follows:

- Digestion of chyme through churning with digestive juices and movement of digested food towards the ileum.
- Slow flow of chyme through small intestine through presence of circular folds.
- Nutrient absorption.
- Water absorption.
- Increase surface area for absorption through villi – approximately 200 million villi are present in the jejunum (Nigam et al., 2019a).

1.10.3 ILEUM

The longest part of the small intestine with a length of approximately 3.5 m. It is located between the jejunum and the caecum, and is separated from the large intestine by the ileocaecal valve. The ileocaecal valve prevents reflux of caecal contents back into the ileum. The ileum is where food spends the most time before moving into the large intestine. The ileum absorbs nutrients and moves food waste towards the large intestine via the ileocaecal valve. The ileum is more vascular than the jejunum and the folds are less dense in the ileum than in the jejunum (Cronin et al., 2010). The main functions of the ileum are:

- Absorption of vitamins, minerals, carbohydrates, fats, protein, B12 vitamin and bile salts.
- Movement of food waste towards the large intestine via the ileocaecal valve.
- Completion of enzymatic digestion of carbohydrates and proteins.
- Immune function – lymphoid particles called Peyer's patches reside in the ileum. They monitor for presence of pathogens and harmful bacteria in the ileum and initiate a response to prevent their passage into the bloodstream.

1.10.4 BLOOD SUPPLY AND LYMPHATIC DRAINAGE

The small intestine has a rich blood supply, mainly from the SMA via the pancreaticoduodenal, jejunal and ileal branches. Venous drainage is via corresponding venous blood vessels, which drain into the portal vein. Lymphatic vessels run alongside blood vessels and drain into mesenteric lymph nodes.

1.10.5 SMALL INTESTINE INNERVATION

Branches of the vagus nerve (CN X) and thoracic splanchnic nerves innervate the small intestine. These branches extend throughout the length of the small intestine in the submucosal and myenteric plexuses:

- Submucosal plexus (of Meissner) found in the submucosa of the small intestine and contains only parasympathetic input from the vagus nerve (CN X).
- Myenteric plexus (of Auerbach) located in the muscularis externa of the small intestine, contains both sympathetic and parasympathetic nerve fibres.

1.11 THE LARGE INTESTINE

The large intestine is the terminal part of GI tract. It gets its name as the lumen is larger than that of the small intestine, not because it is longer. The large intestine is composed of a number of sections:

- Caecum and vermiform appendix
- Ascending colon
- Transverse colon
- Descending colon
- Sigmoid colon
- Rectum
- Anal canal

The large intestine has the same four layers found in most parts of the GI tract:

- Mucosa – composed of a columnar epithelium with mucous-secreting goblet cells, lamina propria and muscularis mucosa.
- Submucosa – containing blood vessels and Meissner nerve plexus.
- Muscularis propria – containing continuous inner circular and outer longitudinal muscles arranged in bands and myenteric (Auerbach) nerve plexus. Teniae coli are formed by bands of the outer longitudinal muscles. Teniae coli are not present in the rectum, where the outer longitudinal muscle is continuous.
- Serosa – Visceral peritoneum (Kapoor, 2025).

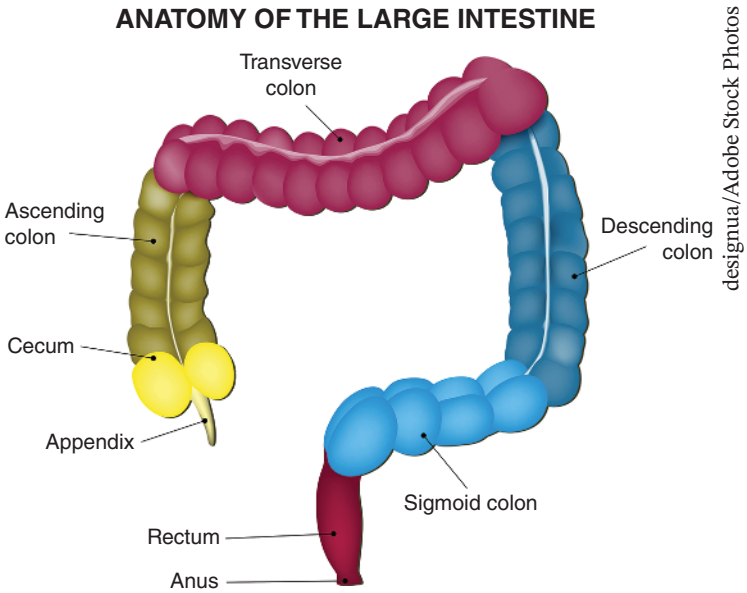
The large intestine is approximately 1.5 m long and begins at the terminal ileum with the caecum. Villi are present in small intestine but are absent in colon. It is distinguished further from the small intestine by the presence of omental appendices, haustra and teniae coli (Kahai et al., 2025). The teniae coli meet at the apex of the caecum to form a triradiate fold which is a landmark for colonoscopy. The caecum and colon have three longitudinal muscular bands called teniae coli and multiple sacculations called haustra. Teniae coli are three longitudinal smooth extensions from the base of the appendix extending along the length of the large intestine, merging with the rectosigmoid musculature. Haustra are sacculations of the large intestine, resulting from contraction of the teniae coli exerting pressure on the wall. Epiploic appendages, pieces of fat-filled connective tissue, are attached to the outer surface of the colon.

Unlike the small intestine, the large intestine produces no digestive enzymes. Chemical digestion is completed in the small intestine before the chyme reaches the large intestine. The large intestine does not release digestive enzymes; however, it does contain bacteria that

further break down nutrients for absorption. Swallowed air, digestion, high-fibre foods and the by-products of these intestinal bacteria generate flatus.

The main functions of the colon include:

- Water and nutrient absorption
- Vitamin absorption
- Faeces compaction
- Potassium and chloride secretion
- Maintaining gut bacteria
- Peristaltic movement of waste material to the rectum



The caecum is an 8–10 cm proximal blind pouch of the ascending colon adjoining the ileum at the ileocaecal junction. The terminal ileum opens into the caecum and is protected from back flow of caecal contents by the ileocaecal valve. The base of the appendix attaches to the posteromedial wall of the caecum approximately 1–2 cm below the ileocaecal junction. The appendix is a thin cylindrical organ with a blind attachment to the caecum. The tip of the appendix hangs in the peritoneal cavity and is most commonly located in a retrocaecal position, though it may also lie post-ileal, pre-ileal, sub-ileal, pelvic, subcaecal or paracaecal. It has a short triangular mesentery, attached to the small intestine mesentery, known as the mesoappendix. The appendix is rich in mucosa-associated lymphoid tissue (MALT). The caecum ascends vertically from right iliac fossa and is continuous with the ascending colon.

The ascending colon is retroperitoneal. It is approximately 20 cm (8 inches) long with a diameter of 6–8 cm (2.5 inches). It runs superiorly on the right side of the abdomen from the right iliac fossa, through the right lumbar region into right hypochondriac region under the liver, making a left turn at the hepatic flexure to join the transverse colon.

The transverse colon is the third, most mobile and longest part of the large intestine at approximately 45 cm (18 inches). It is found between the hepatic (right) and splenic (left) colic flexures, running across the epigastrium to the left hypochondriac region under the spleen. The

splenic flexure is less mobile than the hepatic and is attached to the diaphragm through the phrenocolic ligament. The transverse colon is attached to a mesentery, the transverse mesocolon, which is a broad fold of peritoneum connecting the transverse colon to the posterior wall of the abdomen. The transverse colon has a distinctive triangular shape when seen during endoscopy. It merges with the descending colon at the splenic flexure.

The descending colon is approximately 15–20 cm (6–7.5 inches) long and is retroperitoneal. It descends vertically through the left lumbar region to the left iliac fossa and terminates where it joins the sigmoid colon.

The sigmoid colon is approximately 35–40 cm (14–16 inches) in length and it links the descending colon to the rectum. It is an S-shaped loop that joins the rectum at the level of S3 (Kahai et al., 2025).

The rectum is approximately 12–15 cm (5–6 inches) long. It is fixed, primarily retroperitoneal, and subperitoneal in location. It transitions to the anal canal at the level of the puborectal sling, which is formed by the levator ani muscles. The rectum is anteriorly related to the recto-vesical pouch, prostate, bladder, urethra and seminal vesicles in males. In females, the rectum has an anterior relationship to the recto-uterine pouch, cervix, uterus and vagina (Kahai et al., 2025). The rectum continues from the sigmoid colon to the anal canal and has a thick muscular layer. It follows the curvature of the sacrum and is firmly attached to it by connective tissue. The rectum ends about 5 cm below the tip of the coccyx, at the beginning of the anal canal.

The last 2–3 cm of the digestive tract is the anal canal, which continues from the rectum and opens to the outside at the anus. The mucosa of the rectum is folded to form longitudinal anal columns, each of which contains a terminal branch of the superior rectal artery and vein. The smooth muscle layer is thick and forms the internal anal sphincter at the superior end of the anal canal. When faeces enters the rectum, it triggers nerves that cause the internal sphincter to relax. This sphincter is under involuntary control. There is also an external anal sphincter at the inferior end of the anal canal. This sphincter is composed of skeletal muscle and is under voluntary control.

1.11.1 LARGE INTESTINAL BLOOD SUPPLY

Blood supply to the large intestine is via the SMA and the inferior mesenteric artery (IMA). The ileocolic artery supplies the caecum, which is a terminal branch of the SMA. The ileocolic artery gives rise to the appendicular artery, which supplies the appendix. The ileocolic and right colic arteries, both branches of the SMA, supply the ascending colon and the hepatic flexure. The arterial supply to the transverse colon is from the middle colic artery, which is another branch of SMA. It also receives blood supply from the distal branches of the superior and inferior mesenteric arteries known as ‘anastomotic arcades’ between the right and left colic arteries, which collectively form the marginal artery. The descending and sigmoid colon receive their blood supply from the left colic and sigmoid arteries, which are branches of the IMA. The superior rectal artery supplies the rectum and anal canal, which is a continuation of the IMA. They also receive supply from branches of the internal iliac arteries, the middle and inferior rectal arteries. The inferior rectal artery is a branch of the internal pudendal artery (Bruzzi et al., 2020).

Venous drainage usually accompanies arterial colonic supply. The inferior mesenteric vein (IMV) drains into the splenic vein, and the SMV joins the splenic vein to form the hepatic portal vein, which returns blood to the liver. Veins draining the distal parts of the rectum and anus merge with the internal iliac veins, which subsequently merge with the inferior vena cava, therefore bypassing the liver and portal circulation. This is an important consideration for administration of medicines as the rectal route may represent a practical alternative for administration of drugs both locally and systemically. Lymphatics of the large intestine drain into the lymph nodes associated with the main vessels that supply them (Harkins and Ahmad, 2025).

1.11.2 INNERVATION OF THE LARGE INTESTINE

The ascending colon and proximal two-thirds of the transverse colon receive parasympathetic, sympathetic and sensory nerve supply from the superior mesenteric plexus. The distal third of the transverse colon, descending and sigmoid colon, receive parasympathetic, sympathetic and sensory nerve innervation from the inferior mesenteric plexus (Kahai et al., 2025).

When chyme that has not been absorbed by the small intestine passes into the large intestine at the caecum via the ileocaecal valve, the caecum continues the absorption process. As absorption of water and electrolytes continues, the residual chyme begins to move along the large intestine, up the ascending colon through each segment until absorption is complete and food waste (faeces) is ready to be discharged from the rectum via the anal canal. Sodium is absorbed by intestinal cells and potassium moves in the other direction, secreted into the lumen to mix with faeces. Movement of intestinal contents from the caecum triggers haustral contractions, which move the contents along the large intestine through a series of contractions and distentions, mixing the food residue and allowing further absorption of water and electrolytes. This movement and absorption transform the caecal chyme into a semisolid food residue as it travels along the length of the large intestine, eventually becoming faeces by the time it arrives at the rectum. Mucus secreted by goblet cells into the large intestine helps the residue to bind and assists with the movement of semisolid food waste and faeces along the large intestine. As water is absorbed, the residue that remains is largely composed of fibre, undigested food, some remaining water, bacteria and some cellular matter from the lining of the large intestine.

Peristalsis, similar to that in the small intestine, continues in the large intestine. However, this is not the primary method of propulsion in the large intestine. Strong waves, known as colonic mass movements, lasting approximately 30 minutes occur approximately three times daily. These are initiated by ingestion of food and the presence of chyme in the duodenum, triggering the gastrocolic reflex. Mass movements mainly involve the distal section of the large intestine from the transverse colon to the rectum. When faeces enters the rectum, rectal distention stimulates stretch receptors, with the signals spreading to the descending colon, sigmoid and rectum via the myenteric plexus. The process initiates the defecation reflex and forces faeces towards the anus (Mawer and Alhawaj, 2025). The internal anal sphincter is under involuntary control and opens to allow faeces to move towards the anus. The external anal sphincter is under voluntary control and can be controlled, tightening the sphincter to prevent defecation until ready. Defecation occurs when the external anal sphincter is voluntarily relaxed. Delaying defecation for too long can result in the relaxation of the rectal walls and the urge to defecate passing until the next mass movement occurs. This can result in further absorption of water from faeces and constipation.

1.12 REFLECTIVE QUESTIONS

- Describe the structure of the stomach and explain the role of its different layers (mucosa, submucosa, muscularis externa and serosa) in the digestion and movement of food.
- Explain the process of gastric emptying and the role of the pyloric sphincter in regulating the passage of chyme from the stomach to the small intestine.
- Describe the dual role of the pancreas in the body, including its endocrine and exocrine functions.
- How do pancreatic juices contribute to digestion, and what are the primary components of these juices?
- Describe the primary functions of the liver in metabolism, including its role in glucose, protein and lipid metabolism.

- Explain the structure of the liver's blood supply, highlighting the roles of the hepatic portal vein and the hepatic artery in nutrient and oxygen delivery.
- Explain the structure of the small intestine and how its anatomy supports its function in nutrient absorption.
- Describe the role of digestive enzymes in the small intestine, including the contributions of the pancreas and small intestine itself in the breakdown of carbohydrates, proteins and fats.
- Explain the primary functions of the large intestine in the digestive process, focusing on water absorption, electrolyte balance and the formation of faeces.
- Describe the structure and function of the rectum and anal canal in the elimination of waste, including the roles of the internal and external anal sphincters.

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