

Chapter 9

The digestive system

Louise McErlean

Test your prior knowledge

- What is the main function of the digestive system?
- List the structures that form the digestive system.
- List the hormones and enzymes involved in the digestive system.
- Name the main food groups.
- Differentiate between macronutrients and micronutrients.

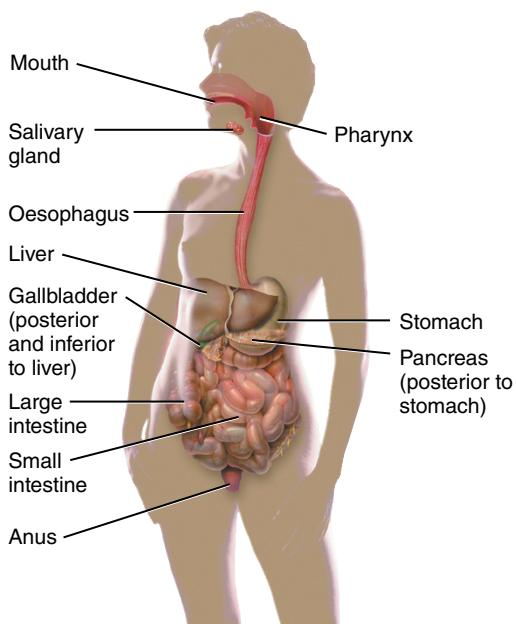
Learning outcomes

After reading this chapter you will be able to:

- Identify the organs of the digestive system, including the accessory organs of the digestive system
- Describe the functions of each of these organs, as well as the overall function of the digestive system
- Explain the action of the enzymes and hormones associated with the digestion of proteins, carbohydrates and fats
- Describe what proteins, carbohydrates and fats are broken down into and how the body uses these constituent parts
- Describe the structure and function of the accessory organs of the digestive system
- List the common vitamins and minerals and the problems associated with a deficit or excess

Body map

258



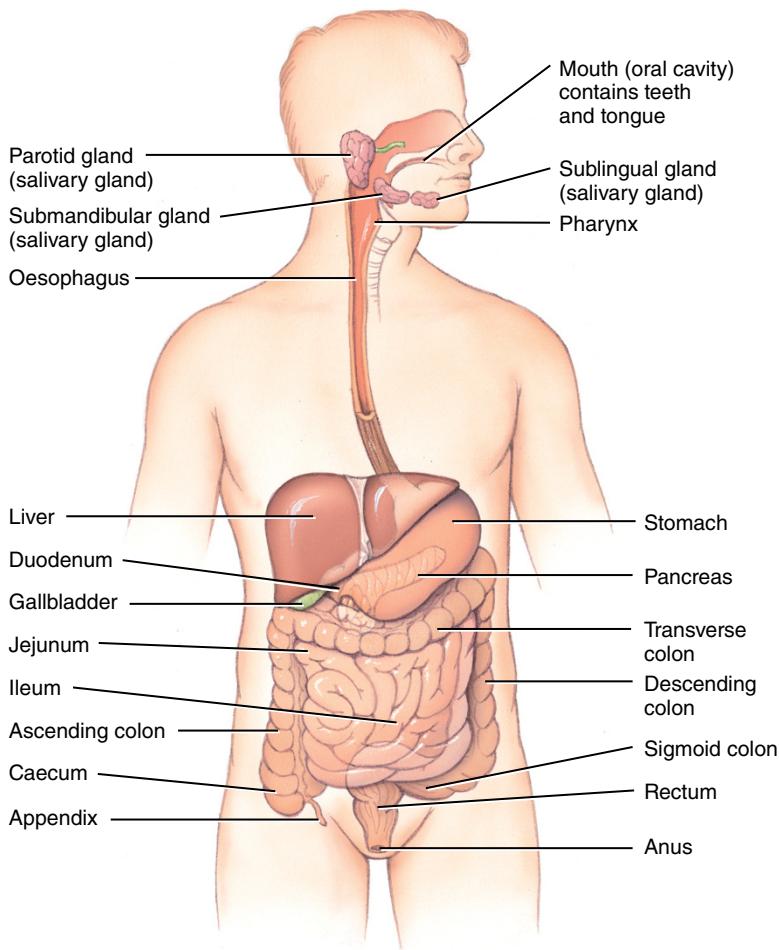
Introduction

The digestive system is also known as the gastrointestinal system or the alimentary canal. This vast system is approximately 10 m long. It travels the length of the body from the mouth through the thoracic, abdominal and pelvic cavities, where it ends at the anus (see Figure 9.1). The digestive system has one major function: to convert food from the diet into a form that can be utilised by the cells of the body in order to carry out their specific functions. This chapter discusses the structure and function of the digestive system and explains how dietary nutrients are broken down and used by the body for cell metabolism and for growth and repair.

The activity of the digestive system

The activity of the digestive system can be categorised into five processes:

- **Ingestion:** taking food into the digestive system.
- **Propulsion:** moving the food along the length of the digestive system.
- **Digestion:** breaking down food. This can be achieved *mechanically* as food is chewed or moved through the digestive system, or *chemically* by the action of enzymes mixed with the food as it moves through the digestive system.
- **Absorption:** the products of digestion exit the digestive system and enter the blood or lymph capillaries for distribution to where they are required.
- **Elimination:** the waste products of digestion are excreted from the body as faeces.



259

Figure 9.1 The digestive system. Source: Tortora and Derrickson (2009). Reproduced with permission of John Wiley & Sons.

The organisation of the digestive system

The digestive system consists of the main digestive system structures and the accessory organs. The main digestive system structures include the mouth, pharynx, oesophagus, stomach, small intestine and large intestine. Accessory organs also contribute to the function of the digestive system. The accessory organs are the salivary glands, the liver, the gallbladder and the pancreas.

The digestive system organs

The mouth (oral cavity)

Food enters the mouth or oral cavity, and this is where the process of digestion begins. The oral cavity consists of several structures (see Figure 9.2). Food enters the oral cavity in a process called **ingestion**. The food mixes with saliva.

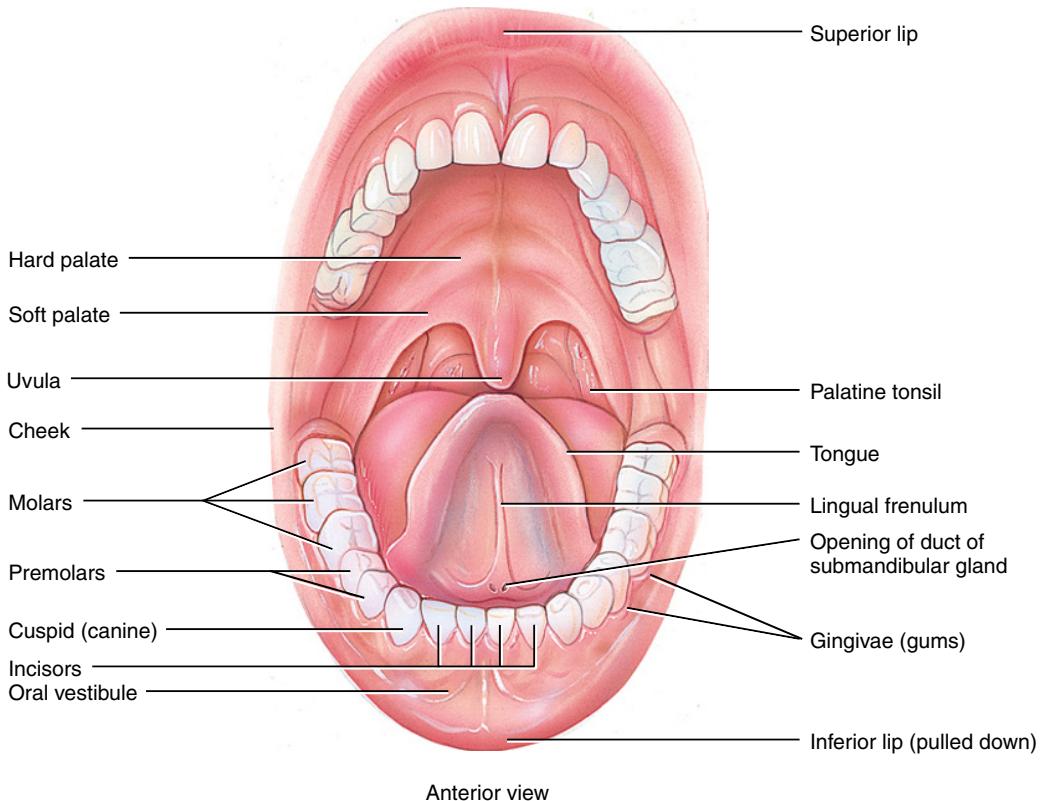


Figure 9.2 The oral cavity. Source: Tortora and Derrickson (2009). Reproduced with permission of John Wiley & Sons.

The **lips** and **cheeks** are formed of muscle and connective tissue. This allows the lips and cheeks to move food mixed with saliva around the mouth and begin **mechanical digestion**. The teeth contribute to mechanical digestion by grinding and tearing food. This process of chewing and mixing food with saliva is called **mastication**. The oral cavity can be exposed to very hot and very cold food as well as rough food particles. It is lined with mucus-secreting, stratified squamous epithelial cells. This layer provides some protection against abrasion, the effects of heat and continuous wear and tear.

The lips and cheeks are also involved in speech and facial expression.

Tongue

The tongue is a large, voluntary muscular structure that occupies much of the oral cavity. It is attached posteriorly to the **hyoid** bone and inferiorly by the **frenulum** (see Figure 9.2).

The superior surface of the tongue is covered in stratified squamous epithelium for protection against wear and tear. This surface also contains many little projections called papillae. The papillae (or taste buds) contain the nerve endings responsible for the sense of taste (Tortora and Derrickson, 2012). The taste buds contribute to our enjoyment of food. As well as taste, other functions of the tongue include swallowing (deglutition), holding and moving food around the oral cavity and speech.

Palate

The palate forms the roof of the mouth and consists of two parts: the hard palate and the soft palate. The hard palate is located anteriorly and is bony. The soft palate lies posteriorly and consists of skeletal muscle and connective tissue (see Figure 9.2). The palate plays a part in swallowing. The **palatine tonsils** lie laterally and are lymphoid tissue. The **uvula** is a fold of tissue that hangs down from the centre of the soft palate.

Teeth

Temporary teeth are also known as deciduous or milk teeth. Temporary teeth begin to appear at about 6 months old. There are 20 temporary teeth, and these are replaced by permanent teeth from about the age of 6 years (Nair and Peate, 2013). There are 32 permanent teeth. Sixteen are located in the maxilla arch (upper) and 16 are located in the mandible (lower) (see Figure 9.3).

261

Canines and incisors are cutting and tearing teeth. Premolars and molars are used for the grinding and chewing of food. Despite their different functions and shape, the structure of each tooth is the same. The visible part of the tooth is called the **crown**. The crown sits above the gum

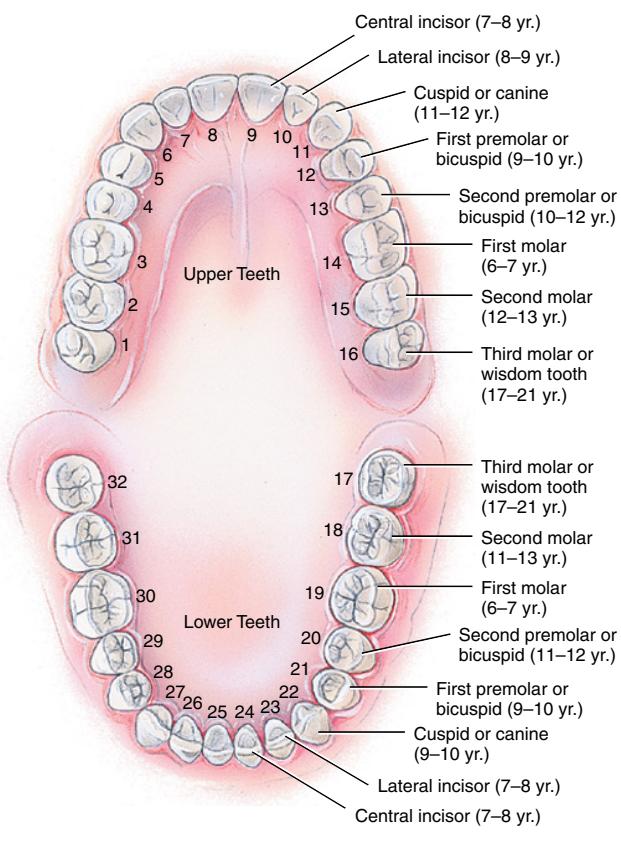
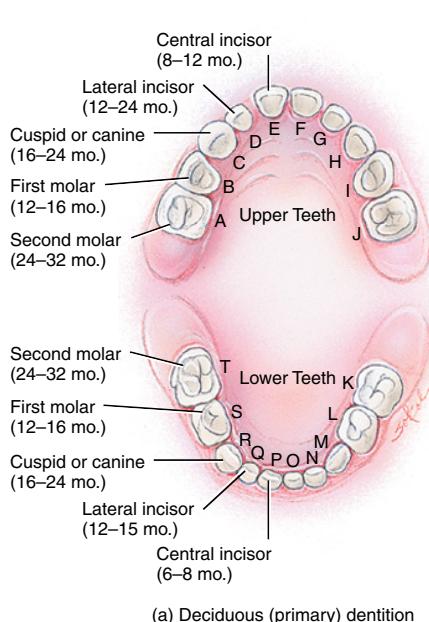


Figure 9.3 (a, b) Teeth. Source: Tortora and Derrickson (2009). Reproduced with permission of John Wiley & Sons.

or **gingiva**. The centre of the tooth is called the **pulp cavity**. Blood and lymph vessels as well as nerves enter and leave the tooth here. The tooth receives nutrients and sensations via the pulp. Surrounding this is a calcified matrix, not unlike bone, called the **dentine**. Surrounding the dentine is a very hard, protective material called **enamel**. The neck of the tooth is where the crown meets the root. The teeth are anchored in a socket with a bone-like material called **cementum**, and the function of the teeth is to chew (masticate) food.

Salivary glands

There are three pairs of salivary glands (see Figure 9.4). The **parotid glands** are the largest and they are located anterior to the ears. Saliva from the parotid glands enters the oral cavity close to the level of the second upper molar tooth. The submandibular glands are located below the jaw on each side of the face. Saliva from these glands enters the oral cavity from beside the frenulum of the tongue. The sublingual glands are the smallest. They are located in the floor of the mouth.

Although saliva is continuously secreted in order to keep the oral cavity moist, the activity of the parasympathetic fibres that innervate the salivary glands will lead to an increased production of saliva in response to the sight, smell or taste of food. The action of sympathetic fibres leads to a decreased secretion of saliva.

In health, approximately 1–1.5 L of saliva are secreted daily. Saliva consists of:

- water
- salivary amylase
- mucus

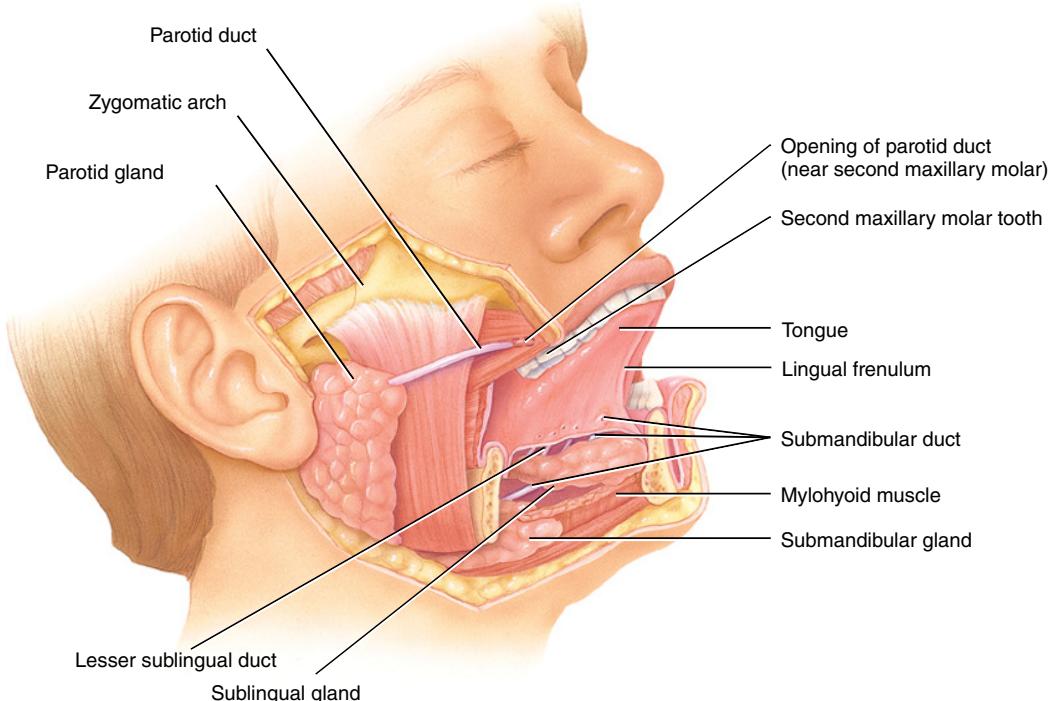


Figure 9.4 Salivary glands. Source: Tortora and Derrickson (2009). Reproduced with permission of John Wiley & Sons.

- mineral salts
- lysozyme
- immunoglobulins
- blood clotting factors.

Saliva has several important functions:

- Salivary amylase is a digestive enzyme responsible for beginning the breakdown of carbohydrate molecules from complex polysaccharides to the disaccharide maltose.
- The fluid nature of saliva helps to moisten and lubricate food that enters the mouth. This makes it easier to hold the food in the mouth and also assists in forming the food into a bolus in preparation for swallowing.
- The continuous secretion of saliva is cleansing and helps to maintain moisture in the oral cavity. A lack of moisture can lead to oral mucosal infections and formation of mouth ulcers.
- The oral cavity is an entry route for pathogens from the external environment. Lysozyme, a constituent of saliva, has an antibacterial action. Immunoglobulin and clotting factors also contribute to the prevention of infection.
- Taste is only possible when food substances are moist. Saliva is required to moisten food.

263

Clinical considerations

Mouth care

Patients who are ill are often dehydrated and therefore the production of saliva is reduced. This can lead to an increased risk of oral infections, as wear and tear within the oral cavity increases. Reduced amounts of saliva lead to less washing away of pathogens to the acid environment of the stomach where they may be destroyed. The oral cavity provides a route for pathogens to enter the respiratory tract, and therefore good oral hygiene practices may help prevent respiratory infections, particularly in patients who are vulnerable because of acute illness, cancer treatments or immobility.

When patients are ill, diet is essential for tissue repair and healing; however, a lack of saliva will lead to the food not tasting as it should. The food will not easily form into the required bolus size for ease of swallowing. This may put the patient off eating and drinking and may lead to the patient losing their appetite and potentially delayed healing.

Ill health can lead to neglect of hygiene standards for individuals. Mouth care is easy for patients to ignore when they are feeling poorly. However, it is an essential consideration for nursing.

Pharynx

The pharynx consists of three parts: the **oropharynx**, the **nasopharynx** and the **laryngopharynx**. The nasopharynx is considered a structure of the respiratory system. The oropharynx and the laryngopharynx are passages for both food and respiratory gases (see Figure 9.5). The **epiglottis** is responsible for closing the entrance to the larynx during swallowing, and this essential action prevents food from entering the larynx and obstructing the respiratory passages.

Swallowing (deglutition)

Once ingested food has been adequately chewed and formed into a bolus it is ready to be swallowed. Swallowing (deglutition) occurs in three phases.

Approved: 0777 023 444

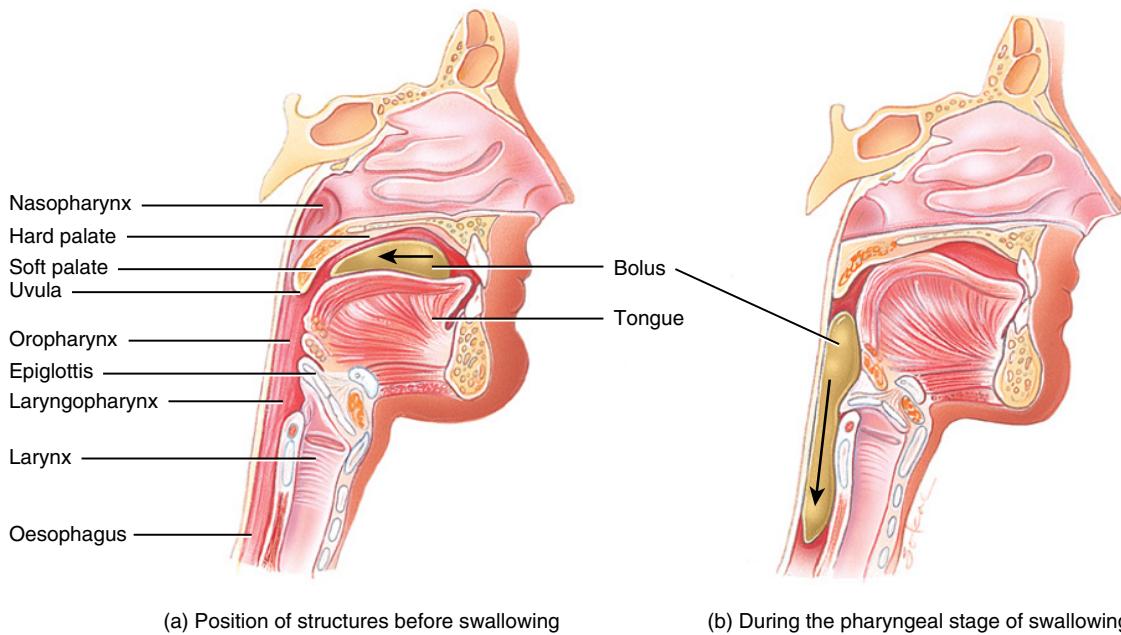


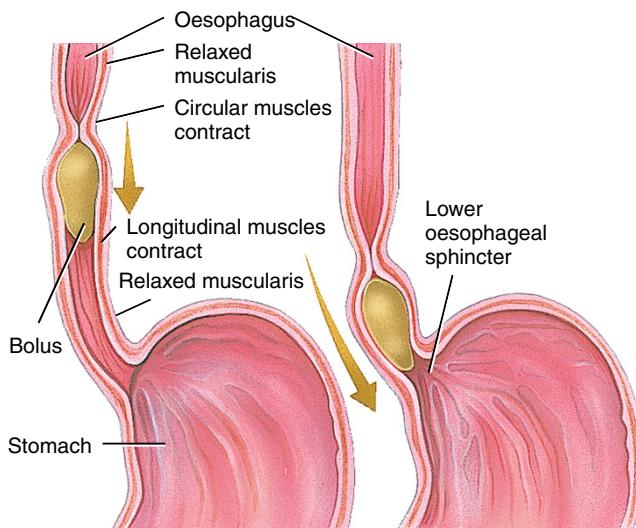
Figure 9.5 (a, b) Swallowing. Source: Tortora and Derrickson (2009). Reproduced with permission of John Wiley & Sons.

- The voluntary phase:** During this phase the action of the voluntary muscles serving the oral cavity manipulates the food bolus into the oropharynx. The tongue is pressed against the palate and this prevents the food from moving forward again.
- The pharyngeal phase:** During this phase a reflex action is initiated in response to the sensation of the food bolus in the oropharynx. This reflex is coordinated by the swallowing centre in the medulla oblongata, and the motor response is contraction of the muscles of the pharynx. The soft palate elevates, closing off the nasopharynx and preventing the food bolus from using this route. The larynx moves up and moves forward, allowing the epiglottis to cover the entrance to the larynx so the food bolus cannot move into the respiratory passages.
- The oesophageal phase:** The food bolus moves from the pharynx into the oesophagus. Waves of oesophageal muscle contractions move the food bolus down the length of the oesophagus and into the stomach. This wave of muscle contraction is known as **peristalsis** (see Figure 9.6).

Oesophagus

The food bolus leaves the oropharynx and enters the oesophagus. The oesophagus extends from the laryngopharynx to the stomach. It is a thick-walled structure, measuring about 25 cm in length and lies in the thoracic cavity, posterior to the trachea. The function of the oesophagus is to transport substances (the food bolus) from the mouth to the stomach. Thick mucus is secreted by the mucosa of the oesophagus, and this aids the passage of the food bolus and also protects the oesophagus from abrasion.

The upper oesophageal sphincter regulates the movement of substances into the oesophagus, and the lower oesophageal sphincter (also known as the cardiac sphincter) regulates the



Anterior view of frontal sections of peristalsis in oesophagus

Figure 9.6 Peristalsis in the oesophagus. Source: Tortora and Derrickson (2009). Reproduced with permission of John Wiley & Sons.

movement of substances from the oesophagus to the stomach. The muscle layer of the oesophagus differs from the rest of the digestive tract, as the superior portion consists of skeletal (voluntary) muscle and the inferior portion consists of smooth (involuntary) muscle. Breathing and swallowing cannot occur at the same time (Nair and Peate, 2013).

Medicines management

Omeprazole

Omeprazole is a medicine used to treat a number of digestive system conditions, including dyspepsia, acid reflux, oesophagitis and peptic ulcer disease. It belongs to a group of medicines known as proton pump inhibitors (Galbraith *et al.*, 2007). Hydrochloric acid produced in the stomach can escape into the oesophagus or the duodenum of the small intestine and irritate the delicate epithelium in these areas. Omeprazole works on the parietal cells in the stomach, inhibiting the production of hydrochloric acid.

Omeprazole is usually prescribed as 20–40 mg once daily.

The common side effects for patients taking omeprazole are:

- vomiting
- diarrhoea
- constipation
- pain (stomach)
- headaches
- increased flatulence
- nausea.

NICE (2014a) produces guidance on the investigation and management of dyspepsia.

The structure of the digestive system

There are four layers of tissue or tunicas that exist throughout the length of the digestive tract from oesophagus to anus (see Figure 9.7).

The **mucosa** is the innermost layer. The products of digestion are in contact with this layer as they pass through the digestive tract. The mucosa consists of three layers: the mucous epithelium (mucous membrane), which is involved in the **secretion** of mucus and other digestive system secretions such as saliva or gastric juice. This layer helps to **protect** the digestive system from the continuous wear and tear it endures. In the small intestine this layer is involved in **absorption** of the products of digestion. The next layer is the **lamina propria**, which consists of loose connective tissue that has a role in supporting the blood vessels and lymphatic tissue of the mucosa. The outermost layer is called the **muscularis mucosa** and consists of a thin smooth muscle layer that helps to form the gastric pits or the microvilli of the digestive system.

The **submucosa** is a thick layer of connective tissue. It contains blood and lymphatic vessels and some small glands. It also contains **Meissner's plexus** – nerves that stimulate the intestinal glands to secrete their products.

The **muscularis** consists of an inner layer of circular smooth muscle and an outer layer of longitudinal smooth muscle. The stomach has three layers of smooth muscle, and the upper oesophagus has skeletal muscle. Blood and lymph vessels and the **myenteric plexus** (a network

266

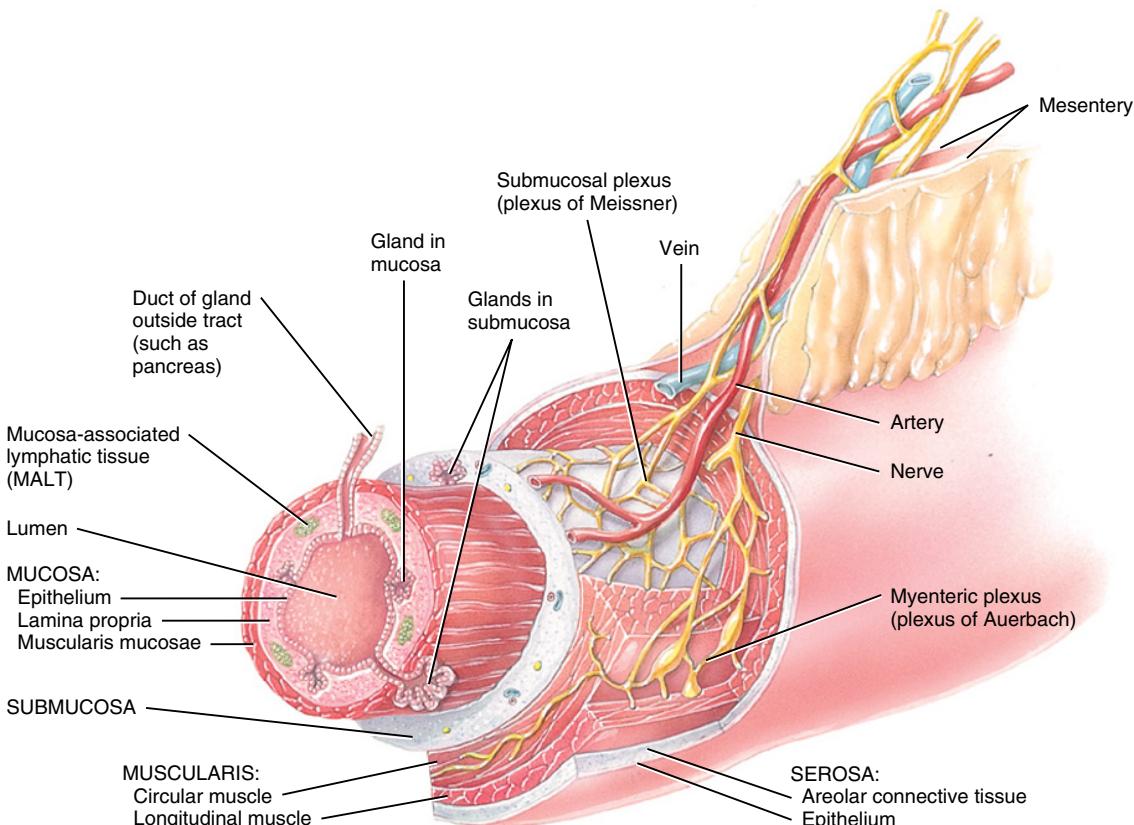


Figure 9.7 Structure of the digestive tract. Source: Tortora and Derrickson (2009). Reproduced with permission of John Wiley & Sons.

Approved: 0777 023 444

of sympathetic and parasympathetic nerves) are located between the two layers of smooth muscle. The wave-like contraction and relaxation of this muscle layer are responsible for moving food along the digestive tract – a process known as **peristalsis** (see Figure 9.7). Peristalsis helps to churn and mechanically digest food.

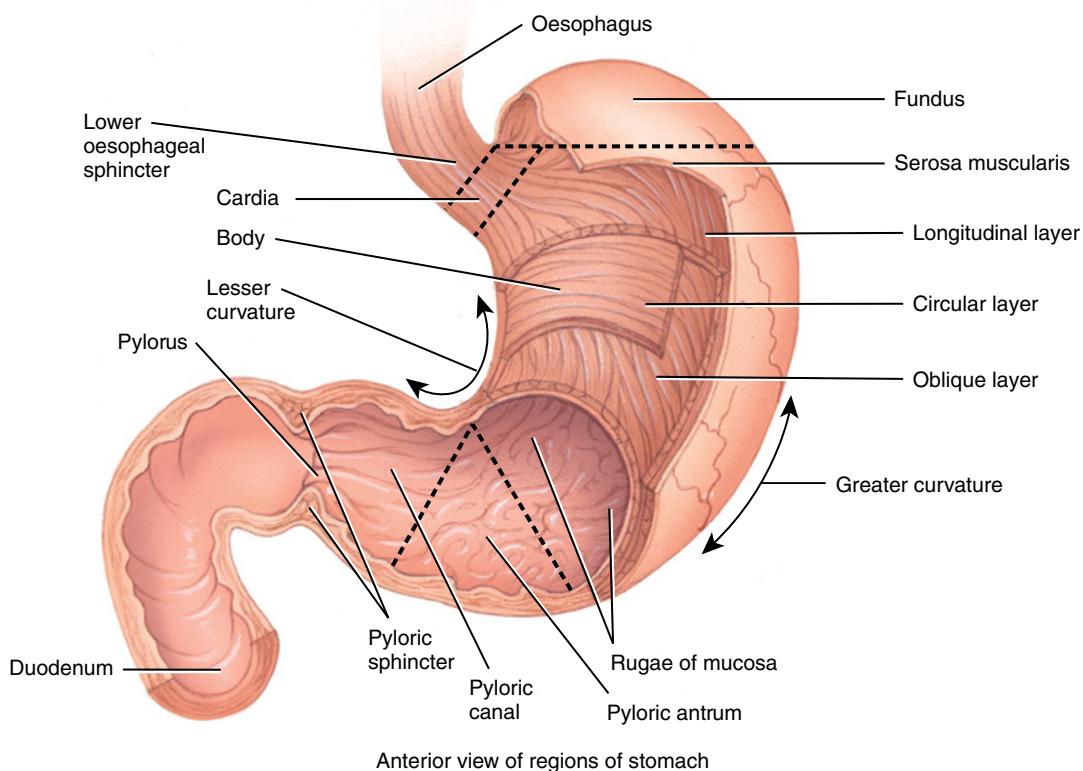
The outer layer of the digestive tract is the **serosa (adventitia)**. The largest area of serosa is found in the abdominal and pelvic cavities and is known as the **peritoneum**. The peritoneum is a closed sac. The visceral peritoneum covers the organs of the abdominal and pelvic cavity, and the parietal peritoneum lines the abdominal wall. A small amount of serous fluid lies between the two layers. The peritoneum has a good blood supply and contains many lymph nodes and lymphatic vessels. It acts as a barrier, protecting the structures it encloses, and can act to isolate areas of infection to prevent damage to neighbouring structures.

267

Stomach

The stomach lies in the abdominal cavity. It lies between the oesophagus superiorly and the duodenum of the small intestine inferiorly. It is divided into regions (see Figure 9.8).

The entrance to the stomach from the oesophagus is via the lower oesophageal sphincter or cardiac sphincter. This leads to a small area within the stomach called the **cardiac region or cardia**. The **fundus** is the dome-shaped region in the superior part of the stomach. The **body region** occupies the space between the lesser and greater curvature of the stomach, and the **pyloric region** narrows into the **pyloric canal**. The **pyloric sphincter** controls the exit of **chyme** from the stomach into the small intestine. Chyme is the name given to the food bolus as it leaves the stomach.



Anterior view of regions of stomach

Figure 9.8 The stomach. Source: Tortora and Derrickson (2009). Reproduced with permission of John Wiley & Sons.

Approved: 0777 023 444

The stomach is supplied with arterial blood from a branch of the celiac artery, and venous blood leaves the stomach via the hepatic vein. The vagus nerve innervates the stomach with parasympathetic fibres that stimulate gastric motility and the secretion of gastric juice. Sympathetic fibres from the celiac plexus reduce gastric activity.

The stomach has the same four layers of tissue as the digestive tract, but with some differences. The muscularis contains three layers of smooth muscle instead of two. It has longitudinal, circular and oblique muscle fibres. The extra muscle layer facilitates the churning, mixing and mechanical digestion of food that occurs within the stomach, as well as supporting the onward journey of the food by peristalsis.

The mucosa within the stomach is also different from the rest of the digestive tract. When the stomach is empty, the mucosal epithelia falls into long folds known as **rugae**. The rugae fill out when the stomach is full. A very full stomach can contain approximately 4 L, while an empty stomach contains only about 50 mL (Marieb and Hoehn, 2010). The shape and size of the stomach vary from person to person and depending on the quantity of food stored within it.

The mucosa also contains many gastric glands that secrete many different substances (see Figure 9.9).

- **Surface mucous cells** produce thick bicarbonate-coated mucus. This thick layer of mucus protects the stomach mucosal epithelia from corrosion by acidic gastric juice. When these cells become damaged they are quickly shed and replaced.

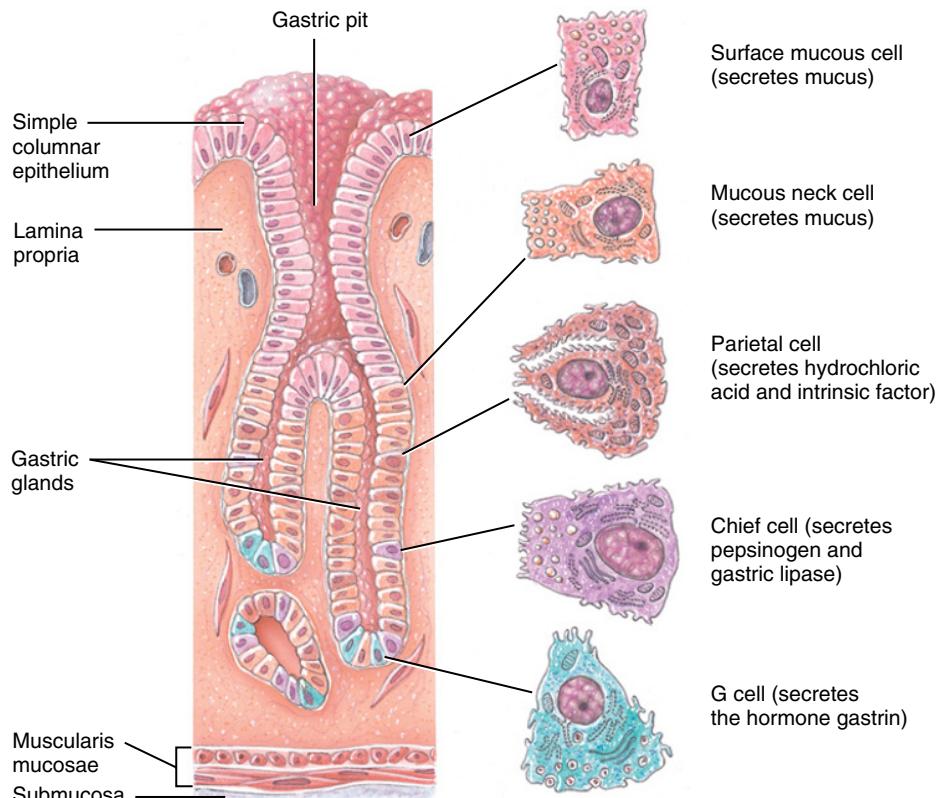


Figure 9.9 Gastric glands and cells. Source: Tortora and Derrickson (2009). Reproduced with permission of John Wiley & Sons.

- **Mucous neck cells** also secrete mucus – this mucus is different from surface cell mucus.
- **Parietal cells** produce **hydrochloric acid** and **intrinsic factor**. Intrinsic factor is necessary for the absorption of vitamin B_{12} . This vitamin is essential for the production of mature erythrocytes. Hydrochloric acid creates the acidic environment of the stomach (pH 1–3) and begins denaturing dietary protein in preparation for the action of pepsin.
- **Chief cells** produce pepsinogen, which is converted to **pepsin** in the presence of hydrochloric acid. Pepsin is necessary for the breakdown of protein into smaller peptide chains.
- **Enteroendocrine cells**, such as g cells, produce a variety of hormones, including **gastrin**. These hormones help regulate gastric motility.

This concoction of secretions plus water and mineral salts is more commonly called gastric juice. About 2 L of gastric juice is produced daily.

269

Snapshot

Hydrogen breath test

This is a test that uses the measurement of hydrogen in the breath to diagnose a number of conditions that cause gastrointestinal symptoms. Limited hydrogen is produced from the small amounts of unabsorbed food that reach the colon; large amounts of hydrogen may be produced when there is a problem with the digestion or absorption of food in the small intestine, which allows more unabsorbed food to reach the colon.

The hydrogen-containing blood travels to the lungs where the hydrogen is released and exhaled in the breath, where it can be measured. Hydrogen breath testing is used in the diagnosis of three conditions. The first is a condition in which dietary sugars are not digested normally. The most common sugar that is poorly digested is lactose. The second condition is to diagnose bacterial overgrowth of the small bowel. The final condition is to diagnose rapid passage of food through the small intestine. All of these conditions may cause abdominal pain, abdominal bloating and distension, flatulence and diarrhoea.

Before the test, the patient fasts for at least 12 h. At the start of the test, the patient blows into and fills a balloon with a breath of air. The concentration of hydrogen is measured in a sample of breath removed from the balloon. The patient then ingests a small amount of the test sugar (lactose, sucrose, sorbitol, fructose, lactulose, depending on the purpose of the test). Additional samples of breath are collected and analysed for hydrogen every 15 min for 3 h and up to 5 h.

The interpretation of the results of hydrogen breath testing depends on the sugar that is used for testing, and the pattern of hydrogen production after the sugar is ingested.

After ingestion of test doses of the dietary sugars, any production of hydrogen means that there has been a problem with digestion or absorption of the test sugar and that some of the sugar has reached the colon.

Regulation of gastric juice secretion is divided into three phases (see Figure 9.10).

1. **The cephalic phase:** The sight, taste or smell of food stimulates the secretion of gastric juice.
2. **The gastric phase:** When food enters the stomach, the hormone gastrin is secreted into the bloodstream, and this stimulates the secretion of gastric juice. The secretion of hydrochloric acid reduces the pH of the stomach contents, and when the pH drops below 2 the secretion of gastrin is inhibited.

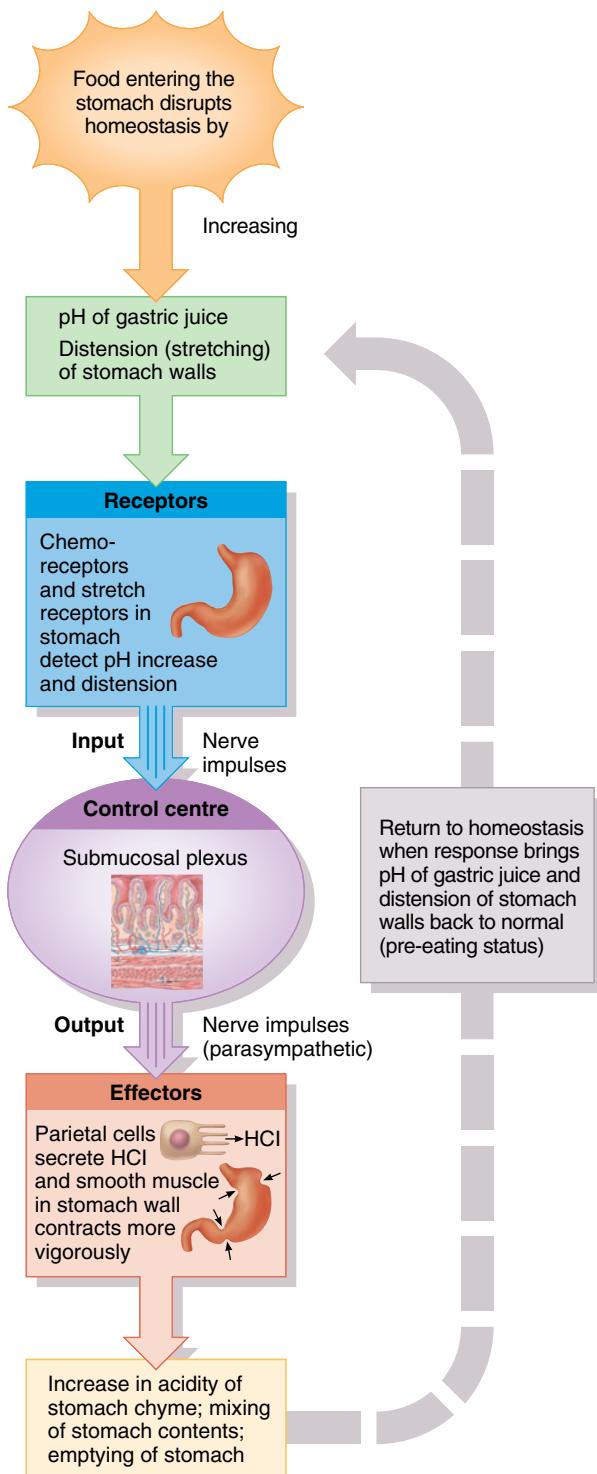


Figure 9.10 Phases of gastric juice secretion. Source: Tortora and Derrickson (2009). Reproduced with permission of John Wiley & Sons.

Approved: 0777 023 444

- 3. The intestinal phase:** As the acidic contents of the stomach enter the duodenum of the small intestine the hormones secretin and cholecystokinin (CKK) are secreted. These hormones also act to reduce the secretion of gastric juice and gastric motility.

The rate of gastric emptying depends on the size and content of the meal. A large meal takes longer than a small meal. Liquids quickly pass through the stomach, while solids require longer to be thoroughly mixed with gastric juice. Most meals will have left the stomach 4 h after ingestion.

The functions of the stomach are:

- to act as a store for food;
- the production of mucus to protect the stomach;
- mechanical digestion, by the churning action facilitated by an additional layer of smooth muscle;
- the mixing food with hydrochloric acid to help eradicate pathogens and denature proteins in preparation for the action of pepsin;
- the production of chyme;
- the production of intrinsic factor.

271

Medicines management

Odansetron

Nausea and vomiting are the most common digestive system symptoms. Vomiting (emesis) occurs when the emetic or vomiting centre in the brain is activated. It can be activated as a result of irritation in the stomach. The irritation could be due to bacteria or often medication. Some medications cross the blood–brain barrier and stimulate the vomiting centre. When stimulated, the abdominal muscles and diaphragm are activated and a reverse peristalsis occurs in the stomach, leading to the ejection of the stomach contents (Marieb, 2009).

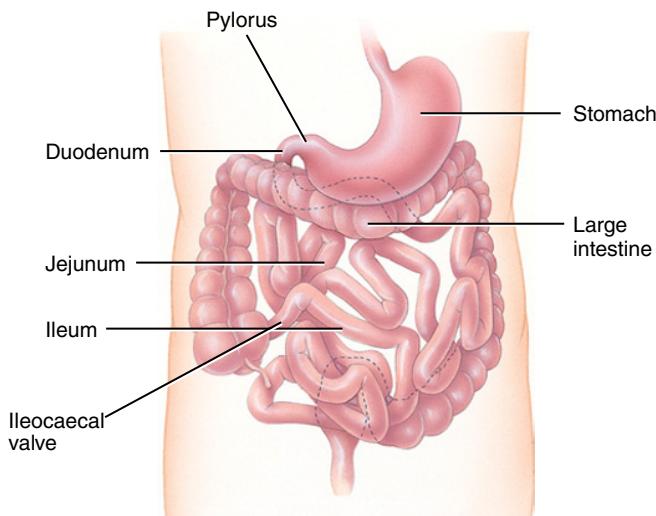
This unpleasant reaction can be treated with medications such as odansetron. Odansetron belongs to a group of medications known as anti-emetics. It acts by blocking serotonin, which promotes vomiting.

The usual adult dose is 8 mg twice daily. This can be adjusted according to need. Odansetron is often prescribed during chemotherapy, and the dose required may be increased if this is prescribed. Odansetron may also be prescribed intravenously if the patient is too nauseous to tolerate oral medication.

The most common side effects associated with odansetron are:

- constipation
- headaches
- flushing.

The side effects associated with this medication are minimal, and allergy reactions are only seen when given intravenously (Galbraith *et al.*, 2007).



272

Figure 9.11 The small intestine. Source: Tortora and Derrickson (2009). Reproduced with permission of John Wiley & Sons.

Small intestine

The small intestine is approximately 6 m long. In the small intestine food is further broken down by mechanical and chemical digestion, and absorption of the products of digestion takes place. The small intestine is divided into three parts (see Figure 9.11):

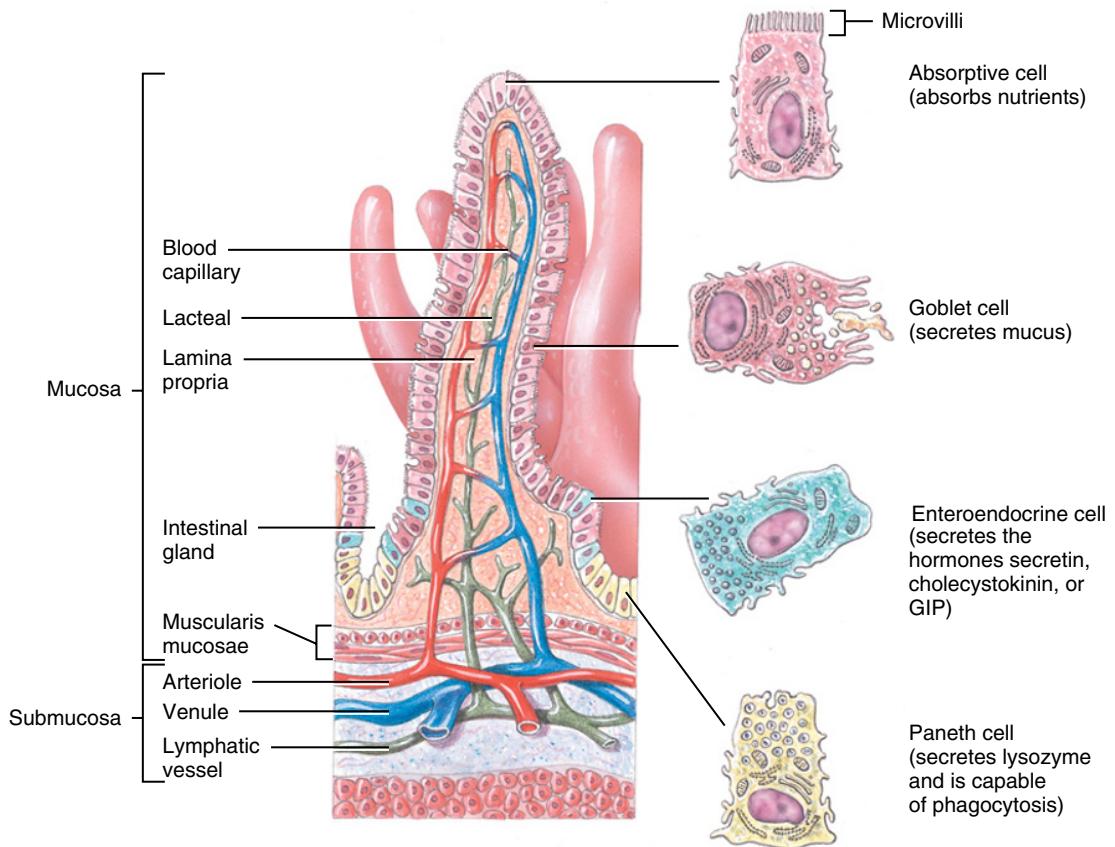
1. The **duodenum** is approximately 25 cm long. It is the entrance to the small intestine.
2. The **jejunum** measures 2.5 m and is the middle part of the small intestine.
3. The **ileum** measures 3.5 m. It meets the large intestine at the **ileocaecal valve**. This valve prevents the backflow of the products of digestion from the large intestine back into the small intestine.

The small intestine is innervated with both parasympathetic and sympathetic nerves. It receives its arterial blood supply from the **superior mesenteric artery** and nutrient-rich venous blood drains into the **superior mesenteric vein** and eventually into the **hepatic portal vein** towards the liver.

There are four types of cell present in the mucosa of the small intestine (see Figure 9.12):

- The absorptive cell produces digestive enzymes and absorbs digested foods.
- Goblet cells secrete mucus to protect the intestine from abrasion and from the acidic chyme entering the small intestine.
- Enteroendocrine cells produce regulatory hormones such as secretin and CKK. These hormones are secreted into the bloodstream and act on their target organs to release pancreatic juice and bile.
- Paneth cells produce lysozyme, which protects the small intestine from pathogens that have survived the acid conditions of the stomach. Peyer's patches (lymphatic tissue of the small intestine) also protect the small intestine.

Partially digested food enters the small intestine and spends from 3–6 h moving through its 6 m length. The smooth muscle activity within the small intestine continues the process of



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

Figure 9.12 The cells within the villi of the small intestine. Source: Tortora and Derrickson (2009). Reproduced with permission of John Wiley & Sons.

mechanical digestion. There are two types of mechanical digestion in the small intestine: segmental contractions, which help to mix the various enzymes in the small intestine with the contents of the chyme, and peristalsis, which propels the food down the length of the small intestine as well as facilitating mixing.

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

Chemical digestion

Within the small intestine, any carbohydrates that have not been broken down by the action of salivary amylase will be broken down by pancreatic amylase.

Bile will emulsify fat and fatty acids, making it easier for lipase (also from the pancreatic juice) to break the fats into fatty acids and glycerol. Proteins are denatured by hydrochloric acid in the stomach. In the small intestine they are further acted upon by the enzymes trypsin, chymotrypsin and carboxypeptidase. The end product of protein digestion is tripeptides, dipeptides and amino acids.

The small intestine produce 1–2 L of intestinal juice daily. It is secreted from the cells of the **crypts of Lieberkühn** (located between the villi) in response to either acidic chyme irritating the intestinal mucosa or distension from the presence of chyme in the small intestine. Intestinal juice is slightly alkaline (pH 7.4–8.4) and watery. Intestinal juice and pancreatic juice from the pancreas mix with the acidic chyme as it enters the duodenum and increase the pH, thus preventing the corrosive action of chyme on the mucosa of the duodenum. Intestinal juice also contains mucus, which helps protect the intestinal mucosa, mineral salts and enterokinase.

The primary function of the small intestine is absorption of water and nutrients, and it has several anatomical adaptations to facilitate this:

- 274
- Permanent circular folds, called **plicae circulares**, within the mucosa and submucosa slow down the movement of the products of digestion, allowing time for absorption of nutrients to occur.
 - On the surface of the mucosa are tiny, finger-like projections called **villi**. At the centre of the villi is a capillary bed and a **lacteal** (lymph capillary). This allows nutrients to be absorbed directly into the blood or the lymph.
 - On the surface of the villi are cytoplasmic extensions called **microvilli**. The presence of the microvilli greatly increases the surface area available for absorption. The appearance of the microvilli resembles the surface of a brush; hence it is called the **brush border**. The brush border produces some enzymes used to further break down carbohydrates such as lactase, maltase, dextrinase and sucrase. It also produces enzymes to further break down proteins: aminopeptidase, carboxypeptidase and dipeptidase.

The absorption of nutrients occurs by diffusion or active transport. Some nutrients will be absorbed into the blood capillary and some will be absorbed into the lacteal.

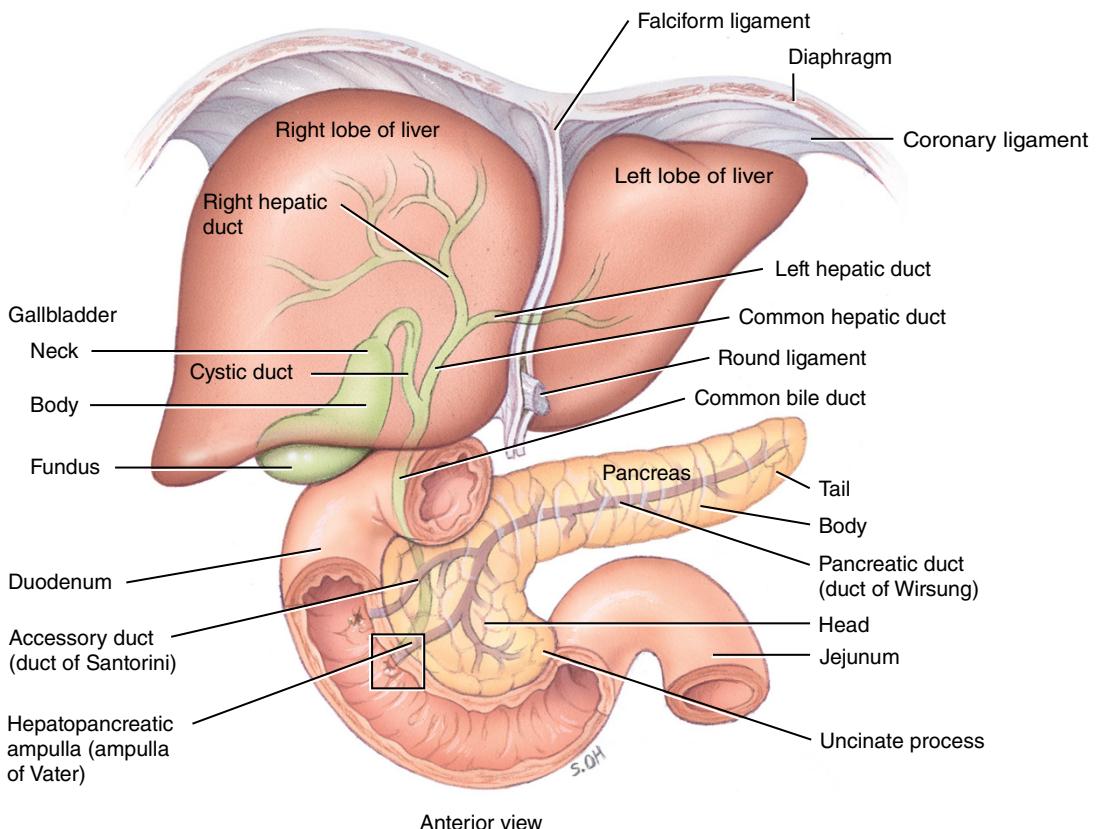
Function of the small intestine

- Production of mucus to protect the duodenum from the effects of the acidic chyme.
- Secretion of intestinal juice and pancreatic juice from the pancreas increase the pH of the chyme to facilitate the action of the enzymes.
- Bile enters the small intestine to emulsify fat so that it can be further broken down by the action of lipase.
- Many enzymes are secreted to complete the chemical digestion of carbohydrates, proteins and fats.
- Mechanical digestion is by peristalsis and segmentation, and slows down to allow adequate mixing and maximum absorption.
- The small intestine is structurally designed with a large surface area for maximum absorption of the products of digestion.
- The small intestine is where the majority of nutrients, electrolytes and water are absorbed.

The pancreas

The pancreas is composed of exocrine and endocrine tissue. It consists of a head, body and tail (see Figure 9.13). The cells of the pancreas are responsible for making the endocrine and exocrine products.

- The islet cells of the **islets of Langerhans** produce the endocrine hormones **insulin** and **glucagon**. These hormones control carbohydrate metabolism.



275

Figure 9.13 The liver, gallbladder and pancreas. Source: Tortora and Derrickson (2009). Reproduced with permission of John Wiley & Sons.

- The **acini glands** of the exocrine pancreas produce 1.2–1.5 L of **pancreatic juice** daily. Pancreatic juice travels from the pancreas via the pancreatic duct into the duodenum at the hepatopancreatic ampulla.
- The cells of the pancreatic ducts secrete bicarbonate ions, which gives pancreatic juice its high pH (pH 8). This helps to neutralise acidic chyme from the stomach, thus protecting the small intestine from damage by the acidity. Additionally, the actions of amylase and lipase are most effective at the higher pH (pH 6–8).

Pancreatic juice consists of:

- water;
- mineral salts;
- pancreatic amylase, which completes the digestion of carbohydrates;
- lipase, used in the digestion of fat;
- **trypsinogen**, **chymotrypsinogen** and **procarboxypeptidase**, which are released in an inactive form to protect the digestive system structures from the protein-digesting enzymes that they become – once they enter the duodenum they are activated by enterokinase from intestinal juice and become trypsin, chymotrypsin and carboxypeptidase respectively and are then used in the digestion of protein.

Two hormones regulate the secretion of pancreatic juice. **Secretin**, produced in response to the presence of hydrochloric acid in the duodenum, promotes the secretion of bicarbonate ions. **CKK**, secreted in response to the intake of protein and fat, promotes the secretion of the enzymes present in pancreatic juice. Parasympathetic vagus nerve stimulation also promotes the release of pancreatic juice.

In summary, the exocrine function of the pancreas is to secrete pancreatic juice into the duodenum. The actions of pancreatic juice lead to the further breakdown of carbohydrate, fat and protein.

Medicines management

276

Creon

Creon is a medication prescribed for patients who have cystic fibrosis or pancreatic insufficiency. It contains the following enzymes:

- amylase – for the breakdown of carbohydrate
- lipase – for the breakdown of fats
- proteases - for the breakdown of protein.

Pancreatic insufficiency can occur as a result of pancreatic cancer, pancreatic surgery and acute or chronic pancreatitis. In cystic fibrosis the ducts that transport the pancreatic enzymes become obstructed with the increased mucus production associated with this disease pathway.

The dosage of creon required will depend on the diet of the patient. If the symptoms of loose stool and weight loss persist, then the dose of creon may be increased. Creon is usually taken for life. There are some side effects associated with creon, and these include

- abdominal distension
- nausea
- vomiting
- diarrhoea
- constipation.

The tablets are enteric coated to protect them from inactivation in the stomach (Galbraith *et al.*, 2007).

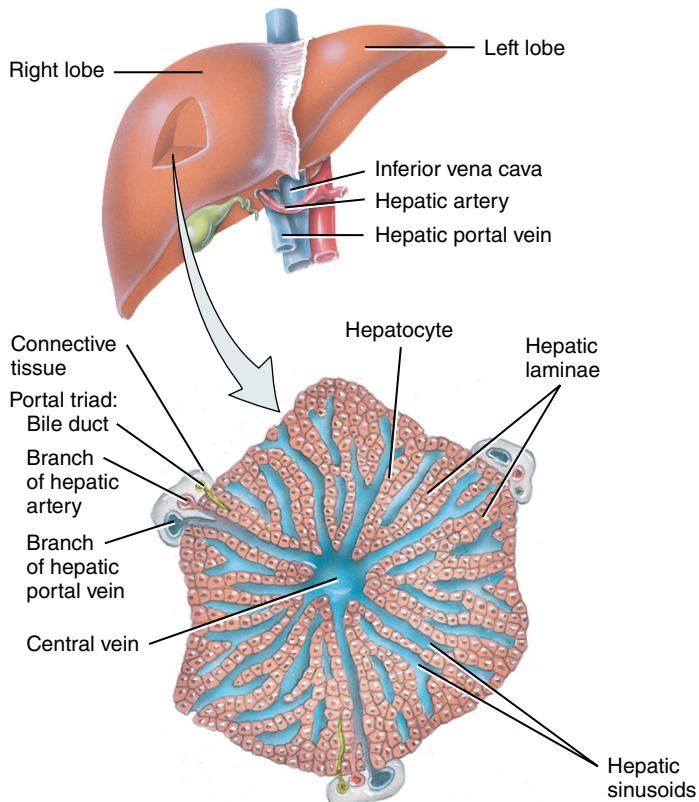
NICE (2010) produces a Clinical Knowledge Summary on managing chronic pancreatitis.

The liver and production of bile

The liver is the body's largest gland. It weighs between 1 and 2 kg. It lies under the diaphragm protected by the ribs. The liver occupies most of the right hypochondriac region and extends through part of the epigastric region into the left hypochondriac region. The right lobe is the largest of the four liver lobes. On the posterior surface of the liver there is an entry and exit to the organ called the portal fissure. Blood, lymph vessels, nerves and bile ducts enter and leave the liver through the portal fissure.

The liver is composed of tiny hexagonal-shaped lobules that contain hepatocytes (see Figure 9.14). The hepatocytes are protected by Kupffer cells (hepatic macrophages). The Kupffer cells deal with any foreign particles and worn-out blood cells.

Approved: 0777 023 444



Overview of histological components of liver

Figure 9.14 Liver lobule. Source: Tortora and Derrickson (2009). Reproduced with permission of John Wiley & Sons.

Each corner of the hexagonal-shaped lobule has a portal triad. A branch of the hepatic artery, a branch of hepatic portal vein and a bile duct are present here. The hepatic artery supplies the hepatocytes with oxygenated arterial blood. The hepatic portal vein delivers nutrient-rich deoxygenated blood from the digestive tract to the hepatocytes. The hepatocytes' function is to filter, detoxify and process the nutrients from the digestive tract. Nutrients can be used for energy, stored or used to make new molecules. The liver sinusoids are large, leaky capillaries that drain the blood from the hepatic artery and hepatic portal vein into the central vein. This processed blood is then drained into the hepatic vein and on to the inferior vena cava.

As the blood flows towards the centre of the triad to exit at the central vein, the bile produced by the hepatocyte as a metabolic by-product moves in the opposite direction towards the bile canaliculi and on to the bile ducts. Bile then leaves the liver via the common hepatic duct towards the duodenum of the small intestine.

The liver produces and secretes up to 1 L of yellow/green alkaline bile per day. Bile is composed of:

- bile salts such as bilirubin from the breakdown of haemoglobin
- cholesterol
- fat-soluble hormones

- fat
- mineral salts
- mucus.

The function of bile is to emulsify fats, giving the fat-digesting enzymes (trypsin, chymotrypsin and carboxypeptidase) a larger surface area to work on.

Bile is stored and concentrated in the gallbladder.

The functions of the liver

Apart from the production of bile and the metabolism of carbohydrate, fat and protein (discussed further on in this chapter), the liver has many additional functions:

- 278
- detoxification of drugs – the liver deals with medication, alcohol, ingested toxins and the toxins produced by the action of microbes;
 - recycling of erythrocytes;
 - deactivation of many hormones, including the sex hormones, thyroxine, insulin, glucagon, cortisol and aldosterone;
 - production of clotting proteins;
 - storage of vitamins, minerals and glycogen;
 - synthesis of vitamin A;
 - heat production.

The gallbladder

The gallbladder is a small, green, muscular sac that lies posterior to the liver. It functions as a reservoir for bile. It also concentrates bile by absorbing water. The mucosa of the gallbladder, like the rugae of the stomach, contains folds that allow the gallbladder to stretch in order to accommodate varying volumes of bile. When the smooth muscle walls of the gallbladder contract, bile is expelled into the cystic duct and down into the common bile duct before entering the duodenum via the hepatopancreatic ampulla.

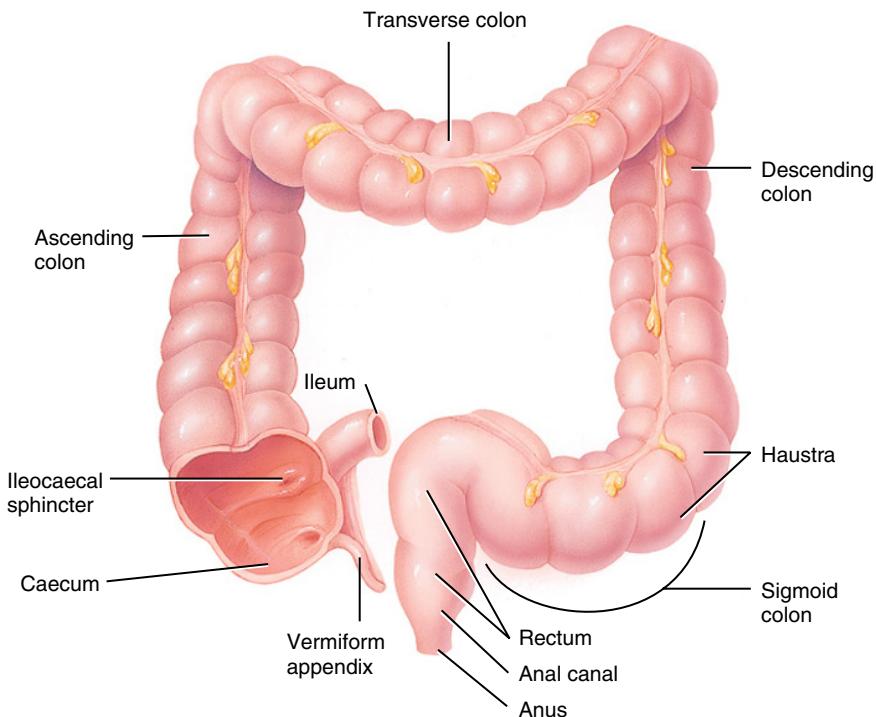
The stimulus for gallbladder contraction is the hormone CKK. This enteroendocrine hormone, secreted from the small intestine into the blood, is produced in response to the presence of fatty chyme in the duodenum. CKK stimulates the secretion of pancreatic juice and the relaxation of the hepatopancreatic sphincter. When the sphincter is relaxed, both bile and pancreatic juice can enter the duodenum. Figure 9.15 summarises the production and release of bile.

The large intestine

The contents of the small intestine move slowly through it by a process called segmentation. This allows time to complete digestion and absorption. Entry to the large intestine is controlled by the ileocaecal sphincter. The sphincter opens in response to the increased activity of the stomach and the action of the hormone gastrin. Once food residue has reached the large intestine it cannot backflow into the ileum (see Figure 9.15).

The large intestine measures 1.5 m in length and 7 cm in diameter. It is continuous with the small intestine from the ileocaecal valve and ends at the anus.

Food residue enters the caecum and has to pass up the ascending colon along the transverse colon, down the descending colon and out of the body via the rectum, anal canal and anus. The caecum is a descending, sac-like opening into the large intestine. The vermiform appendix is a narrow, tube-like structure that leaves the caecum but is closed at its distal end. It is composed



279

Figure 9.15 The large intestine. Source: Tortora and Derrickson (2009). Reproduced with permission of John Wiley & Sons.

of lymphoid tissue and has a role in immunity. Two sphincter muscles control exit from the anus. The internal anal sphincter is smooth muscle and is under the control of the parasympathetic nervous system, whereas the external anal sphincter is composed of skeletal muscle and is under voluntary control.

Clinical considerations

Appendicitis

The narrow lumen of the appendix does not allow much room for inflammation. If it becomes blocked by faecaliths (hard faecal material) or becomes twisted and kinked, this results in inflammation of the appendix. The swelling associated with this can lead to ulceration of the mucosal lining. This presents initially as central abdominal pain that eventually localises at the region of the appendix. Appendicitis can subside, but often it results in abscess formation and even rupture.

The large intestine mucosa contains large numbers of goblet cells that secrete mucus to ease the passage of faeces and protect the walls of the large intestine. The simple columnar epithelium changes to stratified squamous epithelium at the anal canal. Anal sinuses secrete mucus in response to faecal compression. This protects the anal canal from the abrasion associated with defaecation.

The longitudinal muscle layer of the large intestine is formed into bands called the taeniae coli. These give the large intestine its gathered appearance. The sac created by this gathering is called a haustrum.

The food residue from the ileum is fluid when it enters the caecum and contains few nutrients. The small intestine is responsible for some of the absorption of water, but the primary function of the large intestine is to absorb water and turn the food residue into semi-solid faeces. The large intestine also absorbs some vitamins, minerals, electrolytes and drugs. Food residue usually takes 24–48 h to pass through the large intestine; 500 mL of food residue enters the large intestine daily and approximately 150 mL leaves as faeces.

As faeces enters the rectum, the stretching of the walls of the rectum initiates the **defaecation reflex**. Acquired, voluntary control of the defaecation reflex occurs between the ages of 2 and 3 years. The external anal sphincter is under voluntary control, and, if it is appropriate to do so, defaecation can occur. Contraction of the abdominal muscles and diaphragm (the Valsalva manoeuvre) creates intra-abdominal pressure and assists in the process of defaecation. If it is not appropriate to defaecate, as it is under voluntary control, it can be postponed. After a few minutes the urge to go will subside and will only be felt again when the next mass movement through the large intestine occurs.

Faeces is a brown, semi-solid material. It contains fibre, stercobilin (from the breakdown of bilirubin), water, fatty acids, shed epithelial cells and microbes. Stercobilin gives faeces its brown colour. An excess of water in faeces results in **diarrhoea**. This occurs when food residue passes too quickly through the large intestine, so that the absorption of water cannot occur. Conversely, **constipation** occurs if food residue spends too long in the large intestine.

Medicines management

Lactulose

Lactulose belongs to a group of medications called laxatives or aperients. It is used to treat constipation. Constipation occurs as a result of a lack of fluid intake or dehydration, a lack of exercise or immobility, during pregnancy or due to a lack of dietary fibre.

People who suffer from constipation should try to increase their mobility and fluid levels. They should examine their diet to see whether additional fibre can be taken. Lactulose may also be prescribed.

The usual adult dose for lactulose is 15 mL three times a day. Lactulose acts in the large intestine and can take 48 h to have an effect. Increasing fluid intake to 2 L will also help.

Lactulose is an osmotic laxative (Galbraith *et al.*, 2007). Lactulose leads to a change in the osmotic pressure in the bowel, and therefore more water is available in the intestine. This leads to the stool having more water content, making it pass through the intestine easier.

The side effects of taking lactulose include:

- nausea
- diarrhoea
- flatulence
- abdominal discomfort.

NICE (2014b) produces a Clinical Knowledge Summary on constipation.

Digestive tract hormones

Many hormones are responsible for the activity of the digestive system. A summary of their role is contained in Table 9.1.

Nutrition, chemical digestion and metabolism

This chapter has hitherto concentrated on how the digestive tract deals with food ingested in order to break it down into its constituent parts for use by the cells of the body. This section will consider nutrition and the role of a balanced diet in health.

An adequate intake of nutrients is essential for health. Nutrition also has an important role in social and psychological well-being. If managed inappropriately, nutrition can lead to many physical and psychological illnesses. Therefore, it is important to have an understanding of the role of nutrients within the body in order to understand how a lack or excess of nutrients will lead to ill health.

The remainder of this chapter will identify the macro- and micronutrients and the food groups that provide the source of macro- and micronutrients. It will examine what the nutrients are broken down into and how the body uses these constituent parts.

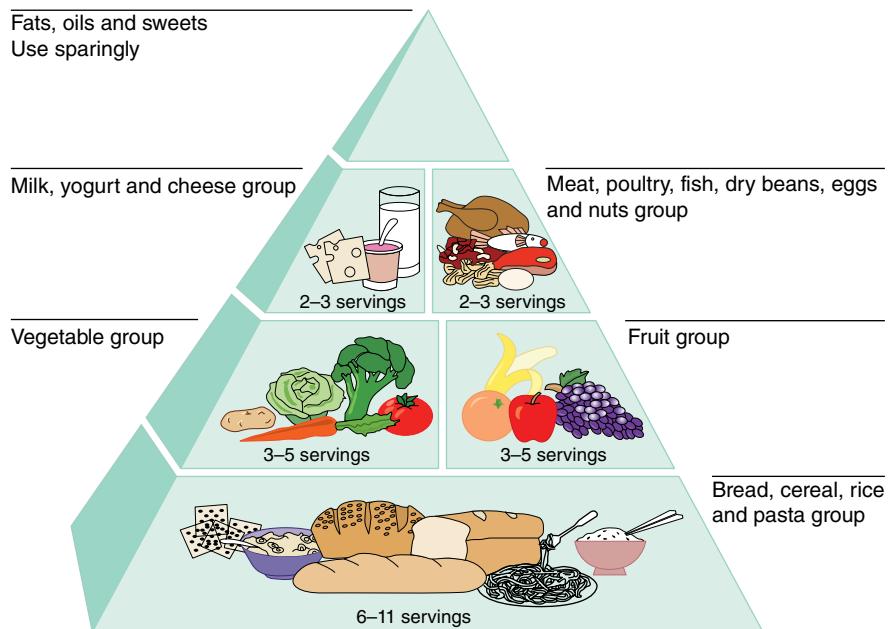
281

Nutrients

A nutrient is a substance that is ingested and processed by the gastrointestinal system. It is digested and absorbed and can be used by the body to produce energy or become the building block for a new molecule or to participate in essential chemical reactions. Nutrients are required for body growth, repair and maintenance of cell function. Not all of food ingested can be classed as nutrients. Some non-digestible plant fibres are not nutrients but are required for healthy functioning of the digestive system.

Table 9.1 Summary of the role of the digestive system hormones

Hormone	Origin	Target	Action	Stimulus
Gastrin	Stomach	Stomach	Increases gastric gland secretion of hydrochloric acid Gastric emptying	Presence of protein in the stomach
Secretin	Duodenum	Stomach	Inhibits gastric gland secretion Inhibits gastric motility	Acidic and fatty chyme in the duodenum
		Pancreas	Increases pancreatic juice secretion Promotes cholecystokinin action	
		Liver	Increases bile secretion	
Cholecystokinin	Duodenum	Pancreas	Increases pancreatic juice secretion	Chyme in the duodenum
		Gallbladder	Stimulates contraction	
		Hepatopancreatic sphincter	Relaxes – entry to duodenum open	



282

Figure 9.16 The food pyramid. Source: Tortora and Derrickson (2009). Reproduced with permission of John Wiley & Sons.

Balanced diet

The body has the ability to break down some nutrients in order to create new molecules, but this ability is finite and there remains a group of essential nutrients that the body cannot make but are required to be ingested in the diet for homeostasis to be maintained. A balanced diet is therefore essential for health (Department of Health, 2003). The daily recommended portions of food groups required for a balanced diet are shown in the food pyramid (see Figure 9.16). Lack of a balanced diet can lead to malnourishment, and overindulgence can lead to obesity.

Snapshot

Bariatric surgery

Bariatric surgery is used as a last resort to treat those who are severely obese. The procedure works by reducing intake or the absorption of calories and is used to treat people with potentially life-threatening obesity if other treatments (e.g. lifestyle changes) have not worked. Indications include:

- a body mass index (BMI) greater than 40;
- a BMI of 35 or above and having another serious health condition that may be improved if weight is lost (e.g. type 2 diabetes or hypertension);
- other non-surgical methods have failed to maintain weight loss for at least 6 months;
- the person commits to long-term follow-up.

Weight loss surgery can help to significantly and quickly reduce excess body fat for those who meet the criteria. Bariatric surgery has to be undertaken in a specialist centre with long-term follow-up of patients. National guidelines are available concerning bariatric surgery. Contraindications include those who are unfit for surgery and those people with an uncontrolled alcohol or drug dependency.

Dietary nutrients begin life as large food molecules. They enter the digestive tract and are broken down into smaller molecules. This process is called catabolism. Digestive enzymes facilitate the breakdown of foods by a process called hydrolysis. Hydrolysis is the addition of water to break down the chemical bonds of the food molecules. Each of the three different types of food is broken down (lysed) by different enzymes.

Nutrient groups

Carbohydrates, proteins and lipids are known as the major nutrients or macronutrients. They are required in quite large quantities. Vitamins and minerals are required in much smaller quantities, but they also are crucial for the maintenance of health. They are also known as the micronutrients. There are therefore six classes of nutrients:

283

- water
- carbohydrates
- proteins
- lipids (fats)
- vitamins
- minerals.

Water

Water is essential for the action of many digestive system functions. It is required to produce the many different juices of the digestive system. As the enzymes act on the different food molecules within the diet, water is added. This process is known as hydrolysis (Cohen and Hull, 2015).

Carbohydrates

Monosaccharides, disaccharides and polysaccharides are all carbohydrates. The dietary source of carbohydrates is plants. However, the milk sugar lactose is a form of carbohydrate found in cow and human milk. Carbohydrates are found in many foods, such as bread, pasta, cereal, biscuits, vegetables and fruit.

Carbohydrates consist of carbon, hydrogen and oxygen. They can be complex, such as the polysaccharides starch and glycogen, or simple, such as the disaccharides sucrose (table sugar) and lactose (milk sugar) and the monosaccharides glucose, fructose and galactose.

Digestion of carbohydrates supplies the body with fructose, galactose and glucose. The liver converts fructose and galactose to glucose as glucose is the molecule used by the body's cells.

Digested carbohydrates are absorbed into the blood via the villi of the small intestine. They enter the hepatic portal circulation and are transported to the liver for processing. The liver is a highly metabolic organ that requires a plentiful supply of glucose to carry out its metabolic activity.

Glucose is used by the cells to produce adenosine triphosphate (ATP). Glucose plus oxygen makes ATP, carbon dioxide and water. The process of breaking down glucose is called glycolysis.

Insufficient carbohydrate intake will lead to an inability to meet the cells' energy demands. If this happens, the body will break down amino acids and lipids to create new glucose, a process called gluconeogenesis.

Excess glucose is converted to glycogen and stored in the liver. It can also be converted to fat and stored.

Fats

Dietary sources of fat include butter, eggs, cheese, milk, oily fish and the fatty part of meat. These contain saturated fat, which is mainly saturated fatty acids and glycerol. Vegetable oils and margarine are sources of unsaturated fats. The body can also create fat from excess carbohydrate and protein intake.

Fat also contains carbon, hydrogen and oxygen, but in a different combination from carbohydrates.

When fat enters the small intestine it mixes and is emulsified by bile. The action of pancreatic lipase completes the digestion of fat and it is broken down into monoglycerides, glycerol and fatty acids. The monoglycerides and some of the fatty acids enter the lacteals of the villi and are transported via the lymph to the thoracic duct and into the circulation, where they eventually reach the liver. Glycerol and the remaining fatty acids are absorbed more directly into the capillary blood and reach the liver via the hepatic portal vein.

The liver uses some of the fatty acids and glycerol to provide energy and heat. In fact, hepatocytes and skeletal muscle use triglycerides as their major energy source. Excessive triglycerides can also be stored as adipose tissue, and this can also be used as an energy store when glucose is not available to body cells.

Dietary fats make food seem tender and lead to a feeling of satisfaction with food. They are necessary for the absorption of fat-soluble vitamins. Adipose tissue protects, cushions and insulates vital organs in the body. Phospholipids are required to form the myelin sheath and cell membranes. Cholesterol is obtained from egg yolk and dairy produce but is also synthesised in the body to form steroid hormones and bile salts.

Excess fat in the diet can lead to obesity and cardiovascular disease. A lack of fat in the diet can lead to weight loss, poor growth and skin lesions.

Proteins

Dietary sources of protein include meat, eggs and milk. Beans and peas (legumes), nuts, cereals and leafy green vegetables are also sources of amino acids.

Protein digestion begins in the stomach and is completed in the small intestine. Proteins are broken down into amino acids. They are absorbed via the villi of the small intestine, where they reach the capillaries and then the hepatic portal circulation to the liver or general circulation.

Proteins are used by the body for many purposes. They are used to form muscle, collagen and elastin, necessary for body structure and tissue repair. The hormones insulin and growth hormone are required for this. Amino acids are also used to form hormones and enzymes within the body. All of the amino acids required to form a required protein must be available within the cell in order for that protein to be made. This is called the all or nothing rule. Protein can also be used as a source of energy for the body. The amino acid is broken down mainly at the liver, where the nitrogenous part of the amino acid is removed and converted first to ammonia and then to urea. Urea is excreted as a waste product in urine. The remainder of the amino acid is used to produce energy. Protein cannot be stored by the body. Any excess amino acids are converted to carbohydrate or fat to be stored as adipose tissue.

Too much protein in the diet can lead to obesity. A lack of dietary protein can lead to muscle/tissue wasting and weight loss. A lack of plasma proteins can lead to oedema.

Table 9.2 Vitamins summary**K M C**

Vitamin	Source	Function	Deficiency
Fat soluble			
A, retinol	Manufactured from beta-carotene. Egg yolk, cream, fish oil, cheese, liver	Skin, mucosa integrity; bone and tooth development during growth; photoreceptor pigment synthesis in the retina, normal reproduction, antioxidant	Night blindness, dry skin and hair, loss of skin integrity, increased infection particularly respiratory, gastrointestinal and urinary
D	Manufactured by the skin. Cheese, eggs, fish oil, liver	Regulates calcium and phosphate metabolism	Rickets in children, osteomalacia in adults
E	Egg yolk, wheat germ, whole cereals, milk and butter	Antioxidant	In severe deficiency, ataxia and visual disturbances, decreased life span of red blood cells
K	Synthesised by bacteria in the large intestine. Liver, fish, fruit and leafy green vegetables	Formation of clotting proteins at the liver	Prolonged clotting times, bruising, bleeding
Water soluble			
B ₁ , thiamine	Egg yolk, liver, nuts, meat, legumes cereal germ	Coenzyme required for carbohydrate metabolism	Beriberi – muscle wasting, stunted growth polyneuritis and infection. Vision disturbances, confusion, unsteadiness, memory loss, fatigue, tachycardia, heart enlargement
B ₂ , riboflavin	Milk, green vegetables, yeast, cheese, fish roe, liver	Coenzyme required for carbohydrate and protein metabolism	Skin-cracking, particularly around the corners of the mouth, blurred vision, corneal ulcers, intestinal mucosa lesions
Folic acid	Liver, kidney, yeast, fresh leafy vegetables, eggs, whole grains	Coenzyme essential for DNA synthesis, red blood cell formation	Anaemia, spina bifida in newborn, increased risk of heart attack and stroke
Niacin, nicotinic acid	Liver, cheese, yeast, eggs, cereals, nuts, fish	Coenzyme involved in glycolysis, fat breakdown – assists with breakdown and inhibits cholesterol production	Pellagra – skin reddening to light, anorexia, nausea and dysphagia, delirium and dementia
B ₆ , pyridoxine	Meat, liver, fish, grains, bananas, yeast	Coenzyme involved in amino acid metabolism	Increased risk of heart disease, eye and mouth lesions. In children, nervous irritability, convulsions, abdominal pain and vomiting
B ₁₂ , cyanocobalamin	Meat, fish, liver, eggs, milk	Coenzyme in all cells, involved in DNA synthesis. Formation and maintenance of myelin around nerves	Pernicious anaemia, peripheral neuropathy
B ₅ , pantothenic acid	Meat, grains, legumes, yeast, egg yolk	Coenzyme associated with amino acid metabolism and formation of steroids	Non-specific symptoms
Biotin	Egg yolk, liver, legumes, tomatoes	Coenzyme in carbohydrate metabolism	Pallor, anorexia, nausea, fatigue
C, ascorbic acid	Fruit, particularly citrus fruit, vegetables	Antioxidant, enhances iron absorption and use, maturation of red blood cells	Poor wound healing, joint pain, anaemia, scurvy

Vitamins

Vitamins are organic molecules that are required in small amounts for healthy metabolism. Essential vitamins cannot be manufactured by the body and must come from the diet, highlighting again the importance of a balanced diet. Some vitamins can be manufactured. Vitamin K is synthesised by intestinal bacteria; the skin makes vitamin D; and vitamin A is made from beta-carotene, found for example in carrots.

Many vitamins act as *coenzymes* (Seeley *et al.*, 2008). These vitamins combine with enzymes to make them functional. For example, the formation of clotting proteins requires the presence of vitamin K.

During metabolism a reaction takes place involving oxygen. Potentially harmful free radicals are formed as part of this process. Vitamins A, C and E are antioxidants that disarm free radicals and protect tissue from their potentially dangerous effects.

Vitamins are either fat soluble or water soluble. The fat-soluble vitamins combine with lipids from the diet and are absorbed in this way. Apart from vitamin K, the fat-soluble vitamins can be stored in the body; therefore, there can be problems associated with toxicity when these vitamins accumulate.

The water-soluble vitamins are absorbed with water along the digestive tract. They cannot be stored, and any excess ingested will be excreted in urine. A summary of vitamins and their functions is given in Table 9.2.

Minerals

Small quantities of inorganic compounds called minerals are required by the body for many purposes. For example, calcium gives structure and strength to tissues, and sodium forms ions essential for maintaining osmotic pressure. They also form approximately 5% of the body weight (Nair and Peate, 2013).

There are minerals that are required in moderate amounts, such as calcium and magnesium, and many others known where trace amounts are required, such as cobalt and copper. A summary of some of the minerals and their function is given in Table 9.3.

Clinical considerations

Obesity

Obesity is on the increase in Western society. Obesity occurs when more calories are taken in than are used by the body. Lack of exercise, a sedentary lifestyle and generous diet all contribute to weight gain. Obesity has serious health consequences as it predisposes people to indigestion, gallstones, hernias, cardiovascular disease, varicose veins, osteoarthritis and type 2 diabetes mellitus.

Conclusion

Digestion and nutrition play a vital role in the maintenance of health. The digestive tract processes ingested nutrients by breaking them down chemically and mechanically. Accessory structures, such as the pancreas, liver and gallbladder, have an essential role in providing the digestive tract with bile and pancreatic juice to facilitate the digestion of the macronutrients protein, carbohydrate and fat. The small intestine provides the large surface area available for the absorption of nutrients, and the liver processes the products of digestion. The large intestine

Table 9.3 Minerals summary

Mineral	Source	Function	Deficiency(D)/excess(E)
Calcium	Milk, egg yolk, shellfish, cheese, green vegetables	Bones and teeth, cell membrane permeability, nerve impulse transmission, muscle contraction, heart rhythm, blood clotting	D: osteomalacia, osteoporosis, muscle tetany. In children – rickets and retarded growth
			E: lethargy and confusion, kidney stones
Chloride	Table salt	Works with sodium to maintain osmotic pressure of extracellular fluid	D: alkalosis, muscle cramps
			E: vomiting
Magnesium	Nuts, milk, legumes, cereal	Constituent of coenzymes. Muscle and nerve irritability	D: neuromuscular problems, irregular heartbeat
			E: diarrhoea
Sodium	Table salt	Extracellular cation. Works with chloride to maintain osmotic pressure of extracellular fluid. Muscle contraction, nerve impulse transmission, electrolyte balance	D: rare – nausea
			E: hypertension, oedema
Potassium	Fruit and vegetables and many foods	Intracellular cation. Muscle contraction, nerve impulse transmission electrolyte balance	D: Rare – muscle weakness, nausea, tachycardia
			E: cardiac abnormalities, muscular weakness
Iron	Liver, kidney, beef, green vegetables	Constituent of haemoglobin	D: anaemia
			E: haemochromatosis, liver damage
Iodine	Saltwater fish, vegetables	Constituent of thyroid hormones	D: hypothyroidism
			E: thyroid hormone synthesis depressed

287

plays an excretory role, ridding the body of the waste products from digestion and absorbing any remaining water back into the body.

The maintenance of homeostasis is achieved through the ingestion of a balanced diet, containing a variety of elements from each of the food groups.

Without all of this activity, normal cell functioning would be at risk and this would lead to ill health. Digestive health contributes greatly to physical, psychological and social well-being.

Glossary

Absorption Process whereby the products of digestion move into the blood or lymph fluid.

Acini glands Produce pancreatic juice.

Amylase Carbohydrate-digesting enzyme.

Anus End of the digestive tract.

- Bile** Fluid produced by the liver and required for the digestion of fat.
- Bile duct** Tube that carries bile from the liver.
- Body region** Region of the stomach.
- Caecum** Beginning of the large intestine.
- Canine** Type of tooth.
- Carbohydrate** One of the major food groups.
- Cardiac region** Region of the stomach closest to the oesophagus.
- Catabolism** Process of breaking down substances into simpler substances.
- Chief cells** Pepsinogen-producing cells.
- Cholecystokinin** Digestive system hormone.
- Chyme** Creamy, semi-fluid mass of partially digested food mixed with gastric secretions.
- Deglutition** Swallowing.
- Digestion** The chemical and mechanical breakdown of food for absorption.
- Duodenum** First part of the small intestine.
- Enamel** Covering of the tooth.
- Epiglottis** Cartilage that covers the larynx during swallowing.
- Faeces** Brown, semi-solid digestive system waste.
- Fats** One of the major food groups.
- Frenulum** Fold between the lip and gum.
- Fundus** Anatomical base region of the stomach.
- Gluconeogenesis** The creation of glucose from non-carbohydrate molecules.
- Glycolysis** The anaerobic breakdown of glucose to form pyruvic acid.
- Goblet cell** Mucus-producing cell.
- Haustrum** Sac-like section of the large intestine.
- Hepatocyte** Liver cell.
- Hepatic portal vein** Vein that delivers dissolved nutrients to the liver.
- Hepatopancreatic ampulla** The site where the bile duct and pancreatic duct meet.
- Hepatopancreatic sphincter** Muscular valve that controls the entrance of pancreatic juice and bile to the duodenum.
- Hyoid bone** Bone that acts as the base of the tongue.
- Hydrochloric acid** Acid produced by the parietal cells of the stomach.
- Hydrolysis** Addition of water to breakdown food molecules.
- Hypochondriac region** Upper lateral divisions of the abdominopelvic cavity.
- Ileum** The end part of the small intestine.
- Ileocaecal valve** Site where the small and large intestine meet.
- Ingestion** The process of taking food into the body via the mouth.

- Incisors** Type of tooth.
- Intestinal crypts** Also known as the crypts of Lieberkühn – glands found in the villi of the small intestine.
- Intrinsic factor** Substance required for the absorption of vitamin B₁₂.
- Jejunum** The middle part of the small intestine between the duodenum and the ileum.
- Kupffer cell** Hepatic macrophage.
- Lacteal** Lymphatic capillary of the small intestine.
- Lamina propria** Loose connective tissue layer of the digestive tract.
- Laryngopharynx** Where the larynx and pharynx meet.
- Lipase** Fat-digesting enzyme.
- Liver** Accessory organ located in the abdominal cavity that has many metabolic and regulatory functions.
- Liver sinusoid** Liver capillary.
- Lower oesophageal sphincter** Valve between the oesophagus and stomach.
- Lysozyme** Bactericidal enzyme.
- Macronutrient** Food consumed in large quantities.
- Mastication** Chewing.
- Metabolism** Sum total of the chemical reactions occurring in the body.
- Meissner's plexus** Nerves of the small intestine.
- Mesenteric plexus** Digestive tract innervation.
- Micronutrient** Nutrient required in small quantities.
- Microvilli** Cytoplasmic extensions of the villi.
- Minerals** Salts – inorganic compounds.
- Molars** Type of tooth.
- Mucosa** Layer of the digestive tract.
- Mucous neck cells** Mucus-secreting cells of the stomach.
- Muscularis mucosa** Muscular layer of the digestive tract.
- Nutrient** Product obtained from the digestion of food and used by the body.
- Oesophagus** Muscular tube from laryngopharynx to stomach.
- Oral cavity** The first part of the digestive system.
- Oropharynx** Part of the pharynx closest to the oral cavity.
- Palate** Roof of the mouth.
- Pancreatic duct** Duct that links the pancreas and common bile duct.
- Paneth cell** Cell that produces lysozyme.
- Papillae** Small mucosal projections.
- Parasympathetic fibres** Autonomic nervous system nerve fibres.

- Parietal cells** Hydrochloric acid-producing cell of the stomach.
- Parotid glands** Salivary glands located close to the ears.
- Pepsin** Enzyme required for the breakdown of protein.
- Pepsinogen** Enzyme precursor of pepsin.
- Peristalsis** Wave-like contractions that move food through the digestive tract.
- Peritoneum** Serous membrane that lines the abdominal cavity.
- Peyer's patches** Lymphatic tissue of the small intestine.
- Pharyngeal phase** Second phase of swallowing.
- Pharynx** Tube between the mouth and the oesophagus.
- Plicae circulares** Permanent circular folds in the small intestine.
- Portal fissure** Area where blood vessels and nerves enter and leave the liver.
- Portal triad** Corner of liver lobule.
- Premolars** Type of tooth located between the canine and molar teeth.
- Propulsion** The process of moving the food along the length of the digestive system.
- Proteins** Substance that contains carbon, hydrogen, oxygen and nitrogen.
- Pulp cavity** Centre of the tooth.
- Pyloric canal** Area where the stomach opens into the small intestine.
- Pyloric region** Area of the stomach that occurs where the stomach meets the small intestine.
- Pyloric sphincter** Valve that controls food movement from the stomach to the small intestine.
- Rectum** Final portion of the large intestine.
- Rugae** Folds or ridges found in the digestive tract.
- Salivary amylase** Carbohydrate-digesting enzyme found in saliva.
- Secretin** Hormone that regulates secretion of pancreatic juice.
- Segmentation** Movement of chyme in the small intestine.
- Serosa** Outer layer of the digestive tract.
- Sphincter of Oddi** Valve that controls the movement of bile and pancreatic juice into the small intestine.
- Splanchnic circulation** Blood vessels of the digestive system.
- Stercobilin** Waste product of bilirubin breakdown.
- Stomach** Food reservoir where the digestion of protein begins.
- Sublingual glands** Salivary gland located on the floor of the mouth.
- Submandibular glands** Salivary glands located below the jaw bilaterally.
- Submucosa** Thick connective tissue layer of the digestive tract.
- Superior mesenteric artery** Vessel that supplies the small intestine with arterial blood.
- Superior mesenteric vein** Blood vessel that drains venous blood from the small intestine.
- Surface mucous cells** Mucus-secreting cells of the stomach.

Stomach Reservoir for food involved in both chemical and mechanical digestion.

Taeniae coli Muscle bands in the large intestine.

Upper oesophageal sphincter Controls the movement of food into the oesophagus from the oropharynx.

Uvula Small piece of tissue that protrudes from the soft palate.

Vermiform appendix Blind-ended tube connected to the caecum and composed of lymphatic tissue.

Villi Tiny, finger-like projections found on the surface of the mucosa of the small intestine.

Visceral peritoneum The innermost part of the peritoneum that is in contact with the abdominal organs.

Vitamins Essential organic compounds require in small amounts.

Voluntary phase The first phase of swallowing.

291

References

- Cohen, B.J. and Hull, K.L. (2015) *Memmler's The Human Body in Health and Disease*, 13th edn. Philadelphia, PA: Wolters Kluwer.
- Department of Health (2003) *The Essence of Care: Patient-Focused Benchmarks for Clinical Governance*. London: The Stationery Office.
- Galbraith, A., Bullock, S., Manias, E., Hunt, B. and Richards, A. (2007) *Fundamentals of Pharmacology. An Applied Approach for Nursing and Health*, 2nd edn. Abingdon: Routledge.
- Marieb E.N. (2009) *Essentials of Human Anatomy & Physiology*, 9th edn. San Francisco, CA: Pearson Benjamin Cummings.
- Marieb, E.N. and Hoehn K. (2010) *Human Anatomy and Physiology*, 8th edn. San Francisco, CA: Pearson Benjamin Cummings.
- Nair, M. and Peate, I. (2013) *Fundamentals of Applied Pathophysiology. An Essential Guide for Nursing Students*, 2nd edn. Chichester: John Wiley & Sons, Ltd.
- NICE (2010) *Pancreatitis – Chronic*. <http://cks.nice.org.uk/pancreatitis-chronic> (accessed 25 November 2015).
- NICE (2014a) *Gastro-oesophageal Reflux and Dyspepsia in Adults: Investigation and Management*. NICE guidelines [CG184]. <http://www.nice.org.uk/guidance/cg184> (accessed 25 November 2015).
- NICE (2014b) *Constipation*. <http://cks.nice.org.uk/constipation#lscenariorecommendation:4> (accessed 25 November 2015).
- Seeley, R.R., Stephens, T.D. and Tate, P. (2008) *Anatomy and Physiology*, 8th edn. New York: McGraw-Hill.
- Tortora, G.J. and Derrickson, B.H. (2009) *Principles of Anatomy and Physiology*, 12th edn. Hoboken, NJ: John Wiley & Sons, Inc.
- Tortora, G.J. and Derrickson, B.H. (2012) *Essentials of Anatomy and Physiology*, 9th edn. New York: John Wiley & Sons, Inc.

Further reading

<http://www.crohnsandcolitis.org.uk/>

Crohn's & Colitis UK is a charity for those affected by inflammatory bowel disease.

<https://www.nice.org.uk/guidance/cg152>

Link to clinical guidelines on Crohn's disease: management in adults, children and young people.

Approved: 0777 023 444

<http://www.colostomyassociation.org.uk/>

The Colostomy Association is a charity for people with colostomy.

<http://www.nationalsmilemonth.org/>

An initiative to improve oral health and hygiene. It is organised by a charity called the British Dental Health Foundation.

Activities

Multiple choice questions

292

1. Which of these vitamins is essential for blood clotting?
 - (a) vitamin A
 - (b) vitamin B₁₂
 - (c) vitamin E
 - (d) vitamin K
2. Which mineral found in broccoli provides the body with an essential constituent of the thyroid hormone thyroxine?
 - (a) iron
 - (b) iodine
 - (c) calcium
 - (d) potassium
3. Which of these is true of fat?
 - (a) it is used for the growth and repair of body cells
 - (b) it is a constituent of myelin sheaths
 - (c) it is essential for the transport of the water-soluble vitamins
 - (d) all of the above
4. Which layer of the digestive tract is responsible for peristalsis?
 - (a) mucosa
 - (b) submucosa
 - (c) muscularis
 - (d) peritoneum
5. Which of these structures is considered an accessory organ?
 - (a) salivary gland
 - (b) pancreas
 - (c) liver
 - (d) all of them
6. Where does most of the absorption of nutrients occur?
 - (a) small intestine
 - (b) large intestine
 - (c) stomach
 - (d) oesophagus
7. Which of these is *not* a constituent of gastric juice?
 - (a) hydrochloric acid
 - (b) mucus
 - (c) intrinsic factor
 - (d) trypsinogen

8. Which enzyme is involved in the breakdown of protein?
 - (a) chymotrypsin
 - (b) lipase
 - (c) amylase
 - (d) bile
9. Where is bile produced?
 - (a) the small intestine
 - (b) the gallbladder
 - (c) the pancreas
 - (d) the liver
10. Which part of the large intestine is lymphoid tissue?
 - (a) the appendix
 - (b) the caecum
 - (c) the ascending loop
 - (d) the sigmoid colon

293

True or false

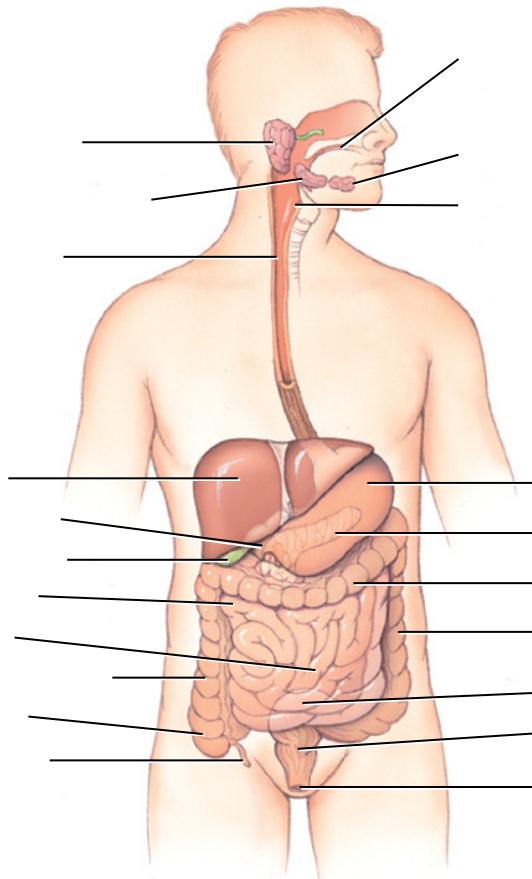
1. The large intestine is colonised with bacteria.
2. The first section of small intestine is called the jejunum.
3. Pancreatic juice reaches the duodenum through the cystic duct.
4. The function of bile is to emulsify fats.
5. There are 20 milk teeth.
6. The enzyme that acts on carbohydrate is lipase.
7. The sense of taste is improved when food is not dry.
8. The oesophagus contains only smooth muscle.
9. Intrinsic factor is produced by enteroendocrine cells.
10. The secretion of gastric juice is increased during the intestinal phase.

Label the diagram 1

Label the diagram using the following list of words:

Parotid gland (salivary gland), Submandibular gland (salivary gland), Oesophagus, Liver, Duodenum, Gallbladder, Jejunum, Ileum, Ascending colon, Caecum, Appendix, Mouth (oral cavity), Sublingual gland (salivary gland), Pharynx, Stomach, Pancreas, Transverse colon, Descending colon, Sigmoid colon, Rectum, Anus

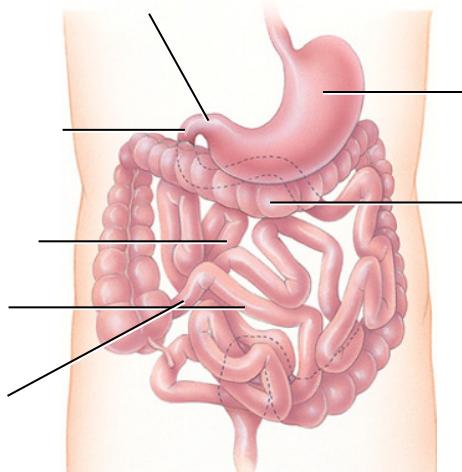
294

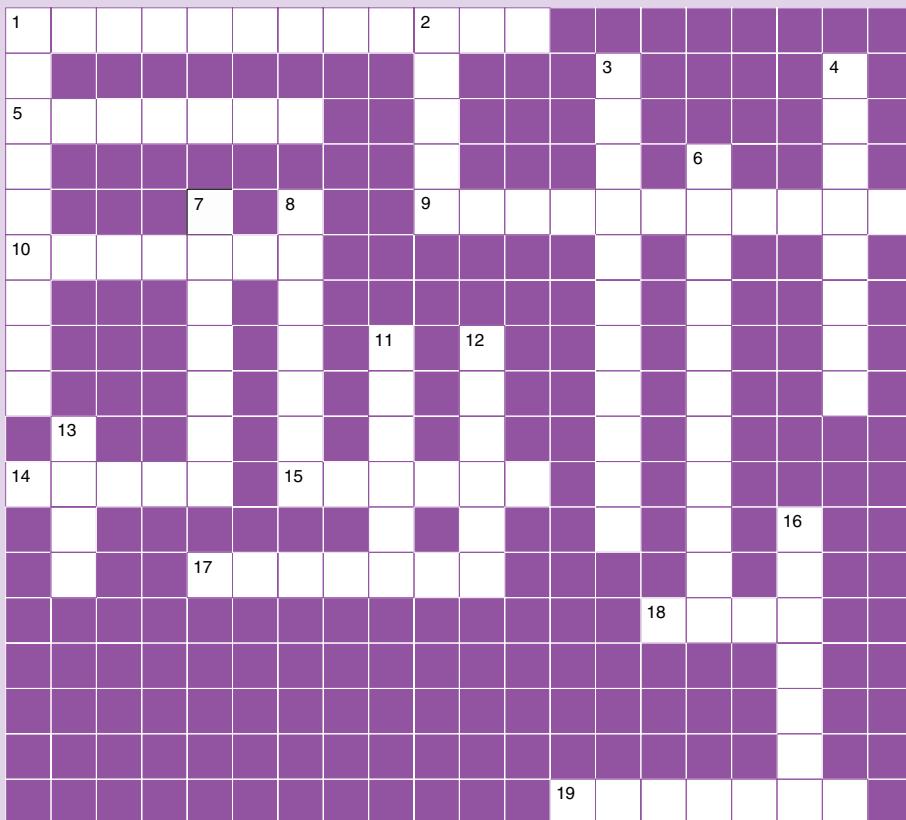


Label the diagram 2

Label the diagram using the following list of words:

Pylorus, Duodenum, Jejunum, Ileum, Ileocaecal value, Stomach, Large intestine



Crossword**Across:**

1. Another name for vitamin C (8, 4).
5. A cutting tooth (7).
9. Function of the large intestine (11).
10. Enzyme responsible for carbohydrate breakdown (7).
14. Another name for fat (5).
15. Innermost layer of the digestive tract (6).
17. Essential organic molecule (7).
18. End of the digestive system (4).
19. Passageway for air and food (7).

Down:

1. Protein is broken down into this (5, 4).
2. Food mixed with hydrochloric acid (5).
3. Describes the movement of the digestive tract (11).
4. Anti-bacterial constituent of saliva (8).
6. Another word for chewing (11).
7. Salivary gland (7).
8. Middle portion of the small intestine (7).
11. Entry to large intestine from the small intestine (6).
12. Enzyme responsible for the digestion of protein (6).
13. Made in the liver and required for the digestion of fat (4).
16. Hormone that stimulates the secretion of hydrochloric acid (7).

Fill in the blanks

The digestive system is also known as the _____ canal. The action of enzymes on ingested food is known as _____ digestion. The churning of ingested food by the muscular activity of the digestive system is known as _____ digestion. The digestive system is protected from invading pathogens by the presence of _____ in salivary amylase and _____ produced by the _____ cells of the stomach.

Digestion of _____ begins in the stomach. _____ is the name of the enzyme involved in the breakdown of carbohydrates. Fat digestion relies on the presence of _____ and _____.

mechanical, lysozyme, alimentary, lipase, hydrochloric acid, chemical, amylase, parietal, protein, bile

296

Find out more

1. What is gingivitis and what advice would you give to help prevent this condition?
2. Oral candidiasis (oral thrush) affects many hospital in-patients. Can you suggest why this might be and discuss the treatment available?
3. What is the role of the nurse in caring for a patient with dysphagia?
4. Discuss the conditions that may lead to a patient requiring an ileostomy.
5. Differentiate between colostomy and ileostomy.
6. A 28-year-old woman has had a colostomy formed. She asks you how the colostomy would be affected should she become pregnant. How would you advise this patient?
7. Discuss how the digestive system would respond to starvation.
8. Investigate the services available to patients who have irritable bowel syndrome to help them manage everyday life.
9. A range of medications is available to minimise or eliminate digestive system conditions associated with the acid environment of the stomach. Research these medications and consider when they may be used.
10. Constipation is a very common digestive system condition. What is the role of the nurse in relation to prevention of constipation?

Test your learning

1. Where does bile and pancreatic juice enter the duodenum?
2. Which teeth are used for grinding of food?
3. What is the exocrine pancreatic product essential for?
4. What are carbohydrates broken down into?
5. List the enzymes involved in the breakdown of protein.

Conditions

The following is a list of conditions that are associated with the digestive system. Take some time and write notes about each of the conditions. You may make the notes taken from text books or other resources (e.g. people you work with in a clinical area), or you may make the notes as a result of people you have cared for. If you are making notes about people you have cared for you must ensure that you adhere to the rules of confidentiality.

Peptic ulcer	
Peritonitis	297
Ulcerative colitis	
Paralytic ileus	
Obesity	
Malnutrition	

K M C

Approved: 0777 023 444

Chapter 10

The renal system

Muralitharan Nair

Test your prior knowledge

- Name the functions of the kidneys.
- List the organs of the renal system.
- Describe the components of a nephron.
- List the composition of urine.
- What is the colour of urine? Think about the destruction of the red blood cells.

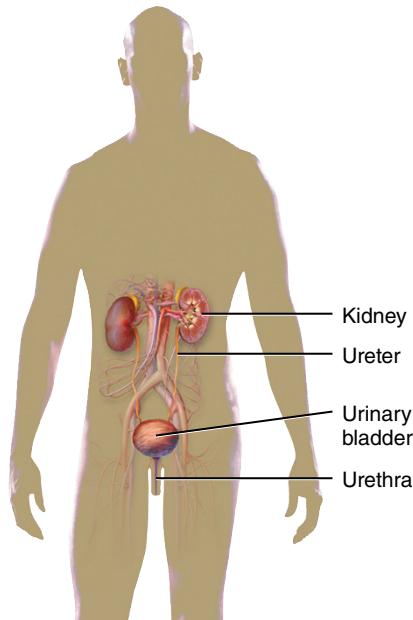
Learning outcomes

After reading this chapter you will be able to:

- Describe the structure and functions of the kidney
- Describe the microscopic structures of the kidney
- Explain glomerular filtration
- List the chemical compositions of urine
- Discuss the structure and functions of the bladder

Body map

300



Introduction

The kidneys play an important role in maintaining homeostasis. They remove waste products through the production and excretion of urine and regulate fluid balance in the body. As part of their function, the kidneys filter essential substances from the blood, such as sodium and potassium, and selectively reabsorb substances essential to maintain homeostasis. Any substances not essential are excreted in the urine. The formation of urine is achieved through the processes of filtration, selective reabsorption and excretion. The kidneys also have an endocrine function, secreting hormones such as renin and erythropoietin. This chapter will discuss the structure and functions of the renal system. It will also include some common disorders and their related nursing management and treatment.

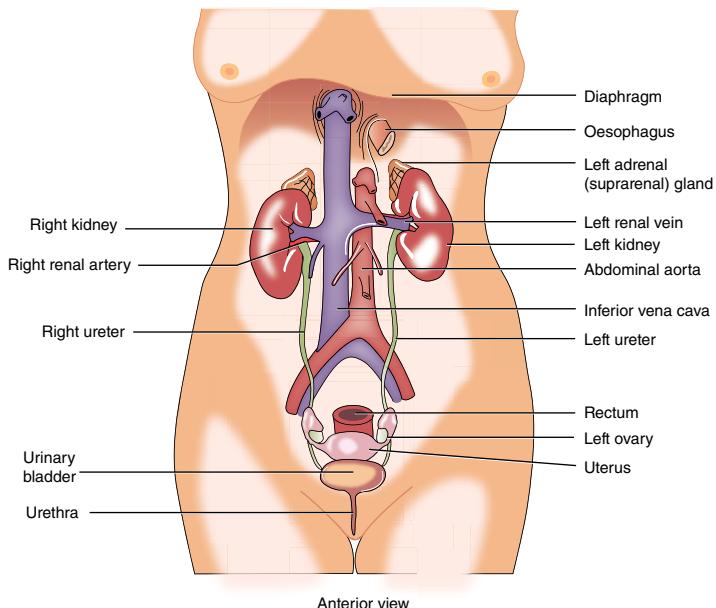
Renal system

The renal system, also known as the urinary system, consists of:

- kidneys, which filter the blood to produce urine;
- ureters, which convey urine to the bladder;
- urinary bladder, a storage organ for urine until it is eliminated;
- urethra, which conveys urine to the exterior.

See Figure 10.1 for the organs of the renal system.

The organs of the renal system ensure that a stable internal environment is maintained for the survival of cells and tissues in the body – homeostasis.



301

Figure 10.1 Organs of the renal system. Source: Tortora and Derrickson (2009). Reproduced with permission of John Wiley & Sons.

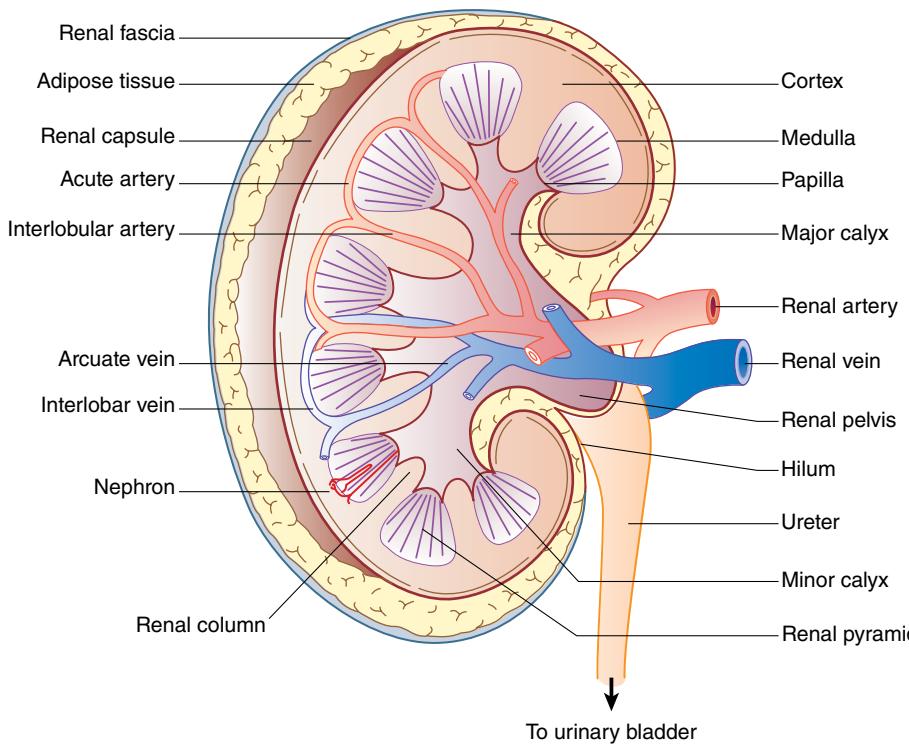
Kidneys: external structures

There are two kidneys, one on each side of the spinal column. They are approximately 11 cm long, 5–6 cm wide and 3–4 cm thick. They are said to be bean-shaped organs, where the outer border is convex; the inner border is known as the hilum (also known as hilus), and it is here that the renal arteries, renal veins, nerves and the ureters enter and leave the kidneys. The renal artery carries blood to the kidneys; and once the blood is filtered, the renal vein takes the blood away. The right kidney is in contact with the liver's large right lobe, and hence the right kidney is approximately 2–4 cm lower than the left kidney.

Covering and supporting the kidneys are three layers:

- renal fascia
- adipose tissue
- renal capsule.

The renal fascia is the outer layer and consists of a thin layer of connective tissue that anchors the kidneys to the abdominal wall and the surrounding tissues. The middle layer is called the adipose tissue and surrounds the capsule. It cushions the kidneys from trauma. The inner layer is called the renal capsule. It consists of a layer of smooth connective tissue that is continuous with the outer layer of the ureter. The renal capsule protects the kidneys from trauma and maintains their shape. See Figure 10.2 for the external layers.



302

Figure 10.2 External layers of the kidney.

Clinical considerations

Renal transplant

The main role of the kidneys is to filter waste products from the blood and convert them to urine. If the kidneys lose this ability, waste products can build up, which is potentially dangerous and can be life threatening. This loss of kidney function, known as end-stage chronic kidney disease or kidney failure, is the most common reason for needing a kidney transplant.

The kidney transplant is a major surgery that could take approximately 3 h. A donor kidney, from a living person, could take 3–5 days to achieve normal function, while a cadaver donor kidney could take 7–15 days to function normally. After surgery, immunosuppressant drugs are used to suppress the immune system from rejecting the donor kidney. These medicines must be taken for the rest of the recipient's life. The most common medication regimen today is a mixture of tacrolimus, mycophenolate and prednisone.

Kidney transplant recipients are discouraged from consuming grapefruit, pomegranate and green tea products. These food products are known to interact with the transplant medications, specifically tacrolimus, cyclosporin and sirolimus; the blood levels of these drugs may be increased, potentially leading to an overdose. A healthy lifestyle after a kidney transplant goes a long way to minimising the risk of complications.

See NHS Choices (2015a).

Kidneys: internal structures

There are three distinct regions inside the kidney:

- renal cortex
- renal medulla
- renal pelvis.

The renal cortex is the outermost part of the kidney. In adults, it forms a continuous, smooth outer portion of the kidney with a number of projections (renal column) that extend down between the pyramids. The renal column is the medullary extension of the renal cortex. The renal cortex is reddish in colour and has a granular appearance, which is due to the capillaries and the structures of the nephron. The medulla is lighter in colour and has an abundance of blood vessels and tubules of the nephrons (see Figure 10.3). The medulla consists of approximately 8–12 renal pyramids (see Figure 10.3). The renal pyramids, also called malpighian pyramids, are cone-shaped sections of the kidneys. The wider portion of the cone faces the renal cortex, while the narrow end points internally, and this section is called the renal papilla. Urine formed by the nephrons flows into cup-like structures, called calyces, via papillary ducts. Each kidney contains approximately 8–18 minor calyces and two or three major calyces. The minor calyces receive urine from the renal papilla, which conveys the urine to the major calyces. The major calyces unite to form the renal pelvis, which then conveys urine to the bladder (see Figure 10.4). The renal pelvis forms the expanded upper portion of the ureter, which is funnel-shaped and it is the region where two or three calyces converge.

303

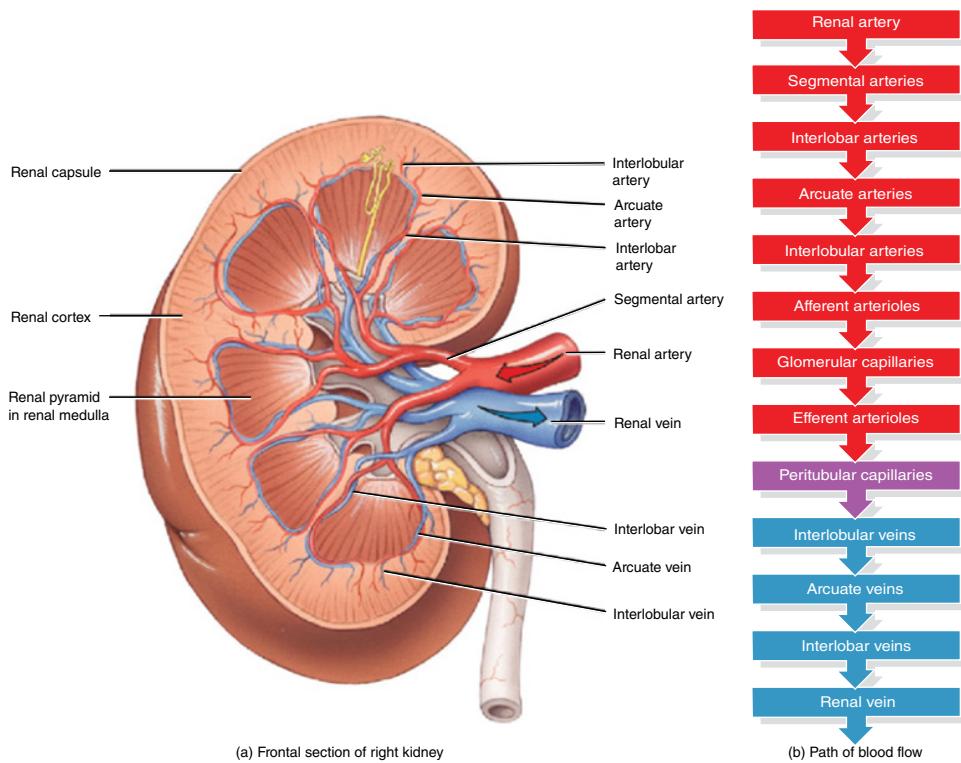


Figure 10.3 (a, b) Internal structures showing blood vessels. Source: Tortora and Derrickson (2009). Reproduced with permission of John Wiley & Sons.

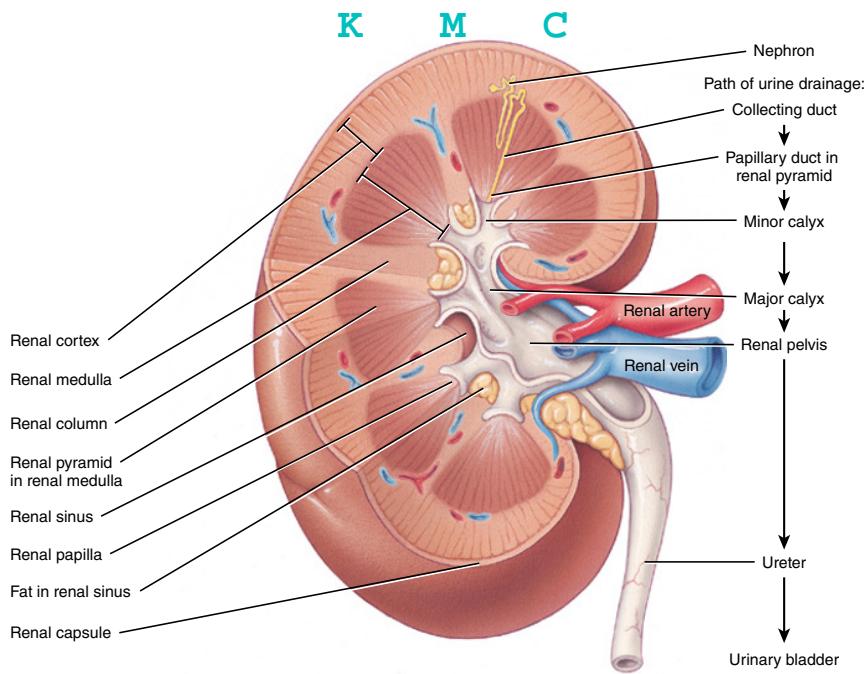


Figure 10.4 Internal structures. Source: Tortora and Derrickson (2009). Reproduced with permission of John Wiley & Sons.

Medicines management

Cyclosporine

Cyclosporine lowers the body's immune system. The immune system helps the body fight infections. The immune system can also fight or 'reject' a transplanted organ such as a liver or kidney. This is because the immune system treats the new organ as an invader. Cyclosporine is used to prevent organ rejection after a kidney, liver or heart transplant.

Signs of an allergic reaction include: hives; difficulty breathing; swelling of the face, lips, tongue or throat.

Some of the serious side effects include:

- urinating less than usual or not at all;
- drowsiness, confusion, mood changes, increased thirst;
- swelling, weight gain, feeling short of breath;
- blurred vision, headache or pain behind your eyes, sometimes with vomiting;
- seizure (convulsions);
- muscle pain or weakness, fast heart rate, feeling light-headed;
- signs of infection, such as fever, chills, sore throat, flu symptoms;
- pale skin, easy bruising or bleeding, unusual weakness; or
- nausea, stomach pain, loss of appetite, itching, dark urine, clay-coloured stools, jaundice (yellowing of the skin or eyes).

Call the doctor at once if the patient has any signs of kidney failure, such as urinating less than usual or not at all, drowsiness, confusion, mood changes, increased thirst, loss of appetite, nausea and vomiting, swelling, weight gain or feeling short of breath.

See RxList (2012).

Snapshot

A patient with obstructive kidney

Suresh Rama, aged 58 years, lives in a detached house with his wife Priya and their two children, Mina and Reena. Suresh is a self-employed businessman, and his wife is a school teacher. Their children go to the same school where Priya teaches.

Suresh has had a constant dull ache below his ribs on his right side for a couple of weeks. He kept this from his wife and tolerated the pain and discomfort. One day, Suresh noticed blood in his urine and broke the news to his wife and also tells her about the pain. Priya is annoyed that he kept this information from her and insisted that he sees his GP to get to the root of the problem.

Suresh makes an appointment to see his GP. Suresh goes to the surgery accompanied by his wife. After some medical history and physical examination, the GP refers Suresh to the local hospital under the care of a urologist.

Suresh is seen by the consultant urologist in the outpatient department. An ultrasound reveals a staghorn calculus of his right kidney. Suresh is admitted the following week for a right nephrectomy. Suresh made an uneventful recovery and was discharged from the hospital under the care of the community team.

If a kidney stone is not detected and treated early, it can grow into the calyces of the kidney (see Figure 10.5) and permanently damage that kidney, as in Suresh's case. If detected early, the kidney could be saved by removing the stone before it damages the kidney. If a kidney stone is too big to be passed naturally (6–7 mm in diameter or larger), it could be removed by:

- extracorporeal shock wave lithotripsy
- ureteroscopy
- percutaneous nephrolithotomy.

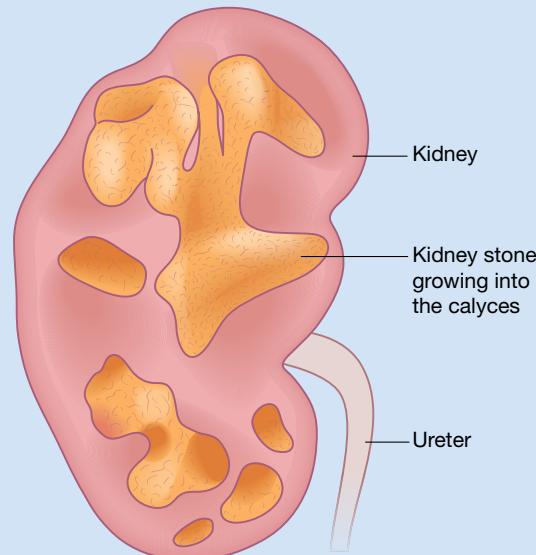


Figure 10.5 Obstructive kidney.

See NHS Choices (2014a).

306

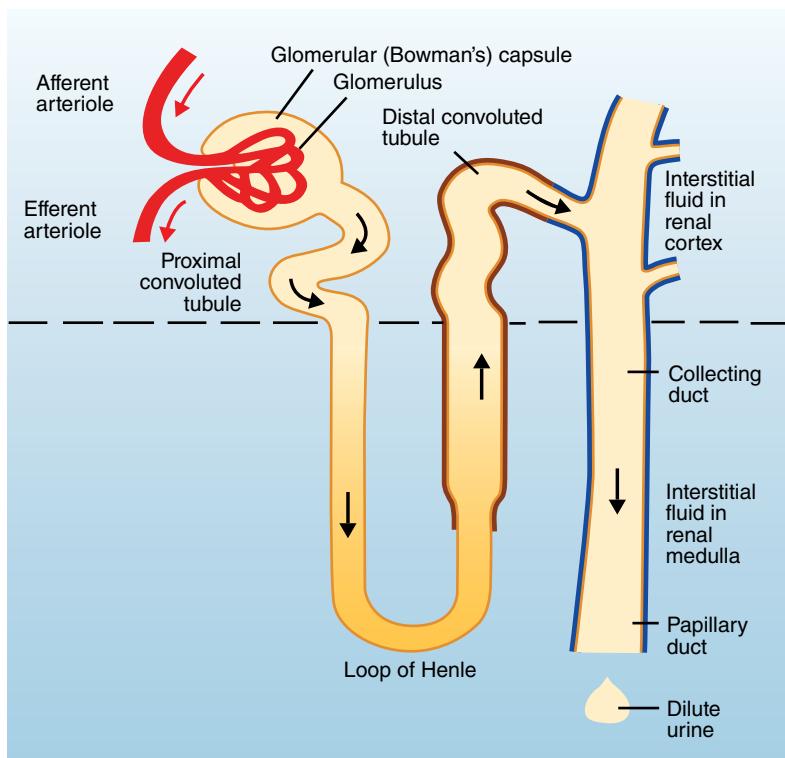


Figure 10.6 Nephron. Source: Tortora and Derrickson (2009). Reproduced with permission of John Wiley & Sons.

Nephrons

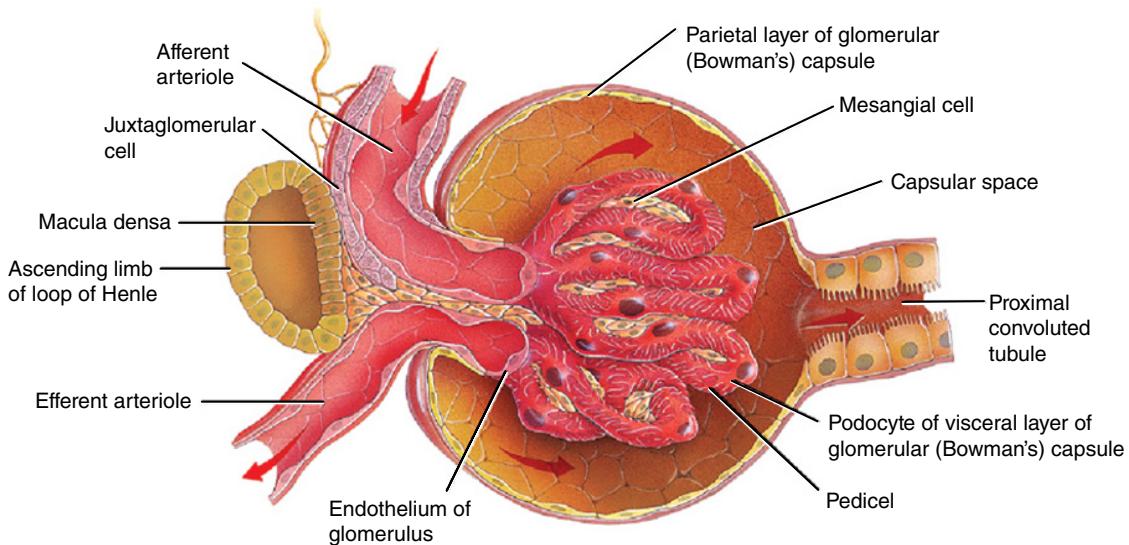
These are small structures and they form the functional units of the kidney. The nephron consists of a glomerulus and a renal tubule (see Figure 10.6). There are approximately over 1 million nephrons per kidney, and it is in these structures where urine is formed. The nephrons:

- filter blood;
- perform selective reabsorption;
- excrete unwanted waste products from the filtered blood.

The nephron is part of the homeostatic mechanism of the body. This system helps regulate the amount of water, salts, glucose, urea and other minerals in the body. The nephron is a filtration system located in the kidney and is responsible for the reabsorption of water and salts. The nephron is divided into several sections:

- Bowman's capsule
- proximal convoluted tubule
- loop of Henle
- distal convoluted tubule (DCT)
- the collecting ducts.

Each section performs a different function; these will be discussed in the following sections.



307

Figure 10.7 Bowman's capsule. Source: Tortora and Derrickson (2009). Reproduced with permission of John Wiley & Sons.

Bowman's capsule

Also known as the glomerular capsule (see Figure 10.7), Bowman's capsule is a cup-like sac and is the first portion of the nephron. Bowman's capsule is part of the filtration system in the kidneys. When blood reaches the kidneys for filtration, it enters Bowman's capsule first, with the capsule separating the blood into two components: a filtrated blood product and a filtrate that is moved through the nephron, another structure in the kidneys. The glomerular capsule consists of visceral and parietal layers (see Figure 10.7). The visceral layer is lined with epithelial cells called podocytes, while the parietal layer is lined with simple squamous epithelium and it is in Bowman's capsule that the network of capillaries called the glomerulus (Marieb and Hoehn, 2013) is found. Filtration of blood takes place in this portion of the nephron.

Proximal convoluted tubule

From Bowman's capsule, the filtrate drains into the proximal convoluted tubule (see Figure 10.6). The surface of the epithelial cells of this segment of the nephron is covered with densely packed microvilli. The microvilli increase the surface area of the cells, thus facilitating their resorptive function. The infolded membranes forming the microvilli are the site of numerous sodium pumps. Resorption of salt, water and glucose from the glomerular filtrate occurs in this section of the tubule; at the same time, certain substances, including uric acid and drug metabolites, are actively transferred from the blood capillaries into the tubule for excretion.

Loop of Henle

The proximal convoluted tubule then bends into a loop called the loop of Henle (see Figure 10.6). The loop of Henle is the part of the tubule that dips or 'loops' from the cortex into the medulla (descending limb), and then returns to the cortex (ascending limb). The loop of Henle is divided into the descending and ascending loops. The ascending loop of Henle is much thicker than the descending portion. The main function of the loop of Henle is to generate a concentration gradient that creates a region of a high concentration of sodium in the medulla of the kidney. The descending portion of the loop of Henle is highly permeable to water and has low

permeability to ions and urea. The ascending loop of Henle is permeable to ions but not to water. When required, urine is concentrated in this portion of the nephron. This is possible because of the high concentration of solute in the substance or interstitium of the medulla. This high concentration of solutes is maintained by the countercurrent multiplier. Different parts of the loop of Henle have different actions:

- 308
- The descending loop of Henle is relatively impermeable to solute but permeable to water, so that water moves out by osmosis and the fluid in the tubule becomes hypertonic.
 - The thin section of the ascending loop of Henle is virtually impermeable to water, but permeable to solute, especially sodium and chloride ions. Thus, sodium and chloride ions move out down the concentration gradient; the fluid within the tubule first becomes isotonic and then hypotonic as more ions leave. Urea, which was absorbed into the medullary interstitium from the collecting duct, diffuses into the ascending limb. This keeps the urea within the interstitium of the medulla, where it also has a role in concentrating urine.
 - The thick section of the ascending loop of Henle and early distal tubule are virtually impermeable to water. However, sodium and chloride ions are actively transported out of the tubule, making the tubular fluid very hypotonic.

Distal convoluted tubule

The thick ascending portion of the loop of Henle leads into the DCT (see Figure 10.6). The DCT is lined with simple cuboidal cells, and the lumen of the DCT is larger than the proximal convoluted tubule lumen because the proximal convoluted tubule has a brush border (microvilli). The DCT is an important site:

- it actively secretes ions and acids;
- it plays a part in the regulation of calcium ions by excreting excess calcium ions in response to calcitonin hormone;
- it selectively reabsorbs water;
- arginine vasopressin receptor 2 proteins are also located there;
- it plays a role in regulating pH by absorbing bicarbonate and secreting protons (H^+) into the filtrate.

The final concentration of urine, in this section, is dependent on a hormone called antidiuretic hormone (ADH). If ADH is present, the distal tubule and the collecting duct become permeable to water. As the collecting duct passes through the medulla with a high solute concentration in the interstitium, the water moves out of the lumen of the duct and concentrated urine is formed. In the absence of ADH the tubule is minimally permeable to water, so a large volume of dilute urine is formed.

Collecting ducts

The DCT then drains into the collecting ducts (see Figure 10.6). Several collecting ducts converge and drain into a larger system called the papillary ducts, which in turn empty into the minor calyx (plural: calices). From here the filtrate, now called urine, drains into the renal pelvis. This is the final stage where sodium and water are reabsorbed. When a person is dehydrated, approximately 25% of the water filtered is reabsorbed in the collecting duct. However, the cells of the collecting ducts are impermeable to water, but with the aid of the ADH and aquaporins water is reabsorbed from the collecting ducts. Aquaporins are proteins embedded in the cell membrane that regulate the flow of water. Aquaporins selectively transport water molecules in and out of the cell, while preventing the passage of ions and other solutes. Aquaporin 1 is abundant in proximal convoluted tubule and the descending thin limb of the loop of Henle, and aquaporins 2, 3 and 4 are present in the collecting ducts; however aquaporin 4 is predominantly found in the brain.

Clinical considerations

Chronic pyelonephritis

Chronic pyelonephritis is characterised by renal inflammation and fibrosis induced by recurrent or persistent renal infection, vesicoureteral reflux, or other causes of urinary tract obstruction. Chronic pyelonephritis is associated with progressive renal scarring, which can lead to end-stage renal disease.

In most patients, renal damage occurs slowly over a long period of time in response to a chronic inflammatory process or infections. This results in thinning of the renal cortex along with deep, segmental, coarse cortical scarring. Club-shaped deformity of the renal calyces occurs as the papilla(e) retract into the scar(s). One scar or several may be present, in one or both kidneys.

Some of the investigations carried out include:

- Dipstick urinalysis may show leucocytes, haematuria or proteinuria and is typically the test of choice for screening of kidney disease. It may be normal in chronic kidney disease, so should be done in conjunction with serum creatinine, which reflects the severity of renal impairment.
- Full blood count may show raised leukocytosis or normocytic, normochromic anaemia.
- Ultrasound is often recommended if renal obstruction is suspected but not confirmed by computed tomography. A kidney–ureter–bladder X-ray is less useful than computed tomography, but is a useful baseline investigation, and may show radiopaque calcifications in the renal tract.
- Urine cultures are done to detect urinary tract infection. Urine cultures are often positive for *Proteus* (60%), or less often for *Escherichia coli*, *Klebsiella*, *Staphylococcus aureus*, or mixed organisms.

Chronic pyelonephritis results in renal failure. The patient will need dialysis or a kidney transplant. Remember, recurrent attacks with acute pyelonephritis can result in chronic pyelonephritis.

See Knott (2013).

309

Functions of the kidney

The kidneys maintain fluid balance, electrolyte balance and the acid–base balance of the blood.

- The kidneys remove wastes and excess water (fluid) collected by, and carried in, the blood as it flows through the body. Approximately 190 L of blood enter the kidneys every day via the renal arteries. Millions of tiny filters, called glomeruli, inside the kidneys separate wastes and water from the blood. Most of these unwanted substances come from what we eat and drink. The kidneys automatically remove the right amount of salt and other minerals from the blood to leave just the quantities the body needs.
- By removing just the right amount of excess fluid, healthy kidneys maintain what is called the body's fluid balance. In women, fluid content stays at about 55% of total weight. In men, it stays at about 60% of total weight. The kidneys maintain these proportions by balancing the amount of fluid that leaves the body against the amount entering the body. When a large volume of fluid is drunk, healthy kidneys remove the excess fluid and produce a lot of urine. On the other hand, if fluid intake is low, the kidneys retain fluid and the patient does not pass much urine. Fluid also leaves the body through sweat, breath and faeces. If the weather is hot and we lose a lot of fluid by sweating, then the kidneys will not pass much urine.
- Kidneys synthesise hormones such as renin and angiotensin. These hormones regulate how much sodium (salt) and fluid the body keeps, and how well the blood vessels can expand and contract. This, in turn, helps control blood pressure.

- Kidneys produce a hormone known as erythropoietin, which is carried in the blood to the bone marrow where it stimulates the production of red blood cells. These cells carry oxygen throughout the body. Without enough healthy red blood cells anaemia develops, a condition that causes weakness, cold, tiredness and shortness of breath.
- Healthy kidneys keep bones strong by producing the hormone calcitriol. Calcitriol maintains the right levels of calcium and phosphate in the blood and bones. Calcium and phosphate balance are important to keep bones healthy. When the kidneys fail they may not produce enough calcitriol. This leads to abnormal levels of phosphate, calcium and vitamin D, causing renal bone disease. For a summary of the functions of the kidney, see Table 10.1.

Table 10.1 Summary of the functions of the kidneys

310

Regulation of electrolytes – help to regulate ions such as sodium, potassium, calcium, chloride and phosphate ions
Regulation of blood pH – excrete hydrogen ions into the urine and conserve bicarbonate ions, thus helping to regulate pH of blood
Regulation of blood volume – by conserving or eliminating water in the urine
Secretes renin (regulates blood pressure) and erythropoietin (production of red blood cells)
Production of calcitriol for the regulation of calcium level
Aids in regulation of blood glucose level by gluconeogenesis
Detoxification of free radicals and drugs
Excretion of waste products, such as urea, uric acid and creatinine

Medicines management

Nephrotoxic drugs

Renal impairment may be acute or chronic – both of which can result in problems with medications. Renal impairment may be the result of a variety of renal or systemic diseases, such as diabetic nephropathy or systemic lupus erythematosus. Normal ageing results in a decline in renal function due to loss of nephrons. When prescribing for elderly patients, it should therefore be assumed that some degree of renal impairment exists.

Reasons for problems with medications in renal failure include:

- failure to excrete a drug or its metabolites;
- many side effects being poorly tolerated by patients in renal failure;
- some drugs ceasing to be effective when renal function is reduced.

For example, prescribing any drug that increases potassium level is potentially very dangerous – for example, potassium supplements and potassium-sparing diuretics. Other products that contain potassium include ispaghula husk laxatives. Non-steroidal anti-inflammatory drugs (NSAIDs), even in short courses, can cause acute kidney injury as a result of renal under perfusion. Angiotensin-converting enzyme (ACE) inhibitors can also cause a deterioration in renal function.

(Continued)

However, this is a problem only in patients with compromised renal perfusion, particularly those with renal artery stenosis. Care should be taken when an ACE inhibitor and NSAID are prescribed together, as this combination may precipitate an acute deterioration in renal function.

Drugs that may cause interstitial nephritis include penicillins, cephalosporins, sulphonamides, thiazide diuretics, furosemide, NSAIDs and rifampicin.

Therefore, care should be taken when administering medications to patients with renal problems. Always check with the pharmacist or consult the British National Formulary for drug interactions before administering medications.

See Rull (2013).

311

Snapshot

Cystitis

Michele Watts is a 26-year-old third-year nursing student. She is married to John, who is also a third-year nursing student in the same cohort. They live in a flat, which they rent and they travel to the university for their nursing studies. They do not have any children but plan to have a family on completion of their course. Michele does not take birth-control pills; instead, she uses a coil for birth control.

Michele woke up one morning with severe lower back pain, frequency, urgency and burning sensation on urination. She noticed that her urine was slightly cloudy. Michele tells John that she had to get up twice at night with frequency and it was painful to pass urine. John decided to ring the university to inform them of their absence as he was taking his wife to see their GP.

At the surgery, the practice nurse carried out some vital signs recordings: temperature 37.5 °C, pulse 95 beats per minute, blood pressure 115/58 mmHg and respiration 23 breaths per minute. On consultations with her GP, Michele states that she has had these episodes three times in the past but has managed without any antibiotics. Now she feels that she has to urinate frequently and has difficulty starting her urine and has burning pain and cramping when voiding. The nurse does a dip stick test, which shows that she has leucocytes, blood, protein and urea.

The GP informs Michele that he would like a midstream specimen of urine (MSU) from her and gives her a course of antibiotics (Trimethoprim 200 mg BD for 3 days), informing her that when the results return and if the antibiotic is not suitable then he will change it.

Michele is encouraged to drink a lot of fluid and told to rest for a few days. Once the symptoms subside Michele can resume her studies. Her MSU results show a coliform infection and that Michele is on the right antibiotic.

Blood supply of the kidney

The role of the kidney is to filter at least 20–25% of blood during the resting cardiac output. Approximately 1200 mL of blood flows through the kidney each minute. Each kidney receives its blood supply directly from the aorta via the renal artery (see Figure 10.4), which is divided into anterior and posterior renal arteries. There are several arteries that deliver blood to the kidneys:

- renal artery – arises from the abdominal aorta at the level of first lumbar vertebra;
- segmental artery – branch of the renal artery;
- interlobar artery – branch of the segmental artery;
- arcuate artery – renal columns leading to the corticomedullary junction;
- interlobular arteries – divisions of the arcuate arteries.

Dialysis

Dialysis is the artificial process of eliminating waste (diffusion) and unwanted water (ultrafiltration) from the blood. Some patients, however, may have failed or damaged kidneys that cannot carry out the function properly – they may need dialysis. Dialysis may be used for patients who have become ill and have acute kidney injury (temporary loss of kidney function), or for fairly stable patients who have permanently lost kidney function (stage 5 chronic kidney disease).

Approximately 1500 L of blood are filtered by a healthy person's kidneys each day. We could not live if waste products were not removed from our kidneys. Patients whose kidneys either do not work properly or not at all experience a build-up of waste in their blood. Without dialysis the amount of waste products in the blood would increase and eventually reach levels that would cause coma and death.

Haemodialysis

Haemodialysis is the type of dialysis that most people are aware of. It involves inserting a needle, which is attached by a tube to a dialysis machine, into a blood vessel. Blood is transferred from the body into the machine, which filters out waste products and excess fluids. The filtered blood is then passed back into the body. Most people require three sessions a week, each lasting 4 h.

Peritoneal dialysis

Peritoneal dialysis is a less well known type of dialysis, but it is becoming more common. It involves using the lining of the abdomen (the peritoneum) as a filter. Like the kidneys, the peritoneum contains thousands of tiny blood vessels, making it a useful filtering device.

A small flexible tube called a catheter is attached to an incision in the abdomen (see Figure 10.8). A special fluid called dialysis fluid is allowed to drain into the space surrounding the peritoneum (the peritoneal cavity) via a giving set allowed to sit there for several hours while it absorbs waste products, and excess fluid from the blood and into the dialysis fluid then drained out.

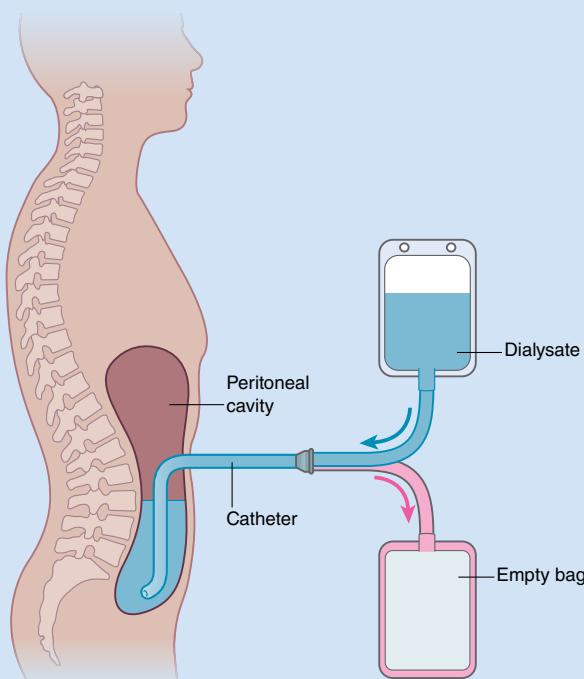


Figure 10.8 Peritoneal dialysis.

The branches of the interlobular artery enter the nephrons as afferent arterioles. Each nephron receives one afferent arteriole, which further subdivides into a tuft of capillaries called the glomerulus. The glomerular capillaries reunite and leave Bowman's capsule as efferent arterioles. Efferent arterioles unite to form peritubular capillaries and then interlobular veins that unite to form the arcuate veins and finally into interlobar veins. Blood leaves the kidneys through the renal vein, which then flows into the inferior vena cava. The diameter of the afferent arteriole is larger than the diameter of the efferent arteriole.

Urine formation

Three processes are involved in the formation of urine:

- filtration
- selective reabsorption
- secretion.

313

Filtration

Urine formation begins with the process of filtration, which goes on continually in the renal corpuscles. Filtration takes place in the glomerulus which lies in Bowman's capsule. The blood for filtration is supplied by the renal artery. In the kidney the renal artery divides into smaller arterioles. The arteriole entering Bowman's capsule is called the afferent arteriole, which further subdivides into a cluster of capillaries called the glomerulus.

As blood passes through the glomeruli, much of its fluid, containing both useful chemicals and dissolved waste materials, soaks out of the blood through the membranes (by osmosis and diffusion) where it is filtered and then flows into Bowman's capsule. This process is called glomerular filtration. The water, waste products, salt, glucose and other chemicals that have been filtered out of the blood are known collectively as glomerular filtrate.

The fluid from the filtered blood is protein free but contains electrolytes such as sodium chloride, potassium and waste products of cellular metabolism; for example, urea, uric acid and creatinine (McCance *et al.*, 2010). The filtered blood then returns into circulation via the efferent arteriole and finally into the renal vein.

Selective reabsorption

Selective reabsorption processes ensure that any substances in the filtrate that are essential for body function are reabsorbed into the plasma. Substances such as sodium, calcium, potassium and chloride are reabsorbed to maintain fluid and electrolyte balance and the pH of blood. However, if these substances are in excess to body requirements, they are excreted in the urine. Only 1% of the glomerular filtrate actually leaves the body; 99% is reabsorbed into the bloodstream. The reabsorption occurs via three processes:

- osmosis
- diffusion
- active transport.

See Table 10.2 for a summary.

Blood glucose is entirely reabsorbed into the blood from the proximal tubules. In fact, it is actively transported out of the tubules and into the peritubular capillary blood. None of this valuable nutrient is wasted by being lost in the urine. Sodium (Na^+) and other ions are only partially reabsorbed from the renal tubules into the blood. For the most part, however, sodium ions are actively transported back into blood from the tubular fluid. The amount of sodium reabsorbed varies depending largely on how much salt we take in from the foods that we eat.

Table 10.2 Summary of filtration, reabsorption and excretion in the nephron and collecting ducts

Reabsorption	Excretion
Proximal convoluted tubule	
Water, approximately 65% Sodium and potassium, 65% Glucose, 100% Amino acids, 100% Chloride, approximately 50% Bicarbonate, calcium and magnesium Urea	Hydrogen ions Urea Creatinine Ammonium ions
Loop of Henle	
Water Sodium and potassium, approximately 30% Chloride, approximately 35% Bicarbonate, approximately 20% Calcium and magnesium	Urea
Distal convoluted tubule	
Water, approximately 15% Sodium and chloride, approximately 5% Calcium Some urea	Potassium, depending on serum values Hydrogen ions, depending on pH of blood
Collecting duct	
Bicarbonate, depending on serum values Urea Water, approximately 9% Sodium, approximately 4%	Potassium, depending on serum values Hydrogen ions, depending on pH of blood

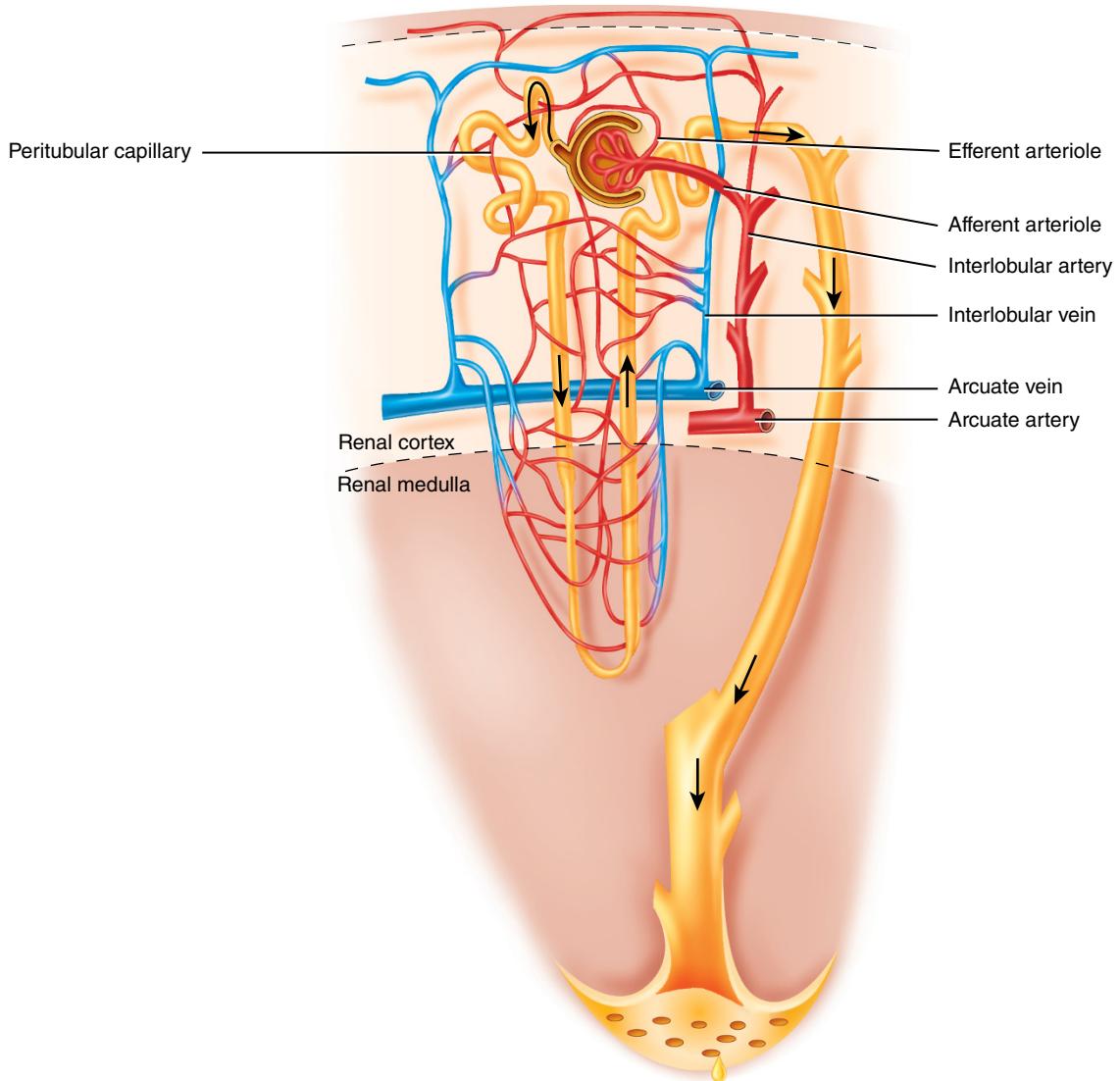
Source: Adapted from Tortora and Derrickson (2006).

As a person increases the amount of salt intake into the body, kidneys decrease the amount of sodium reabsorption into the blood. That is, more sodium is retained in the tubules. Therefore, the amount of salt excreted in the urine increases. The process works the other way as well. The less the salt intake, the greater the amount of sodium reabsorbed into the blood, and the amount of salt excreted in the urine decreases.

Excretion

Any substances not removed through filtration are secreted into the renal tubules from the peritubular capillaries (see Figure 10.9) of the nephron (Waugh and Grant, 2014); these include drugs and hydrogen ions. Tubular secretion mainly takes place by active transport. Active transport is a process by which substances are moved across biological membranes. Tubular secretion occurs from epithelial cells lining the renal tubules and the collecting ducts. Substances secreted into the tubular fluid include:

- potassium ions (K^+)
- hydrogen ions (H^+)
- ammonium ions (NH_4^+)
- creatinine
- urea
- some hormones.



315

Figure 10.9 Nephron with capillaries. Source: Tortora and Derrickson (2009). Reproduced with permission of John Wiley & Sons.

It is the tubular secretion of hydrogen and ammonium ions that helps to maintain the pH of blood. See Table 10.2 for a summary.

Hormonal control of tubular reabsorption and secretion

Four hormones play a role in the regulation of fluid and electrolytes:

- angiotensin II
- aldosterone
- ADH
- atrial natriuretic peptide.

Approved: 0777 023 444

Angiotensin and aldosterone

As the blood volume and blood pressure decrease, the juxtaglomerular cells secrete a hormone called renin. Juxtaglomerular cells are found near the glomerulus, and these cells synthesise, store and secrete the hormone renin. Renin acts on a plasma protein called angiotensinogen and converts it into angiotensin I. Angiotensinogen is produced by the hepatocytes of the liver. Angiotensin I is transported by the blood to the lungs. In the lung capillaries there are enzymes called ACE. ACE is predominantly found in the lung capillaries, but this enzyme is also found throughout the body. ACE converts angiotensin I into angiotensin II. Angiotensin II is a short-acting, powerful vasoconstrictor, thus increasing blood pressure. Angiotensin II promotes the reabsorption of sodium, chloride and water in the proximal convoluted tubule. It also has an effect on the release of aldosterone.

Aldosterone is a steroid hormone secreted by the adrenal glands. It serves as the principal regulator of the salt and water balance of the body and thus is categorised as a mineralocorticoid. It also has a small effect on the metabolism of fats, carbohydrates and proteins. Aldosterone is synthesised in the body from corticosterone, a steroid derived from cholesterol. Production of aldosterone (in adult humans, about 20–200 µg per day) in the zona glomerulosa of the adrenal cortex is regulated by the renin–angiotensin system.

Antidiuretic hormone

The third principal hormone is ADH, which is produced by the hypothalamus gland and is stored by the posterior pituitary gland. This hormone increases the permeability of the cells in the DCT and the collecting ducts. In the presence of ADH, more water is reabsorbed from the renal tubules; therefore, the patient will pass less urine. In the absence of ADH, less water is reabsorbed and the patient will pass more urine. Thus, ADH plays a major role in the regulation of fluid balance in the body.

The most important variable regulating ADH secretion is plasma osmolarity, or the concentration of solutes in blood. Osmolarity is sensed in the hypothalamus by neurones known as osmoreceptors, and those neurones, in turn, stimulate secretion from the neurones that produce ADH. When plasma osmolarity is below a certain threshold, the osmoreceptors are not activated and the secretion of ADH is suppressed. When osmolarity increases above the threshold, the osmoreceptors recognise this and stimulate the neurones that secrete ADH.

Atrial natriuretic peptide

The fourth hormone involved in tubular secretion and reabsorption is atrial natriuretic peptide (ANP) hormone. ANP is a powerful vasodilator and is a protein produced by the myocytes of the atria of the heart in response to increased blood pressure. ANP stimulates the kidneys to excrete sodium and water from the renal tubules, thus decreasing blood volume, which in turn lowers blood pressure. The hormone also inhibits the secretion of aldosterone and ADH.

ANP is involved in the long-term regulation of sodium and water balance, blood volume and arterial pressure. There are two major pathways of natriuretic peptide actions: vasodilator effects and renal effects, which lead to natriuresis and diuresis. ANP directly dilates veins (increases venous compliance) and thereby decreases central venous pressure, which reduces cardiac output by decreasing ventricular preload. ANP also dilates arteries, which decreases systemic vascular resistance and systemic arterial pressure.

Medicines management

Drugs for incontinence

There are two main types of urinary incontinence:

1. *Stress incontinence* – this is when urine leaks because there is a sudden extra pressure within the abdomen and on the bladder. This pressure (or stress) is caused by things like coughing, laughing, sneezing or exercising (such as running or jumping).
2. *Urge incontinence* – this is when urine leaks before one gets to the toilet when there is an urgency to void urine.

For people with stress incontinence a medicine called duloxetine may be prescribed. It is thought to work by interfering with certain chemicals that are used in transmitting nerve impulses to muscles. This helps the muscles around the urethra to contract more strongly. It is prescribed for a month and the patient is reassessed. If the condition improves, the drug is discontinued. The most commonly reported side effects are nausea, dry mouth, fatigue and constipation. Advise the patient never to stop taking this medicine suddenly because they can get withdrawal symptoms such as dizziness, nausea and headaches.

Medicines called antimuscarinics (also called anticholinergics) are used to help treat urge incontinence. There are several different types and many different brand names. They include older medicines such as oxybutynin, tolterodine and flavoxate, as well as newer medicines such as darifenacin, fesoterodine, propiverine, solifenacain and trospium. These medicines work by blocking certain nerve impulses to the bladder that relax the bladder muscle, so increasing the bladder capacity. Antimuscarinics are prescribed for a month or so. If it is helpful, the treatment may continue for up to 6 months or so and then stopped to see how symptoms are without the medication. The most common side effect is a dry mouth, and simply having frequent sips of water may counter this. Other common side effects include dry eyes, constipation and blurred vision.

See NHS Choices (2014b).

317

Composition of urine

Urine is a sterile and clear fluid of nitrogenous wastes and salts. It is translucent with an amber or light yellow colour. Its colour is due to the pigments from the breakdown of haemoglobin. Concentrated urine tends to be darker in colour than normal urine. However, other factors, such as diet, medications and certain diseases, may affect the colour of the urine. It is slightly acidic, and the pH may range from 4.5 to 8. The pH is affected by an individual's dietary intake and state of health. Diet that is high in animal protein tends to make the urine more acidic, while a vegetarian diet may make the urine more alkaline. The volume of urine produced depends on the circulating volume of blood. ADH regulates the amount of urine passed by the individual. If the person is dehydrated, more ADH is released from the posterior pituitary gland, resulting in water reabsorption and less urine being produced. On the other hand, if the person has consumed a large amount of fluid, which increases the circulating volume, less ADH is released and more water is passed as urine.

Urine is 96% water and approximately 4% solutes derived from cellular metabolism. The solutes include organic and inorganic waste products and unwanted substances such as drugs. Normally there is no protein or blood. If these are present then the person may be suffering from a disease. See Table 10.3 for a summary of solutes.

Approved: 0777 023 444

Table 10.3 Solutes in the urine

Inorganic solutes	Organic solutes
Sodium	Urea
Potassium	Creatinine
Calcium	Uric acid
Magnesium	
Iron	
Chloride	
Sulphate	
Phosphate	
Bicarbonate	
Ammonia	

Source: Adapted from Mader (2005).

Characteristics of normal urine

The volume produced is one of the physical characteristics of urine. Other physical characteristics that can apply to urine include colour, turbidity (transparency), smell (odour), pH (acidity/alkalinity) and density.

- **Colour:** Typically yellow–amber, but varies according to recent diet, medication and the concentration of the urine. Drinking more water generally tends to reduce the concentration of urine, and therefore causes it to have a lighter colour. However, if a person does not drink a large amount of fluid, this may increase the concentration and the urine will have a darker colour. See Table 10.4 for foods, medications and illnesses that may affect colour of the urine.
- **Smell:** The smell, or odour, of urine may provide health information. For example, the urine of diabetics may have a sweet or fruity odour due to the presence of ketones (organic molecules of a particular structure). Generally, fresh urine has a mild smell, but stale urine or infected urine has a stronger odour, similar to that of ammonia.
- **Acidity:** pH is a measure of the acidity (or alkalinity) of a solution. The pH of a substance (solution) is usually represented as a number in the range 0 (strong acid) to 14 (strong alkali, also known as a 'base'). Pure water is 'neutral', in the sense that it is neither acid nor alkali; it therefore has a pH of 7. The pH of normal urine is generally in the range 4.5–8, a typical average being around 6.0. Much of the variation is due to diet. For example, high-protein diets result in more acidic urine, but vegetarian diets generally result in more alkaline urine.
- **Specific gravity:** Specific gravity is also known as 'relative density'. This is the ratio of the weight of a volume of a substance compared with the weight of the same volume of distilled water. Given that urine is mostly water, but also contains some other substances dissolved in the water, its relative density is expected to be close to, but slightly greater than, 1.000.

Table 10.4 Colours of urine

Food that changes colour of urine	
These are some of the foods that may change the colour of urine.	
Dark yellow or orange:	carrots
Green:	asparagus
Pink or red:	beetroot, blackberries, rhubarb
Brown:	fava beans, rhubarb
Medicines and vitamins that may change the colour of urine	
Yellow or yellow-green:	cascara, sulfasalazine, the B vitamins
Orange:	rifampicin, sulfasalazine, vitamin B, vitamin C
Pink or red:	phenolphthalein, propofol, rifampicin, laxatives containing senna
Green or blue:	amitriptyline, cimetidine, indomethacin, promethazine, propofol, triamterene, several multivitamins
Brown or brownish-black:	levodopa, metronidazole, nitrofurantoin, some antimalarial agents, methyldopa, laxatives containing cascara or senna
Medical conditions that may change the colour of urine	
Yellow:	concentrated urine caused by dehydration
Orange:	a problem with the liver or bile duct
Pink or red:	blood in the urine, haemoglobinuria (a condition linked to haemolytic anaemia), myoglobinuria (a condition linked to the destruction of muscle cells)
Deep purple:	porphyria, a rare inherited red blood cell disorder
Green or blue:	urinary tract infection may cause green urine if caused by <i>Pseudomonas</i> bacteria; familial hypercalcaemia, a rare genetic condition, can cause blue urine
Brown or dark brown:	blood in the urine, a liver or kidney disorder

Source: Mayo Clinic Staff (2015).

319

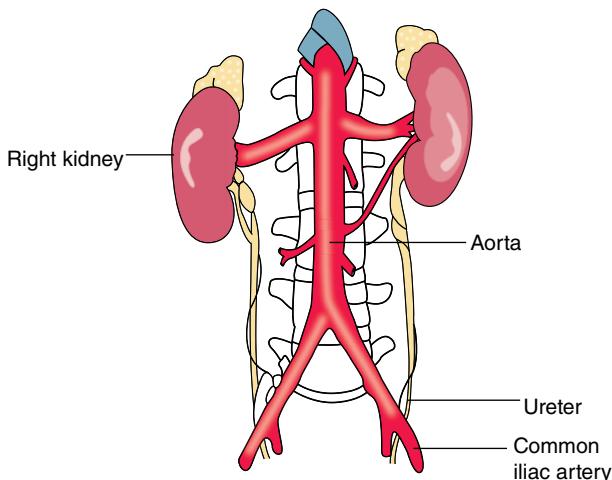
Snapshot

Mary with urinary incontinence

Mary Goldwater is a 78-year-old retired council worker. Her husband passed away with cancer of the prostate over 5 years ago. Mary has one daughter, who visits her every week to make sure that she is fine. Mary is adamant that she can cope and refuses any help from the social services. Her daughter notices a strong smell of urine in the house whenever she visits her mother. When the daughter wants to take her out, Mary is reluctant to go out and becomes very aggressive.

Concerned, the daughter asks Mary's GP to do a home visit and see if he can help her. During her GP's visit, Mary admits that she has an urine incontinence problem. She reports that when she coughs or laughs, she wets herself.

After a full assessment of Mary, her GP suggests that she should go to a care home to be looked after. After much persuasion by her GP and her daughter, Mary agrees to this.



320

Figure 10.10 Common iliac vessels and ureter. Source: Nair and Peate (2009). Reproduced with permission of John Wiley & Sons.

Ureters

The ureters are tubular organs that run from the renal pelvis to the posterolateral base of the urinary bladder. The ureters are approximately 25–30 cm in length and 5 mm in diameter (Mader, 2005). The ureters terminate at the bladder and enter obliquely through the muscle wall of the bladder. They pass over the pelvic brim at the bifurcation of the common iliac arteries (see Figure 10.10).

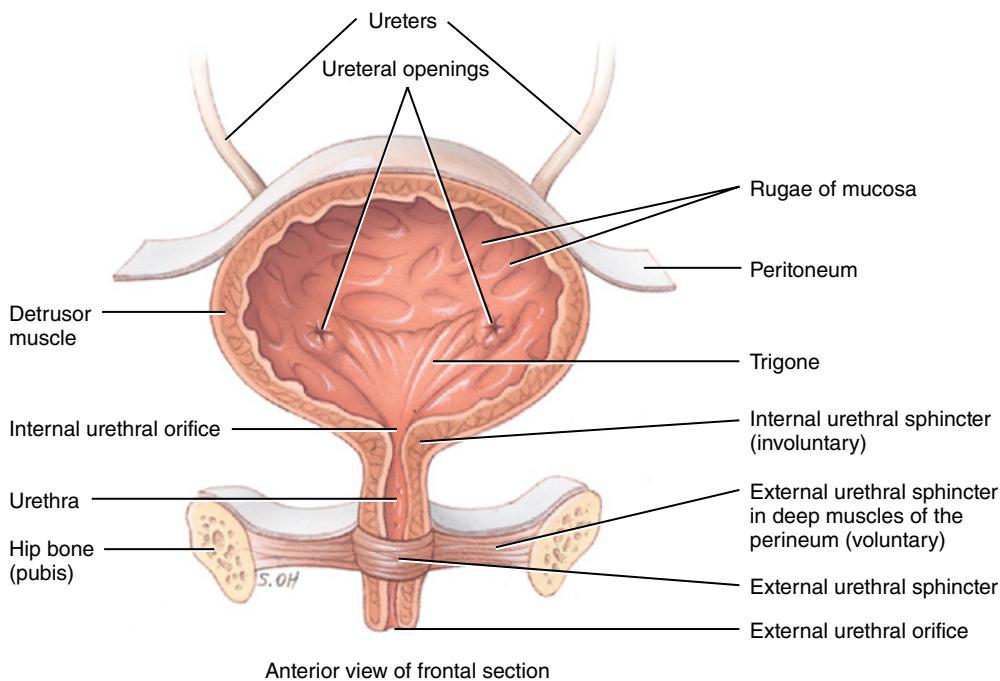
The ureters have three layers:

- transitional epithelial mucosa (inner layer);
- smooth muscle layer (middle layer);
- fibrous connective tissue (outer layer).

Urine is transported through the ureters via muscular movements of the urinary tract's peristaltic muscular waves. When the renal pelvis becomes laden with urine, the peristaltic wave action encourages urine to leave the body. The amount of urine in the renal pelvis determines the frequency of the peristaltic wave action, which can range from one to every few minutes to one to every few seconds. This action creates a pressure force that moves the urine through the ureters and into the bladder in small spurts.

Urinary bladder

The urinary bladder is a hollow muscular organ and is located in the pelvic cavity posterior to the symphysis pubis. In the male the bladder lies anterior to the rectum, and in the female it lies anterior to the vagina and inferior to the uterus (Mader, 2005); it is a smooth muscular sac that stores urine. Although the shape of the bladder is spherical, the shape is altered from pressure of surrounding organs. When the bladder is empty, the inner section of the bladder forms folds, but as the bladder fills with urine the walls of the bladder become smoother. As urine accumulates, the bladder expands without a significant rise in the internal pressure of the bladder. The bladder normally distends and holds approximately 350–750 mL.



321

Figure 10.11 Layers of the urinary bladder. Source: Tortora and Derrickson (2009). Reproduced with permission of John Wiley & Sons.

of urine. In females the bladder is slightly smaller because the uterus occupies the space above the bladder.

The inner lining of the urinary bladder is a mucous membrane of transitional epithelium that is continuous with that in the ureters. When the bladder is empty, the mucosa has numerous folds called rugae. The rugae and transitional epithelium allow the bladder to expand as it fills. The second layer in the walls is the submucosa, which supports the mucous membrane. It is composed of connective tissue with elastic fibres.

The inner floor of the bladder includes a triangular section called the trigone. The trigone is formed by three openings in the floor of the urinary bladder. Two of the openings are from the ureters and form the base of the trigone. Small flaps of mucosa cover these openings and act as valves that allow urine to enter the bladder but prevent it from backing up from the bladder into the ureters. The third opening, at the apex of the trigone, is the opening into the urethra (see Figure 10.11). A band of the detrusor muscle encircles this opening to form the internal urethral sphincter.

The walls of the bladder consist of muscle fibres:

- transitional epithelial mucosa;
- a thick muscular layer;
- a fibrous outer layer.

Urinary tract infection and cystitis are more common in women than men. If untreated they can result in a more serious renal problem. Urinary tract infection can be prevented by ensuring adequate intake of fluid and good personal hygiene.

The urinary tract can become blocked or obstructed (e.g. from a kidney stone, tumour, expanding uterus during pregnancy or enlarged prostate gland). The build-up of urine can lead to infection and injury of the kidney. With a kidney stone, the blockage is often painful. Other obstructions may produce no symptoms and be detected only when a blood or urine test is abnormal or when an imaging procedure, such as an X-ray or ultrasound, detects it.

Urinary tract infections, such as cystitis (an infection of the bladder), can lead to more serious infections further up the urinary tract. Symptoms include fever, frequent urination, sudden and urgent need to urinate, and pain or a burning feeling during urination. There is often pressure or pain in the lower abdomen or back. Sometimes the urine has a strong or foul odour or is bloody. Pyelonephritis is an infection of kidney tissue; most often, it is the result of cystitis that has spread to the kidney. An obstruction in the urinary tract can make a kidney infection more likely. Infections elsewhere in the body, including, for example, streptococcal infections, the skin infection impetigo or a bacterial infection in the heart, can also be carried through the bloodstream to the kidney and cause a problem there.

322

Urethra

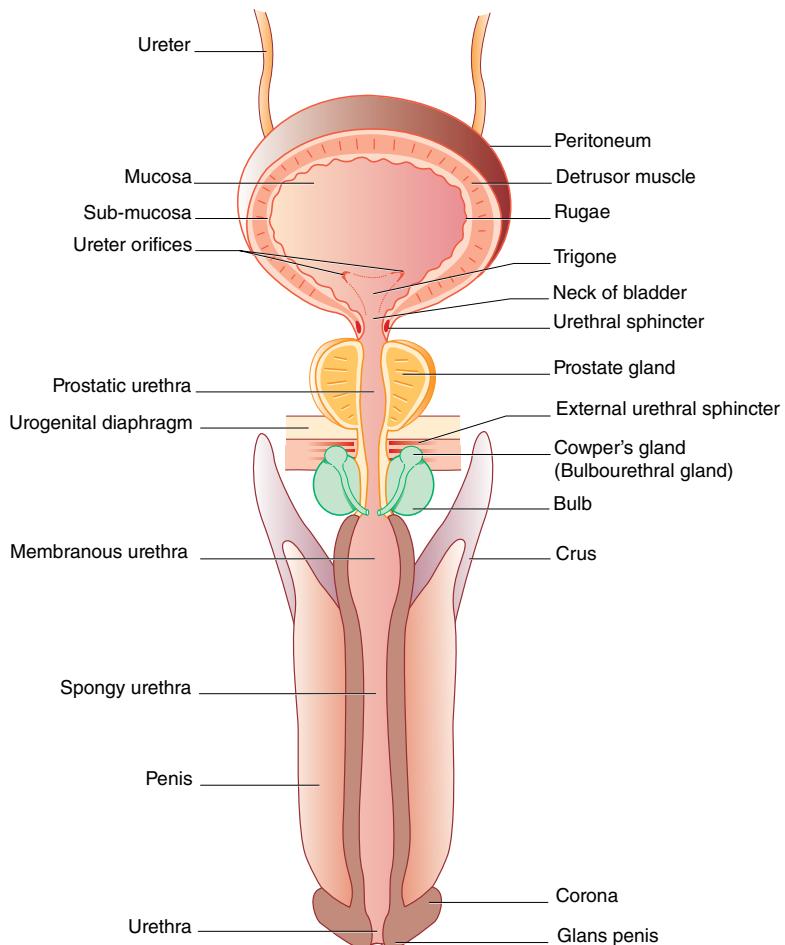
The urethra is a muscular tube that drains urine from the bladder and conveys it out of the body. It contains three coats, and they are muscular, erectile and mucous; the muscular is the continuation of the bladder muscle layer. The urethra is encompassed by two separate urethral sphincter muscles. The internal urethral sphincter muscle is formed by involuntary smooth muscles, while the lower voluntary muscles make up the external sphincter muscles. The internal sphincter is created by the detrusor muscle. The urethra is longer in males than in females. Sphincters keep the urethra closed when urine is not being passed. The internal urethral sphincter is under involuntary control and lies at the bladder–urethra junction. The external urethral sphincter is under voluntary control.

Male urethra

The male urethra passes through four different regions:

- Prostatic region – passes through the prostate gland.
- Membranous portion – passes through the pelvis diaphragm.
- Bulbar urethra – located inside the perineum and scrotum, extends from the external distal urinary sphincter to the peno-scrotal junction, and is surrounded by the corpus spongiosum. It contains the opening of the ducts of the Cowper glands, and differs in length from person to person.
- Penile region – extends the length of the penis.

In the male, the urethra not only excretes fluid wastes but is also part of the reproductive system. Rather than the straight tube found in the female body, the male urethra is S-shaped to follow the line of the penis. It is approximately 20 cm long. The male urethra can be segregated into various portions: the spongy portion, the prostatic portion and the membranous portion. The spongy urethra can be subdivided into fossa navicularis, pendulous urethra and bulbous (bulbar) urethra. The proximal portion, which is also the prostatic portion, is only about 2.5 cm long and passes along the neck of the urinary bladder through the prostate gland. This section is designed to accept the drainage from the tiny ducts within the prostate and is equipped with two ejaculatory tubes (see Figure 10.12).



323

Figure 10.12 Male urethra.

Female urethra

The female urethra is bound to the anterior vaginal wall. The external opening of the urethra is anterior to the vagina and posterior to the clitoris. In the female, the urethra is approximately 4 cm long and leads out of the body via the urethral orifice. In the female, the urethral orifice is located in the vestibule in the labia minora. This can be found located in between the clitoris and the vaginal orifice. In the female body the urethra's only function is to transport urine out of the body (see Figure 10.13).

Micturition

When the volume of urine in the bladder reaches about 300 mL, stretch receptors in the bladder walls are stimulated and excite sensory parasympathetic fibres that relay information to the sacral area of the spine. This information is integrated in the spine and relayed to two different sets of neurones. Parasympathetic motor neurones (in the pons) are excited and act to contract

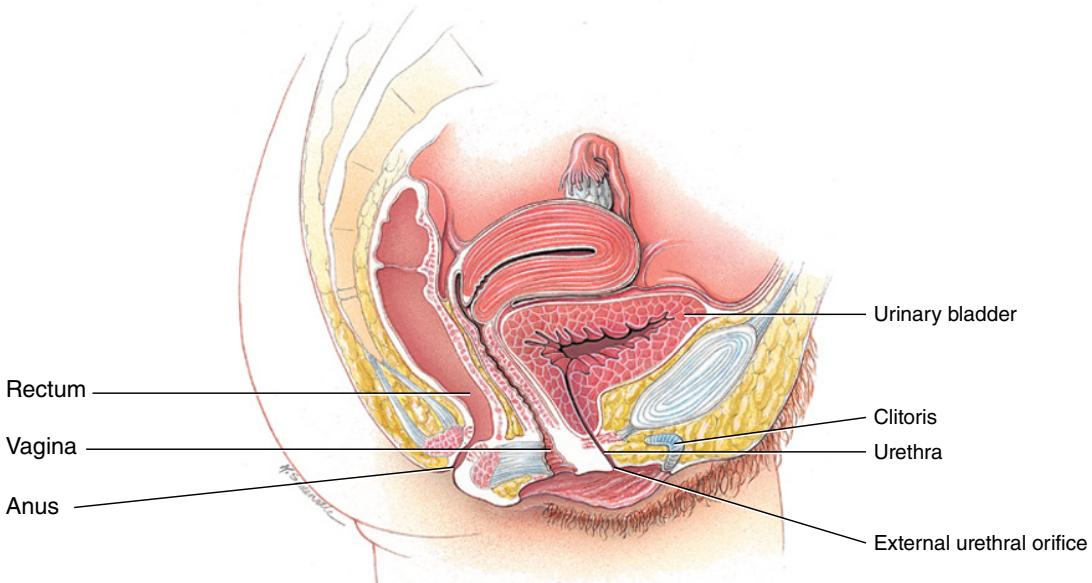


Figure 10.13 Location of female urethra. Source: Nair and Peate (2013). Reproduced with permission of John Wiley & Sons.

the detrusor muscles in the bladder so that bladder pressure increases and the internal sphincter opens. At the same time, somatic motor neurones supplying the external sphincter via the pudendal nerve are inhibited, allowing the external sphincter to open and urine to flow out, assisted by gravity.

A person has great control of the bladder. They can increase or decrease the rate of flow of urine, and stop and start at will (unless there are physiological problems), thus making micturition a simple reflex action.

Conclusion

The renal system consists of the kidneys, ureters, urinary bladder and the urethra. These systems collectively play an important role in maintaining homeostasis. They remove the waste products of metabolism, secrete hormones, regulate fluid balance and maintain homeostasis. Some of the functions it carries out include:

- regulating blood volume through urine production and blood pressure by releasing renin;
- regulating the electrolyte balance in the body through hormones such as aldosterone;
- maintaining the acid-base balance by regulating the secretion of hydrogen and bicarbonate ions;
- excreting waste products (e.g. urea and uric acid) and conserving valuable nutrients essential for the body.

Urine is formed by filtration, selective reabsorption and secretion. The selectivity of the glomerular filtrate is determined by the size of the opening of the filter and blood pressure. There are other factors that regulate urine production and electrolyte balance; they include hormone regulation such as ADH, aldosterone and ANP hormones and neuronal regulation through the autonomic nervous system.

The urinary bladder is a storage organ for urine and is located in the pelvic cavity. It contains three layers: the muscular, erectile and mucous layers. Urine is stored in the bladder until the person gets the urge to empty their bladder. The process of micturition is under the control of the sympathetic and parasympathetic system. During micturition, strong muscles in the bladder walls (the detrusor muscles) compress the bladder, pushing its contents into the urethra, thus voiding urine.

Glossary

325

Anterior Front.

Bifurcation Dividing into two branches.

Calyses Small, funnel-shaped cavities formed from the renal pelvis.

Diuresis Excess urine production.

Erythropoietin Hormone produced by the kidneys that regulates red blood cell production.

Excretion The elimination of waste products of metabolism.

Filtration A passive transport system.

Glomerulus A network of capillaries found in Bowman's capsule.

Hilum (hilus) An indentation near to the centre of the concave area of the kidney, where its vessels, nerves and ureter enter/leave.

Kidneys Organs situated in the posterior wall of the abdominal cavity.

Nephron Functional unit of the kidney.

Posterior Behind.

Renal artery Blood vessel that takes blood to the kidney.

Renal cortex The outermost part of the kidney.

Renal medulla The middle layer of the kidney.

Renal pelvis The funnel-shaped section of the kidney.

Renal pyramids Cone-shaped structures of the medulla.

Renal vein Blood vessel that returns filtered blood into circulation.

Renin A renal hormone that alters systemic blood pressure.

Sphincter A ring-like muscle fibre that can constrict.

Ureter Membranous tube that drains urine from the kidneys to the bladder.

Urethra Muscular tube that drains urine from the bladder.

References

- Knott, L. (2013) *Pyelonephritis*. <http://www.patient.co.uk/doctor/pyelonephritis> (accessed 26 November 2015).
- Mader, S.S. (2005) *Understanding Human Anatomy and Physiology*, 5th edn. Boston, MA: McGraw-Hill.
- Marieb, E.N. and Hoehn, K. (2013) *Human Anatomy and Physiology*, 9th edn. San Francisco: Pearson Benjamin Cummings.

- McCance, K.L. Huether, S.E., Brashers, V.L. and Rote, N.S. (2010) *Pathophysiology: The Biological Basis for Disease in Adults and Children*, 6th edn. St Louis, MO: Mosby.
- Mayo Clinic Staff (2015) *Urine Color*. <http://www.mayoclinic.org/diseases-conditions/urine-color/basics/causes/con-20032831> (accessed 26 November 2015).
- Nair, M. and Peate, I. (2009) *Fundamentals of Applied Pathophysiology: An Essential Guide for Nursing Students*. Oxford: John Wiley & Sons, Ltd.
- Nair, M. and Peate, I. (2013) *Fundamentals of Applied Pathophysiology: An Essential Guide for Nursing and Healthcare Students*, 2nd edn. Oxford: John Wiley & Sons, Ltd.
- NHS Choices (2014a) *Kidney Stones – Treatment*. <http://www.nhs.uk/Conditions/Kidney-stones/Pages/Treatment.aspx> (accessed 26 November 2015).
- NHS Choices (2014b) *Urinary Incontinence – Non-Surgical Treatment*. <http://www.nhs.uk/Conditions/Incontinence-urinary/Pages/Treatment.aspx> (accessed 26 November 2015).
- NHS Choices (2015a) *Kidney Transplant*. <http://www.nhs.uk/conditions/Kidney-transplant/Pages/Introduction.aspx> (accessed 26 November 2015).
- NHS Choices (2015b) *Dialysis*. <http://www.nhs.uk/Conditions/dialysis/Pages/Introduction.aspx> (accessed 26 November 2015).
- Rull, G. (2013) *Drug Prescribing in Renal Impairment*. <http://www.patient.co.uk/doctor/drug-prescribing-in-renal-impairment> (accessed 26 November 2015).
- RxList (2012) *Sandimmune Patient Information Including If I Miss a Dose*. <http://www.rxlist.com/sandimmune-drug/patient-avoid-while-taking.htm> (accessed 26 November 2015).
- Tortora, G.J. and Derrickson, B. (2006) *Principles of Anatomy and Physiology*, 11th edn. Hoboken, NJ: John Wiley & Sons, Inc.
- Tortora, G.J. and Derrickson, B.H. (2009) *Principles of Anatomy and Physiology*, 12th edn. Hoboken, NJ: John Wiley & Sons, Inc.
- Waugh, A. and Grant, A. (eds) (2014) *Ross and Wilson Anatomy and Physiology in Health and Illness*. Edinburgh: Churchill Livingstone.

Further reading

National Institute for Health and Care Excellence

<http://www.nice.org.uk/guidance/cg73> (accessed 26 November 2015)

This guidance relates to early identification and management of chronic kidney disease in adults in primary and secondary care.

<http://guidance.nice.org.uk/QS5> (accessed 26 November 2015)

This NICE quality standard defines clinical best practice within this topic area. It provides specific, concise quality statements, measures and audience descriptors to provide patients and the public, health- and social-care professionals, commissioners and service providers with definitions of high-quality care.

Cancer Research UK

<http://www.cancerresearchuk.org/cancer-help/type/kidney-cancer/> (accessed 26 November 2015)

A useful website to get information about cancer. They include symptoms, causes and tests to diagnose cancer. Information about treatments (including surgery) and current research can be found on this website.

Activities

Multiple choice questions

1. The urine flows through:
 - (a) the pelvis of the kidney → urethra → ureter → bladder
 - (b) the bladder → pelvis of the kidney → ureter → urethra

- (c) the pelvis of the kidney → ureter → bladder → urethra
(d) the ureter → pelvis of the kidney → urethra → bladder
2. Which of the following structures are found in the renal medulla?
- (a) glomerulus
 - (b) Bowman's capsule
 - (c) loop of Henle
 - (d) proximal convoluted tubule
3. The kidneys produce renin when:
- (a) blood pressure is low
 - (b) blood pressure is high
 - (c) pH of blood is low
 - (d) pH of blood is high
4. What is the name of the gland sitting above the kidneys?
- (a) pancreas
 - (b) liver
 - (c) hypothalamus
 - (d) adrenal
5. The urinary bladder is composed of:
- (a) transitional epithelium
 - (b) skeletal muscles
 - (c) cardiac muscle
 - (d) simple squamous epithelium
6. A patient with a urinary tract infection will probably present with:
- (a) clear urine
 - (b) leucocytes in the urine
 - (c) glycosuria
 - (d) ketones
7. The specific gravity of urine is in the range:
- (a) 1.001–1.073
 - (b) 1.020–1.025
 - (c) 1.000–1.078
 - (d) 1.001–1.035
8. The light yellow colour of urine results from:
- (a) the pigments from the breakdown of haemoglobin
 - (b) breakdown of white blood cells
 - (c) eating too many carrots
 - (d) fats in the urine
9. Blood glucose is entirely reabsorbed in:
- (a) the glomerulus
 - (b) the distal convoluted tubule
 - (c) the proximal convoluted tubule
 - (d) the collecting ducts
10. Renal calculi may develop as a result of:
- (a) sarcoma of the bones
 - (b) drinking too much water
 - (c) eating too many carrots
 - (d) eating too much spinach

327

True or false

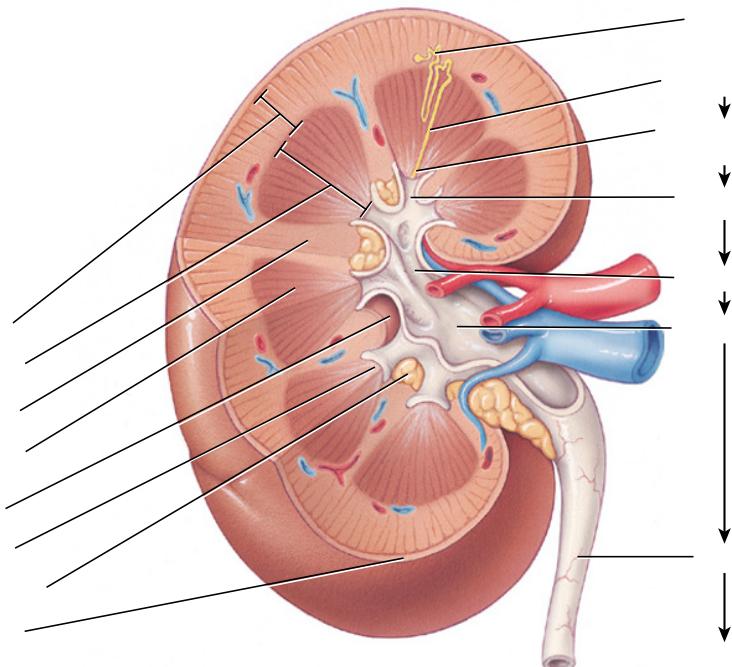
1. Urea is the end-product of nitrogen metabolism.
2. The energy for filtration of fluid in the glomeruli is generated by the heart.
3. Inulin clearance is used to estimate the renal plasma flow.
4. Creatinine is an endogenous chemical.
5. Bowman's capsule consists of endothelial cells.
6. The flow of urine down the ureter is by peristalsis.
7. Concentration of urine occurs in the bladder.
8. The muscle of the bladder wall is striated muscle.
9. Erythrocytes are present in the glomerular filtrate.
10. Renal tubular secretion occurs in the glomeruli.

328

Label the diagram 1

Label the diagram using the following list of words:

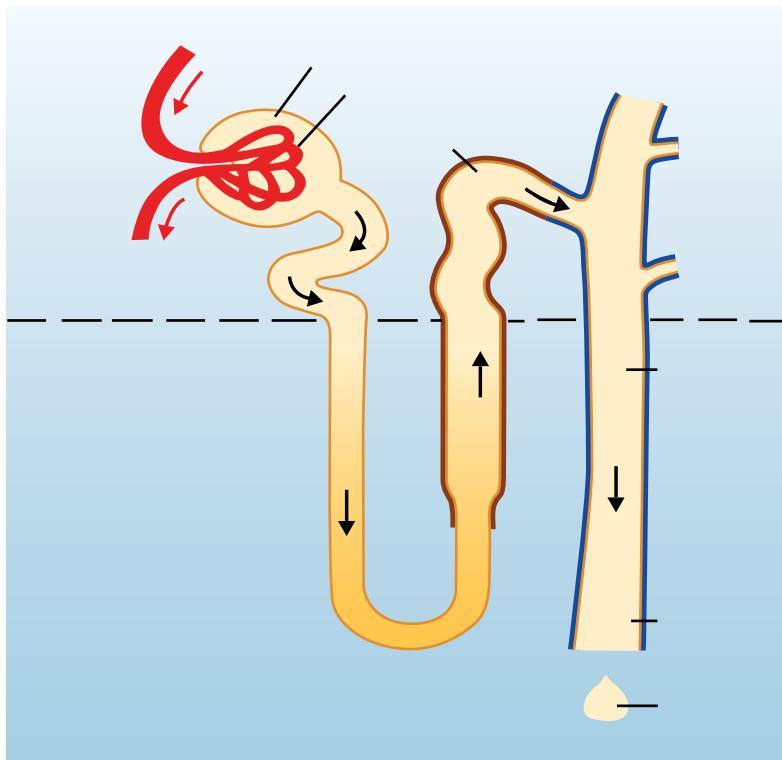
Renal cortex, Renal medulla, Renal column, Renal pyramid in renal medulla, Renal sinus, Renal papilla, Fat in renal sinus, Renal capsule, Nephron, Path of urine drainage: Collecting duct, Papillary duct in renal pyramid, Minor calyx, Major calyx, Renal pelvis, Ureter, Renal artery, Renal vein, Urinary bladder



Label the diagram 2

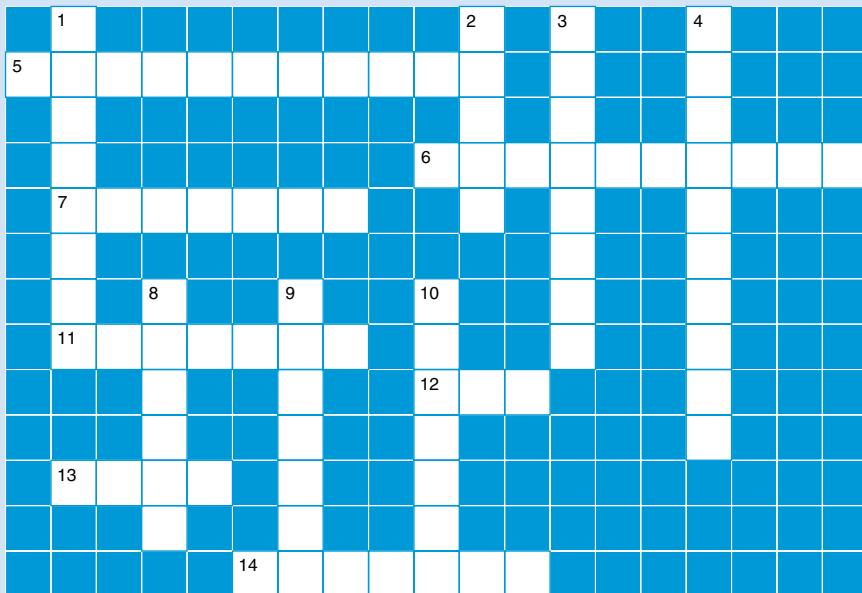
Label the diagram using the following list of words:

Afferent arteriole, Efferent arteriole, Proximal convoluted tubule, Glomerular (Bowman's) capsule, Glomerulus, Distal convoluted tubule, Interstitial fluid in renal cortex, Collecting duct, Interstitial fluid in renal medulla, Papillary duct, Dilute urine, Loop of Henle



329

Crossword



330

Across:

5. Hormone that regulates electrolyte balance (11).
6. One of the functions of the kidney (10).
7. Also carries sperm in man (7).
11. Gland that sits on top of each kidney (7).
12. Hormone that regulates fluid balance (3).
13. One of the waste products found in the urine (4).
14. Functional unit of the kidney (7).

Down:

1. Scanty urine output (8).
2. Hormone produced by the juxtaglomerular cells (5).
3. Inflammation of the bladder (8).
4. An invasive investigation of the bladder (10).
8. Conveys urine from the kidney to the bladder (6).
9. Outer protective layer of the kidney (7).
10. Storage organ for urine (7).

Word search

R	K	N	F	U	L	A	M	I	X	O	R	P	O	E
E	E	M	U	R	E	T	E	R	N	K	O	M	U	J
N	O	N	O	I	T	A	R	T	L	I	F	N	R	X
I	R	R	O	Z	Y	U	I	Z	Q	J	N	N	C	G
N	F	E	O	R	D	Y	R	Z	A	B	L	I	R	C
S	P	I	N	V	E	D	R	E	L	E	W	L	E	Y
E	B	Y	Y	A	P	T	J	K	T	C	F	U	A	S
C	K	Z	V	K	L	G	S	I	C	H	W	N	T	T
R	I	I	L	U	R	E	M	O	L	G	R	I	I	I
E	D	I	O	G	B	L	A	D	D	E	R	A	N	T
T	N	E	P	H	R	O	N	J	T	L	G	T	I	I
I	E	I	N	F	E	C	T	I	O	N	A	R	N	S
O	Y	T	U	B	U	L	E	M	S	T	A	F	E	L
N	L	A	T	S	I	D	G	M	I	K	K	X	G	D
D	M	A	I	R	U	T	A	M	E	A	H	T	Q	N

331

Renal, Glomeruli, Tubule, Kidney, Bladder, Creatinine, Secretion, Urethra, Ureter, Renin, Aldosterone, Filtration, Inulin, Proximal, Distal, Nephron, Haematuria, Cystitis, Infection

Fill in the blanks

The _____, _____, _____ and the _____ form the normal urinary system. The kidneys _____ the _____ in order to remove the wastes and _____ from the body and form the _____. This travels to the _____ via the _____. The urinary bladder _____ the urine until it is passed out of the body via the urethra.

Within the kidneys are nearly a _____ small filtering units called _____. Blood flows through _____ and intricate networks of _____ within the kidneys to the glomeruli in order to undergo the _____.

The function of the _____ is, among other things, to get rid of the _____ that result from the body's _____. One of the major _____ of the metabolism of _____ (muscle) is _____. The kidneys remove the waste products by extracting them from the blood and sending them along the _____ to the _____, from where they are _____ in the _____. If the kidney function _____, the waste products _____ in the _____ and the body. The term for this build-up is _____.

accumulate, azotaemia, bladder, blood, blood vessels, by-products, excess fluids, excreted, fails, filter, filtration process, glomeruli, kidneys, kidneys, metabolism, million, protein, stores, tiny tubes, urea, ureter, ureters, ureters, urinary bladder, urinary bladder, urine, urine, waste products

Find out more

1. Describe the role of kidney in maintaining homeostasis.
2. Discuss the renin-angiotensin system.
3. What do you understand by erythropoietin doping?
4. Describe the functions of aldosterone II.
5. Explain glomerular filtration rate.
6. Explain the role of the kidneys in a person suffering from congestive cardiac failure.
7. Explain the effects of high blood pressure in a patient who is on bed rest.
8. A person with kidney disease is diagnosed as having proteinuria. The person's limbs are swollen. Explain proteinuria and why it causes swollen limbs in this person.
9. Discuss the role of the autonomic system in micturition.
10. Explain the term countercurrent at the loop of Henle.

332

Conditions

The following is a list of conditions that are associated with the renal system. Take some time and write notes about each of the conditions. You may make the notes taken from text books or other resources (e.g. people you work with in a clinical area), or you may make the notes as a result of people you have cared for. If you are making notes about people you have cared for you must ensure that you adhere to the rules of confidentiality.

Nephrotic syndrome	
Glomerulonephritis	
End-stage renal disease	
Polycystic renal disease	
Hydronephrosis	