Anatomy and Physiology: The Renal System

CHAPTER 1

The renal system is also known as the urinary system; it plays a crucial role in maintaining homeostasis within the body. Comprising the kidneys, ureters, bladder and urethra, this system is responsible for filtering and eliminating waste products from the blood while regulating fluid and electrolyte balance.

The body is an intricately designed collection of systems and organs, relying on the precise coordination of various functions to maintain equilibrium. At the epicentre of this physiological coordination is the renal system, which is a complex network responsible for filtering blood, regulating fluid balance and arranging the expulsion of waste. This chapter explores the renal system, the anatomy, functions and mechanisms that define its role in sustaining the delicate balance of internal homeostasis.

The renal system is located in the lower back, where the two bean-shaped organs house nephrons, the microscopic components of urine formation. The intricate structures and functions of the kidneys are responsible for selective filtration, reabsorption and secretion taking place within these vital organs.

The ureters, bladder and urethra are also key components of the renal system. Together, these components form a dynamic group that facilitates the storage and expulsion of urine, contributing to the body's fluid and electrolyte balance.

The renal system is responsible for a number of regulatory functions. From the delicate regulation of blood pressure to the adjustment of acid–base balance, the renal system ensures that the internal environment remains finely tuned for optimal cellular function.

RENAL SYSTEM

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

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

The organs of the renal system are depicted in Figure 1.1.

KIDNEYS (EXTERNAL)

There are usually two kidneys, one on each side of the spinal column (located in the posterior abdomen, retroperitoneally). They are approximately 11 cm long, 5–6 cm wide and 3–4 cm thick. The adrenal glands sit immediately superior to the kidneys. The kidneys are said to be bean-shaped organs where the outer border is convex; the inner border is known as the hilum (or hilus) and at this point, the renal arteries, renal veins, nerves and ureters enter and leave the kidneys (Figure 1.1). The renal artery transports blood to the kidneys and once the blood

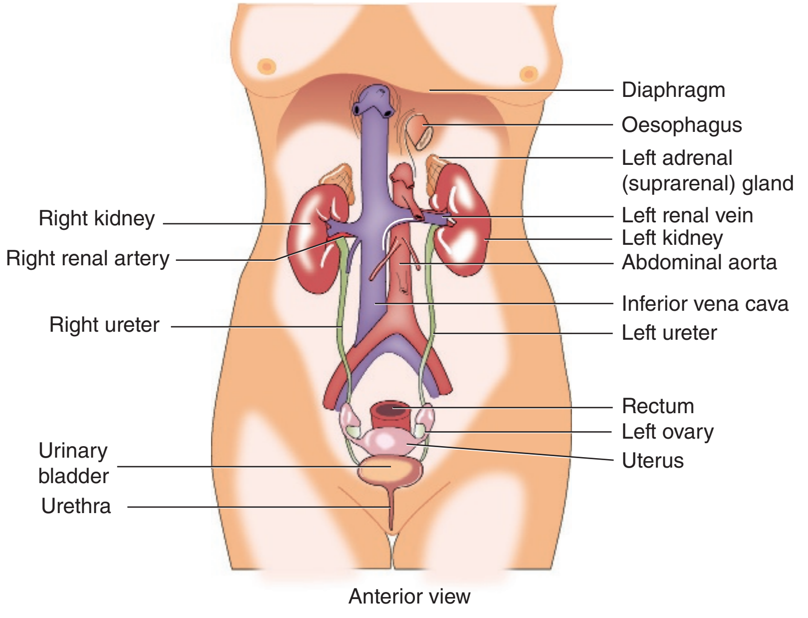

FIGURE 1.1 The renal system and female abdominal cavity

has been filtered, the renal vein takes the blood away. The right kidney is in contact with the liver's large right lobe and, as such, the right kidney is approximately 2–4 cm lower than the left kidney. There are three layers that cover and support the kidneys:

- Renal fascia
- Adipose tissue
- Renal capsule

The renal fascia provides 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 1.2).

KIDNEYS (INTERNAL)

Inside the kidney, there are three distinct regions. They are:

- Renal cortex
- Renal medulla
- Renal pelvis

The outermost part of the kidney is the renal cortex. The renal cortex forms a continuous, smooth outer portion of the kidney with a number of projections (the renal columns) extending down between the pyramids. The renal column is the medullary extension of the renal cortex; it is reddish in colour and has a granular appearance, which is due to the

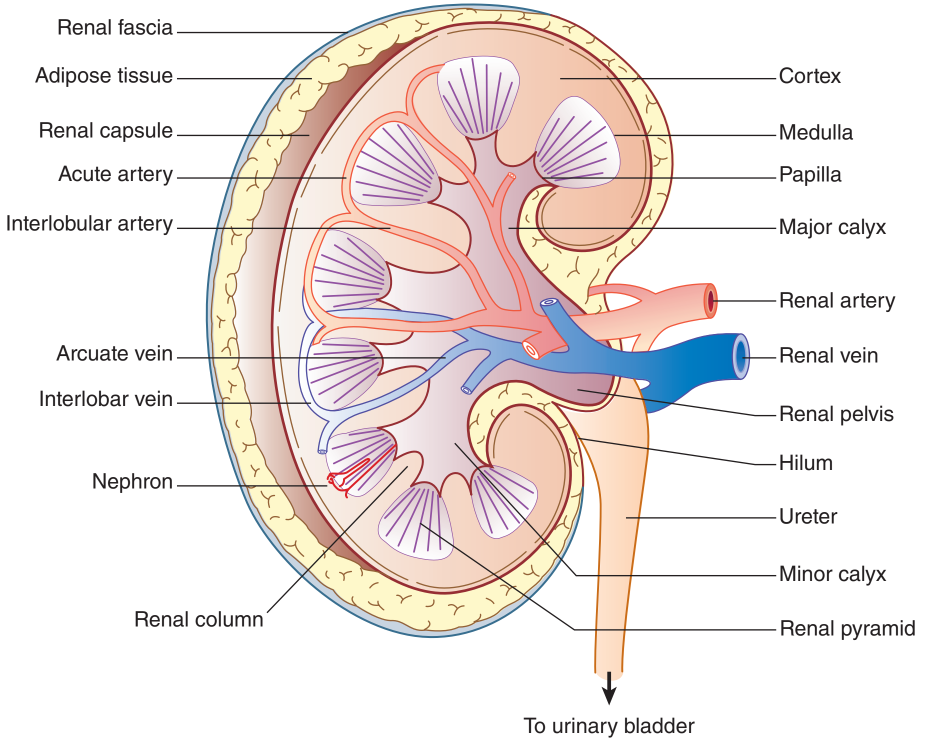

FIGURE 1.2 The external layers of the kidney

capillaries and the structures of the nephron. The medulla is lighter in colour with an abundance of blood vessels and tubules of the nephrons. The medulla is made up of approximately 8–12 renal pyramids. Figure 1.3a shows the frontal section of the right kidney and Figure 1.3b the path of blood flow. The renal pyramids, also called malpighian pyramids, are the cone-shaped sections of the kidneys. The wider portion of the cone faces the renal cortex, with the narrow ends pointing internally, and this section is known as 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 1.4). The renal pelvis forms the expanded upper aspect of the ureter, which is funnel-shaped, and it is in the region where two or three calyces converge.

NEPHRONS

The nephrons are small structures that form the functional units of the kidney. The nephron consists of a glomerulus and a renal tubule (see Figure 1.5). There are around one million nephrons in each kidney. It is within these structures that urine is formed. The nephrons:

- Filter blood
- Perform selective reabsorption
- Excrete unwanted waste products from the filtered blood

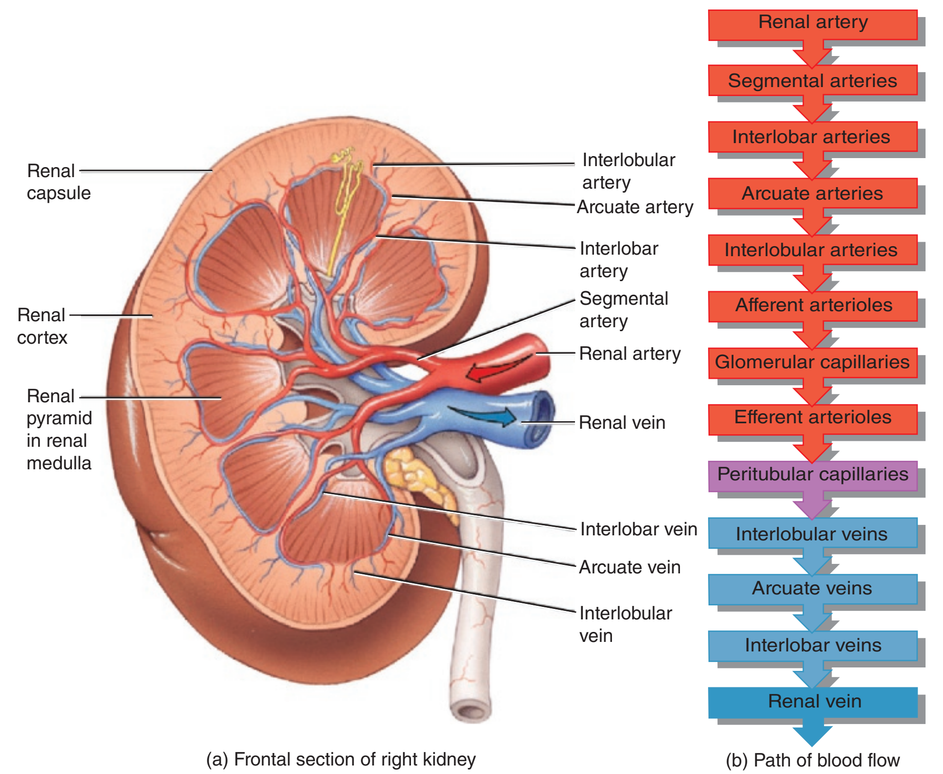

FIGURE 1.3 (a and b) The internal structures. *Source:* Tortora and Derrickson (2009). Reproduced with permission from John Wiley & Sons.

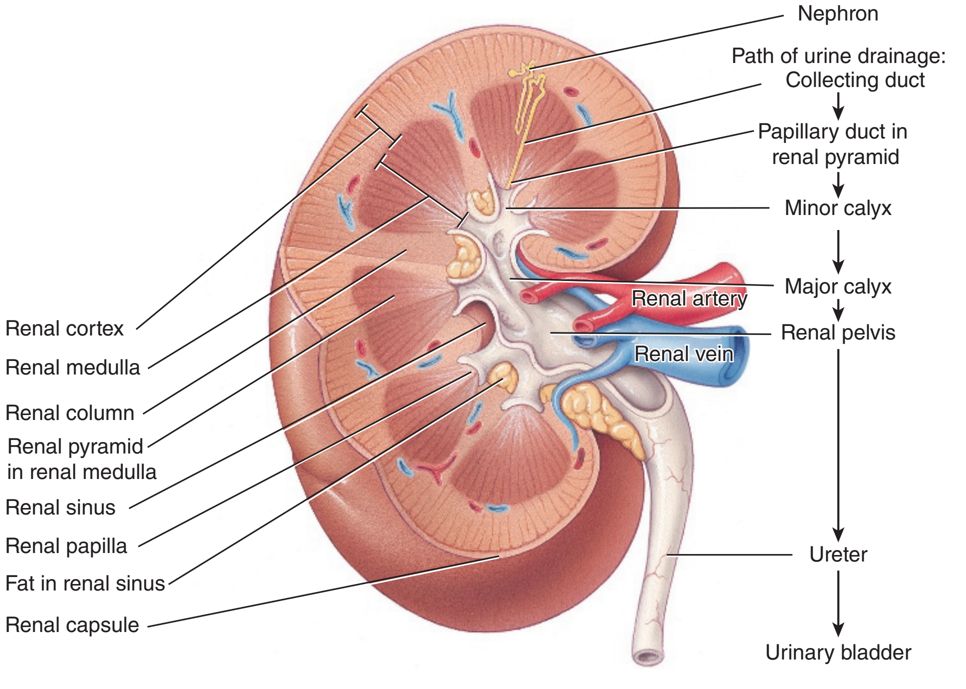

FIGURE 1.4 The internal structures showing blood vessels. *Source:* Tortora and Derrickson (2009). Reproduced with permission from John Wiley & Sons.

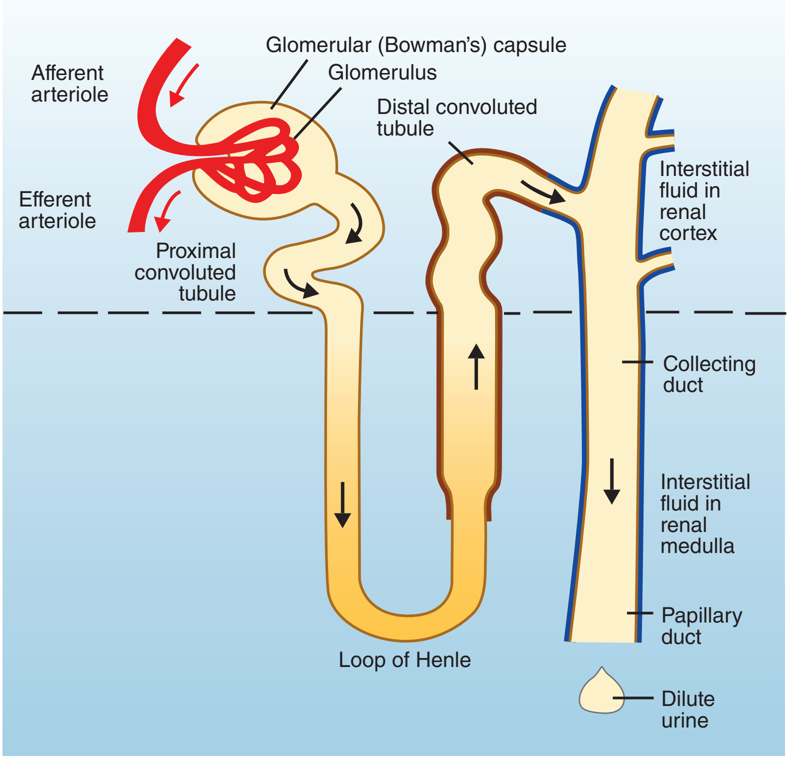

FIGURE 1.5 Nephron. *Source:* Tortora and Derrickson (2009). Reproduced with permission from John Wiley & Sons.

The nephron plays a key part in homeostasis. This system helps to regulate the amount of water, salts, glucose, urea and other minerals in the body. The nephron is a filtration system situated 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)
- Collecting ducts

Each section carries out a different function; these are discussed in the following sections.

BOWMAN'S CAPSULE

Also known as the glomerular capsule (see Figure 1.6), 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 first enters Bowman's capsule, 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. Epithelial cells, known as podocytes, line the visceral layer,

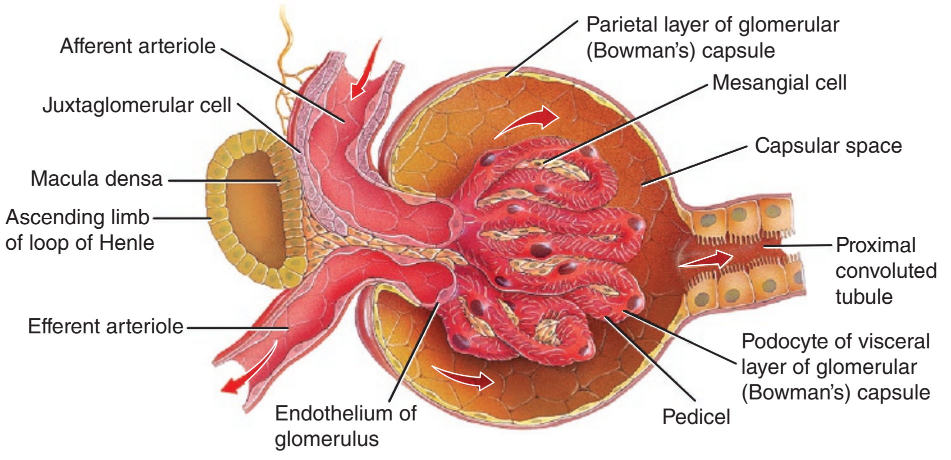

FIGURE 1.6 Bowman's capsule. *Source:* Tortora and Derrickson (2009). Reproduced with permission from John Wiley & Sons.

while the parietal layer is lined with simple squamous epithelium; it is in Bowman's capsule that the network of capillaries called the glomerulus (Marieb and Hoehn 2019) is found. Filtration of blood takes place in this portion of the nephron.

PROXIMAL CONVOLUTED TUBULE

From the Bowman's capsule, the filtrate drains into the proximal convoluted tubule (see Figure 1.6). The surface of the epithelial cells of this segment of the nephron is covered with densely packed microvilli, which 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 bends into a loop known as the loop of Henle (see Figure 1.5). The loop of Henle dips or 'loops' from the cortex into the medulla (descending limb) and then returns to the cortex (ascending limb). 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 creating 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 with 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. Different sections of the loop of Henle have different actions:

- The descending loop of Henle is relatively impermeable to solute but permeable to water, 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, particularly sodium and chloride ions. As sodium and chloride ions move

out down the concentration gradient, fluid within the tubule first becomes isotonic and then hypotonic as more ions leave. Urea diffuses into the ascending limb, keeping 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 1.6). 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 (a 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 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 1.5). Several collecting ducts converge, draining 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. In dehydration, approximately 25% of the water filtered is reabsorbed in the collecting duct. The cells of the collecting ducts are impermeable to water. 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 the 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.

THE FUNCTIONS OF THE KIDNEY

The kidneys maintain fluid balance, electrolyte balance and the acid–base balance of the blood, removing waste products and excess water (fluid) collected by, and carried in, the blood as it flows through the body. Approximately 190 L of blood enters the kidneys daily via the renal arteries. Millions of tiny filters, called glomeruli, inside the kidneys separate waste products and water from the blood. Most of these unwanted substances come from what is ingested. The kidneys automatically remove the right amount of salt and other minerals from the blood to leave just the quantities the body needs.

In removing just the right amount of excess fluid, healthy kidneys maintain the body's fluid balance. Fluid content stays at about 55% of total weight in women; in men, this is 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, producing a lot of urine. If fluid intake is low, the kidneys retain fluid and not much urine is passed. Fluid also leaves the body via sweat, breath and faeces. In hot weather, a lot of fluid is lost by sweating and the kidneys do not produce much urine.

Kidneys synthesise hormones such as renin and angiotensin. These hormones regulate how much sodium and fluid the body retains and how well the blood vessels can expand and contract. This, in turn, helps control blood pressure.

Kidneys produce a hormone – erythropoietin, which is transported in the blood to the bone marrow here it stimulates the production of red blood cells. These cells carry oxygen throughout the body. Without enough healthy red blood cells anaemia develops.

Healthy kidneys keep bones strong by producing calcitriol. Calcitriol maintains the right levels of calcium and phosphate in the blood and bones. Calcium and phosphate balance is important in keeping bones healthy. When the kidneys fail, they may not produce enough calcitriol, leading to abnormal levels of phosphate, calcium and vitamin D, resulting in renal bone disease. A summary of the functions of the kidney is found in Box 1.1.

BOX 1.1 FUNCTIONS OF THE KIDNEY

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

Source: Nagalingam (2020).

KIDNEY BLOOD SUPPLY

The kidney filters at least 20–25% of blood during the resting cardiac output. Approximately 1200 mL of blood flows through the kidney each minute. Both kidneys receive their blood supply directly from the aorta via the renal artery, which is divided into anterior and posterior renal arteries. There are several arteries delivering blood to the kidneys:

- Renal artery: arises from the abdominal aorta at the level of the 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.

The branches of the interlobular artery enter the nephrons as afferent arterioles. Each nephron receives one afferent arteriole, further subdivided into a tuft of capillaries called the glomerulus. The glomerular capillaries reunite, leaving Bowman's capsule as efferent arterioles. Efferent arterioles unite, forming peritubular capillaries and then interlobular veins that unite to form the arcuate veins and finally the 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

There are three processes involved in the formation of urine:

- Filtration
- Selective reabsorption
- Secretion

FILTRATION

Urine formation starts with the process of filtration, which goes on continually in the renal corpuscles. Filtration takes place in the glomerulus within 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 the afferent arteriole, further subdividing 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). Here it is filtered and 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 collectively known 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 and Huether 2018). The filtered blood 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 essential for body function are reabsorbed into the plasma. Substances, for example, sodium, calcium, potassium and chloride, are reabsorbed to maintain fluid and electrolyte balance and the pH of the blood. However, if these substances are in excess of body requirements, they are excreted in the urine. Only 1% of the glomerular filtrate actually leaves the body; 99% is reabsorbed into the bloodstream (Swales 2022). The reabsorption occurs via three processes:

- Osmosis
- Diffusion
- Active transport

Blood glucose is entirely reabsorbed into the blood from the proximal tubules. It is actively transported out of the tubules and into the peritubular capillary blood. None of these valuable nutrients are 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 the blood from the tubular fluid. The amount of sodium reabsorbed varies, depending largely on how much salt is taken in from the food eaten.

As a person increases their salt intake, the 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 also works the other way. 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

Substances not removed through filtration are secreted into the renal tubules from the peritubular capillaries (see Figure 1.7) of the nephron (Martini, Nath, and Bartholomew 2018). These include drugs and hydrogen ions. Tubular secretion primarily takes place by active transport, 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

It is the tubular secretion of hydrogen and ammonium ions that helps to maintain the pH of the blood.

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 (ANP)

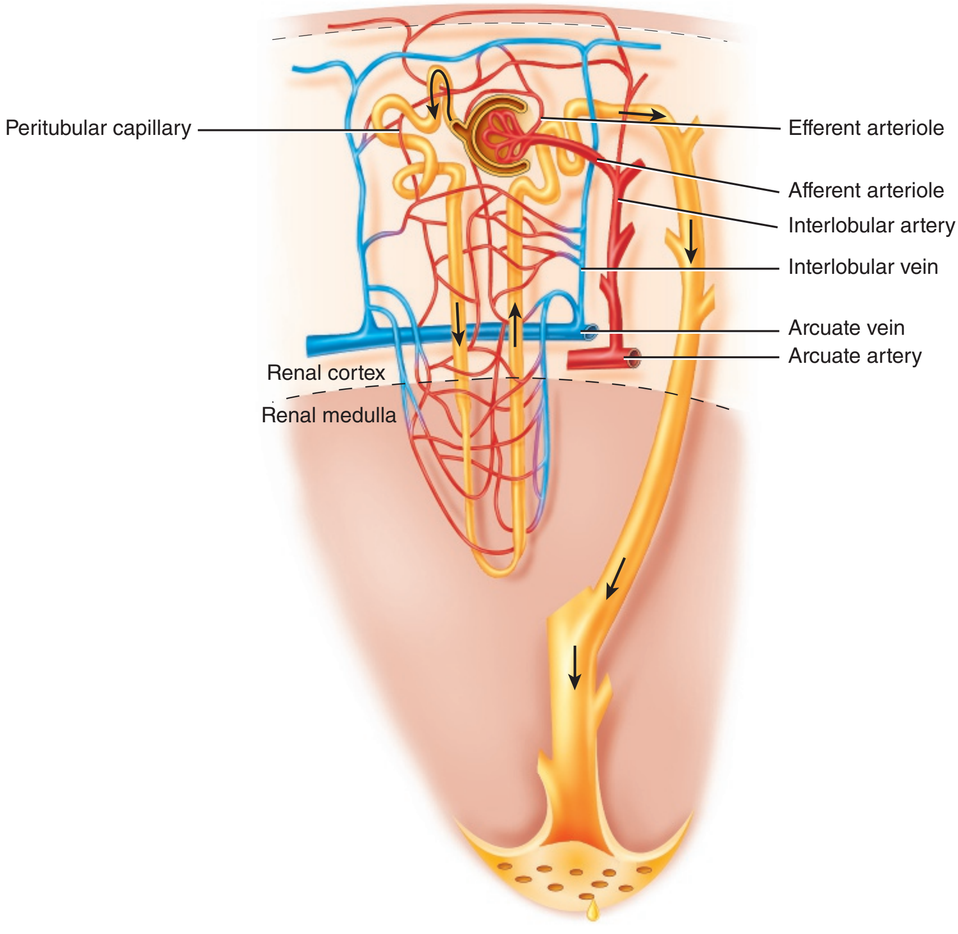

FIGURE 1.7 Nephron with capillaries. *Source:* Tortora and Derrickson (2009). Reproduced with permission from John Wiley & Sons.

ANGIOTENSIN AND ALDOSTERONE

As blood volume and blood pressure decrease, the juxtaglomerular cells secrete a hormone called renin. Juxtaglomerular cells are found near the glomerulus. These cells synthesise, store and secrete renin. Renin acts on a plasma protein called angiotensinogen and converts it into angiotensin I. Angiotensinogen is produced by the hepatocytes. Angiotensin I is transported by the blood to the lungs. In the lung capillaries, there are enzymes called angiotensin-converting enzymes (ACEs). ACE is predominantly located in lung capillaries, but 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 (Jones and Stegall 2019). 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, a steroid hormone, is secreted by the adrenal glands. It serves as the principal regulator of the salt and water balance of the body and 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, produced by the hypothalamus gland and stored by the posterior pituitary gland. This hormone increases 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 passes less urine. In the absence of ADH, less water is reabsorbed, and the patient passes 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 the blood. Osmolarity is sensed in the hypothalamus by neurones called 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 secretion of ADH is suppressed. When osmolarity increases above the threshold, osmoreceptors recognise this and stimulate the neurones that secrete ADH.

ATRIAL NATRIURETIC PEPTIDE

The fourth hormone involved in tubular secretion and reabsorption is ANP. 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; this lowers blood pressure. ANP 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, reducing cardiac output by decreasing ventricular preload. ANP also dilates arteries, which decreases systemic vascular resistance and systemic arterial pressure.

COMPOSITION OF URINE

Urine is normally a sterile and clear fluid of nitrogenous waste 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, for example, diet, medications and certain diseases, may affect the colour of urine. It is slightly acidic and the pH ranges from 4.5 to 8. The pH is affected by an individual's dietary intake and state of health. A diet 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. However, 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 present in the urine; if these are present, then the person may have a medical condition.

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: It is usually yellow–amber, but varies according to recent diet, medication and the concentration of the urine. Drinking more water generally reduces 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.

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 ammonia. Cloudy urine may indicate infection, whereas foamy urine can indicate the presence of protein and glucose.

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 from 0 (strong acid) to 14 (strong alkali, also known as a 'base'). Pure water is 'neutral', neither acid nor alkali; it has a pH of 7. The pH of normal urine is generally in the range of 4.5–8, with a typical average being around 6.0.

Specific gravity: Specific gravity is also known as 'relative density'. This is the ratio of the weight of a volume of a substance compared to the weight of the same volume of distilled water. Given urine is mostly water, but it also contains some other substances dissolved in the water, its relative density is expected to be close to, but slightly greater than, 1.000.

URETERS

The ureters are tubular organs running from the renal pelvis to the posterolateral base of the urinary bladder. They are approximately 25–30 cm in length and 5 mm in diameter (Martini, Nath, and Bartholomew 2018). 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 1.8).

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 pelvis. The amount of urine in the renal pelvis determines the frequency of the peristaltic wave action, which can range from one wave every few minutes to one wave every few seconds. This action creates a pressure force that moves the urine through the ureters and into the bladder in small spurts.

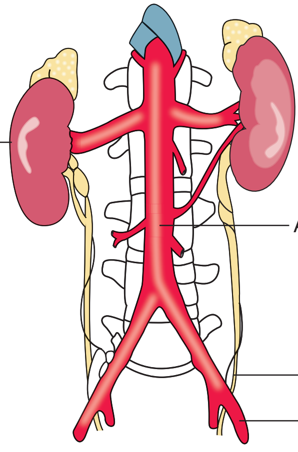

FIGURE 1.8 Common iliac vessels and ureter. *Source:* Nair and Peate (2009). Reproduced with permission from John Wiley & Sons.

URINARY BLADDER

The urinary bladder is a hollow muscular organ, located in the pelvic cavity posterior to the symphysis pubis. In the male, the bladder lies anterior to the rectum; in the female, it lies anterior to the vagina and inferior to the uterus (Martini, Nath, and Bartholomew); it is a smooth muscular sac storing urine. Although the shape of the bladder is spherical, this is altered by the pressure of surrounding organs. When the bladder is empty, the inner section of the bladder forms folds (rugae). 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 of urine. In females, the bladder is slightly smaller, as the uterus occupies the space above the bladder.

The inner lining of the urinary bladder is a mucous membrane of transitional epithelium, continuous with that in the ureters. When the bladder is empty, the rugae and transitional epithelium allow the bladder to expand as it fills. The second layer on 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, acting as valves allowing urine to enter the bladder but preventing 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 1.9). 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

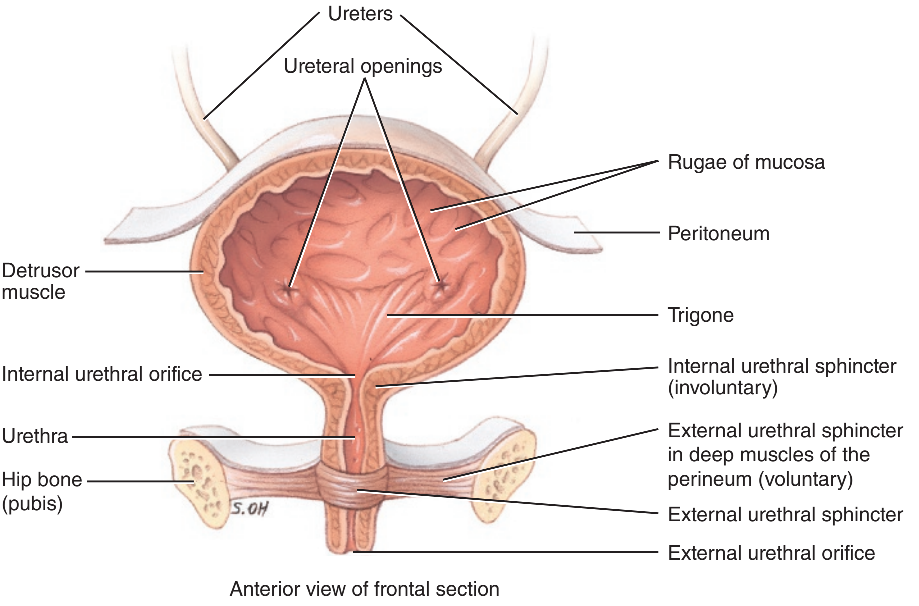

FIGURE 1.9 Layers of the urinary bladder. *Source:* Tortora and Derrickson (2009). Reproduced with permission from John Wiley & Sons.

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 to the kidney (Peate 2020).

Urinary tract infections, such as cystitis (an infection of the bladder), can lead to more serious infections further up the urinary tract. 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.

URETHRA

The urethra is a muscular tube draining urine from the bladder, conveying it out of the body. It contains three coats: 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; 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:

1. Prostatic region: passes through the prostate gland.
2. Membranous portion: passes through the pelvic diaphragm.

3. Bulbar urethra: located inside the perineum and scrotum, extends from the external distal urinary sphincter to the penoscrotal 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.
4. Penile region: extends the length of the penis.

In the male, the urethra not only excretes fluid waste products but is also part of the reproductive system. Rather than the straight tube found in the female's 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 1.10).

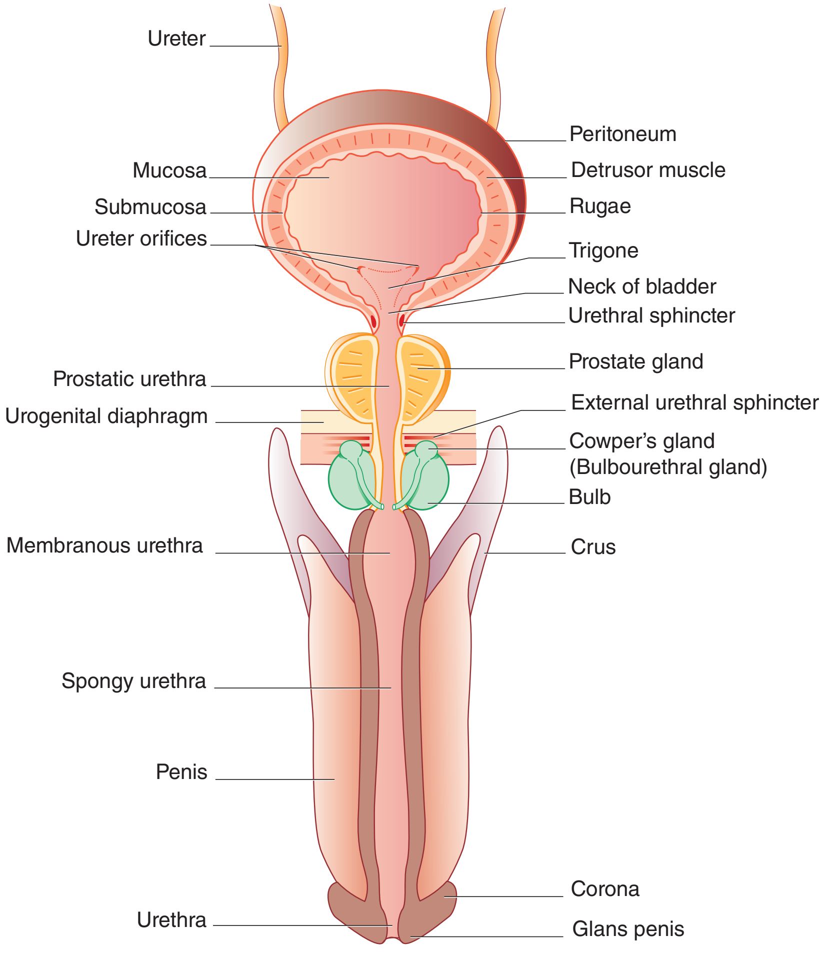

FIGURE 1.10 Male urethra

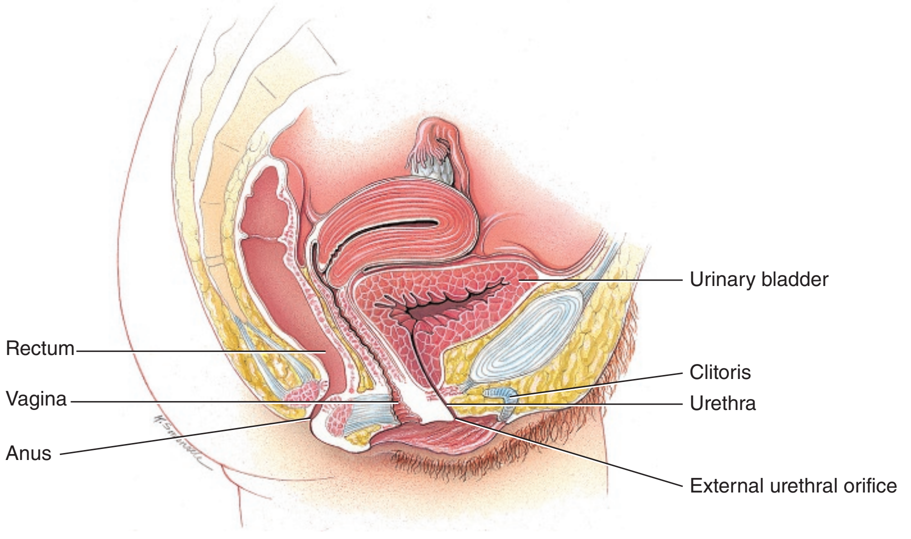

FIGURE 1.11 Location of the female urethra. *Source:* Nair and Peate (2013). Reproduced with permission from John Wiley & Sons.

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. The urethra in the female 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 of the labia minora, 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 1.11).

MICTURITION

When the volume of urine in the bladder reaches approximately 300 mL, stretch receptors in the bladder walls are stimulated and excite sensory parasympathetic fibres relaying information to the sacral area of the spine. This information is assimilated into the spine and relayed to two different sets of neurones. Parasympathetic motor neurones are excited and act to contract 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 usually has control over bladder function. 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. Collectively, these components play an important role in maintaining homeostasis. The renal system removes waste products of metabolism, secretes hormones, regulates fluid balance and maintains homeostasis. Some of the functions it carries out include:

- Regulating blood volume through urine production and blood pressure by releasing renin.
- Regulating electrolyte balance in the body through hormones such as aldosterone.

- Maintaining 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 regulating 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, 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 OF TERMS

Anterior: Referring to the front.

Bifurcation: Dividing into two branches.

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

Diuresis: Excessive urine production.

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

Excretion: The elimination of waste products from metabolism.

Filtration: A passive transport system.

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

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

Nephron: Functional unit of the kidney.

Posterior: Pertaining to the back, behind.

Renal artery: A blood vessel that takes blood to the kidney.

Renal cortex: The outermost part of the kidney.

Renal medulla: The middle aspect of the kidney.

Renal pelvis: The funnel-shaped section of the kidney.

Renal pyramids: Cone-shaped structures of the medulla.

Renal vein: A 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.

MULTIPLE CHOICE QUESTIONS

1. What is the primary function of the renal system?
   a) Digestion
   b) Filtration of blood
   c) Respiratory exchange
   d) Hormone secretion

2. Where does filtration of blood take place in the kidney?
   a) Glomerulus
   b) Renal cortex
   c) Renal medulla
   d) Ureter

3. Which hormone stimulates the production of red blood cells in the bone marrow?
   a) Insulin
   b) Thyroxine
   c) Erythropoietin
   d) Adrenaline

4. What is the normal function of the loop of Henle in the nephron?
   a) Filtration
   b) Reabsorption of water and electrolytes
   c) Secretion of hormones
   d) Storage of urine

5. What is the purpose of the ureters in the renal system?
   a) Filtration of blood
   b) Storage of urine
   c) Transport of urine from the kidneys to the bladder
   d) Reabsorption of water

6. The bladder is a muscular organ that primarily functions for:
   a) Filter blood
   b) Store urine
   c) Produce hormones
   d) Reabsorb water

7. The functional unit of the kidney responsible for filtration, reabsorption and secretion is called:
   a) Nephron
   b) Glomerulus
   c) Renin
   d) Ureter

8. What is the role of angiotensin-converting enzyme (ACE) in the renal system?
   a) Stimulating erythropoiesis
   b) Regulating blood pressure
   c) Facilitating urine excretion
   d) Enhancing glucose metabolism

9. What is the primary function of the nephron's distal convoluted tubule?
a) Filtration
b) Reabsorption of water
c) Secretion of substances into urine
d) Initial filtration of blood

10. What hormone acts on the distal tubules and collecting ducts to promote the reabsorption of sodium and water?
a) Aldosterone
b) Antidiuretic hormone (ADH)
c) Renin
d) Erythropoietin

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