6 HOMEOSTASIS CONTROLS FLUID AND GAS LEVELS

UNIT 3 CONTENT

SCIENCE INQUIRY SKILLS

» identify, research and construct questions for investigation; propose hypotheses; and predict possible outcomes
» design investigations, including the procedure(s) to be followed, the materials required, and the type and amount of primary and/or secondary data to be collected; conduct risk assessments; and consider research ethics, including animal ethics
» conduct investigations, including the collection of data related to homeostasis and the use of models of disease transmission, safely, competently and methodically for the collection of valid and reliable data
» represent data in meaningful and useful ways, including the use of mean, median, range and probability; organise and analyse data to identify trends, patterns and relationships; discuss the ways in which measurement error, instrumental accuracy, the nature of the procedure and the sample size may influence uncertainty and limitations in data; and select, synthesise and use evidence to make and justify conclusions
» select, use and/or construct appropriate representations, including diagrams, models and flow charts, to communicate conceptual understanding, solve problems and make predictions
» communicate to specific audiences, and for specific purposes, using appropriate language, nomenclature, genres and modes, including scientific reports

SCIENCE UNDERSTANDING

Homeostasis

» homeostatic processes involve nerves and hormones in maintaining the body's internal environment within tolerance limits through the control of metabolism and physiological and behavioural activities
» body fluid concentrations are maintained by balancing water and salts via the skin, digestive system and the kidneys, which involve the actions of antidiuretic hormone (ADH) and aldosterone on the nephron, and the thirst reflex
» gas concentrations are controlled by balancing the intake of oxygen and the removal of carbon dioxide via the lungs, through the actions of the medulla oblongata and the autonomic nervous system

Source: School Curriculum and Standards Authority, Government of Western Australia

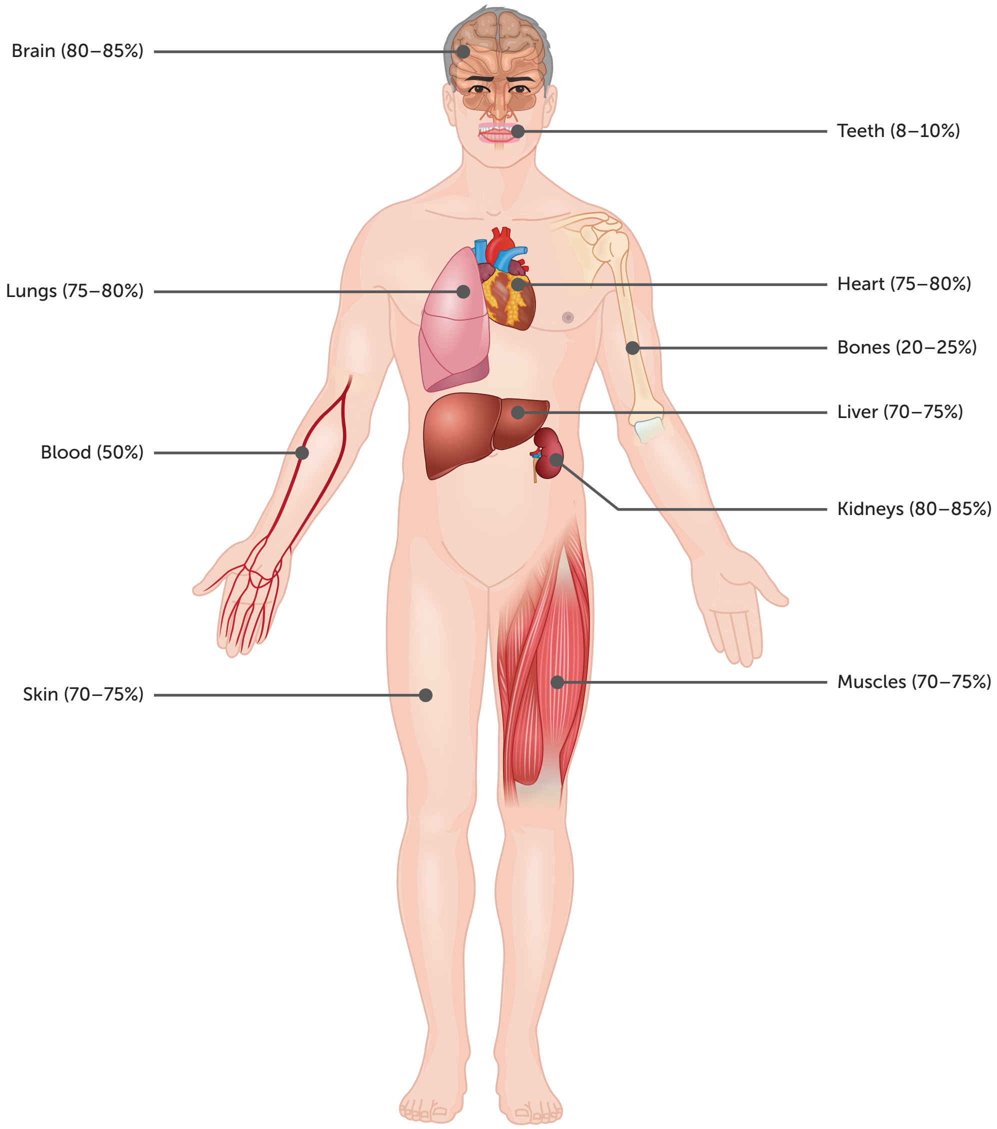
6.1 REGULATION OF THE COMPOSITION OF BODY FLUIDS

Water makes up a large proportion of the human body, ranging from 75% by mass in infants, to 50% for adult females and 60% for adult males, to 45% in old age. It is not pure water; rather, it contains dissolved substances. This fluid plays many important roles in the body, including transporting substances from one area of the body to another, facilitating movement across membranes and being the site of chemical reactions. Therefore, it is vital that the volume of water and concentration of dissolved substances is controlled to remain within the tolerance levels for the body.

Distribution of body fluids

The body of a male weighing 70 kg, with a water content of 60%, would contain 42 L of water. This large amount of water is distributed between the various body fluids.

FIGURE 6.1 The water content of different body structures



- Fluid inside the cells is called **intracellular fluid**, or **cytosol**.
- Fluid outside the cells is **extracellular fluid**. Extracellular fluid includes the:
  - blood plasma located within the blood vessels, also known as **intravascular fluid**
  - fluid between the cells, known as **interstitial fluid**, **intercellular fluid** or **tissue fluid**
  - fluid in specific body regions, known as **transcellular fluid**, which includes the fluid in the brain and spinal cord, eyes and joints, and surrounding the heart.

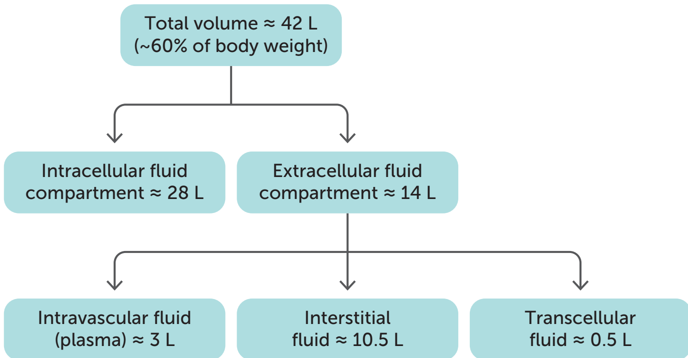


FIGURE 6.2 Distribution of body fluid in an average male adult

TABLE 6.1 Body fluids

TYPE OF BODY FLUID	PROPORTION OF TOTAL BODY FLUID	COMPONENTS OF THE BODY FLUID
Intracellular fluid	2/3 of total body water	Fluid inside the cell – the cytosol
Extracellular fluid	1/3 of total body water	Fluid that is outside the cells
Plasma (intravascular fluid)	Approx. 1/4 of extracellular fluid	The fluid part of the blood
Interstitial fluid and transcellular fluid	Approx. 3/4 of extracellular fluid	Lymph, cerebrospinal fluid, synovial fluid in joints, fluids of eyes and ears, fluid in the chest and abdominal cavities and around the heart, fluids of the alimentary canal, kidney filtrate

The different body fluids are not isolated from one another – there is a continuous exchange of materials between them. Plasma is separated from the interstitial fluid by the thin walls of the capillaries, and there is a relatively free exchange of materials between the two. However, dissolved materials that are large molecules, such as the proteins of the plasma, tend to remain within the blood vessels as they are too large to move through the capillary walls.

Water moves easily through plasma membranes, and so any difference in **osmotic concentration** between the intracellular fluid and the extracellular fluid does not last very long. If an imbalance in osmotic concentration does occur in any tissue, osmosis normally restores the balance within seconds. The tendency of a solution to take in water is known as **osmotic pressure**. The greater the difference in osmotic concentrations between two solutions, the greater the osmotic pressure. For more information about the exchange of materials across cell membranes refer to *Human Perspectives ATAR Units 1 & 2*.

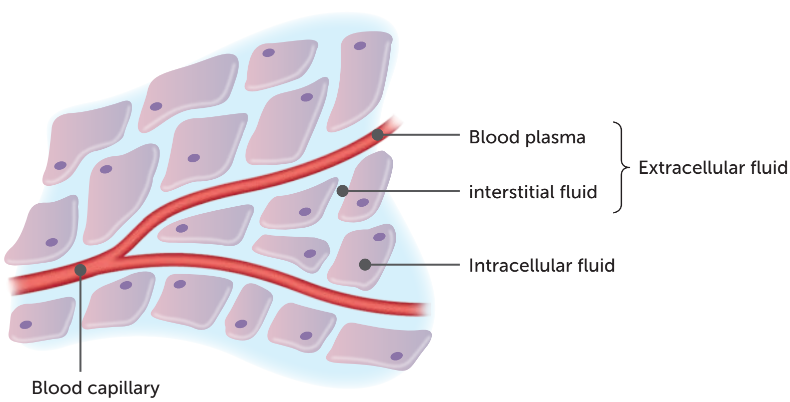


FIGURE 6.3 Body fluids

Osmoregulation and osmotic balance
This website has more information about osmotic pressure and osmosis.

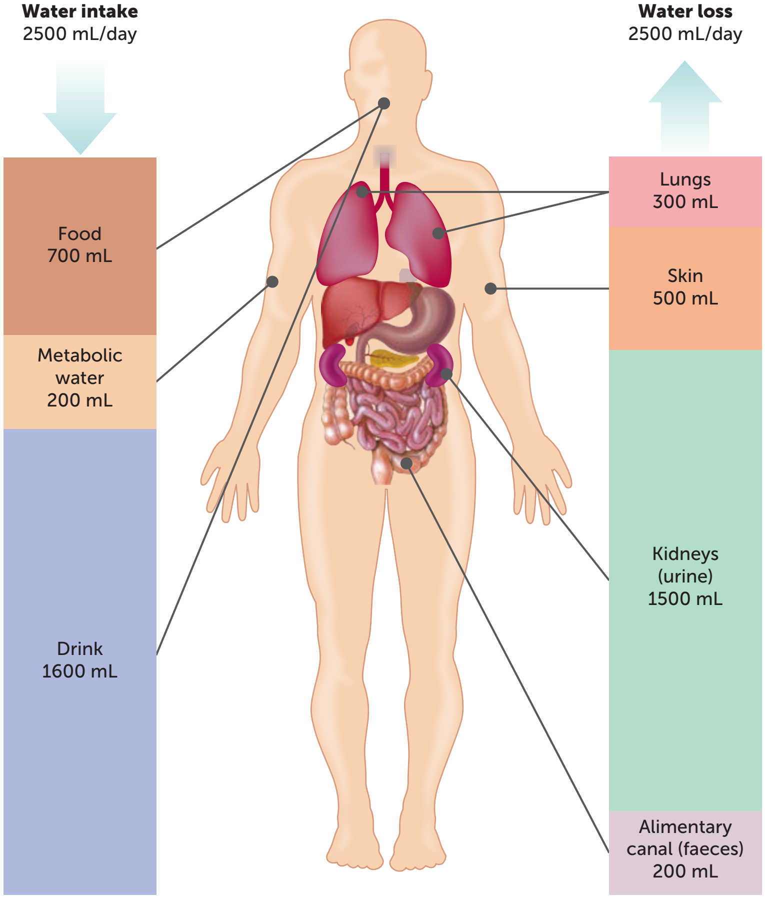
Maintaining fluid balance

In the same way that heat gain must be equal to heat loss in order to maintain a constant body temperature, fluid gain must equal fluid loss if the composition of body fluids is to be kept fairly constant.

Most body fluid is obtained from water that is either taken in as a liquid or contained in food that is eaten. A small amount is obtained as a by-product of chemical processes occurring within the cells. This water is referred to as **metabolic water**.

Fluids are lost from the body via the kidneys, through the skin, from the surface of the lungs and from the alimentary canal. Typically, about 2.5 L of fluid are lost each day. Figure 6.4 summarises the sources of fluid intake and the avenues of output.

FIGURE 6.4 Daily fluid intake and output



Excretion

Excretion is the removal of the waste products of metabolism from the body. Many wastes are toxic and would be harmful to health if allowed to accumulate in the body fluids. Every cell produces waste products, so their removal before they reach harmful concentrations is extremely important.

Several organs in the body take part in excretion.

- The lungs are involved in the excretion of carbon dioxide. Carbon dioxide and water are produced by all body cells during cellular respiration. The body cannot use carbon dioxide and it is carried in the blood until it reaches the lungs, where it is excreted. Some water is also lost from the lungs, in the form of water vapour, as we exhale.
- Sweat glands in the skin secrete water containing by-products of metabolism such as salts, urea and lactic acid.

- The alimentary canal passes out bile pigments that entered the small intestine with the bile. These pigments are the breakdown products of haemoglobin from red blood cells. They leave the body with the faeces. The bulk of the faeces is composed of undigested food materials. These are not considered to be excretory products, as they have not been produced by the cells.
- The **kidneys** are the principal excretory organs. They are responsible for maintaining a constant concentration of materials in the body fluids. One of the important wastes removed by the kidneys is urea, which is produced in the liver during the breakdown of proteins.

Kidneys

As you can see from Figure 6.4, about 60% of the water lost from the body each day is excreted by the kidneys as urine. Water loss from the lungs and from the alimentary canal cannot be regulated. Water loss from the skin (sweat) is directly linked to temperature regulation. This means that only water loss from the kidneys can be regulated to achieve a constant concentration of dissolved substances in the body fluids. Thus, the kidneys are not just excretory organs; they also play a major role in regulating the composition of body fluids.

The kidneys are a pair of reddish-brown organs located in the abdomen. They are on either side of the vertebral column, at about the level of the lowest ribs, and are attached to the rear wall of the abdominal cavity. Each kidney is about 11 cm long and, due to the presence of the liver, the right kidney is usually slightly lower than the left. The kidneys are embedded in, and held in position by, a mass of fatty tissue.

A tube, the **ureter**, leaves each kidney and drains into a muscular reservoir, the **urinary bladder**, which empties to the outside through another tube, the **urethra**.

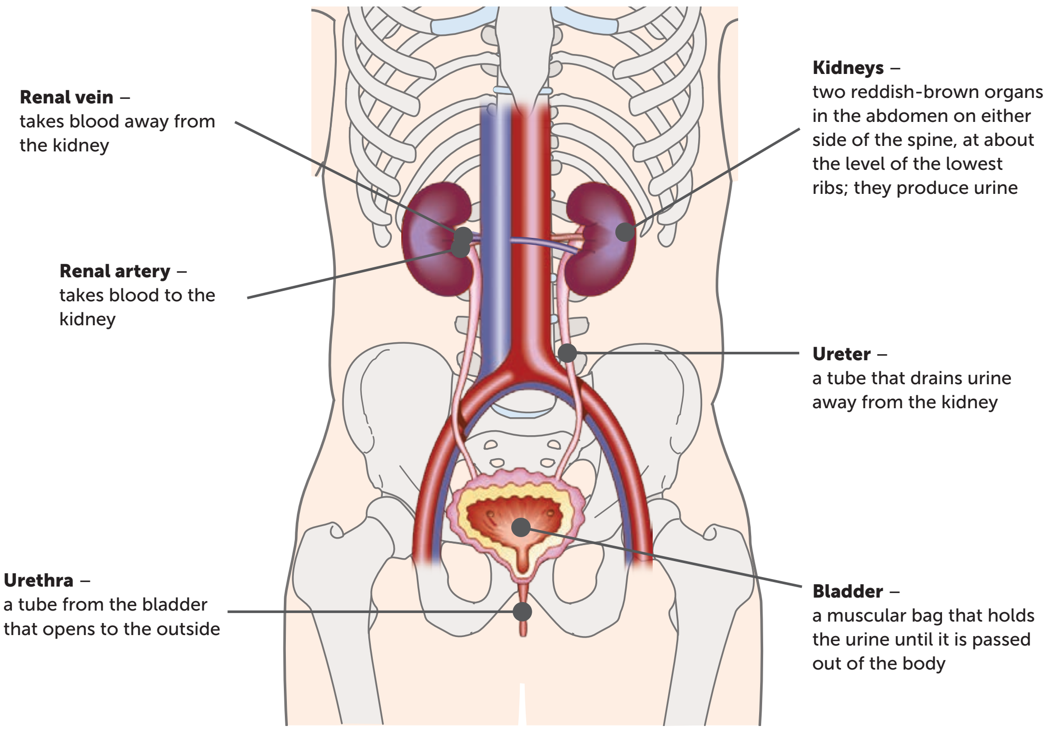


FIGURE 6.5 Kidneys and associated organs

Each kidney contains about 1.2 million microscopic units called nephrons. The **nephron** is the functional unit of the kidney; that is, it is the nephrons that carry out the kidney's role in excretion and water regulation. Figure 6.6 shows a nephron and explains how it functions. Detailed information about the structure and function of the nephron was covered in *Human Perspectives ATAR Units 1 & 2.*

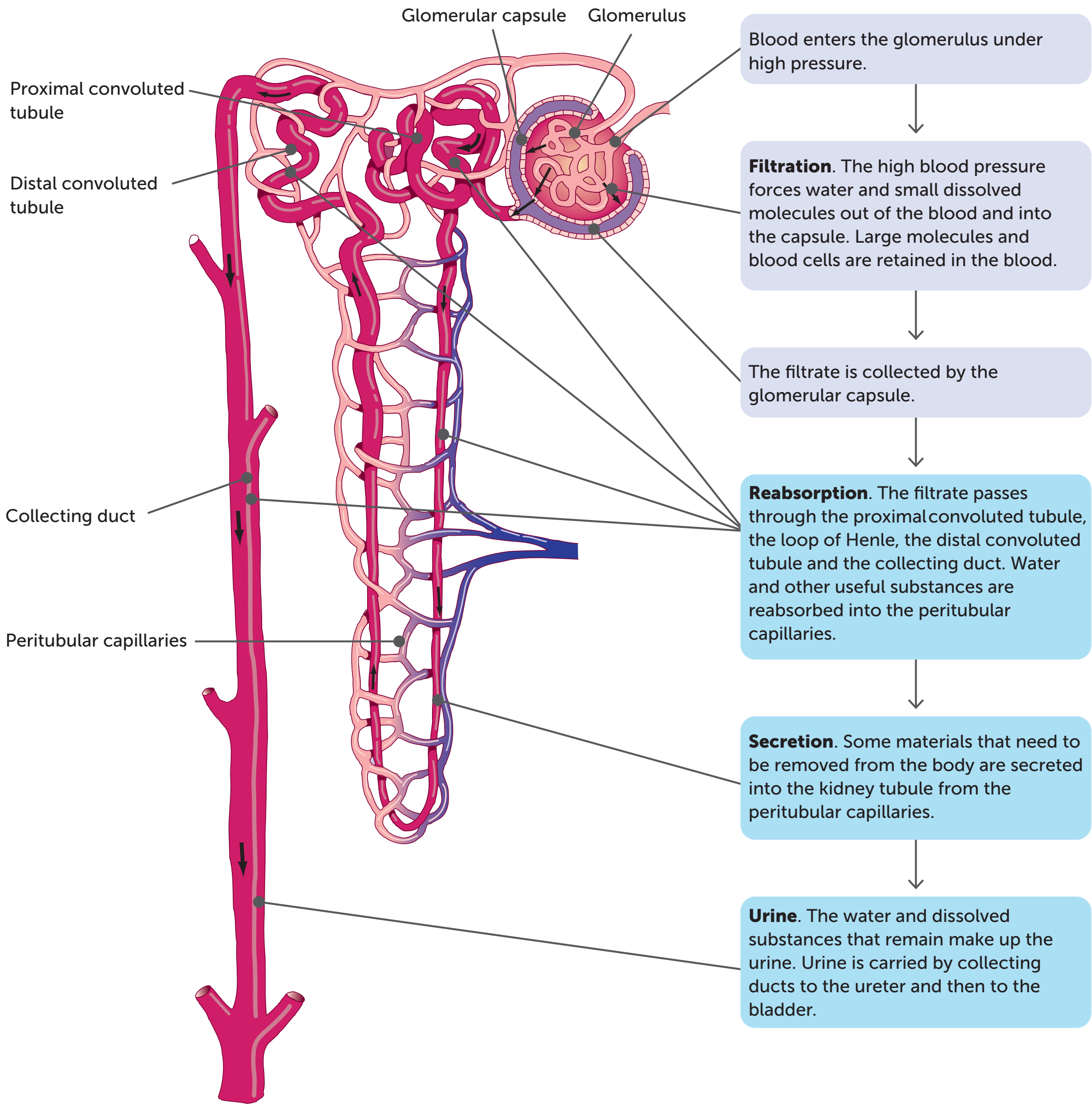


FIGURE 6.6 The functional unit of the kidney is the nephron

Key concept

The nephrons in the kidneys play a vital role in controlling the water content of the body.

Controlling water levels

Water is continually lost from the body in sweat, urine, faeces and exhaled breath. Normally, this is balanced by water intake. However, at times of strenuous activity or extreme heat this water loss can be quite high. As water is lost, the plasma becomes more concentrated and hence has a higher osmotic pressure. As a result, water moves from the interstitial fluid into the plasma by osmosis. This makes the interstitial fluid more concentrated and, therefore, water diffuses out of the cells, so the cells start to shrink from dehydration. When this happens, **osmoreceptors** in the hypothalamus detect the increase in osmotic pressure. A number of responses are then triggered that increase the water content and, hence, lower the osmotic pressure.

The kidneys and antidiuretic hormone

The volume and composition of urine produced by the kidneys depends on how much water there is in the body fluids. If you drink a large volume of water, you will quite soon produce a large volume of dilute urine. If you become dehydrated by not drinking enough water, you will produce a smaller volume of concentrated urine.

Approximately 99% of the water filtered through the glomeruli of the kidneys is reabsorbed. This reabsorption occurs through the walls of the kidney tubules along their entire length. The reabsorption occurring at the proximal convoluted tubule and loop of Henle is by osmosis, while reabsorption at the distal convoluted tubule and collecting tubule is active reabsorption. The level of active reabsorption is controlled by a hormone known as **antidiuretic hormone (ADH)**.

ADH is produced by the hypothalamus and released from the posterior lobe of the pituitary. The permeability of the walls of the distal convoluted tubule and collecting duct is controlled by ADH. When the concentration of ADH in the blood plasma is high, the tubules are very permeable to water, and thus water is able to leave the tubule and enter the surrounding capillary network. This outward flow of water from the fluid within the tubules reduces its volume and hence increases the concentration of the materials remaining. On the other hand, when the concentration of ADH in the plasma is low, the tubules are not very permeable to water, and little water is reabsorbed into the plasma of the blood. In this situation, the fluid within the tubules remains fairly dilute, as its volume is not reduced to any significant extent.

The action of ADH in controlling water balance is another example of a feedback process maintaining the internal environment of the body. For example, if water was lost through excess sweating, the following process would occur.

- *Stimulus:* The osmotic pressure of the blood is raised due to the decrease in water in the blood.
- *Receptors:* Osmoreceptors in the hypothalamus detect the increased osmotic pressure of the blood.
- *Modulator:* The hypothalamus stimulates the posterior lobe of the pituitary gland to release ADH into the bloodstream.
- *Effector:* ADH is carried all over the body by the blood but it affects its target organs, which are the nephron tubules in the kidney. The permeability to water of the distal convoluted tubules and the collecting ducts is increased.
- *Response*: More water is then reabsorbed into the blood plasma from the distal convoluting tubule and collecting duct.
- *Feedback:* The reabsorption of water increases the amount of water in the plasma and so the osmotic pressure of the blood is decreased. This adjustment has eliminated or reduced the original stimulus; a negative feedback has occurred.

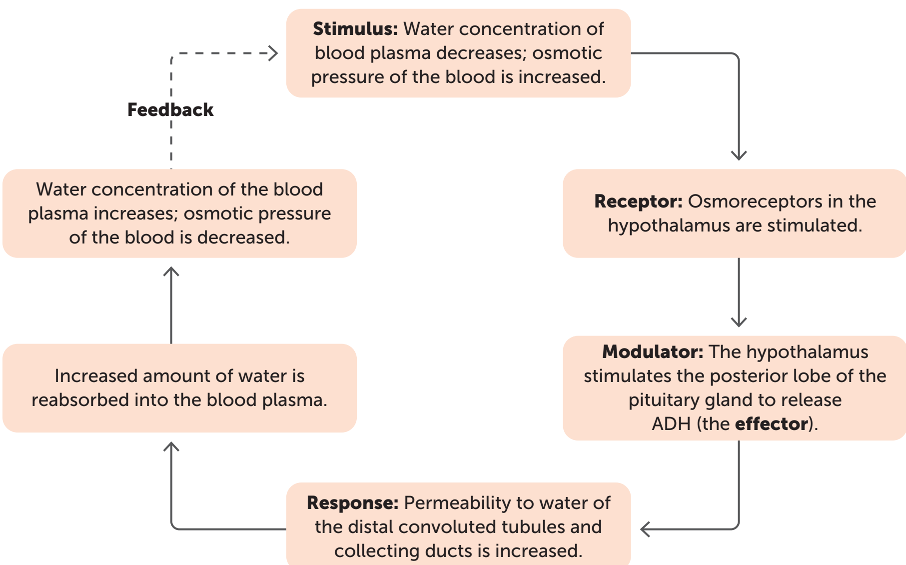


FIGURE 6.7 Regulation of water output by antidiuretic hormone

The kidneys and aldosterone

Aldosterone is another hormone that plays a part in the regulation of water output. Aldosterone, sometimes called the salt-retaining hormone, is secreted by the adrenal cortex in response to a:

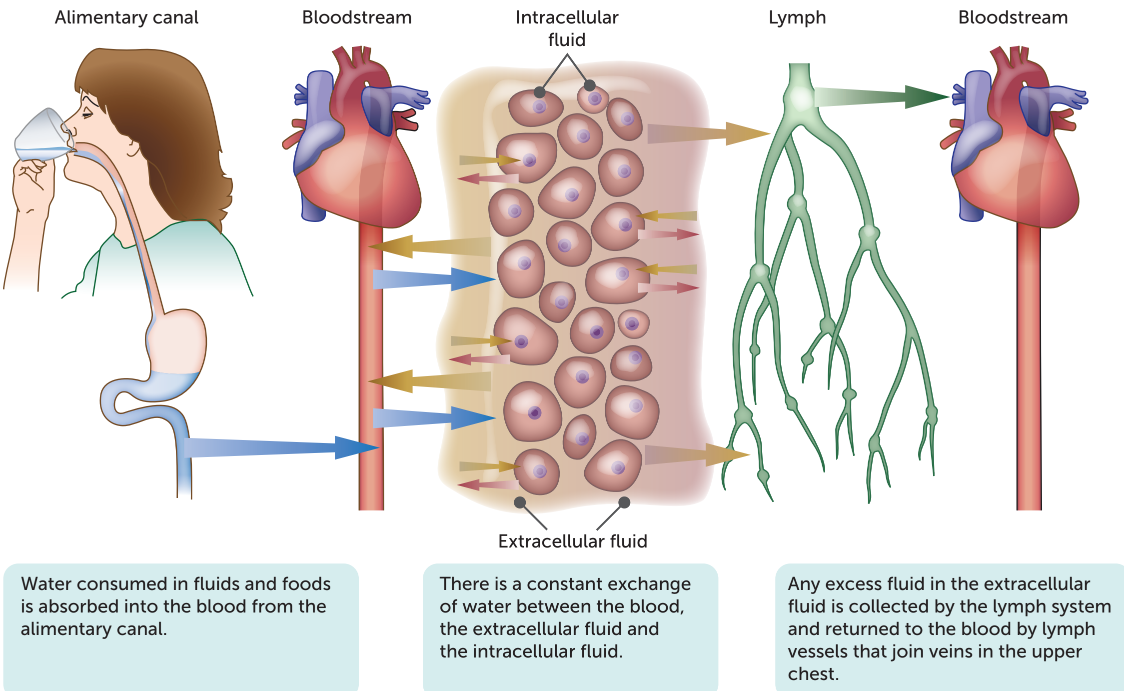
- decrease in the concentration of sodium ions in the blood
- decrease in blood volume
- decrease in blood pressure
- increase in the concentration of potassium ions in the blood.

Aldosterone acts on the distal convoluted tubules and collecting ducts to increase the amount of sodium ions reabsorbed into the bloodstream and the amount of potassium secreted in the urine. It achieves this through active transport using a sodium-potassium pump. For every three sodium ions reabsorbed, two potassium ions are secreted. There is thus a net movement of ions into the blood and the subsequent transport of water into the blood via osmosis. Therefore, aldosterone has a role in regulating water content of the body.

The thirst response

In addition to reducing water loss, the water level of the body can be increased by taking in more fluid. Osmoreceptors are able to stimulate the **thirst centre** in the hypothalamus, prompting the person to drink water. This fluid is absorbed across the wall of the alimentary canal into the blood, decreasing the osmotic pressure.

FIGURE 6.8 Movement of water between the various parts of the body



- *Stimulus:* As water is lost from the various body fluids, there is a reduction in plasma volume and an increase in osmotic concentration of the extracellular fluid.
- *Receptor:* Osmoreceptors in the thirst centre in the hypothalamus detect the rising osmotic concentration of the blood. Other stimuli such as a dry mouth are also involved.
- *Modulator:* Stimulation of the thirst centre in the hypothalamus makes the person feel thirsty.
- *Effector:* The conscious feeling of thirst stimulates the person to drink.
- *Response:* The fluid consumed is absorbed from the alimentary canal into the plasma in the blood.
- *Feedback:* As the blood circulates through the body, it enables the interstitial fluid and intracellular fluid to return to the normal osmotic concentration. After drinking, the thirst centre is no longer stimulated and the desire to take in water ceases.

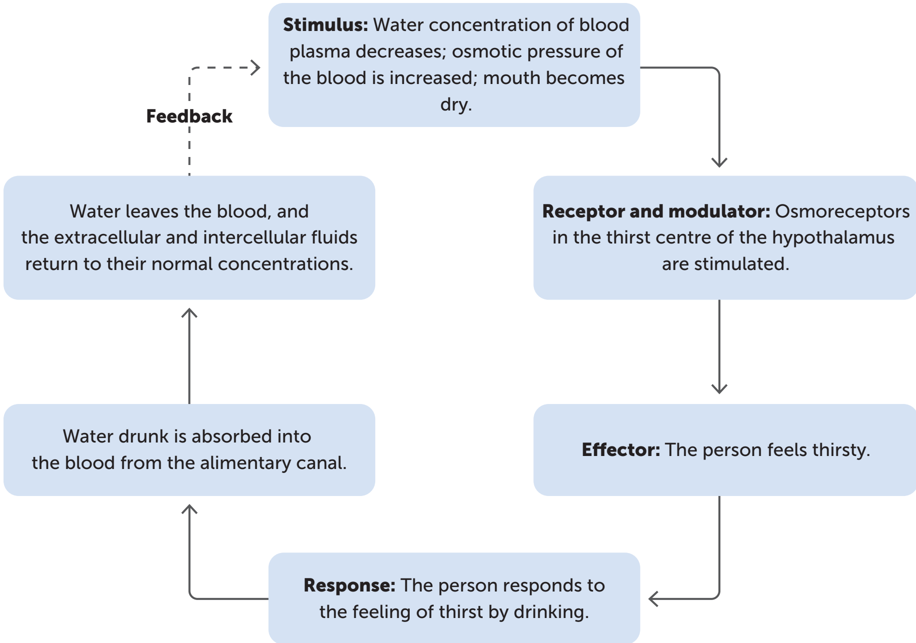


FIGURE 6.9 Regulation of water balance by the thirst mechanism

Activity 6.1
Simulated urinalysis

Key concept

The water content of the body is altered by the action of antidiuretic hormone and aldosterone on the kidneys, as well as by the thirst centre in the hypothalamus.

Too much and too little water

You have probably read stories or news reports about people dying in the desert through lack of water. When water loss exceeds water intake, there is not enough water in the body for it to carry out normal functions. This is called **dehydration**. Symptoms of dehydration become noticeable when a person has lost about 2% of their normal body water. The loss may be through sweating, vomiting or diarrhoea. Elderly people can suffer from dehydration because the thirst reflex becomes less effective as we grow older. Symptoms of dehydration include severe thirst, low blood pressure, dizziness and headache. If the condition remains untreated the patient becomes delirious, loses consciousness and dies.

It is also possible to have *too much* water in the body. This is called **water intoxication**, or sometimes water poisoning. It occurs when body fluids become diluted and cells take in extra water by osmosis. This may happen if a person loses a lot of water and salts through sweating and replaces the loss with plain water. In such cases, the water consumed should contain dissolved substances to replace the lost salts as well as the water. The first sign of water intoxication is usually lightheadedness. Headache, vomiting and collapse may follow.

Water intoxication
This website provides more information about water intoxication.

Strange but true: Drinking too much water can kill
An article about drinking too much water.

Dehydration
This website provides more information about dehydration.

What you should know about dehydration
Another article about dehydration.

WS

6.1 Homeostasis of body fluids

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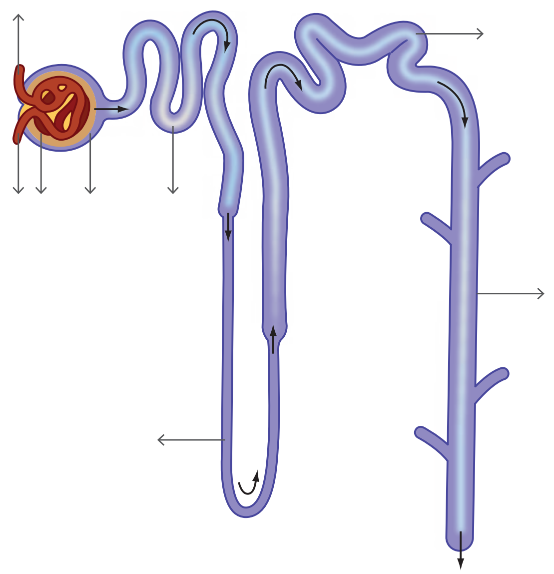
Questions 6.1

RECALL KNOWLEDGE

1 List three functions of water in the body.
2 What organ has the greatest percentage of water?
3 Complete the following sentence.
   The ____________________ is the fluid found outside the cells. It is made up of the intravascular fluid, which is also known as ____________________, the ____________________ fluid between the cells and transcellular fluid – for example, ____________________ (CSF).
4 True or false? There is more fluid found in the plasma than in the cells.
5 Describe osmosis.
6 List the ways that fluid is:
   a gained
   b lost.
7 Label the parts of a nephron on the diagram below.



8 Name the receptors that detect a change in water content of the body, and state where they are located.
9 a What does 'ADH' stand for?
   b What part of the nephrons does ADH act on?
   c What effect does ADH have on the structures identified in **b**?
   d Is ADH secreted due to a high or low osmotic pressure?
10 Describe the role of aldosterone in maintaining the concentration of sodium ions in the blood. Identify any relevant structures in your description.

APPLY KNOWLEDGE

11 What is the mass of water in an adult female weighing 62 kg?
12 Suggest why the proportion of water in a baby's body is larger than in their grandparent's body.
13 Explain why water toxicity can cause cells to swell.
14 Explain why the homeostatic mechanisms that control body fluids are focused on the kidneys and not the alimentary canal, lungs or skin, even though water is also lost through these organs.
15 Draw a feedback loop to show what would happen if you drank more water than you lost.
16 Explain why, after running a cross-country course, Alex had a dry throat and was very thirsty.

6.2 REGULATION OF GAS CONCENTRATIONS

Cellular respiration occurs in cells to provide energy for its functions. As it uses oxygen and produces carbon dioxide, cells need a continuous supply of oxygen and removal of carbon dioxide. Therefore, it is crucial that the levels of these gases in the body are regulated.

$$\text{Oxygen + glucose} \rightarrow \text{carbon dioxide + water + energy}$$
$$6O_2 + C_6H_{12}O_6 \rightarrow 6CO_2 + 6H_2O + \text{energy}$$

The respiratory system is responsible for taking in oxygen and excreting carbon dioxide from the body. In particular, the lungs are the organs in which the exchange of carbon dioxide for oxygen occurs. Therefore, changes in breathing change the amount of oxygen taken in and the amount of carbon dioxide excreted.

The circulatory system carries oxygen from the lungs to the cells, where it is used. It also takes away the carbon dioxide produced and delivers it to the lungs for excretion from the body. Thus, the circulatory system is also involved in the regulation of gas concentrations.

Control of breathing

The muscles that cause air to move in and out of the lungs are:

- the diaphragm, a muscle that separates the thorax from the abdomen
- the intercostal muscles, the muscles between the ribs.

These are skeletal muscles and require stimulation from nerve impulses to initiate contraction. The diaphragm is stimulated by impulses from the phrenic nerve, while impulses from the intercostal nerves stimulate the intercostal muscles. These spinal nerves have their origin in the spinal cord at the level of the neck and thorax.

The nerve impulses that travel to the diaphragm and intercostal muscles are controlled by a **respiratory centre** located in the medulla oblongata of the brain. There are two regions within the respiratory centre: one that controls expiration (breathing out) and one that controls inspiration (breathing in). To coordinate breathing, messages need to pass back and forth between the neurons in these two regions.

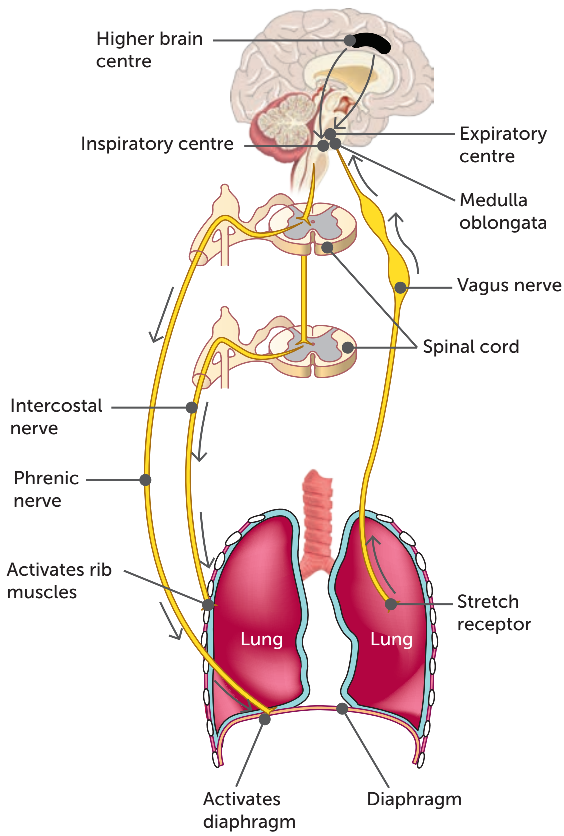


FIGURE 6.10 Control of breathing by respiratory centres in the brain

Chemicals affecting breathing

Both oxygen and carbon dioxide are carried in the blood and their concentrations affect the breathing rate and depth. In addition, the concentration of carbon dioxide in the blood plasma affects the concentration of hydrogen ions (H^+). When carbon dioxide dissolves in water, it forms carbonic acid (H_2CO_3), which breaks down readily to form hydrogen ions and bicarbonate ions (HCO_3^-), as shown in the following chemical equation.

$$CO_2 + H_2O \rightleftharpoons H_2CO_3 \rightleftharpoons H^+ + HCO_3^-$$

Oxygen, carbon dioxide and hydrogen ions all have some effect on the regulation of breathing activity.

Chemoreceptors

There are two types of **chemoreceptors**: peripheral chemoreceptors and central chemoreceptors.

- *Peripheral chemoreceptors* are groups of cells within the walls of the aorta and carotid arteries that are sensitive to changes in the concentration of oxygen, carbon dioxide and hydrogen ions in the blood plasma. These are known as the **aortic** and **carotid bodies**.
- *Central chemoreceptors* are located in the medulla oblongata. These are sensitive to changes in the concentration of carbon dioxide in the blood and hydrogen ions in the cerebrospinal fluid.

When chemoreceptors are stimulated, they send a nerve impulse to the area of the respiratory centre that regulates breathing.

Oxygen concentration

As oxygen is consumed by the cells, its concentration in the blood begins to fall. If the concentration of oxygen falls below normal while other factors are held constant, the breathing rate increases. However, within the normal range of blood oxygen concentration, the effect on breathing rate is only slight. The concentration has to fall to very low levels before it has a major stimulatory effect. Thus, under normal circumstances, oxygen plays little part in the regulation of breathing.

A large decrease in oxygen concentration stimulates the peripheral chemoreceptors, and nerve impulses are transmitted to the respiratory centre. These nerve impulses stimulate the transmission of messages to the diaphragm and intercostal muscles, and so the breathing rate and depth increases.

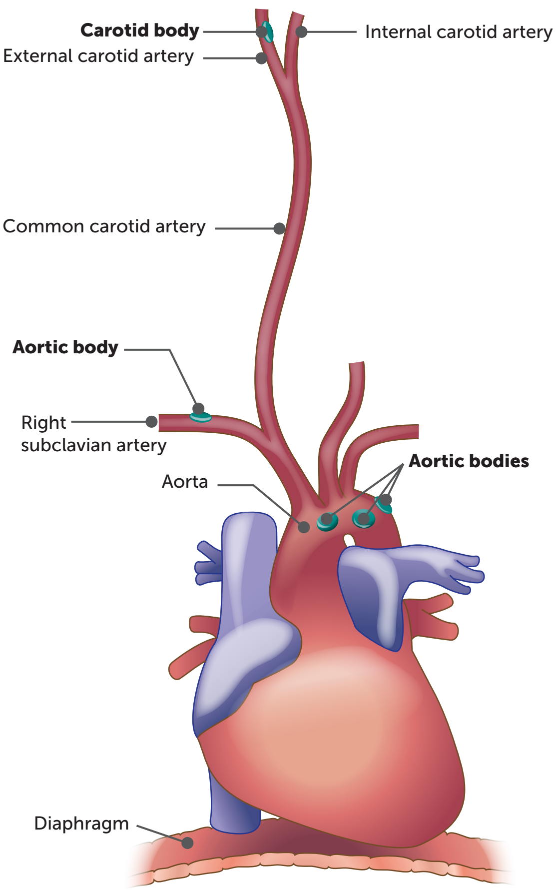


FIGURE 6.11 Location of the aortic and carotid bodies

Carbon dioxide concentration

The concentration of carbon dioxide in the blood plasma is a major factor in the regulation of breathing rate. A relatively small increase in the concentration of carbon dioxide is enough to cause a marked increase in the rate and depth of breathing.

As mentioned above, the concentration of carbon dioxide in the plasma is associated with the concentration of hydrogen ions. Any increase in carbon dioxide results in an associated increase in hydrogen ion concentration. The increase in concentration of both these chemicals in the blood stimulates the central and peripheral chemoreceptors. These in turn transmit nerve impulses to the respiratory centre, resulting in an increase in breathing rate and depth.

The chemoreceptors most sensitive to changes in the concentration of carbon dioxide in the plasma are those located in the medulla oblongata. These chemoreceptors are responsible for 70–80% of the increase in breathing rate that results from an increase in the carbon dioxide concentration of the blood. However, this response takes several minutes.

The immediate increase in breathing rate that occurs following an increase in the carbon dioxide concentration of the plasma is produced by the stimulation of the aortic and carotid bodies. These bodies are stimulated by the associated increase in hydrogen ion concentration, as described below.

Hydrogen ion concentration

As the hydrogen ion concentration of the blood increases, the pH decreases. A decrease in the pH directly stimulates chemoreceptors in the aortic and carotid bodies, which then transmit impulses to the respiratory centre, resulting in an increase in the breathing rate and depth.

The regulation of the breathing rate in response to changes in the concentration of carbon dioxide and hydrogen ions (pH) is illustrated in Figure 6.12.

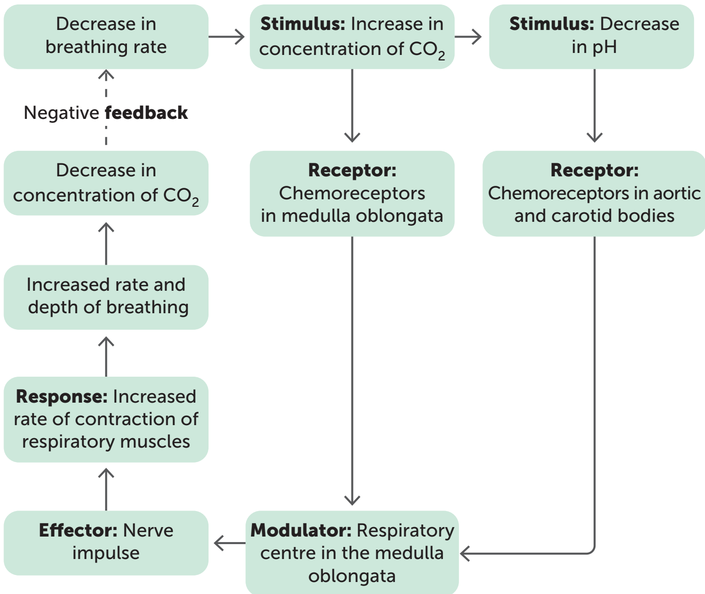


FIGURE 6.12 Negative feedback control of breathing rate through changes in the concentration of carbon dioxide and the pH of the blood plasma

None of the three factors (oxygen concentration, carbon dioxide concentration and hydrogen ion concentration) is independent in the regulation of breathing rate. Each factor interacts with the others. Nor are these the only factors to play a role in the control of breathing. At any instant, therefore, the rate of breathing is regulated by a number of factors, and the sensitivity of some factors, such as oxygen, is generally not as great as the sensitivity of others, such as carbon dioxide.

WS **6.2 Homeostasis of gas concentrations**

Key concept

Chemoreceptors recognise changes in the concentration of oxygen, carbon dioxide and hydrogen ions in the blood. They send nerve impulses to the respiratory centre in the medulla oblongata, which controls the rate and depth of breathing. Messages are sent from the respiratory centre, along the descending tract of the spinal cord and then to the phrenic and intercostal nerves to cause the contraction and relaxation of the diaphragm and intercostal muscles. Increasing the rate of the cycle of contraction and relaxation will increase the rate and depth of breathing and, therefore, the inhalation of oxygen and exhalation of carbon dioxide. This, in turn, will increase the concentration of oxygen and decrease the concentration of carbon dioxide.

Voluntary control of breathing

Humans are able to voluntarily control their rate and depth of breathing, factors very important in speech. We can even stop breathing for a limited period. This voluntary control comes via connections from the cerebral cortex to descending tracts in the spinal cord. Voluntary control thus bypasses the respiratory centre in the medulla oblongata. This is a protective device as it enables us to prevent irritating gases and water from entering the lungs.

Holding our breath

While it is possible to hold our breath, we cannot stop breathing forever! The build-up of carbon dioxide in the plasma stimulates the inspiratory centre to send impulses to the inspiratory muscles. Thus, we are eventually forced to take a breath whether we want to or not.

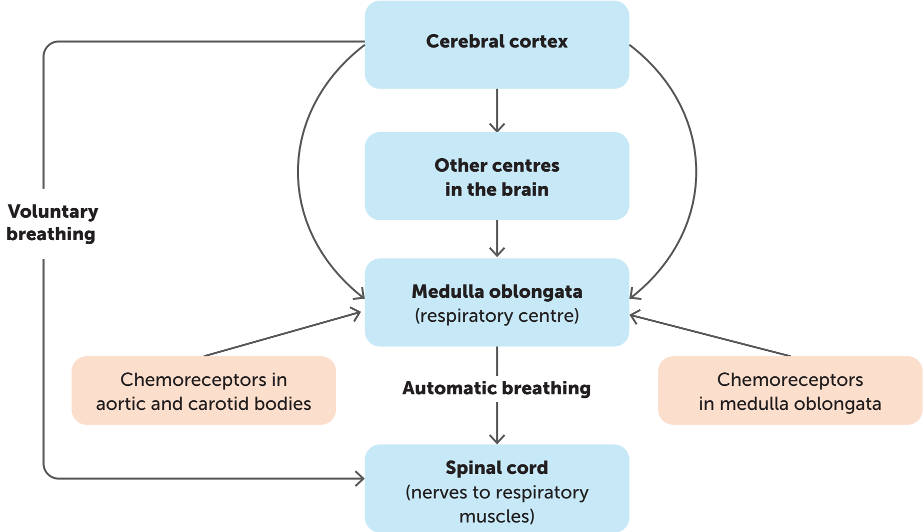


FIGURE 6.13 Voluntary and involuntary control of breathing by the central nervous system

Hyperventilation

Rapid, deep breathing can provide more oxygen than required and remove more carbon dioxide than necessary. This is called **hyperventilation**. It can occur voluntarily or may be stimulated by physical stress such as severe pain or emotional stress such as extreme anxiety. Hyperventilation usually corrects itself because the reduction in carbon dioxide concentration means that the chemoreceptors are not stimulated, reducing the rate and depth of breathing until carbon dioxide levels return to normal.

A very dangerous practice is to hyperventilate before swimming under water. Although this practice does allow a person to stay under water longer, it is not because of extra oxygen in the blood; it is due to the loss of carbon dioxide. The breath-holding ability could be increased to such an extent that the individual loses consciousness from lack of oxygen to the brain before feeling the urge to breathe. Many drowning deaths in Australia have been the direct result of hyperventilation.

Respiration control
This website provides more information on the regulation of breathing.

Activity 6.2
Investigating breathing rate

Activity 6.3
Investigating behaviour and homeostatic mechanisms

Exercise and breathing

During exercise, the contracting muscle cells require large amounts of oxygen and produce large amounts of carbon dioxide. In responding to this increased demand for gas exchange, the respiratory system increases both the rate and depth of breathing.

During heavy exercise, the volume of air going into and out of the lungs each minute may increase 10- to 20-fold. The same factors that influence breathing at rest appear to be involved in this increase – that is, the concentrations in the blood plasma of carbon dioxide, hydrogen ions and, to a lesser extent, oxygen.

Questions 6.2

RECALL KNOWLEDGE

1 What is the name of the peripheral chemoreceptors that influence breathing?

2 Write the word equation for cellular respiration.

3 Describe the relationship between carbon dioxide and the concentration of hydrogen ions in the blood.

4 Which nerve sends impulses to:
   a the diaphragm?
   b the intercostal muscles?

5 Which chemoreceptors detect changes in:
   a oxygen?
   b carbon dioxide?
   c hydrogen ions?

6 Explain how an increased rate and depth of breathing is able to decrease the concentration of carbon dioxide in the blood.

7 Explain why it is not possible to die from holding your breath unless you are under water.

APPLY KNOWLEDGE

8 Use a flow chart to show the pathway of messages from the respiratory centre to the diaphragm during inspiration.

9 Why is it important that the muscles responsible for breathing are skeletal muscles, and not smooth or cardiac muscles?

10 Draw a feedback loop to show what would happen in the body if the concentration of oxygen decreased by a:
   a small amount
   b large amount.

11 Both central and peripheral chemoreceptors respond when there is an increase in carbon dioxide levels. Explain why it is important that both of these receptors are stimulated.

12 People with chronic obstructive pulmonary disease have inflamed airways that make it difficult to breathe. This can lead to a condition known as hypercapnia, an increased level of carbon dioxide.
   a One symptom of hypercapnia is that the blood becomes acidic. Explain why this would occur.
   b Explain why giving oxygen to patients with hypercapnia could be dangerous.

CHAPTER 6 ACTIVITIES

SOUTHERN Biological Developed exclusively by Southern Biological

ACTIVITY 6.1 Simulated urinalysis

In this investigation, you are tasked with performing a urinalysis. You will test the colour, pH, glucose, protein and specific gravity of three known urine samples. The known urine samples are low, normal and high simulated urine samples that are engineered to produce results indicative of those characteristics. Following this, you are also tasked with conducting a urinalysis of two unknown simulated urine samples. You will be required to interpret the results and identify whether the results indicate any diseases.

Aim

To perform a simulated urinalysis and determine the characteristics of two unknown samples
Time requirement: 30 minutes

You will need

Simulated urine samples 100 mL approx. (low, normal, high, unknown A and unknown B); graduated cylinder; 5 plastic urine specimen containers; marker; 5 pH test strips and pH colour chart; 5 urine reagent strips; hydrometer and jar; disposable gloves; paper towel

Risks

WHAT ARE THE RISKS IN THIS INVESTIGATION?	HOW CAN YOU MANAGE THESE RISKS TO STAY SAFE?
Simulated urine can cause skin or eye irritation.	Avoid any direct contact. If contact does occur, immediately flush the affected area with water.
Simulated urine can stain clothing and skin.	Wear gloves at all times and avoid any direct contact.

What to do

Colour and pH testing

1 Collect three plastic urine specimen containers. Using a marker, label them Low, Normal and High.
2 Using a graduated cylinder, transfer 10 mL of Low, Normal and High simulated urine into the corresponding urine specimen containers. Wash the measuring cylinder between each measurement if using the same equipment for each.
3 Inspect the samples and note the colour of each sample in Table 1.
4 Collect three pH test strips and label one end of each 'L', 'N' and 'H', respectively.
5 Dip the 'L' strip into the 'Low' urine sample. Wipe off any excess liquid against the side of the container and lay the strip on a paper towel. Compare the colour of the test strip to the pH colour chart and record the results in Table 1.
6 Repeat step 5 for the 'Normal' and 'High' urine samples using the corresponding pH test strip and record the results in Table 1.

Glucose and protein testing

1 Collect three reagent strips and label the end of each strip that does not contain a test square. Label them 'L', 'N' and 'H', respectively.
2 Observe the colour of the test squares that are attached at one end of the urine reagent strip and determine which square tests for glucose and which tests for protein.

3 Dip the test square end of the 'L' strip into the 'Low' urine sample and then withdraw it. Wipe off any excess liquid against the side of the container and lay the strip on a paper towel. After 30 seconds, a colour change on either square will indicate a positive result for that test, and no colour change will indicate a negative result. Refer to the product information/colour chart provided with the testing strips. Record the results in Table 1.
4 Repeat step 3 for the 'Normal' and 'High' urine samples using the corresponding test strip and record the results in Table 1.

Specific gravity testing

1 Clean the urine hydrometer and jar thoroughly.
2 Fill the jar to the fill line (as marked by the teacher) with the 'Low' urine sample and insert the hydrometer into the jar.
3 Note the fluid level on the hydrometer scale. Add or subtract the calibration factor to your measurement (your teacher will instruct you on this) and record the adjusted value in Table 1.
4 Repeat steps 1 to 3 for the 'Normal' and 'High' urine samples and record the results in Table 1. Ensure you thoroughly clean the urine hydrometer and jar between each sample.

Unknowns testing

1 Repeat the entire testing procedure for samples Unknown A and Unknown B. Note the colour and determine the pH, glucose, protein and specific gravity values of each sample. Record the results in Table 1.
2 Using Tables A and B below as reference, determine if the test results of Unknown A and Unknown B indicate any disease/s. Record your results in Table 2.

TABLE A Urine colour and possible causes

COLOUR	DIET	DRUGS	DISEASE
Light yellow to amber	Normal	None	None
Clear to light yellow	Increased fluid intake	Alcohol	Uncontrolled diabetes mellitus
Yellow-orange to orange	Carrots	Antibiotics, Pyridium	Bilirubin from obstructive jaundice
Green	Green food dyes, asparagus	Diuretics	Bacterial infection
Red to red-brown	Beets	Senna laxatives	Haemoglobin in urine (various causes)
Dark wine	Beets	Anti-inflammatory drugs	Haemolytic jaundice
Brown	Rhubarb (large quantity), fava beans, severe dehydration	Barbiturates	Haemolytic anaemia or liver disease; extremely strenuous exercise or muscle injury
Brown to black	Rhubarb (huge quantity), excessive sorbitol consumption	Antidepressants	Melanin pigment from melanoma (rare)

TABLE B Abnormal urinalysis results and causes

TEST RESULT	DIET	DISEASE
Low pH (<6)	High protein diet; cranberry juice	Uncontrolled diabetes mellitus
High pH (>8)	Diet rich in vegetables; dairy products	Severe anaemia
Low specific gravity (<1.010)	Increased fluid intake	Severe renal damage
High specific gravity (>1.026)	Decreased fluid intake; loss of fluids	Uncontrolled diabetes mellitus; severe anaemia
Glucose present	Large meal	Uncontrolled diabetes mellitus
Protein present	High-protein diet	Severe anaemia

Studying your results

1 Copy and complete Table 1 with the results of your investigation.

TABLE 1 Simulated urine samples

URINE TEST	LOW	NORMAL	HIGH	UNKNOWN A	UNKNOWN B
Colour					
pH					
Glucose					
Protein					
Specific gravity					

2 Place an asterisk next to all abnormal results in Table 1.
3 Copy and fill out Table 2 with the results of your investigation.

TABLE 2 Unknown urine samples

SAMPLE	DISEASE INDICATED	EVIDENCE
Unknown A		
Unknown B		

Discussion

1 What information regarding patient health does examining urine under a microscope provide?
2 Describe how urinalysis results may change for an individual over a 24-hour period. Consider daily activities and how test results may be different in urine samples collected earlier or later in the day.

3 In Table 3, describe the urinalysis results that you would expect to see from 'Patient A' and provide reasoning for each factor. Patient A has been diagnosed with strep throat and has been prescribed amoxicillin to be taken twice a day. They are under instruction to get lots of bed rest and drink plenty of fluids.

TABLE 3 Urinalysis results for Patient A

FACTOR	RESULT	REASONING
Colour		
pH		
Glucose		
Protein		
Specific gravity		

4 What side-effect warning would be appropriate for an anti-inflammatory medication used to treat the symptoms of arthritis?

5 Why do doctors order a urinalysis when attempting to diagnose diabetes? Can these urine tests be used to definitively diagnose diabetes? Discuss.

Taking it further

1 Investigate other types of urine tests, such as drug and pregnancy tests. Describe how each test works.

2 Although rare, false positive results can occur in both pregnancy and certain drug tests. This can be due to diet, medications and other factors. Describe how false positive pregnancy and drug tests occur.

3 Compare urine and blood testing. Identify the advantages and disadvantages of the two tests.

4 Investigate how urinalysis differs between animals and humans as a result of physiological differences.

ACTIVITY 6.2 Investigating breathing rate

In this activity, you will consider the stimuli that could be involved in regulating breathing rate.

You will need

Stopwatch or clock with a second hand; large paper bag

What to do

Warning: Do not act as a subject for this activity if you suffer from any respiratory or heart problems.

Work with a partner. Read through these instructions and draw up a suitable table in which to record your results.

1 Each member of the pair should count their own breathing rate (in breaths per minute) while sitting quietly at rest. Record the resting breathing rate.

2 After a normal quiet expiration, hold your breath for as long as you can. Count and record your breathing rate immediately after holding your breath.

3 Flatten a brown paper bag so that it has little air in it. Place the opening of the bag over your nose and mouth so that you are re-breathing the same air. Breathe into and out of the bag for one minute. Count and record your breathing rate immediately after breathing into the bag.

Studying your results

1. How did your breathing rate change after holding your breath and after breathing into the paper bag?
2. Suggest reasons for the changes in breathing rate.
3. What could be the stimulus that regulates a person's rate of breathing?
4. How does the evidence from the activity you have just done support your answer to Question 3?

ACTIVITY 6.3 Investigating behaviour and homeostatic mechanisms

Design an investigation to test links between one type of behaviour and one aspect of homeostasis. Some behaviours from which you could choose are:

- moderate physical exercise, such as a brisk walk or a jog
- performing relaxation exercises
- playing an exciting computer game
- watching a scary movie
- meditating
- debating a controversial topic with a friend or family member
- listening to a particular type of music – for example, relaxation music, metal or techno
- any other behaviour that you think could affect homeostasis.

Aspects of homeostasis that you could investigate are:

- blood pressure
- heart rate
- breathing
- body temperature
- any other aspect of homeostasis that you can observe or measure.

Planning your investigation

Some of the questions that you will need to answer in your planning are as follows.

- What hypothesis will you test? The hypothesis should link the behaviour you are going to test with the aspect of homeostasis that you are going to investigate. Make sure your investigation really will test your hypothesis.
- What data will you collect? How will you make your observations objective? Quantitative measurements are the best option, if possible.
- What variables will you control, and how will you go about controlling them?
- How will you make sure that your results are valid and reliable? How many repetitions will you perform?
- How will you record your results? Will it be possible to present the results as a table and/or a graph?

Conclusions

Write a conclusion discussing the relationship between your results and your hypothesis.

CHAPTER 6 SUMMARY

- Water makes up 45–75% of the mass of the body and plays a role in transporting substances from one area of the body to another, facilitating movement across membranes and being the site of chemical reactions.
- The fluid in the body is distributed between the intracellular and extracellular fluid. Extracellular fluid is contained in plasma, between the cells, and in certain body regions such as the brain, spinal cord, eyes and joints, and surrounding the heart.
- Fluid is obtained from eating, drinking and metabolic processes, and is lost through the kidneys, skin, lungs and alimentary canal.
- Excretion is the removal of the waste products of metabolism. It is carried out by the lungs, sweat glands, alimentary canal and kidneys.
- The only water loss that can be regulated is from the kidneys.
- Water is reabsorbed from the filtrate by osmosis in the proximal convoluted tubule and loop of Henle, and by active reabsorption in the distal convoluted tubule and collecting duct.
- Antidiuretic hormone (ADH) controls the active reabsorption of water in the nephrons by increasing the permeability of the distal convoluted tubules and collecting ducts. It is produced by the hypothalamus and released from the posterior pituitary gland in response to stimulation of osmoreceptors in the hypothalamus by an increase in osmotic pressure (lower water levels).
- Aldosterone is produced by the adrenal cortex. It stimulates the reabsorption of sodium ions and the secretion of potassium ions. It also increases the reabsorption of water.
- Osmoreceptors stimulate the thirst centre in the hypothalamus when there is an increased osmotic pressure. This makes the person thirsty. When they drink, water is absorbed from the alimentary canal into the blood.
- Dehydration occurs when there is insufficient water in the body. If untreated, it can be fatal as the body cannot carry out essential functions.
- Drinking excessive amounts of water can lead to water intoxication. The body fluids become too dilute and the cells swell due to osmosis.
- Cellular respiration requires oxygen and produces carbon dioxide; therefore, the concentration of these gases needs to be regulated.
- Breathing is responsible for the input of oxygen and the excretion of carbon dioxide. It is caused by the diaphragm and intercostal muscles, which are controlled by spinal nerves.
- The respiratory centre is in the medulla oblongata. It controls and coordinates inspiration and expiration.
- Chemoreceptors detect changes in the concentration of chemicals. Peripheral chemoreceptors are found in the aortic and carotid bodies, and detect the concentration of oxygen, carbon dioxide and hydrogen ions. Central chemoreceptors are found in the medulla oblongata and detect the concentration of carbon dioxide and hydrogen ions.
- An increase in the concentration of carbon dioxide will lead to an increase in the concentration of hydrogen ions due to the reaction between carbon dioxide and water forming carbonic acid, which ionises to form hydrogen ions.
- A large decrease in oxygen is needed before the peripheral chemoreceptors are stimulated.
- A small increase in carbon dioxide will stimulate the central chemoreceptors; however, the response is relatively slow.

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- A small increase in carbon dioxide will lead to an increase in hydrogen ions that can be detected by the peripheral chemoreceptors. This initiates a rapid response.
- When chemoreceptors are stimulated, they send a message to the respiratory centre, which increases the rate and depth of breathing by the contraction and relaxation of the diaphragm and intercostal muscles.
- Breathing can also be initiated and controlled by the cerebral cortex, bypassing the respiratory centre. However, if the concentration of carbon dioxide rises, the respiratory centre will override the voluntary control, forcing the person to take a breath.
- Hyperventilation occurs when the rate of breathing is too fast. It increases the concentration of oxygen and decreases the concentration of carbon dioxide. Under normal circumstances, chemoreceptors detect these changes and reduce the urge to breathe. This can be dangerous while swimming under water, as the person may lose consciousness due to the lack of oxygen before they feel the need to breathe.
- Exercising will increase the use of oxygen and the production of carbon dioxide. Therefore, the rate of breathing will increase.

CHAPTER 6 GLOSSARY

Aldosterone A hormone that acts on the kidney to reduce the amount of sodium in the urine and increase the amount of potassium

Antidiuretic hormone (ADH) A hormone produced by the hypothalamus and released by the posterior lobe of the pituitary gland that stimulates the kidneys to remove water from urine, thus reducing urine production; also known as vasopressin

Aortic body The group of cells within the walls of the aortic arch that are sensitive to changes in the concentrations of oxygen and carbon dioxide in the blood and its pH

Carotid body The group of cells within the walls of the carotid arteries that are sensitive to changes in the concentrations of oxygen and carbon dioxide in the blood and its pH

Chemoreceptor A receptor sensitive to particular chemicals

Cytosol The liquid part of the cytoplasm of a cell

Dehydration Excessive loss of water and accompanying salts from the body; results when the body loses more fluid than it takes in

Excretion Removal of the wastes of metabolism from the body

Extracellular fluid Fluid outside the body cells; includes tissue fluid and blood plasma

Hyperventilation Extremely rapid or deep breathing; may result in dizziness, and even fainting, due to the loss of carbon dioxide from the blood

Intercellular fluid *see* interstitial fluid

Interstitial fluid Fluid between the body cells; also known as intercellular fluid or tissue fluid

Intracellular fluid Fluid found inside cells; also known as cytosol

Intravascular fluid Fluid inside the blood vessels; also known as plasma

Kidney One of a pair of excretory organs responsible for maintaining a constant concentration of substances in the body fluids

Metabolic water Water formed as a by-product of cellular respiration

Nephron The functional unit of the kidney

Osmoreceptor A receptor sensitive to osmotic pressure of body fluids

Osmotic concentration The concentration of solutes; also known as osmolarity

Osmotic pressure The tendency of a solution to take in the pure solvent

Respiratory centre The part of the brain that regulates breathing rate; located in the medulla oblongata

Thirst centre The part of the brain that regulates the feeling of thirst; located in the hypothalamus

Tissue fluid *see* interstitial fluid

Transcellular fluid The fluid in specific body regions such as the brain, eyes and joints

Ureter The tube that leaves each kidney and drains into the urinary bladder

Urethra The tube that empties the bladder to the outside; in males, it also carries sperm

Urinary bladder A hollow, muscular organ near the base of the abdominal cavity; collects urine from the two ureters

Water intoxication A potentially life-threatening condition caused by drinking too much water when the amount of salt (and other electrolytes) in the body is low; commonly caused by long bouts of intensive exercise during which electrolytes are not replenished and large amounts of water are consumed

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CHAPTER 6 REVIEW QUESTIONS

Recall

1 State whether the nervous system, endocrine system, or both, are responsible for:
   a body fluid homeostasis
   b gas concentration homeostasis.

2 a What are nephrons?
   b Draw a diagram of a nephron and label the places where filtration, reabsorption and secretion occur.
   c Describe the role of nephrons in homeostasis.

3 Describe the role of antidiuretic hormone (ADH) in regulating water output.

4 Describe the effects of the following factors on breathing rate:
   a concentration of oxygen in the blood
   b concentration of carbon dioxide in the blood
   c hydrogen ion concentration (pH) in the blood.

5 Describe the role of the aortic and carotid bodies in regulating breathing rate.

6 Draw a pie chart to demonstrate the distribution of body fluids.

7 Define ‘metabolic water’.

8 Name and describe the receptors that play a role in the control of:
   a body fluid
   b gas concentrations.

Explain

9 Explain how the respiratory centre controls the rate of breathing.

10 Aldosterone regulates the amount of sodium in the blood. Explain why aldosterone influences the amount of water excreted from the body.

11 We cannot voluntarily control our heart rate or blood sugar level, yet we can voluntarily control our breathing.
   a Explain why it is important for us to be able to voluntarily decide when to take a breath and how deep the breath should be.
   b We cannot voluntarily stop breathing indefinitely. Explain why.

12 Explain why excretion is closely related to maintaining fluid balance.

Apply

13 A person lost in the desert would suffer extreme dehydration. Although the thirst receptors would try to initiate drinking behaviour, the lack of available water would not allow this requirement to be met. Describe the mechanisms the body would employ to conserve water while getting rid of metabolic wastes.

14 A student made the following observations. On a very hot day, the volume of urine produced was small and it was dark in colour. On a cold day, urination occurred more frequently, and the urine was pale in colour. Explain these observations.

15 An athlete had blood samples taken before and after a vigorous training session on a hot, dry day. The sample taken after training had a much higher concentration of ADH than the sample taken before training. Explain why there would be a difference in concentrations.

16 Moderate dehydration occurs when the body loses 7–10% of the body weight in fluid. What is the minimum mass an 80 kg male would need to lose in fluid to be considered moderately dehydrated?

17 Why is it dangerous to hyperventilate before swimming under water?

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18 People sometimes hyperventilate in stressful situations. The hyperventilation may cause dizziness and tingling of the fingers and toes. In such cases, the person may be advised to breathe into a paper bag and re-breathe the same air that was breathed out. How would such a procedure help to overcome the problems of hyperventilation?

19 Draw a stimulus–response–feedback diagram, labelling the receptor, modulator, effector and feedback, to show what happens to breathing rate when:

a the concentration of carbon dioxide in the blood increases

b the hydrogen ion concentration of the blood increases.

Extend

20 Use a flow chart to summarise all of the changes that would occur in the body while playing basketball during a hot day.

21 The table shows the water loss from a person's skin and kidneys under different conditions. Use the data to explain the relationship between regulation of body temperature and regulation of fluid content of the body.

22 Elderly people are much more likely to suffer from water regulation problems than the young. The gradual decline in the effectiveness of the thirst reflex has already been mentioned, but there is also a decline in the effectiveness of the kidneys. Find out the changes in kidney function that occur with age, and describe some of the conditions that can occur in elderly people due to poor kidney function.

ORGAN	WATER LOST (mL/HOUR)		
	AT ROOM TEMPERATURE	IN HOT WEATHER	WITH LENGTHY VIGOROUS EXERCISE
Skin	19	73	225
Kidneys	58	50	20