The Anatomy and Physiology of the Cardiovascular System

CHAPTER 1

INTRODUCTION

Understanding the anatomy and physiology of the cardiovascular system is essential, as it provides a solid foundation for delivering effective and safe patient care. The cardiovascular system has a central role to play in maintaining life by transporting oxygen, nutrients and hormones throughout the body while removing waste products (Marieb and Keller 2022). Comprehending how this system functions is critical for accurate patient assessment, clinical decision-making and effective care interventions.

A thorough understanding of cardiovascular anatomy and physiology enables those caring for people to assess vital signs, such as blood pressure, heart rate (HR) and oxygen saturation, with confidence and competence (see Chapter 5 of this book). Recognising the difference between normal and abnormal findings is key to identifying potential health issues early. This knowledge also helps in interpreting diagnostic tests, including electrocardiograms (see Chapter 6 of this book), and responding to signs of cardiovascular compromise, such as chest pain, hypotension or irregular heart rhythms (dysrhythmias).

In clinical practice, those caring for people and offering support frequently perform interventions that directly or indirectly affect the cardiovascular system. Positioning a patient to improve circulation or administering medications such as antihypertensives or anticoagulants requires an understanding of how these actions can influence heart and vascular function. Moreover, during emergencies such as cardiac arrest, knowledge of the cardiovascular system is vital for performing life-saving procedures, for example, cardiopulmonary resuscitation and recognising early warning signs of deterioration (see Chapter 7 of this book).

Pathophysiological conditions, including heart failure, coronary artery disease or arrhythmias, alter the normal functioning of the cardiovascular system. Understanding these changes helps to tailor care plans to meet the specific needs of patients. Equally important is the role of health educators. Care providers must be able to explain cardiovascular conditions to patients (and their families, if appropriate), offer guidance on managing risk factors such as smoking and obesity and emphasise the importance of lifestyle modifications and medication adherence (see Chapters 2 and 3 of this book).

Furthermore, the cardiovascular system is closely connected to other body systems, such as the respiratory, renal and nervous systems. A comprehensive understanding can enable the provision of holistic, person-centred care, considering how cardiovascular issues may impact overall health.

In summary, understanding the anatomy and physiology of the cardiovascular system is a fundamental requirement for those who offer care and support to people. It equips them with the skills and knowledge to assess, intervene and educate effectively, ensuring that they are providing high-quality care while promoting positive patient outcomes.

THE CARDIOVASCULAR SYSTEM

The cardiovascular system, also referred to as the circulatory system, is a vital network that is responsible for transporting blood, nutrients, oxygen, hormones and waste products. At its core is the heart; this muscular organ acts as a pump. When working effectively, it propels blood through an intricate network of blood vessels. The heart has four chambers, two atria and two ventricles; working together, they circulate blood to the lungs and the rest of the body.

The blood vessels form the pathways through which blood travels. The arteries carry oxygen-rich blood from the heart to tissues, while veins return oxygen-depleted blood back to the heart. Capillaries, these are the smallest of these vessels, are the sites where oxygen, nutrients and waste products are exchanged between blood and body tissues.

Blood itself is the essential fluid that circulates within the cardiovascular system. It delivers oxygen and nutrients to cells, removes carbon dioxide and waste products and has a key role to play in immune defence and also temperature regulation.

The cardiovascular system is indispensable for maintaining homeostasis. By ensuring that every cell in the body receives the necessary resources for survival and function while removing harmful byproducts, it supports overall health and well-being.

THE ANATOMY AND PHYSIOLOGY OF THE CARDIOVASCULAR SYSTEM

The heart is a muscular organ divided into four chambers, primarily responsible for pumping blood throughout the body. It drives blood flow through the pulmonary circulation to the lungs and the systemic circulation to the rest of the body. On average, the heart beats approximately 100,000 times a day without pause, maintaining a continuous cycle of contraction and relaxation.

THE BLOOD VESSELS

Blood vessels are a key part of the circulatory system, responsible for transporting blood throughout the body. There are three primary types of blood vessels (see Figure 1.1):

- Arteries: These vessels carry blood away from the heart.
- Capillaries: These tiny, thin-walled vessels facilitate the exchange of water, nutrients, gases and chemicals between the blood and surrounding tissues.
- Veins: These vessels return blood from the capillaries back to the heart.

There are a few exceptions. Most arteries carry oxygenated blood; however, the pulmonary arteries (and the umbilical arteries in the fetus) carry deoxygenated blood. Similarly, veins generally transport deoxygenated blood from the tissues back to the heart, except for the pulmonary veins (and the umbilical vein), which carry oxygenated blood.

Capillaries, forming the microcirculatory system, serve as the connection between arteries and veins. Their extremely thin walls allow the exchange of oxygen, nutrients and water from the blood into tissue fluid, while waste products from the tissues enter the bloodstream for removal. These small vessels play a critical role in maintaining the body's internal environment by ensuring efficient exchange between blood and tissues.

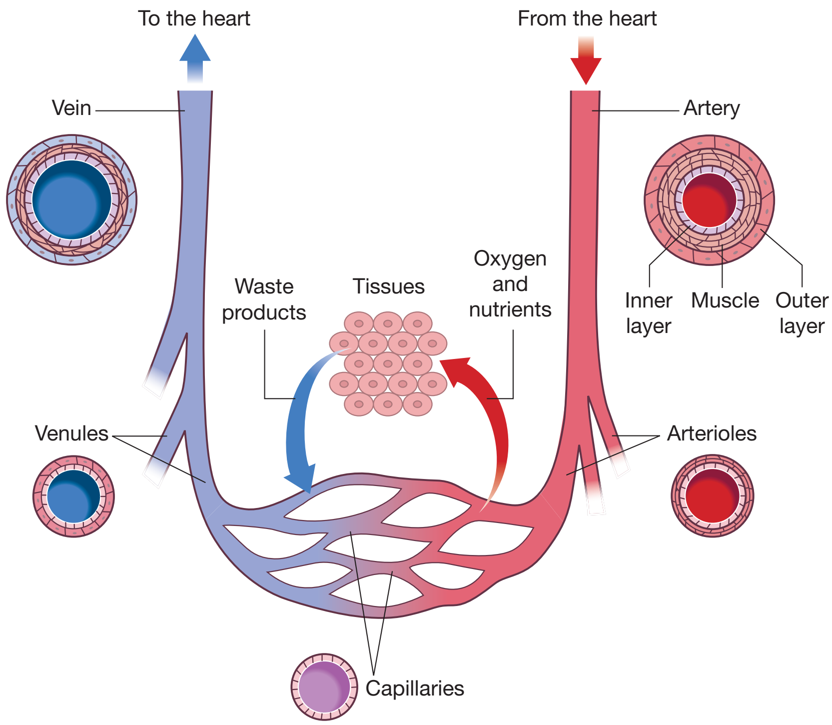

FIGURE 1.1 The blood vessels. *Source*: Peate and Nair (2011). With permission of John Wiley & Sons.

STRUCTURE OF THE BLOOD VESSELS

The arterial system is primarily responsible for the transportation of oxygenated blood from the heart to the capillaries, where the exchange of oxygen and nutrients with tissues occurs. The walls of larger blood vessels are composed of three distinct layers (see Figure 1.2):

- Tunica intima: The innermost layer, consisting of a thin layer of endothelial cells
- Tunica media: The middle layer, made up of smooth muscle and elastic fibres
- Tunica externa: The outermost layer, composed of fibroblasts, nerves and collagenous tissue

The endothelium, which lines the tunica intima, is an epithelial layer that is only one cell thick. As a result, the tunica intima is always extremely thin, which facilitates efficient interaction with the blood flowing through the vessel.

ARTERIES

Arteries receive blood under high pressure from the heart's ventricles. Due to this high pressure, the walls of the arteries are designed to stretch with each heartbeat without collapsing. The structure of arterial walls consists of three distinct layers:

- Outer layer: Composed of white fibrous connective tissue, this layer merges with surrounding loose connective tissue. It secures the arteries in place, which enables them to withstand the significant pressure that is exerted by blood flow.

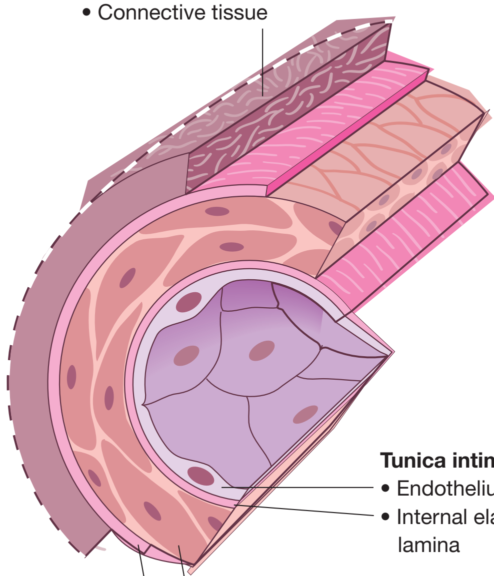

FIGURE 1.2 Layers of the blood vessels

- Middle layer: This thick layer is made up of elastic connective tissue and involuntary muscle fibres. It is supplied by two sets of nerves: one that causes the muscles to relax, allowing the artery to widen and another that stimulates the circular muscles to contract, thereby narrowing the artery.
- Inner layer: This is the endothelial layer, which consists of tightly packed flat epithelial cells, continuous with the endocardium of the heart. Its smooth surface reduces friction between the blood and the arterial walls, ensuring efficient blood flow.

VEINS

Veins, the main vessels of the venous system, carry blood back to the heart. As the pressure in veins is much lower than in arteries, their middle muscular wall is thinner, and their overall diameter is larger. Unlike arteries, veins have semilunar valves that prevent blood from flowing backwards (see Figure 1.3).

These valves are essential for maintaining the direction of blood flow, especially against gravity. Blood returning to the heart from the feet, for example, must travel upwards; these valves assist with this. Acting as one-way gates, they provide 'footholds' for the blood, preventing it from falling back. Muscle contractions in surrounding tissues also help squeeze the veins, propelling blood towards the heart.

Veins receive blood from capillaries after the exchange of oxygen and carbon dioxide has occurred. This carbon dioxide-rich blood is transported back to the heart and lungs, where

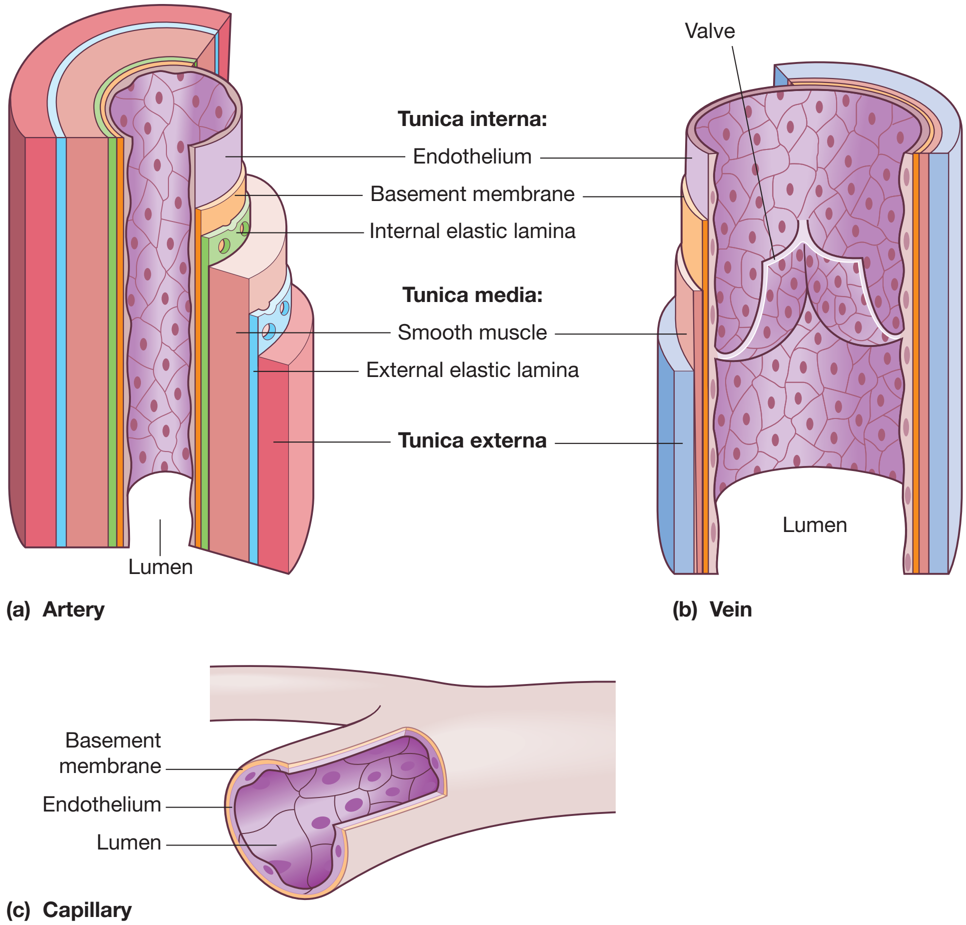

FIGURE 1.3 Components of an artery, vein and capillary. *Source*: Peate and Nair (2011). With permission of John Wiley & Sons.

reoxygenation takes place. The semilunar valves ensure the blood flows in the correct direction, preventing pooling or backward flow (Marieb and Keller 2022).

CAPILLARIES

Capillaries are the smallest blood vessels, with diameters ranging from 5 to 20 μm. These vessels form dense networks within most organs and tissues (see Figure 1.4). The walls of capillaries are composed of a single layer of endothelial cells, which are thin enough to allow the diffusion of oxygen, water, lipids and other molecules into surrounding tissues. Similarly, waste products such as carbon dioxide and urea diffuse back into the blood for removal from the body.

Due to their small size, red blood cells must change their shape to pass through capillaries in a single file. Blood flow in capillaries is regulated by precapillary sphincters, located between arterioles and capillaries. These muscle-containing structures contract or relax to control blood flow into the capillary beds.

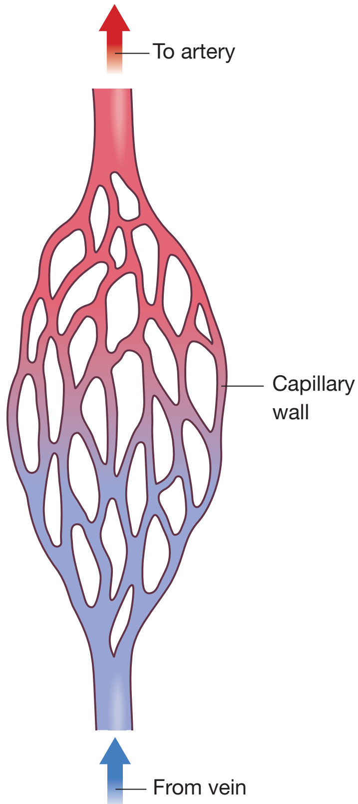

FIGURE 1.4 Capillary network

When the sphincters are open, blood flows freely into the capillary networks, facilitating fluid and nutrient exchange with tissues. When closed, blood bypasses the capillary beds. The exchange of oxygen, nutrients and waste products occurs at the capillary beds, playing a critical role in maintaining tissue health and function.

COMPONENTS OF BLOOD

The blood is composed of both formed elements and plasma. The formed elements include red blood cells (erythrocytes), white blood cells (leucocytes) and platelets, while the plasma, the fluid portion, contains various proteins and other soluble substances. When a blood sample is centrifuged, this is a process that allows for the physical separation of blood components so that each can be measured or analysed individually. The formed elements make up around 45% of the total blood volume, with plasma accounting for the remaining 55%.

Red blood cells, which are named for their characteristic red colour, constitute more than 99% of the formed elements. White blood cells (these appear pale) and platelets together make up less than 1% of the formed elements. A layer known as the buffy coat, which contains white blood cells and platelets, lies between the plasma and the erythrocytes (see Figure 1.5).

The proportion of formed elements, referred to as the haematocrit or packed cell volume, is a blood test measuring the percentage of red blood cells in whole blood. The total volume of blood remains relatively constant unless physiological issues occur, such as blood loss from haemorrhage.

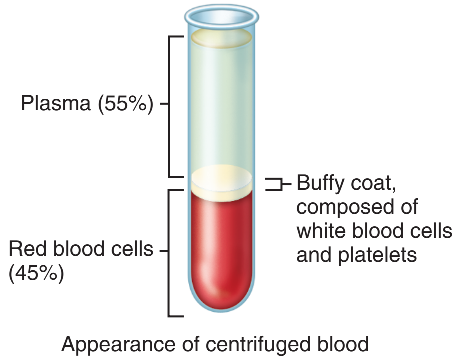

FIGURE 1.5 Blood components. *Source*: Tortora and Derrickson (2009). With permission of John Wiley & Sons.

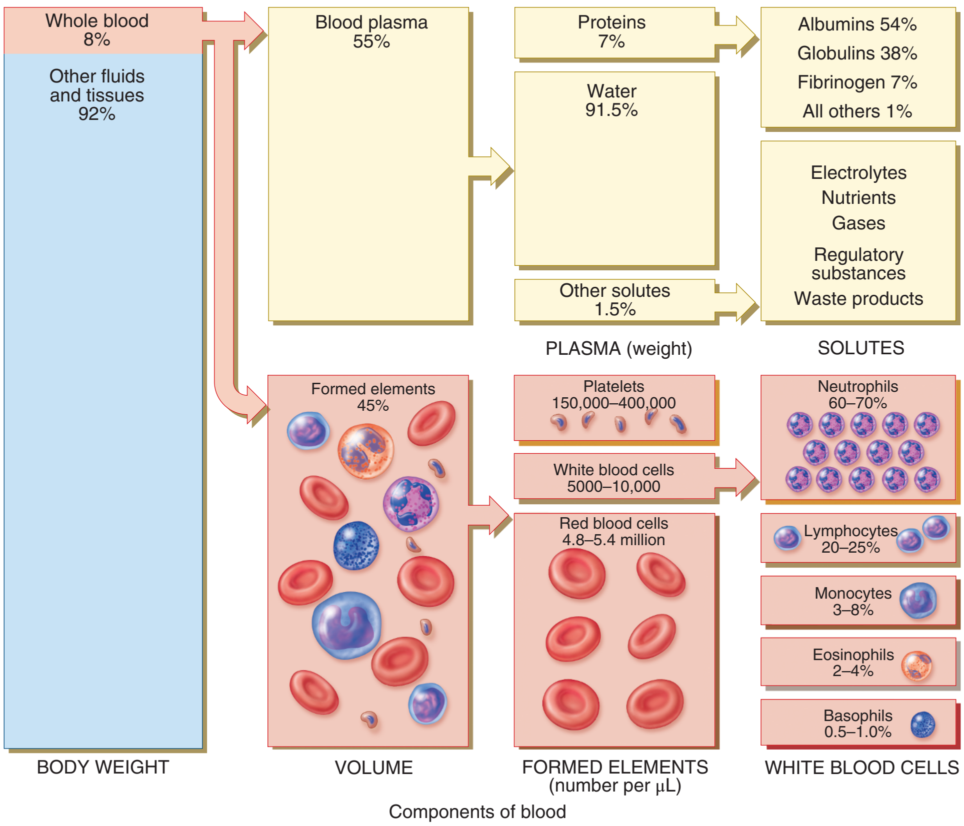

FIGURE 1.6 Cells of the blood. *Source*: Tortora and Derrickson (2009). With permission of John Wiley & Sons.

Plasma is a yellowish fluid that contains nutrients, hormones, minerals and various dissolved substances. The formed elements of blood, including red blood cells, white blood cells and platelets, are suspended in the plasma (see Figure 1.6). Both the plasma and the formed elements are crucial in maintaining homeostasis.

Blood plasma's total volume in an adult is approximately 2.5–3 L. Blood plasma is approximately 91% water and 10% solutes, most of which are proteins. Plasma constitutes approximately 55% of blood's volume.

CHARACTERISTICS AND COMPOSITION OF BLOOD

The average adult has a blood volume of around 5 L, making up about 7–9% of the body weight (Caon 2020). Men typically have 5–6 L of blood, while women have 4–5 L. Blood is thicker, denser and flows more slowly than water due to the presence of red blood cells and plasma proteins, such as albumin and fibrinogen. Plasma proteins include albumin, fibrinogen, prothrombin and gamma globulins, making up around 8% of blood plasma. These proteins are essential for maintaining water balance, affecting osmotic pressure, increasing blood viscosity and helping to regulate blood pressure. All plasma proteins, except for gamma globulins, are produced in the liver.

Plasma osmolality, a measure of how many dissolved particles, such as salts and sugars, are in the blood, is tightly regulated by homeostatic mechanisms. Osmoreceptors in the circulatory system detect changes in plasma osmolality.

Blood flows more slowly than water due to its high viscosity. This thickness is affected by the number of red blood cells and proteins in the blood. More red blood cells and proteins make the blood thicker, slowing its flow. As blood moves through smaller vessels, capillaries, it becomes less thick. Blood has a specific gravity between 1.045 and 1.065, and its pH is ranges from 7.35 and 7.45.

FUNCTIONS OF BLOOD

The functions of the blood are highlighted in Table 1.1.

Table 1.1 The functions of blood

Function	Discussion
Transportation	Carries nutrients and respiratory gases to and from cells.
Regulating body temperature	Helps maintain body temperature by evenly distributing heat produced by cellular activity throughout the body.
Maintaining acid–base balance	Helps control pH by excreting or reabsorbing hydrogen ions and bicarbonate ions.
Fluid balance regulation	Helps maintain fluid balance by either excreting or reabsorbing excess fluid in the kidneys.
Waste removal	Carries waste products away from tissues and cells to organs such as kidneys, lungs, intestines and skin for excretion.
Blood clotting	The clotting mechanisms in blood prevent excessive loss of blood cells and fluids.
Defence	Defends the body against microorganisms and their toxins through the phagocytic actions of neutrophils and monocytes, as well as the presence of antibodies and antitoxins.

Source: Adapted from Knight et al. (2024) and Jones (2020).

FORMATION OF BLOOD CELLS

Red blood cells, most white blood cells and platelets are produced in the bone marrow, a soft, fatty tissue found in bone cavities. These are the formed elements of blood (see Figure 1.7). All blood cells originate from an unspecialised stem cell. When a stem cell divides, it becomes an immature red blood cell, white blood cell or platelet-producing cell. These immature cells then divide, mature and ultimately become mature red blood cells, white blood cells or platelets.

To produce blood cells, multipotent stem cells in the bone marrow divide into myeloid and lymphoid stem cells. Myeloid stem cells further divide to produce red blood cells, platelets and certain white blood cells (basophils, eosinophils, neutrophils and monocytes). Lymphoid stem cells develop into B- and T-lymphocytes. B-lymphocytes complete their development in the bone marrow before migrating to other lymph organs, while T-lymphocytes continue their development in the thymus before moving to other lymph tissues.

RED BLOOD CELLS

Red blood cells (erythrocytes) are the most abundant blood cells. They are biconcave discs containing haemoglobin for oxygen transport (see Figure 1.8). The biconcave shape is maintained by a protein network called spectrin, which allows the cells to change shape as they move through blood vessels. Red blood cells lack a nucleus and organelles, enhancing their oxygen-carrying capacity. There are approximately 4–5.5 million red blood cells per cubic millimetre of blood.

HAEMOGLOBIN

Haemoglobin in red blood cells transports oxygen and about 20% of carbon dioxide. In tissues, haemoglobin picks up carbon dioxide and releases oxygen, while in the lungs, it releases carbon dioxide and picks up oxygen. Red blood cells lack mitochondria, relying on anaerobic

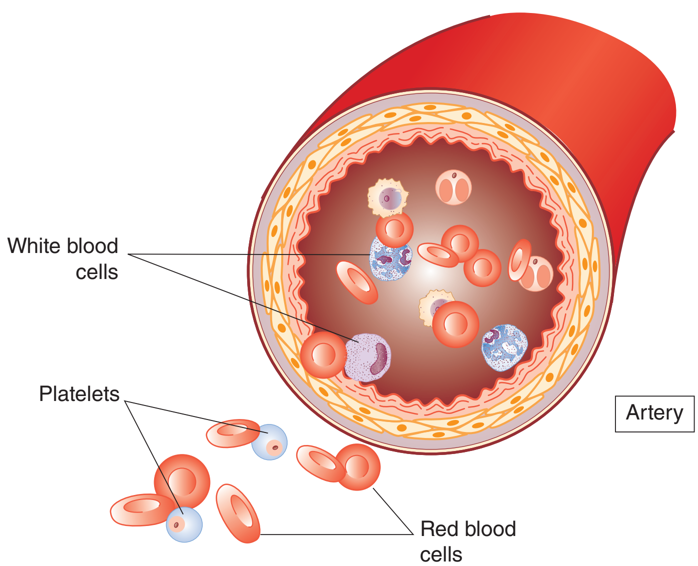

FIGURE 1.7 Formed elements of blood

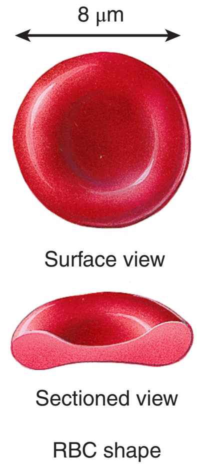

FIGURE 1.8 Red blood cell. *Source*: Tortora and Derrickson (2009). With permission of John Wiley & Sons.

respiration for energy, so they do not consume the oxygen they carry. Haemoglobin also helps maintain blood pressure and flow.

Haemoglobin consists of globin protein and iron-containing haem pigments. Each haemoglobin molecule has four iron atoms, each carrying one oxygen molecule, so one haemoglobin molecule transports four oxygen molecules. With around 250 million haemoglobin molecules in each red blood cell, a single cell can carry one billion oxygen molecules. At the capillaries, haemoglobin releases oxygen into the interstitial fluid for cell use.

FORMATION OF RED BLOOD CELLS

Erythroblasts, immature red blood cells, mature in the red bone marrow to become red blood cells. During this process, they lose their nucleus and organelles while accumulating more haemoglobin, increasing their oxygen-carrying capacity. Mature red blood cells lack a nucleus and have a lifespan of around 120 days. Approximately two million red blood cells are destroyed every second, but an equal number are produced to maintain balance. The hormone erythropoietin regulates red blood cell production (see Box 1.1). Key components required for red blood cell synthesis include iron, folic acid and vitamin B12.

BOX 1.1 ERYTHROPOIETIN

Erythropoietin is a hormone produced by the kidneys and released into the bloodstream, where it travels to the bone marrow. In the bone marrow, erythropoietin stimulates the production of red blood cells, which are then released into circulation. The production and release of erythropoietin is regulated by a negative feedback mechanism (see Figure 1.9).

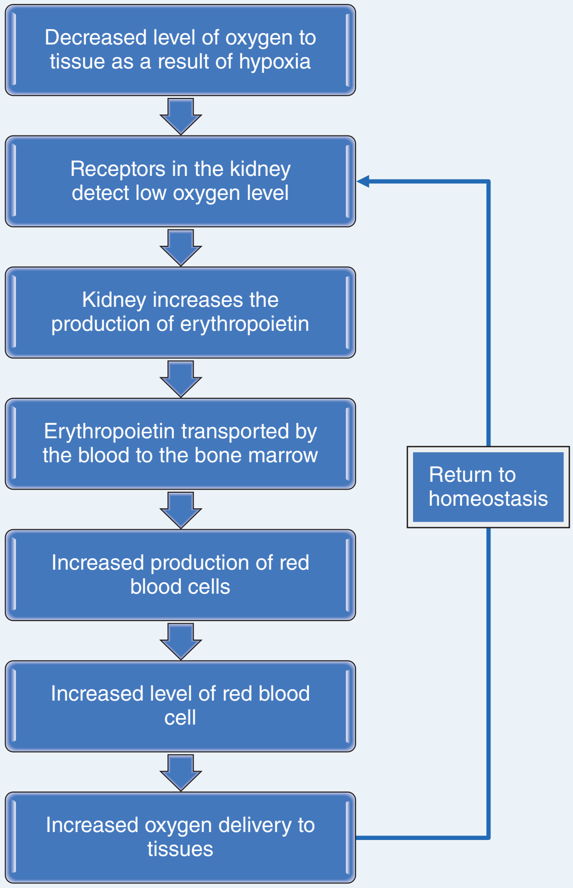

FIGURE 1.9 Mechanism of negative feedback for erythropoietin. *Source*: Adapted from Jones (2020).

Without a nucleus and other organelles, the red blood cell cannot synthesise new structures to replace the ones that are damaged. The breakdown (haemolysis) of the red blood cells is carried out by macrophages in the spleen, liver and the bone marrow. The globin is broken down into amino acids and reused for protein synthesis. Iron is separated from haem and is stored in the muscles and the liver and reused in the bone marrow to manufacture new red blood cells. Haem is the portion of the haemoglobin that is converted to bilirubin and is transported by plasma albumin to the liver and eventually secreted in bile. In the large intestine, bacteria convert bilirubin into urobilinogen, some of which is reabsorbed into the bloodstream, where it is converted into a yellow pigment called urobilin, which is excreted in urine, giving the urine a yellowish colour. The remainder of the urobilinogen is eliminated in faeces as a brown pigment called stercobilin.

Red blood cells lack a nucleus and other organelles and therefore cannot repair or replace damaged structures. Their breakdown (haemolysis) is carried out by macrophages in the spleen, liver and bone marrow. Globin is degraded into amino acids and reused for protein synthesis, while iron is separated from haem, stored in the liver and muscles, and recycled in the bone marrow for the production of new red blood cells. The haem component is converted into bilirubin, which is transported by plasma albumin to the liver and secreted in bile. In the large

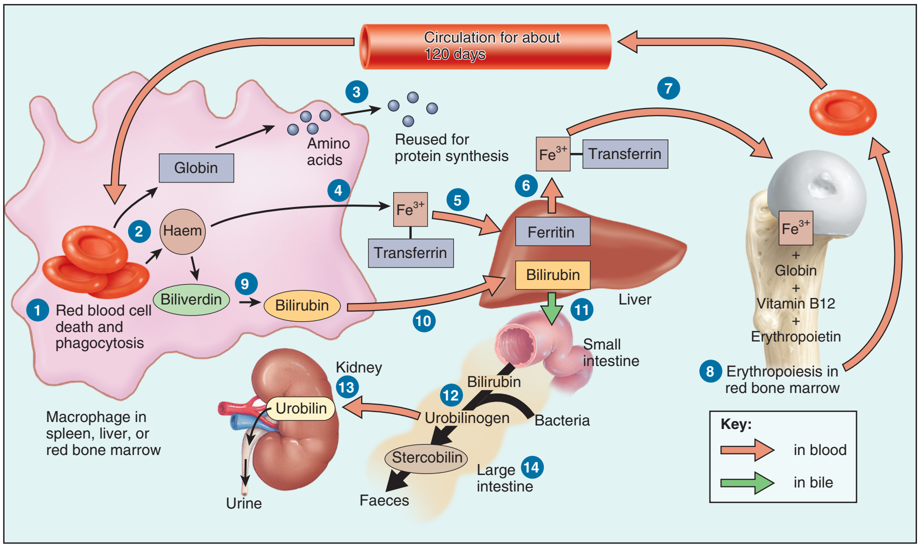

FIGURE 1.10 Red blood cell destruction. *Source*: Tortora and Derrickson (2009). With permission of John Wiley & Sons.

intestine, bacterial action converts bilirubin into urobilinogen. Some urobilinogen is reabsorbed into the bloodstream, converted into urobilin and excreted in urine, giving it a yellow colour. The remainder is converted into stercobilin and excreted in faeces, producing their brown colour. A detailed illustration of red blood cell destruction is shown in Figure 1.10.

The primary function of red blood cells is to carry oxygen from the lungs to body tissues. In the lungs, oxygen from the alveoli binds to iron in haemoglobin, forming oxyhaemoglobin, which is then delivered to the tissues via the bloodstream. Red blood cells appear bright red when oxygen levels are high and dark bluish-red when oxygen levels decrease (Colbert et al. 2012). Besides oxygen transport, red blood cells also carry carbon dioxide from the tissues back to the lungs for exhalation.

WHITE BLOOD CELLS

White blood cells or leucocytes are present in the blood at a concentration of approximately 5000–10,000/mm^3. During infections, their number can rise to around 25,000/mm^3. An increase in white blood cells is termed leucocytosis, while an abnormally low count is called leucopenia. Unlike red blood cells, white blood cells have nuclei and can move out of blood vessel walls into surrounding tissues. They produce energy continuously and synthesise proteins, allowing them to live for several days to years. White blood cells are classified into two main types:

- Granulocytes (contain cytoplasmic granules):
  - Neutrophils
  - Eosinophils
  - Basophils
- Agranulocytes (contain a few cytoplasmic granules):
  - Monocytes
  - Lymphocytes

NEUTROPHILS

Neutrophils, the most abundant white blood cells, make up 60–65% of granulocytes and are vital to the immune system. These 10–12 μm cells are phagocytic, capable of ingesting micro-organisms and contain lysozymes, helping protect against foreign materials. They move out of blood vessel walls via diapedesis and are the first immune cells to respond to infections through chemotaxis. Inactive neutrophils live about 12 hours, while active ones may last one to two days.

EOSINOPHILS

Eosinophils make up 2–4% of granulocytes and have a B-shaped nucleus. Measuring 10–12 μm in diameter, they migrate from blood vessels and are phagocytic, though less active than neutrophils. Their granules contain lysosomal enzymes and peroxidase, which are toxic to parasites and help destroy them.

BASOPHILS

Basophils are the least abundant granulocytes, making up about 1%. They are 8–10 μm in diameter and have elongated lobed nuclei. In inflamed tissue, they become mast cells, releasing granules with heparin, histamine and proteins, thereby promoting inflammation. They also release lipid mediators such as leukotrienes and cytokines. Basophils are key in immunity against parasites and allergic responses, as their surface IgE binds to allergens, triggering the release of chemicals causing allergy symptoms.

MONOCYTES

Monocytes, comprising about 5% of agranulocytes, are large circulating white blood cells (12–20 μm in diameter) with kidney or horseshoe-shaped nuclei. Produced in the bone marrow, they circulate for one to three days before migrating into tissues, where they develop into macrophages. These macrophages play a key role in immunity and inflammation by engulfing pathogens and destroying specific antigens.

LYMPHOCYTES

Lymphocytes make up 25% of white blood cells and are mainly found in lymphatic tissues such as lymph nodes and spleen. Small lymphocytes are 6–9 μm in diameter, while larger ones range from 10 to 14 μm. They are named after the lymph fluid that transports them and have a lifespan from hours to years. Lymphocytes are not phagocytes; there are two types:

- T-lymphocytes, originating in the thymus and mediate cellular immune responses
- B-lymphocytes, originating in bone marrow, producing antibodies to target antigens

PLATELETS

These are small, non-nucleated blood cells, around 2–4 μm in diameter, produced from megakaryocyte fragments in bone marrow. They have a lifespan of five to nine days, with old platelets removed by macrophages in the spleen and liver. Platelets contain proteins, helping them stick to collagen in blood vessel walls. They play a key role in clotting by forming plugs to seal blood vessel holes and releasing chemicals that aid clot formation. Low platelet counts can lead to excessive bleeding, while high counts may cause clotting disorders such as stroke or heart attack.

HAEMOSTASIS AND COAGULATION

Haemostasis is the process that stops bleeding and prevents haemorrhage from smaller blood vessels, consisting of three main components.

- Vasoconstriction: Constriction of blood vessels, triggered by smooth muscle contraction (vascular spasm), reduces blood flow. The sympathetic nervous system induces vasoconstriction and platelets release thromboxanes, which also constrict vessels and aid platelet aggregation.
- Platelet aggregation: Platelets adhere to exposed collagen in damaged vessels, releasing chemicals such as adenosine diphosphate and thromboxane, which attract more platelets to form a plug.
- Coagulation: When vasoconstriction and platelet aggregation are not sufficient, coagulation occurs. This complex process involves clotting factors, mainly produced in the liver, to form a clot. Key stages include:

  1. Thromboplastinogenase activates thromboplastin.
  2. Thromboplastin converts prothrombin to thrombin.
  3. Thrombin converts fibrinogen into fibrin, forming a clot by trapping blood cells.

Two pathways trigger clotting: the extrinsic pathway, activated by blood vessel rupture, and the intrinsic pathway, activated by damage to vessel walls.

BLOOD GROUPS

Blood groups are determined by antigens on the surface of red blood cells. These antigens are unique to each person, except in identical twins, and are essential for matching blood types during transfusions to prevent serious reactions. The ABO system is used to classify blood types:

- Group A has A antigens.
- Group B has B antigens.
- Group AB has both A and B antigens.
- Group O has neither A nor B antigens.

The ABO system also includes antibodies in the plasma that attack foreign antigens. For example, blood group A has anti-B antibodies, blood group B has anti-A antibodies, blood group AB has no antibodies and blood group O has both anti-A and anti-B antibodies (see Figure 1.11). If a person receives the wrong blood type, these antibodies can destroy the transfused red blood cells, which can be life-threatening.

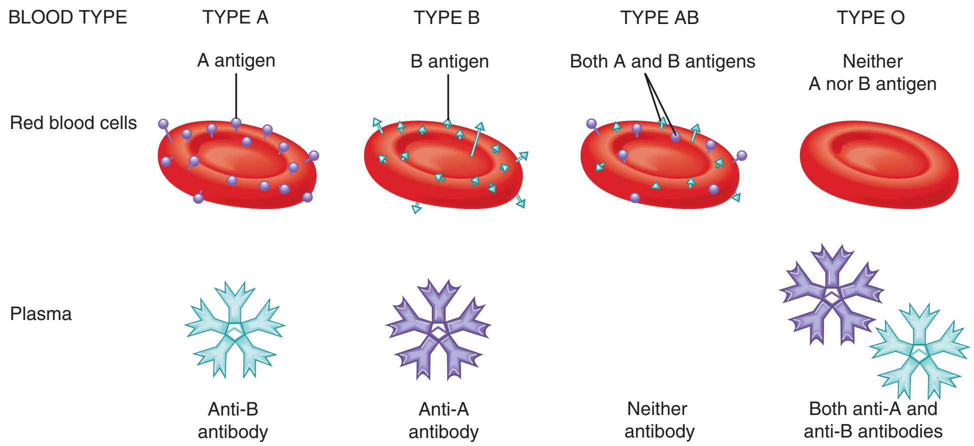

FIGURE 1.11 ABO blood groups. *Source*: Tortora and Derrickson (2009). With permission of John Wiley & Sons.

Table 1.2 Blood groups

Blood type	Antigens	Antibodies	Can donate blood to	Can receive blood from
A	Antigen A	Anti-B	A, AB	A, O
B	Antigen B	Anti-A	B, AB	B, O
AB	Antigen A Antigen B	None	AB	A, B, AB, O
O	None	Anti-A Anti-B	A, B, AB, O	O

Source: Adapted from Jones (2020).

In addition to the ABO blood group system, the Rhesus (Rh [D]) factor is important. Rh antigens may or may not be present on red blood cells. If the Rh antigen is present, the person is Rh positive; if absent, they are Rh negative. For example, someone with blood group A and Rh positive is A+, while A negative is A− (Caon 2020). This applies to all blood groups (B, AB, O). The Rh factor is crucial when matching blood for transfusions to prevent complications such as agglutination (see Table 1.2).

THE LYMPHATIC SYSTEM

The lymphatic system (see Figure 1.12) is a part of the circulatory system that transports lymph, a clear fluid. It starts with tiny, closed-ended vessels called lymphatic capillaries (Figure 1.13), which are in contact with tissues and interstitial fluid. The system includes:

- Lymph
- Lymph vessels
- Lymph nodes
- Lymphatic organs, such as the spleen and thymus

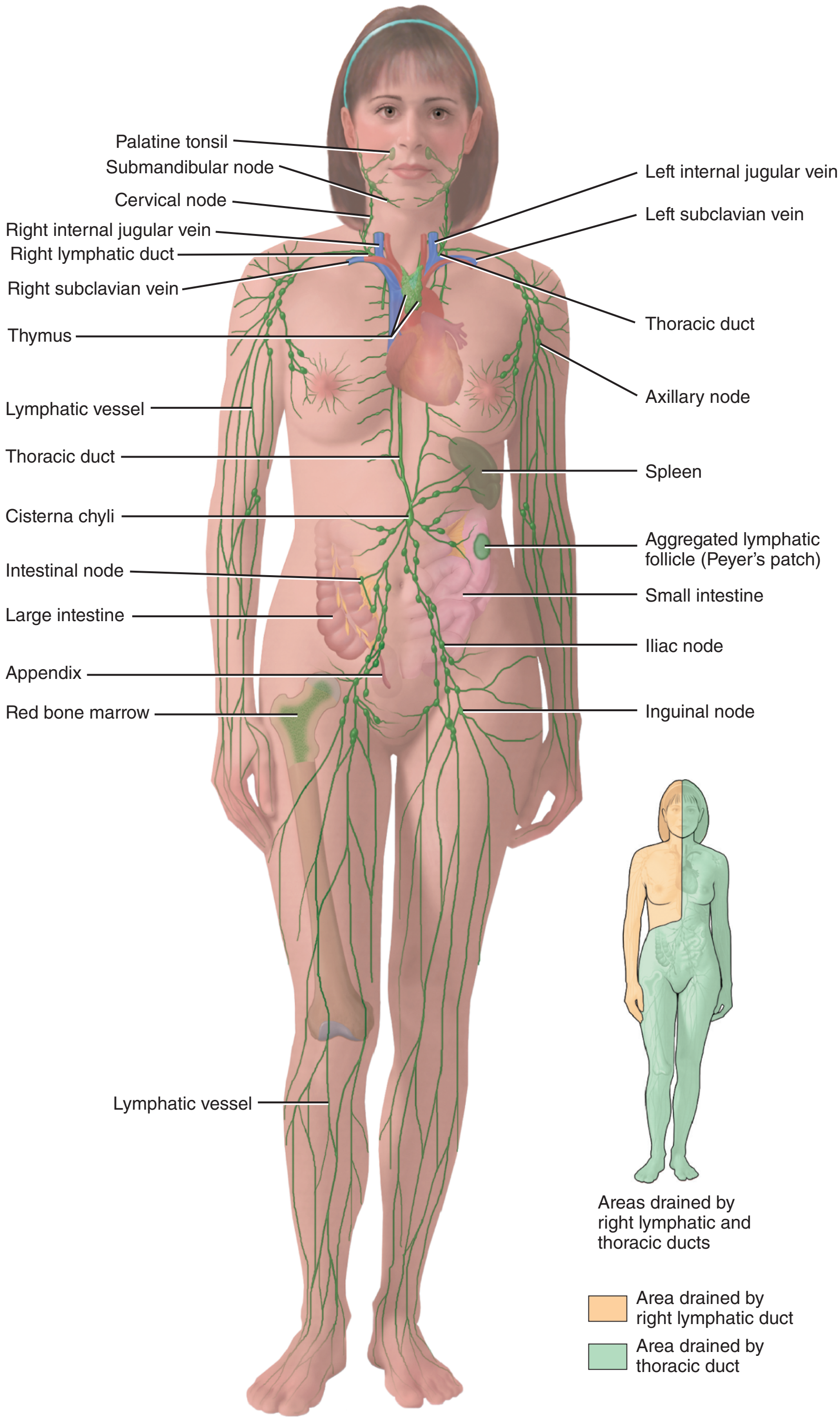

FIGURE 1.12 Lymphatic system. *Source*: Tortora and Derrickson (2009). With permission of John Wiley & Sons.

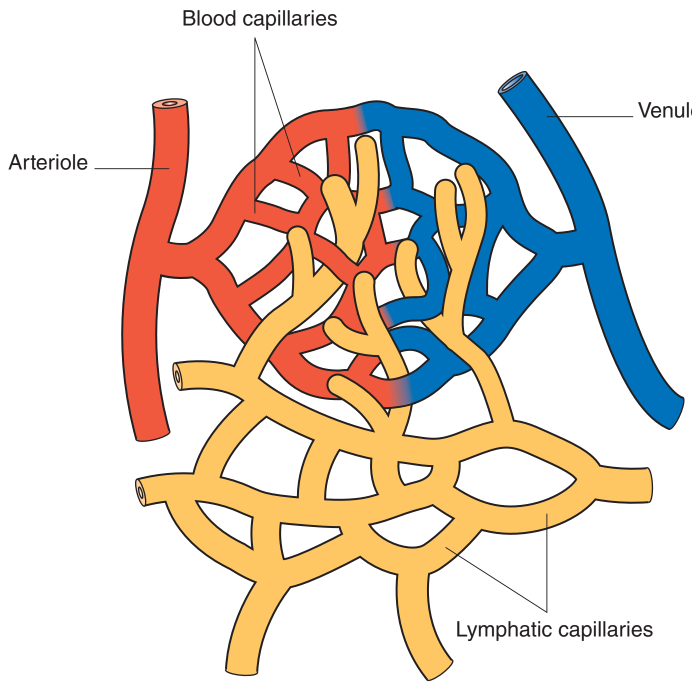

FIGURE 1.13 Lymphatic capillaries

LYMPH

This is a clear fluid in the lymphatic capillaries, similar to plasma. It forms when blood pressure pushes fluid and small proteins from blood vessels into tissues and then into the lymphatic capillaries. The body holds approximately 1–2 L of lymph, which makes up 1–3% of body weight. Lymph carries plasma proteins, bacteria and fats from the small intestine and damaged tissues to the lymph nodes for removal. It also contains lymphocytes and macrophages, which help fight infections.

LYMPH NODES

Lymph nodes are small, bean-shaped organs located along lymphatic vessels, mainly in the neck, axillae, chest, abdomen and groin, with smaller clusters behind the elbows and knees (Migliozzi 2020). They filter harmful substances from lymph and play a key role in the immune system. Each node has an outer fibrous capsule with partitions inside, dividing it into sections (see Figure 1.14). Lymph enters the node through four or five afferent vessels and leaves through a single efferent vessel.

LYMPHATIC ORGANS

Two key organs of the lymphatic system are the spleen and the thymus gland. Table 1.3 provides an overview of the lymphatic organs.

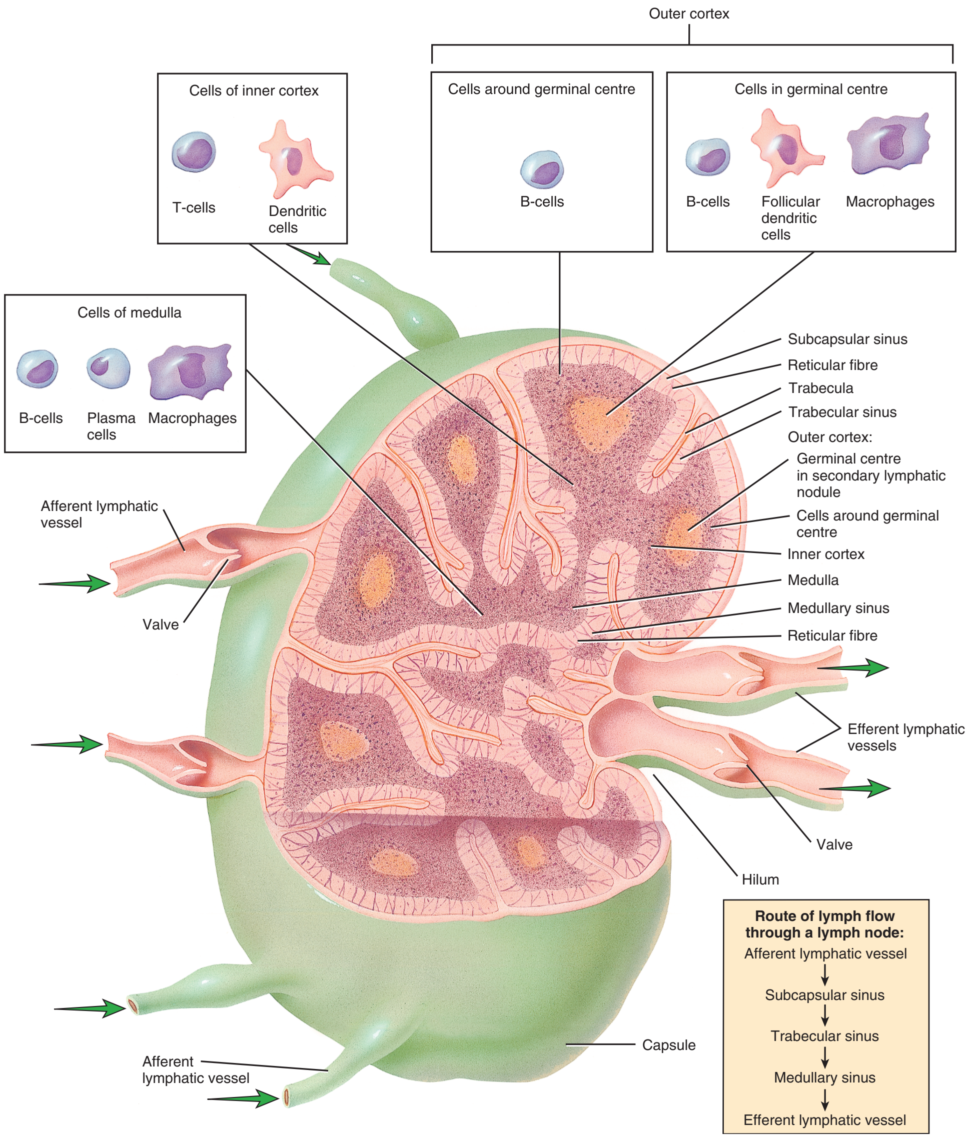

FIGURE 1.14 Lymph node. *Source*: Tortora and Derrickson (2009). John Wiley & Sons.

THE SIZE AND THE LOCATION OF THE HEART

Cardiology is the scientific study of the heart, including its normal functions as well as associated diseases. Despite its critical role, the heart is a relatively small organ; it is roughly the size of a closed fist, though it is not the same shape. It measures approximately 12 cm in length, 9 cm at its widest point and 6 cm in thickness, with an average weight of 250 g in adult females and 300 g in adult males. Positioned on the diaphragm near the midline of the thoracic cavity, the heart is located in the mediastinum (see Figure 1.15). This anatomical region spans from the sternum to the vertebral column, the first rib to the diaphragm and lies between the lungs. Approximately two-thirds of the heart's mass is located to the left of the body's midline. The heart's pointed apex, formed by the tip of the left ventricle (one of the lower chambers), rests

Table 1.3 Lymphatic organs

Organ	Location	Function
Lymph nodes	Neck, armpits, chest, abdomen, groin	Filter lymph, remove harmful substances and support immune responses
Spleen	Left upper abdomen	Filters blood, removes old or damaged red blood cells, stores platelets and supports immune function
Thymus	Behind the sternum, in the chest	Matures T-lymphocytes (T-cells), essential for adaptive immunity
Tonsils	Throat, around the nasopharynx and oral cavity	First line of defence against pathogens entering through the mouth and nose
Bone marrow	Inside bones (e.g. pelvis, sternum)	Produces blood cells, including lymphocytes

Source: Adapted from Knight et al. (2024).

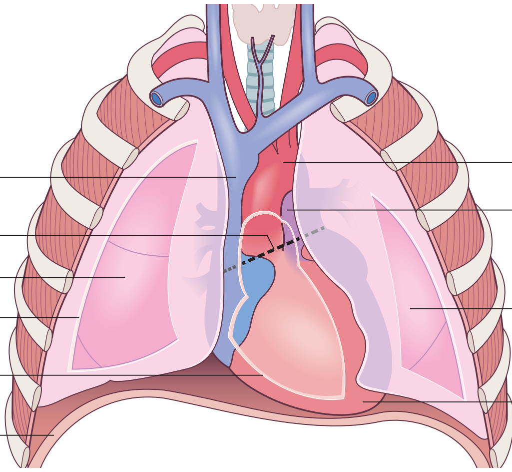

FIGURE 1.15 The location of the heart. *Source*: Peate and Nair (2014). With permission of John Wiley & Sons.

on the diaphragm and points anteriorly, inferiorly and to the left. In contrast, the heart's base, located opposite the apex at the posterior aspect, is formed by its upper chambers, primarily the left atrium.

STRUCTURE OF THE HEART

HEART WALL

The heart is surrounded by a protective membrane called the pericardium, which consists of two closely connected layers: the fibrous pericardium and the serous pericardium (see Figure 1.16). These layers differ in structure and function.

Fibrous pericardium

- A tough, dense, inelastic layer made of connective tissue
- Prevents the heart from overstretching
- Provides protection and anchors the heart in place

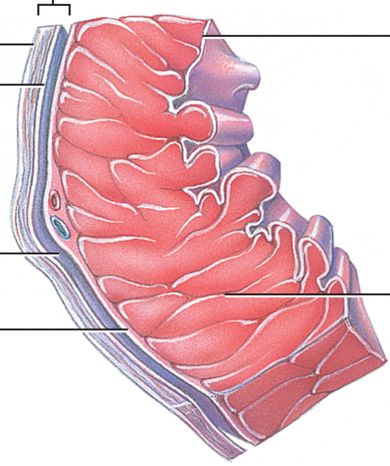

FIGURE 1.16 The wall of the heart. *Source*: Tortora and Derrickson (2009). With permission of John Wiley & Sons.

Serous pericardium

- A thinner, more delicate double-layered membrane
- The outer layer is fused to the fibrous pericardium
- The inner layer, called the visceral pericardium (or epicardium), adheres directly to the heart's surface

Myocardium

The myocardium forms the bulk of the heart and is a muscle unique to this organ, specialised for its specific functions. Its role is divided into two key tasks: the majority of the myocardium performs mechanical work (contraction), while a smaller portion is responsible for initiating and conducting electrical impulses. The cardiac muscle cells (myocytes) are arranged in interlacing spiral or circular bundles of fibres (see Figure 1.17).

The thickness of the myocardium varies across the heart's four chambers. The ventricles have thicker walls than the atria, with the left ventricle having the thickest myocardial wall. This increased thickness allows it to pump blood at higher pressure over long distances, overcoming greater resistance in the systemic circulation.

Endocardium

The innermost layer, known as the endocardium, consists of endothelium resting on a thin layer of connective tissue. This endothelium is continuous with the lining of the large blood vessels connected to the heart. It creates a smooth surface that facilitates the unobstructed flow of blood through the heart chambers.

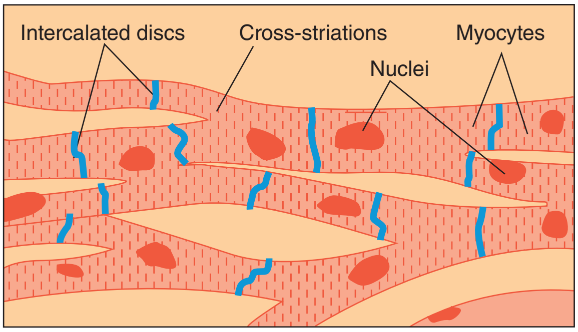

FIGURE 1.17 Cardiac muscle cells

BLOOD FLOW THROUGH THE HEART

The heart contains four chambers: the left and right atria (singular: atrium) and the left and right ventricles. Each atrium features a wrinkled, pouch-like structure on its anterior surface called an auricle, which helps increase the atrium's blood-holding capacity. The ventricles are separated by a wall known as the interventricular septum (Figure 1.18). Similarly, a septum divides the atria. These septa ensure that there is no mixing of blood between the two sides of the heart.

BLOOD FLOW

The circulatory system consists of three key components: pulmonary circulation, coronary circulation and systemic circulation. These systems correspond to the lungs (pulmonary), heart (coronary) and the rest of the body (systemic). Each system operates independently but collaborates to maintain effective blood flow.

PULMONARY CIRCULATION

Pulmonary circulation is a closed-loop system connecting the heart and lungs. Oxygen-poor blood enters the right atrium through the inferior and superior vena cava.

It flows into the right ventricle via the tricuspid valve. When the ventricle contracts, the tricuspid valve closes to prevent backflow. Blood passes through the pulmonary valve into the pulmonary artery, travelling to the lungs. In the lungs, oxygen moves from air sacs into the blood, while carbon dioxide exits the blood and is exhaled. The oxygenated blood returns to the left atrium through the pulmonary veins (see Figure 1.19).

SYSTEMIC CIRCULATION

Systemic circulation delivers oxygen-rich blood to the body and returns oxygen-poor blood to the heart. Oxygenated blood enters the left atrium via the pulmonary veins.

Blood flows through the aortic valve into the aorta, which branches into smaller arteries delivering blood throughout the body. Capillaries facilitate the exchange of oxygen and nutrients with tissues, while waste products are collected in the veins. Deoxygenated blood returns to the heart for pulmonary circulation, completing the cycle (see Figure 1.19).

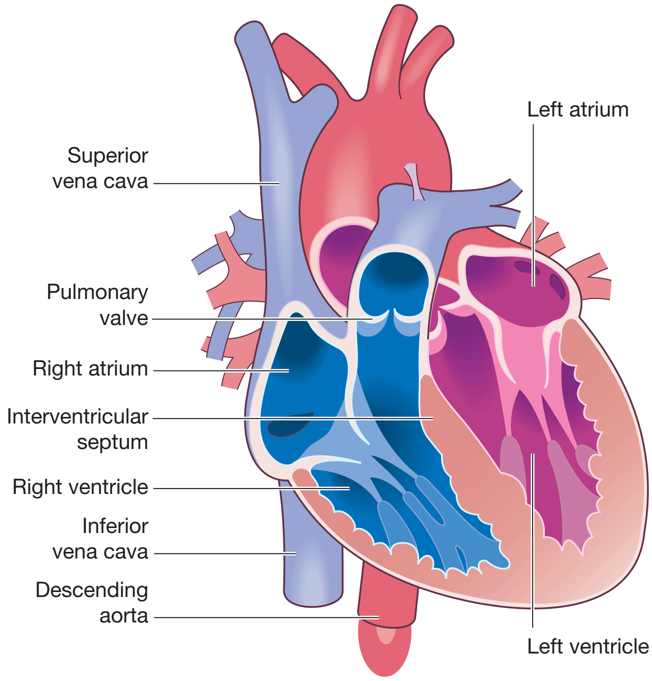

FIGURE 1.18 The chambers of the heart. *Source*: Peate and Nair (2014). With permission of John Wiley & Sons.

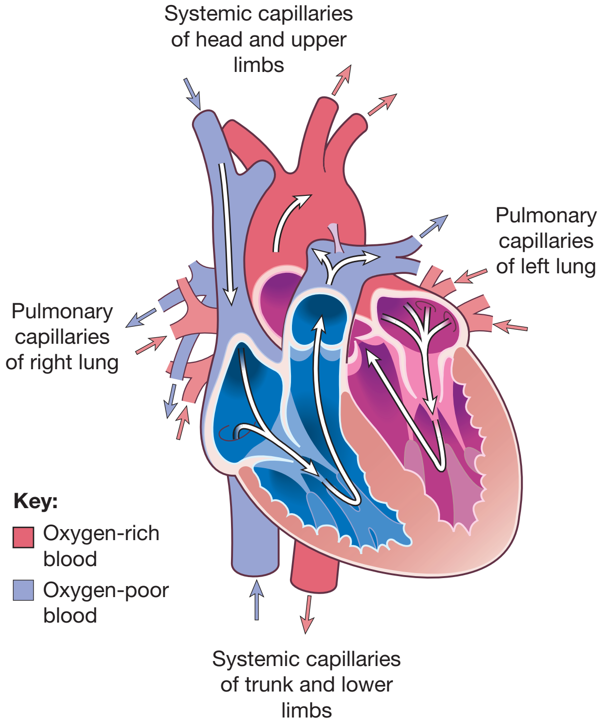

FIGURE 1.19 Blood flow through the heart. *Source*: Peate and Nair (2014). With permission of John Wiley & Sons.

CORONARY CIRCULATION

The heart itself requires around 5% of the body's blood supply to function efficiently. Only the inner 2 mm of the endocardium is nourished directly by blood inside the heart chambers. The rest is supplied by the coronary arteries, which branch off the aorta near the aortic valve. These arteries form an intricate network that delivers oxygen and nutrients to the myocardium and removes waste products to ensure optimal heart function. This continuous flow of blood sustains the body, maintaining oxygenation, nutrient delivery and waste removal at all times.

CORONARY ARTERIES AND VEINS

CORONARY ARTERIES

The coronary arteries supply oxygen-rich blood to the myocardium and branch from the ascending aorta, encircling the heart like a crown. The heart muscle needs a constant supply of oxygen to function and waste-rich, oxygen-depleted blood must be removed. Blood flow through coronary arteries occurs during the heart's relaxation phase, unlike the rest of the body, where flow is continuous during contraction (see Figure 1.20).

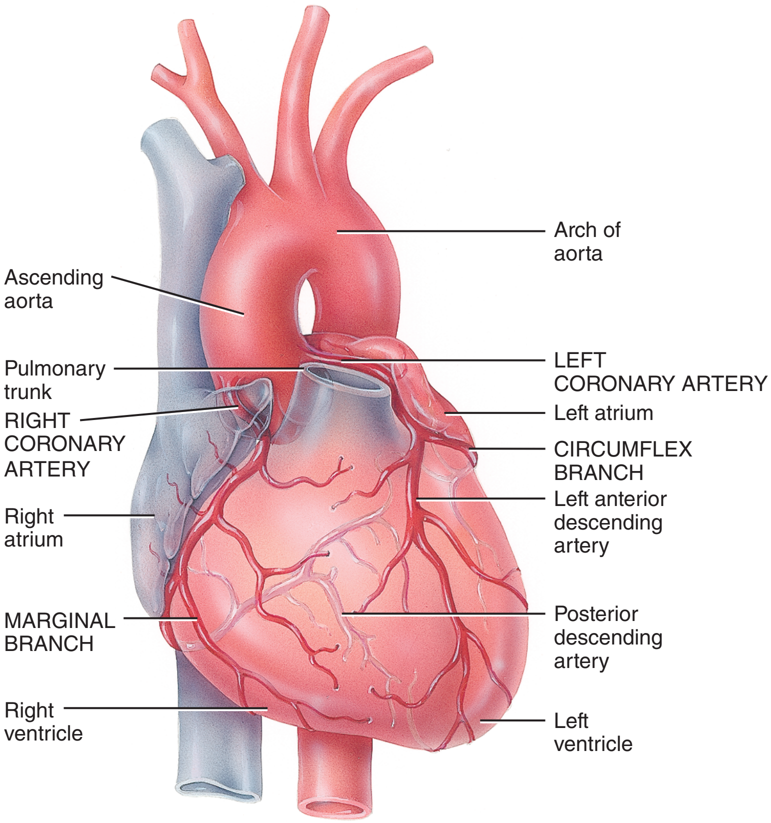

FIGURE 1.20 Coronary arteries. *Source*: Tortora and Derrickson (2009). With permission of John Wiley & Sons.

- Left coronary artery divides into:
  - Anterior interventricular branch: Supplies blood to both ventricles
  - Circumflex branch: Supplies the left ventricle and left atrium
- Right coronary artery divides into:
  - Posterior descending artery: Supplies the right atrium and ventricles
  - Acute marginal artery: Supplies the sinoatrial node (controls heart rhythm) and atrioventricular (AV) node

CORONARY VEINS

Coronary veins return deoxygenated blood from the myocardium to the right atrium for reoxygenation in the lungs.

- Coronary sinus
  - A large vein that collects blood from smaller cardiac veins
  - Delivers blood to the right atrium through the coronary sinus orifice, located between the inferior vena cava and the right AV orifice
  - Protected by a small fold of tissue called the Thebesian valve

Unlike coronary arteries, coronary veins are typically free from atherosclerotic plaques and have valves to prevent backflow. Figure 1.21 depicts the coronary veins.

CONDUCTING SYSTEM OF THE HEART

The cardiac conduction system consists of specialised nodes and conduction cells that regulate and coordinate the contraction of the heart muscle. Cardiac conduction refers to the process by which electrical impulses are generated and transmitted through the heart. These impulses prompt the heart to contract and relax in a continuous cycle, enabling blood to circulate throughout the body. The conduction system includes the following key components:

- Sinoatrial (SA) node
- AV node
- Bundle of His
- Left and right bundle branches
- Purkinje fibres

SINOATRIAL NODE

The SA node, located in the right atrium, is the heart's natural pacemaker (see Figure 1.22). It consists of specialised cells surrounded by fibrous tissue. The SA node generates regular electrical signals, with the rate adjusted based on the body's needs. These signals spread

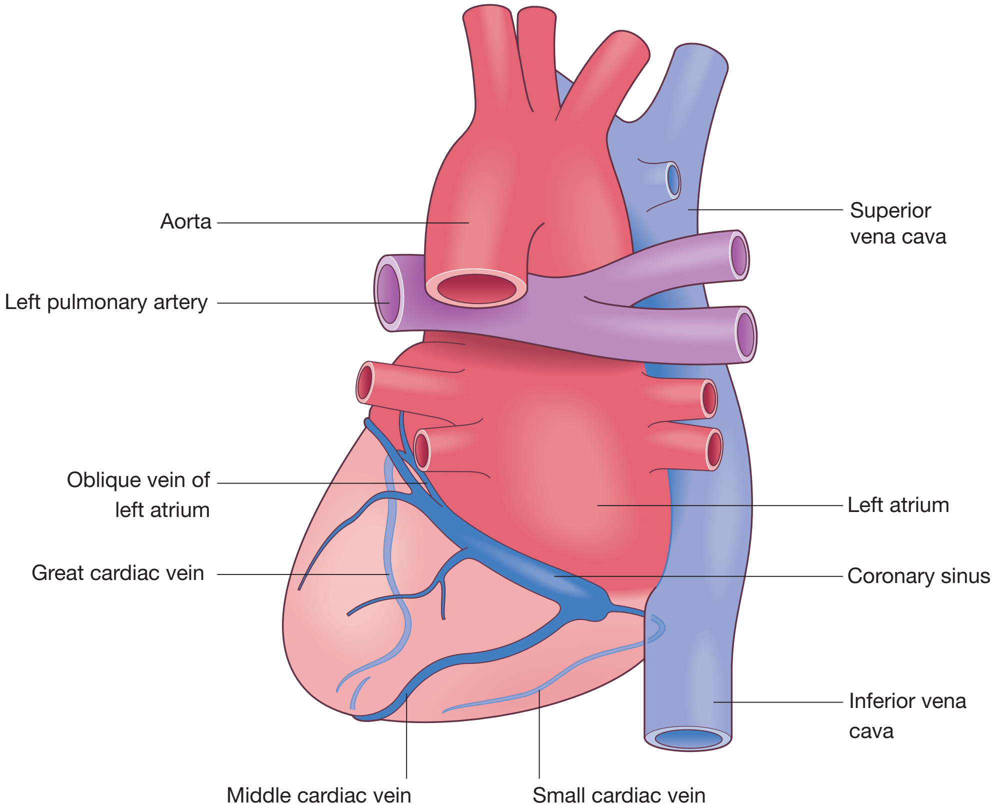

FIGURE 1.21 Coronary veins

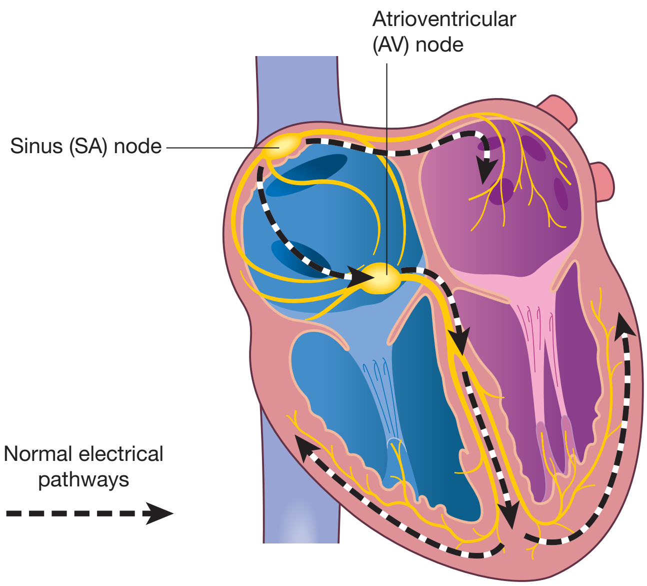

FIGURE 1.22 The conducting system of the heart. *Source*: Peate and Nair (2014). With permission of John Wiley & Sons.

rapidly through the atrial myocardial cells, causing both atria to contract nearly simultaneously. This rapid contraction involves approximately 100 million atrial cells working in less than a third of a second.

ATRIOVENTRICULAR NODE

The AV node is located near the base of the right atrium, along the partition separating the atria (see Figure 1.22). Electrical impulses from the SA node are briefly delayed here, allowing the atria to contract and empty before the ventricles are activated. The AV node also regulates the signals to prevent rapid, uncoordinated contractions and ensures proper timing between atrial and ventricular contractions.

BUNDLE OF HIS

The bundle of His, also called the AV bundle, transmits electrical impulses from the AV node to the ventricles. It is the sole pathway for electrical signals to pass from the atria to the ventricles, ensuring synchronised cardiac activity.

LEFT AND RIGHT BUNDLE BRANCHES

These branches, extensions of the bundle of His, run along the interventricular septum. Each branch directs electrical impulses to its respective ventricle. The branches further subdivide and lead into the Purkinje fibres.

PURKINJE FIBRES

Purkinje fibres are specialised cells rich in glycogen and connected by numerous gap junctions. Found in the inner walls of the ventricles, these fibres conduct electrical signals rapidly and efficiently. They ensure coordinated and synchronised contractions of the ventricles, which is critical for maintaining a steady heart rhythm.

THE CARDIAC CYCLE

The cardiac cycle refers to the series of events that occur during each heartbeat (see Figure 1.23). It has two main phases: diastole and systole. During diastole, the ventricles relax and the heart fills with blood. In systole, the ventricles contract, pumping blood into the arteries. A single cardiac cycle is completed when the heart fills and ejects blood.

FIRST DIASTOLE PHASE

At the beginning of diastole, the atria and ventricles are relaxed and the AV valves are open. Deoxygenated blood flows from the superior and inferior venae cavae into the right atrium. This blood passes into the right ventricle through the open tricuspid valve. When the SA node activates, the atria contract, pushing additional blood into the right ventricle. The tricuspid valve prevents backflow into the right atrium.

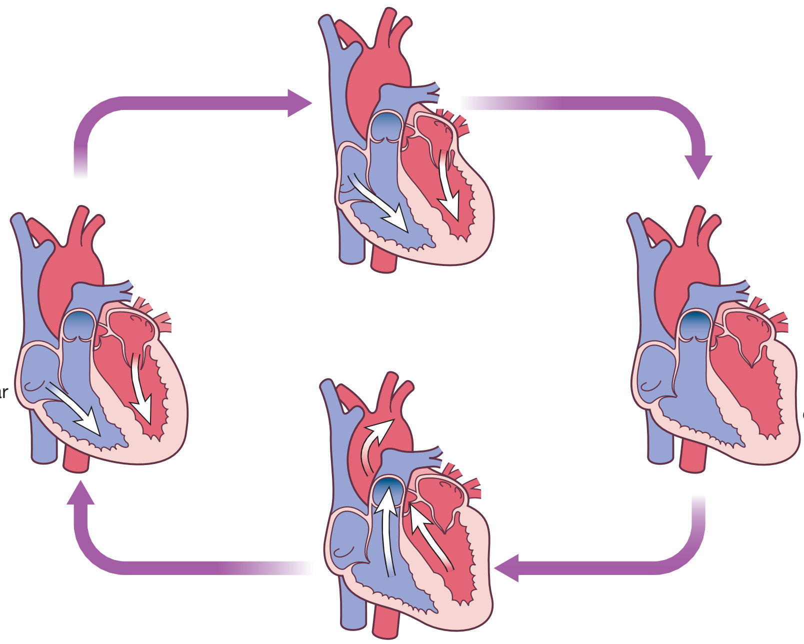

FIGURE 1.23 The cardiac cycle

FIRST SYSTOLE PHASE

During the first systole phase, impulses from the Purkinje fibres stimulate the right ventricle to contract. The AV valves close and the semilunar valves open, allowing deoxygenated blood to be pumped into the pulmonary artery. The pulmonary valve ensures that blood does not flow back into the right ventricle. The pulmonary artery then transports the blood to the lungs for gas exchange. Oxygenated blood returns to the left atrium via the pulmonary veins.

SECOND DIASTOLE PHASE

In the second diastole phase, the semilunar valves close and the AV valves reopen. Oxygenated blood from the pulmonary veins fills the left atrium while deoxygenated blood from the venae cavae continues filling the right atrium. The SA node triggers another contraction of the atria, causing the left atrium to empty its blood into the left ventricle. The mitral valve prevents backflow into the left atrium.

SECOND SYSTOLE PHASE

In the second systole phase, the AV valves close and the semilunar valves open. The left ventricle contracts after receiving impulses from the Purkinje fibres, ejecting oxygen-rich blood into the aorta. The aortic valve prevents blood from flowing back into the left ventricle. The aorta distributes oxygenated blood to the body, while oxygen-depleted blood returns to the heart via the venae cavae, completing the cycle.

CARDIAC OUTPUT

Cardiac output (CO) is the volume of blood ejected by the heart per minute. It is a critical measure of the heart's efficiency and an essential parameter for assessing overall cardiovascular function (Clare 2020).

FORMULA

Cardiac output is calculated using the formula:

$$\text{CO} = \text{stroke volume (SV)} \times \text{heart rate (HR)}$$

- Stroke volume (SV): The amount of blood pumped out of a ventricle with each beat (measured in mL/beat).
- Heart rate (HR): The number of heartbeats per minute (bpm) (measured in bpm).

For example, if the SV is 70 mL/beat and the HR is 70 bpm, the cardiac output would be:

$$\text{CO} = 70\,\text{mL/beat} \times 70\,\text{bpm} = 4900\,\text{mL/min}$$

This means the heart is pumping approximately 4.9 L/min. CO is a dynamic measure that reflects the interplay of HR, SV and the body's metabolic needs. It provides essential insight into cardiovascular health and guides the management of many medical conditions.

NERVE SUPPLY TO THE HEART

THE AUTONOMIC NERVOUS SYSTEM AND HEART REGULATION

Heart function is regulated by the autonomic nervous system (ANS), which consists of the sympathetic and parasympathetic branches, both of which influence the heart's activity through the cardioregulatory centre located in the medulla oblongata (see Figure 1.24). This region of the brainstem receives signals from various sensory receptors and higher brain centres, including the limbic system and cerebral cortex.

SYMPATHETIC NERVOUS SYSTEM

When the sympathetic nervous system is activated, usually in response to stimuli such as exercise or stress, the sympathetic nerve fibres release norepinephrine (noradrenaline) at their cardiac endings. This neurotransmitter stimulates the SA node, increasing its rate of action potential generation, which in turn raises the HR. This is known as the 'fight or flight' response.

PARASYMPATHETIC NERVOUS SYSTEM

In contrast, the parasympathetic nervous system, primarily through the vagus nerve (cranial nerve X), releases acetylcholine at parasympathetic nerve endings. Acetylcholine slows the generation of action potentials in the SA node, thus decreasing HR. The parasympathetic system typically exerts a dominant influence over HR regulation under normal, restful

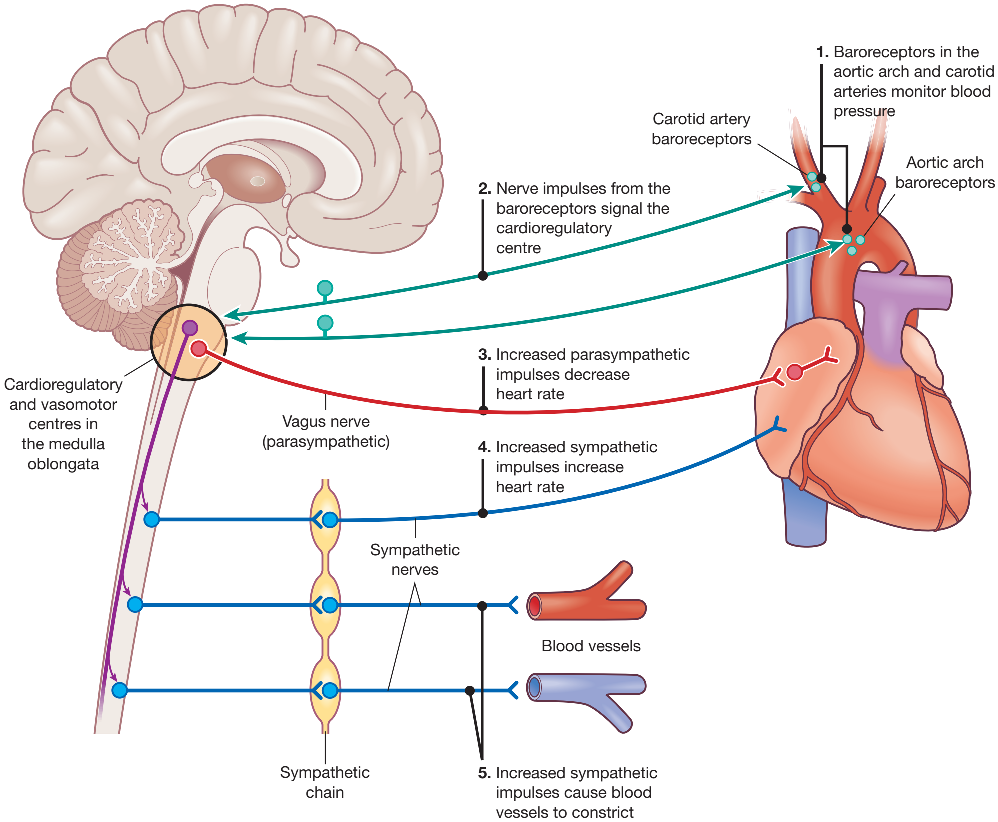

FIGURE 1.24 The cardioregulatory centre

conditions. In cases where the vagus nerve is severed, such as in heart transplant patients, the HR tends to increase to around 100 bpm, as the parasympathetic influence is removed.

CHEMICAL REGULATION OF THE HEART

Various chemical factors can also modulate HR and function:

1. Hormones:
   - Epinephrine and norepinephrine released from the adrenal glands increase both HR and contractility, particularly in response to stress, physical activity or excitement.
   - Thyroid hormones enhance HR and contractility in a similar manner to norepinephrine, affecting cardiac muscle fibres.
2. Ions: The concentration of cations (potassium, sodium, calcium) in the intracellular and extracellular fluid is critical for generating action potentials:
   - Elevated potassium or sodium levels can reduce HR and contractility, leading to potential cardiac dysfunction.

- Increased calcium enhances HR and the force of contraction, while excess sodium can inhibit calcium entry into cardiac cells, weakening contractions.
- Excess potassium impairs action potential generation, which may lead to arrhythmias.

BARORECEPTORS AND THE CARDIOVASCULAR CENTRE

Baroreceptors are specialised sensory cells located in the carotid sinus and aortic arch. These receptors are sensitive to the stretch of blood vessels and relay information to the cardiovascular centre in the medulla oblongata. The cardiovascular centre integrates these signals and adjusts HR and blood vessel tone accordingly (Knight et al. 2024). The cardiovascular centre consists of two main subcentres:

1. Cardioinhibitory centre: This centre controls parasympathetic outflow to the heart, particularly the SA node. Increased activity of the cardioinhibitory centre reduces HR by releasing acetylcholine, which lowers cardiac output and helps return the body to homeostasis after increased physical activity or stress.
2. Vasomotor centre: The vasomotor centre is responsible for regulating vascular tone and the force of ventricular contraction. It has two main components:
   - Pressor area: This area sends sympathetic impulses to the heart, increasing HR and contractility, which raises SV and affects blood pressure.
   - Depressor area: This area inhibits the pressor area, moderating HR and contractility by reducing sympathetic output.

Together, these areas regulate heart function by adjusting vascular resistance and HR to maintain effective circulation and blood pressure.

OTHER FACTORS AFFECTING HEART RATE REGULATION

1. Exercise: Physical activity raises HR to meet the increased demand for oxygen in tissues.
2. Gender: Typically, females have a slightly higher resting HR than males.
3. Age: Heart rate tends to decrease with age, partly due to changes in the ANS and heart tissue.
4. Body temperature:
   - Increased body temperature causes vasodilation, leading to a compensatory increase in HR to maintain blood pressure.
   - Decreased body temperature can lower HR, though extreme cold can eventually increase heart rate as the body attempts to warm up.
5. Body fluid level: Dehydration leads to reduced blood volume, resulting in vasoconstriction of coronary arteries and an increase in HR to maintain circulation with thicker blood.

The regulation of heart function is a complex interaction between the ANS, chemical signals and external factors such as body temperature and exercise. These systems work together to ensure the heart maintains an adequate supply of blood to the tissues based on the body's needs.

CONCLUSION

Understanding the anatomy and physiology of the cardiovascular system is fundamental to comprehending its vital role in maintaining homeostasis and supporting the body's functions. This system, comprising the heart, blood vessels and blood, is intricately designed to ensure the continuous delivery of oxygen and nutrients to tissues, as well as the removal of metabolic waste products.

The heart's structure and specialised conduction system enable it to function as an efficient pump, while the vascular network ensures the regulated distribution of blood to meet the diverse needs of the body's organs. The interaction between the systemic and pulmonary circulations highlights the cardiovascular system's critical integration with the respiratory system, showcasing its role in gas exchange and oxygenation.

Moreover, the regulatory mechanisms, including neural, hormonal and local controls, highlight the system's ability to adapt to dynamic changes in the internal and external environment. These mechanisms ensure that blood pressure and flow remain adequate during varying physiological demands, such as exercise, rest or stress.

A robust understanding of cardiovascular anatomy and physiology equips healthcare professionals with the knowledge necessary to assess and manage conditions affecting this system.

The cardiovascular system is an extraordinary network that personifies the complexity and efficiency of the human body. A thorough grasp of its anatomy and physiology not only enhances clinical expertise but also fosters an appreciation for the intricate balance required to sustain life. This introductory knowledge paves the way for further exploration into cardiovascular pathophysiology, diagnostics and therapeutic interventions.

GLOSSARY OF TERMS

Aorta: The largest artery in the body, responsible for carrying oxygenated blood from the heart to the rest of the body.

Arteries: Blood vessels that carry oxygenated blood away from the heart to tissues and organs.

Arterioles: Small branches of arteries that lead to capillaries, playing a key role in regulating blood flow and pressure.

Atrium (atria): The two upper chambers of the heart (right and left) that receive blood returning to the heart.

Blood pressure (BP): The force exerted by circulating blood on the walls of blood vessels, measured as systolic and diastolic pressures.

Capillaries: The smallest blood vessels where oxygen, nutrients and waste products are exchanged between blood and tissues.

Cardiac cycle: The sequence of events in one heartbeat, including diastole (relaxation) and systole (contraction).

Cardiac output (CO): The volume of blood the heart pumps per minute, calculated as heart rate (HR) × stroke volume (SV).

Coronary arteries: The arteries that supply oxygenated blood to the heart muscle (myocardium).

Diastole: The phase of the cardiac cycle when the heart muscle relaxes, allowing the chambers to fill with blood.

Electrocardiogram (ECG): A diagnostic tool that records the electrical activity of the heart to detect abnormalities in rhythm and function.

Endocardium: The innermost layer of the heart, lining the chambers and valves.

Heart rate (HR): The number of heartbeats per minute.

Hypertension: A condition characterised by persistently high blood pressure.

Inferior vena cava: A large vein that carries deoxygenated blood from the lower body to the right atrium of the heart.

Ischaemia: A condition where there is insufficient blood flow to tissues, often resulting in a lack of oxygen.

Myocardium: The thick, muscular middle layer of the heart wall responsible for contraction and pumping action.

Pericardium: A double-layered membrane surrounding the heart, providing protection and reducing friction.

Pulmonary circulation: The part of the circulatory system that carries deoxygenated blood from the right ventricle to the lungs and returns oxygenated blood to the left atrium.

Stroke volume (SV): The amount of blood ejected by the heart in one contraction.

Superior vena cava: A large vein that carries deoxygenated blood from the upper body to the right atrium of the heart.

Systemic circulation: The part of the circulatory system that carries oxygenated blood from the left ventricle to the body and returns deoxygenated blood to the right atrium.

Systole: The phase of the cardiac cycle when the heart muscle contracts, pumping blood out of the chambers.

Valves: Structures in the heart and veins that prevent the backflow of blood, ensuring unidirectional flow.

Veins: Blood vessels that carry deoxygenated blood towards the heart, except for the pulmonary veins, which carry oxygenated blood.

Ventricles: The two lower chambers of the heart (right and left) responsible for pumping blood out of the heart to the lungs and body.

Venules: Small blood vessels that collect blood from capillaries and join to form veins.

Viscosity: The thickness of blood, which affects its flow through the circulatory system.

MULTIPLE CHOICE QUESTIONS

1. Which chamber of the heart pumps oxygenated blood to the rest of the body?
   a) Right atrium
   b) Left atrium
   c) Right ventricle
   d) Left ventricle

2. What is the primary function of the heart valves?
   a) To pump blood
   b) To prevent the backflow of blood
   c) To carry oxygen to tissues
   d) To regulate heart rate

3. Which blood vessels have thick, elastic walls to handle high pressure?
   a) Veins
   b) Capillaries
   c) Arteries
   d) Venules

4. What is the pacemaker of the heart?
   a) Atrioventricular (AV) node
   b) Bundle of His
   c) Sinoatrial (SA) node
   d) Purkinje fibres

5. What separates the right and left sides of the heart?
   a) Myocardium
   b) Septum
   c) Pericardium
   d) Endocardium

6. Which type of circulation carries blood to and from the lungs?
   a) Systemic circulation
   b) Pulmonary circulation
   c) Coronary circulation
   d) Portal circulation

7. Which of the following is a characteristic of veins?
   a) Thick muscular walls
   b) Valves to prevent backflow
   c) High-pressure vessels
   d) Carry oxygenated blood only

8. Which layer of the heart is responsible for contraction?
   a) Endocardium
   b) Pericardium
   c) Myocardium
   d) Epicardium

9. What is the primary role of capillaries?
   a) Transport blood to the heart
   b) Exchange nutrients and gases between blood and tissues
   c) Maintain blood pressure
   d) Store blood

10. What happens during ventricular systole?
   a) Blood is ejected into the arteries
   b) The ventricles fill with blood
   c) The atria contract
   d) The heart relaxes

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