
The Cardiovascular System: An Essential Guide

1. Introduction

The cardiovascular system is a vital network composed of the **heart** and **blood vessels**. Its primary role is to **supply oxygenated blood to the tissues** throughout the body. Beyond oxygen, it efficiently transports respiratory gases, essential nutrients, and excretory products. Blood acts as the crucial medium through which all these substances are conveyed.

At the core of this system is the **heart**, a powerful muscular pump responsible for circulating blood around the entire body. The blood vessels form a closed system, including:

- **Arteries**: These vessels **carry blood away from the heart**.
- **Veins**: These vessels **bring blood back to the heart**.
- **Capillaries**: These are tiny vessels that branch off from arteries, acting as the sites where blood is delivered to all body tissues.

2. Brief Introduction About the Heart

The heart is a remarkable organ, described as a **conical, hollow, musculotendinous structure**. It is situated within the **thorax**, specifically between the lungs and behind the sternum (breastbone), lying towards the front of your chest. Its base is positioned above, while the apex points below. On average, the heart measures about **10 cm long** and weighs approximately **300 grams**. It sits slightly behind and to the left of your sternum.

a. Structure of the Heart

The heart is encased by an outer covering known as the **Pericardium**. This pericardium consists of two layers: the **visceral pericardium** and the **parietal pericardium**. A lubricating **pericardial fluid** is present between these two layers, allowing for smooth movement.

Beneath the pericardium, the heart's middle layer is made of strong heart muscle fibres, called the **Myocardium**. The innermost lining of the heart is known as the **Endocardium**.

b. Chambers of the Heart

The human heart is divided into **four distinct chambers** that work in a coordinated fashion:

- On the right side: the **Right atrium** and the **Right ventricle**.

- On the left side: the **Left atrium** and the **Left ventricle**.

c. Valves of the Heart

To ensure unidirectional blood flow, the heart is equipped with specialised valves:

- The opening between the right atrium and the right ventricle is guarded by the **Tricuspid valve**.
- The opening between the left atrium and the left ventricle is guarded by the **Mitral valve** (also known as the Bicuspid valve).

Blood Vessels Attached to the Heart

Several major blood vessels are directly connected to the heart chambers:

1. The **right atrium** receives venous blood from the body via the **Superior vena cava** and the **Inferior vena cava**.
2. From the **right ventricle** arises the **Pulmonary artery**, which carries venous (deoxygenated) blood to the lungs for oxygenation.
3. The **left atrium** receives four **Pulmonary veins**, carrying oxygenated blood back from the lungs to the heart.
4. From the **left ventricle** arises the **Aorta**, which then carries oxygenated blood to all other parts of the body.

Blood Supply to the Heart

Even the heart, a powerful pump, requires its own dedicated blood supply to function. This is provided by the **right and left coronary arteries**, which originate directly from the aorta. After supplying the heart muscle, the venous blood is collected by the **Coronary sinus**, which drains directly into the right atrium.

Nerve Supply

The heart's rhythm and rate are influenced by the nervous system. It receives nerve supply from both the **sympathetic and vagus nerves**. Branches from these nerves extend to the **sinoauricular node**, which is critical for initiating the heart's electrical impulses.

3. Blood Circulation

The arterial and venous systems orchestrate the continuous flow of blood throughout the body. The heart pumps blood into **arteries**, which then divide and subdivide, eventually ending in microscopic **capillaries**. These capillaries then unite to form **veins**, which return blood to the heart.

Generally, arteries carry **pure (oxygenated) blood** away from the heart, while veins carry **impure (deoxygenated) blood** back to the heart. However, there are exceptions, such as the pulmonary and umbilical veins, which carry oxygenated blood to the heart. Histologically, arteries, arterioles, and veins are composed of three layers:

1. **Tunica adventitia**: The outer fibrous layer.
2. **Tunica media**: The middle muscle layer.
3. **Tunica intima**: The inner serous layer.

Arteries

The **Aorta** is the main artery in the body, originating from the **left ventricle**. Its opening is guarded by a **semilunar valve**. The aorta is broadly divided into three parts:

1. **Ascending aorta**: This part gives off two crucial branches: the **right coronary artery** and the **left coronary artery**, which supply blood to the heart muscle itself.
2. **Arch of aorta**.
3. **Descending aorta**: This continues into the abdominal region, where it gives rise to several significant branches, including:
    - Branches of the **Abdominal aorta**: the Coeliac plexus (dividing into hepatic, gastric, and splenic arteries), superior and inferior mesenteric arteries (supplying the intestine), and renal arteries (supplying the kidney).
    - Its final branches are the **right and left common iliac arteries**, which further divide into internal and external iliac arteries.

Veins

Veins are blood vessels that carry blood towards the heart. Most veins transport deoxygenated blood from the body tissues back to the heart, with the notable exceptions of the pulmonary and umbilical veins, which carry oxygenated blood.

Major veins in the body include:

- **Veins of the upper limb**: Such as the Radial vein and Ulnar vein.
- **Veins of the lower limb**: The anterior and posterior tibial veins unite to form the Popliteal vein.
- **Veins of head and neck**: Venous blood from the head and neck is drained through the Internal jugular vein and External jugular vein.

Specialised **Venous sinuses** are found between the two layers of the Duramater in the brain. They receive blood from the brain and the interior of the skull, draining into the Internal jugular vein. Examples include the Superior sagittal sinus, Inferior sagittal sinus, Straight sinus, Transverse sinuses, and Cavernous sinuses.

Capillaries

Capillaries are tiny, microscopic blood vessels that are crucial for the transport of blood, nutrients, and oxygen to the cells within your organs and body systems. They are the smallest blood vessels in the vascular system.

Blood Circulation Types

Depending on the course of blood flow, circulation can be classified into several types:

1. **Systemic circulation**: This involves the blood supply to all parts of the body **except the lungs**. It begins from the **aorta**, breaks down into smaller arteries, and eventually ends in capillaries. These capillaries then unite to form venules, which join to form two large venous trunks: the **superior vena cava** and the **inferior vena cava**. These two trunks open into the **right atrium** of the heart, completing the circuit.
2. **Pulmonary circulation**: This is responsible for the **purification (oxygenation) of blood in the lungs**. Impure (deoxygenated) venous blood is pumped by the **right ventricle** into the pulmonary artery, which carries it to the lungs. Once oxygenated, four **pulmonary veins** carry this purified blood from the lungs back to the heart, opening into the **left atrium**.
3. **Coronary circulation**: This circulation provides the **blood supply to the heart itself**. The right and left coronary arteries, which arise from the ascending aorta, supply blood to the heart muscle. The venous blood from the heart is collected by the **coronary sinus**, which then opens into the right atrium.
4. **Portal circulation**: This involves the circulation of blood through the **liver**. In this pathway, the **Portal vein** carries blood to the liver. This portal vein then divides into capillaries, which join with the capillaries of the hepatic artery. The venous blood from the liver is subsequently collected by the **hepatic vein**, which ultimately joins with the inferior vena cava.
5. **Cerebral circulation**: (This type of circulation specifically involves the brain, though further details are not provided here).

4. Conduction System of Heart Rate and Heart Beat

The cardiac muscle has several unique properties that allow the heart to function effectively:

1. **Contractility**: Through contraction, the cardiac muscle pumps blood out of its four chambers.
2. **Conductivity**: The electrical impulses required for cardiac contraction are conveyed throughout the heart via a specialised **conduction system**.
3. **Rhythmicity**: The heart muscle possesses the inherent property of **rhythmic contraction**, allowing it to beat continuously.
4. **Refractory period**: During the **systole** (contraction phase), the heart muscle enters a refractory period, meaning it will not respond to any further stimuli, regardless of their strength.

5. Cardiac Output

Cardiac output (CO) is defined as the **volume of blood ejected from the left ventricle into the aorta each minute**. It is a crucial measure of heart efficiency and is calculated using the following formula:

Cardiac Output = Stroke Volume (SV) x Heart Rate (HR)

- **Stroke volume** is the volume of blood ejected by the ventricle during a single contraction.
- **Heart rate** is the number of heart beats per minute.

For a typical resting adult male, the stroke volume averages **70 ml per beat**, and the heart rate is approximately **75 beats per minute**. Therefore, the average cardiac output can be calculated as:

CO = 70 ml/beat x 75 beats/min = 5250 ml/min = **5.25 litres/min**

This calculated volume is remarkably close to the total blood volume in an adult male, which is typically about **5 litres**.

6. Cardiac Cycle

The **cardiac cycle** encompasses all the events occurring in the heart from the beginning of one heart beat to the beginning of the next. Within this cycle, the term **systole** refers to the phase of **contraction**, while **diastole** refers to the phase of **relaxation**.

A cardiac cycle is typically divided into four main phases:

1. Phase of Ventricular Filling

During the ventricular relaxation phase, a significant amount of blood collects in the atria. Initially, the AV valves are closed. As pressure increases in the atria, the AV valves open, allowing blood to flow into the ventricles, while the semilunar valves remain closed. The initial one-third of this phase is characterised by rapid ventricular filling.

2. Phase of Ventricular Contraction

The QRS complex observed on an electrocardiogram (ECG) signifies the depolarisation of the ventricles, a process that begins at the apex of the ventricles as the action potential is carried from the AV node. The pressure inside the ventricles rises suddenly due to ventricular filling. This rapid rise in pressure forces blood back towards the atria, causing the **AV valves to close** tightly. At this specific point, both the AV valves and the semilunar valves are closed, and the volume inside the ventricles does not change. This brief period is known as **isovolumetric contraction**.

3. Period of Ventricular Ejection

As the ventricles continue to contract, the pressure inside them rises sharply. When this pressure surpasses the aortic pressure and pulmonary trunk pressure, the **semilunar valves open**. Blood is then forcefully ejected out of the ventricles into the aorta and pulmonary artery. This phase is referred to as **ventricular ejection**.

4. Phase of Ventricular Relaxation

Following ejection, the ventricles begin to relax, and the pressure inside them drops suddenly. This abrupt drop in pressure causes a temporary backflow of blood from the pulmonary trunk and aorta. This forceful backflow of blood immediately **closes the semilunar valves**. This pressure change also produces a small bump known as a **dicrotic wave**. During this period, the ventricular volume does not change, leading to it being called **isovolumetric relaxation**.

7. Regulation of the Autonomic Nervous System

The autonomic nervous system (ANS) is an integral component of the peripheral nervous system. It plays a crucial role in regulating many **involuntary physiologic processes**, including heart rate, blood pressure, respiration, digestion, and sexual arousal. The ANS comprises two anatomically distinct divisions that exert opposing effects:

Sympathetic Nervous System

Stimulation by the sympathetic nervous system leads to an elevation in intracellular calcium (Ca^{2+}) levels, which in turn increases the force of contraction in both the atria and ventricles. It also produces a **positive dromotropic effect**, enhancing the conductivity of the heart's electrical signals. Factors such as stress, caffeine, and excitement can temporarily **accelerate your heart rate** through sympathetic activation.

Parasympathetic Nervous System (PNS)

The parasympathetic nervous system releases the hormone **acetylcholine**, which primarily works to **slow the heart rate**. Activities like meditating or taking slow, deep breaths can help to slow down the heart rate by activating the parasympathetic system.

8. Blood Pressure

Blood pressure (BP) is defined as the lateral pressure exerted by blood on the walls of the blood vessels. It is most commonly expressed as **arterial blood pressure** and has two main phases:

1. **Systolic blood pressure**: This represents the **maximum blood pressure**. It occurs during the **systole** (contraction phase) of the heart, typically ranging from **100-120 mm Hg**.
2. **Diastolic blood pressure**: This represents the **minimum blood pressure**. It occurs during the **diastole** (relaxation phase) of the heart, typically ranging from **60-80 mm Hg**.

Blood Pressure Categories

- **Normal**: Systolic less than 120 mm Hg and Diastolic less than 80 mm Hg.
- **Elevated**: Systolic 120-129 mm Hg and Diastolic less than 80 mm Hg.
- **High Blood Pressure (Hypertension phase 1)**: Systolic 130-139 mm Hg or Diastolic 80-89 mm Hg.
- **High Blood Pressure (Hypertension phase 2)**: Systolic 140 mm Hg or Higher or Diastolic 90 mm Hg or Higher.
- **Hypertensive crisis**: Systolic Higher than 140 mm Hg and/or Diastolic Higher than 120 mm Hg. In such cases, immediate medical consultation is necessary.

Factors Affecting Blood Pressure

Several factors can influence blood pressure:

1. **Blood volume**: The total amount of circulating blood in the body directly affects pressure.
2. **Peripheral resistance**: This refers to the resistance encountered by blood flow within the blood vessels, particularly in the arterioles.

3. **Elasticity**: The elasticity of the arterial walls plays a significant role. The aorta distends when the ventricle contracts and then elastically recoils when the ventricle relaxes, pushing blood onward.
4. **Diameter of the lumen of blood vessels**: The width of the blood vessel lumen can be altered. A narrowing of the lumen increases the resistance to blood flow, thereby increasing blood pressure.
5. **Viscosity**: The stickiness and dense nature of the blood also contribute to its resistance to flow.

Regulation of Blood Pressure

Blood pressure is tightly regulated by various mechanisms:

- **Baroreceptor reflex**: This is a neurally-mediated reflex that provides short-term regulation of blood pressure. It is crucial for maintaining blood pressure throughout the day, as even a slight change in posture can lead to significant pressure changes in its absence.
- **Renin-angiotensin-aldosterone pathway**: This pathway is initiated by stimuli such as dehydration, sodium deficiency, or hemorrhage. A decrease in blood volume triggers this system, leading to a decrease in blood pressure.
- **Epinephrine and Nor-epinephrine**: In response to sympathetic stimulation, the adrenal medulla releases these hormones. They increase cardiac output by elevating heart rate and force of contraction, thus raising blood pressure.
- **Antidiuretic hormone (ADH) / Vasopressin**: Produced by the hypothalamus and released from the posterior pituitary, ADH is released in response to dehydration or a decrease in blood volume. It causes **vasoconstriction**, which increases blood pressure.
- **Atrial natriuretic peptide (ANP)**: This hormone is released by cells in the atria of the heart. ANP lowers blood pressure by causing **vasodilation** and by promoting the loss of salt and water in the urine, which ultimately **reduces blood volume**.

Pulse

The **pulse** is a strong, regular beating or throbbing sensation, which is the rhythmic pulse of the blood as it flows through the body. It is the beat resulting from the regular widening of an artery, detectable at various points such as the wrist.

9. Electrocardiogram (ECG)

An **electrocardiogram (ECG)** is a recording of the electrical changes that accompany each cardiac cycle. The conduction of action potentials through the heart generates electrical currents that can be detected at the surface of the body. The instrument used to record these changes is called an **electrocardiograph**.

An ECG typically consists of three main waves:

- **P wave**: This represents **atrial depolarisation**, which spreads from the SA node throughout both atria.
- **QRS wave (complex)**: This represents **ventricular depolarisation**.

- **T wave**: This represents **ventricular repolarisation**.

Specific intervals on the ECG are also important:

- **PQ or PR Interval**: This is the interval between the beginning of contraction of the atria and the beginning of contraction of the ventricles.
- **QT Interval**: During an ECG reading, the size and timing of all these waves and intervals are carefully noted.

Altered ECG notes can indicate various cardiac conditions:

- A **larger P wave** indicates **enlargement of the atrium**.
- An **enlarged Q wave** indicates **myocardial infarction**.
- An **enlarged R wave** indicates **enlargement of the ventricles**.
- A **flatter T wave** indicates **insufficient oxygen supply to the myocardium**.
- A **larger PQ interval** indicates the formation of **scar tissue in the heart** due to coronary artery disease or rheumatic fever.
- A **larger ST segment** (especially if elevated above the baseline) indicates **acute myocardial infarction** and insufficient oxygen supply to the heart muscle (when depressed below the baseline).

10. Disorders of the Cardiovascular System

The cardiovascular system can be affected by various disorders:

Myocardial Infarction

Myocardial infarction, commonly known as a heart attack, is the **death of an area of cardiac tissue** due to a lack of coronary blood supply to that specific segment of the myocardium. This critical lack of blood supply typically occurs due to the **occlusion of a coronary artery**, often caused by a blood clot (**thrombus**) or the deposition of fat.

Cardiac Arrhythmia

Cardiac arrhythmia is a disorder characterised by an abnormal **cardiac rate and rhythm**. It arises from either **defective impulse formation** or **defective impulse conduction** within the heart, leading to irregular heartbeats.
