

وزارة التعليم العالي و البحث العلمي  
لجمهورية الجزائرية الديمقراطية الشعبية

جامعة سوق أهراس



**Course handout**

# **Animal physiology**

**Chapter from *Animal Physiology* on Cardiovascular Systems,**

**Designed for second-year Veterinary Sciences students.**

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**2025-2026**

## **About Animal physiology**

**Total Volume: 45 Hours (VHT = 45H)**

### **1. Teaching Methods:**

The course is delivered through the following methods:

- Lectures (CM): 30 hours (including 9 hours dedicated to the student's personal work).
- Cardiovascular chapter: 09 hours
- Tutorials (TD): 15 hours.

### **2. Prerequisites:**

Basic knowledge in biology.

### **3. Course Objectives:**

The general objective of the course is to understand the function of organs and systems in the animal body, with a particular focus on species of veterinary interest.

The specific objectives are:

1. To learn the scientific laws and methods of physiology.
2. To understand the concepts and characteristics of the functioning of different systems in the animal body.
3. To acquire basic knowledge of the processes and mechanisms that regulate vital functions.
4. To understand the usefulness of this subject and its relation to other subjects within the degree program.
5. To learn how to use bibliographic resources available in this discipline.

#### 4. Assessment Methods:

- Continuous Assessment (CA): The continuous assessment grade will be based on tutorial (TD) performance, quizzes, attendance, participation, and any other criteria deemed appropriate by the instructor in agreement with the administration.
- Final Exam (EMD): A medium-length exam will be scheduled at the end of the course.
- Make-up Exam (ER): A resit exam will be organized for students who need it.

Weighting of the final grade is as follows:

- Final Exam (EMD): 70%
- Continuous Assessment (CA): 30%

Note: All grades must be officially recorded and signed by the course instructor.

Final grade calculation for the regular session:

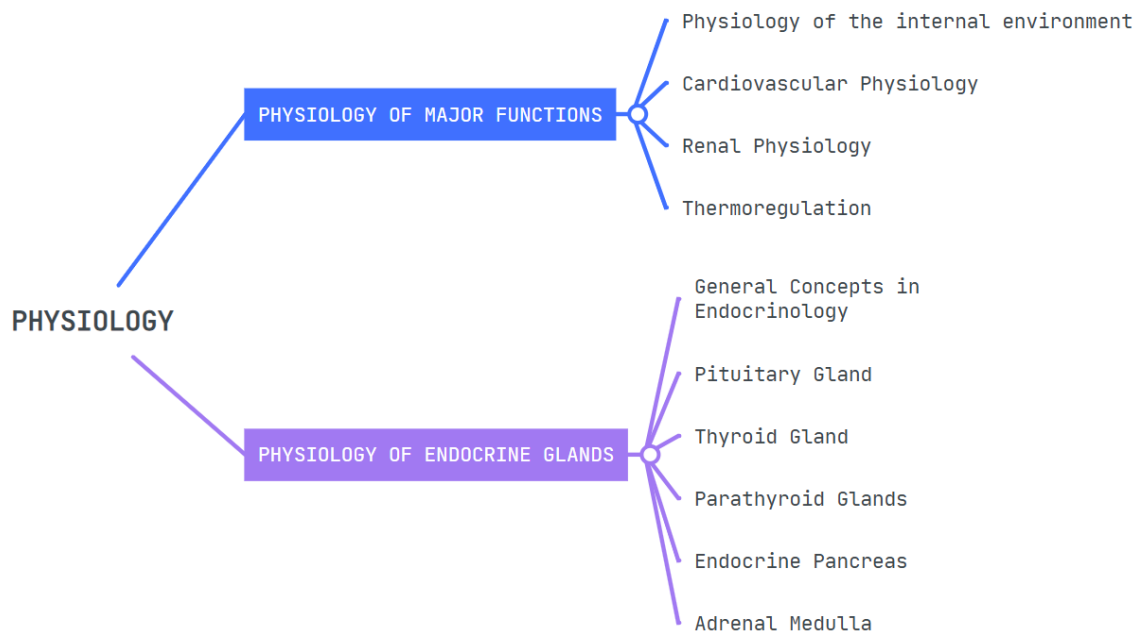
$$\text{Final Grade} = [(EMD \times 0.7) + (CA \times 0.3)] \times 3 \text{ (coefficient)}$$

$$\text{Final Grade} = [(EMD \times 0.7) + (CA \times 0.3)] \times 3 \text{ (coefficient)}$$

Final grade calculation for the make-up session (ER):

$$\text{Final Grade} = [(ER \times 0.7) + (CA \times 0.3)] \times 3 \text{ (coefficient)}$$

## Matter mental card (Cours)



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## I. General Introduction

Animal cardiovascular physiology is the study of the structure, function, and regulation of the heart and blood vessels across diverse animal species. This field explores how the cardiovascular system transports oxygen, nutrients, hormones, and waste products to sustain life and maintain homeostasis.

The cardiovascular system includes the heart, arteries, veins, and capillaries working together to circulate blood. The heart acts as a pump that generates pressure to move blood through vessels. Blood vessels vary in structure and function—arteries carry oxygen-rich blood away from the heart under high pressure, veins return deoxygenated blood under lower pressure, and capillaries enable exchange of gases and nutrients at the tissue level.

Comparative physiology highlights differences in cardiovascular anatomy and function among animals. For example, fish have a two-chambered heart and a single circulatory loop, amphibians have a three-chambered heart allowing partial mixing of blood, and mammals and birds have fully separated four-chambered hearts permitting efficient oxygenation. These variations reflect evolutionary adaptations to environmental challenges and metabolic needs.

Regulation of cardiovascular function occurs via neural, chemical, and local mechanisms that control heart rate, blood pressure, and blood flow distribution. Understanding these principles provides insight into animal health, disease states, and physiological adaptations underlying diverse lifestyles.

This course will cover fundamental concepts of cardiovascular anatomy, cardiac mechanics, hemodynamics, electrical conduction, and regulatory mechanisms across species. It integrates knowledge from anatomy, physiology, and veterinary medicine, equipping students with a comprehensive understanding of animal cardiovascular systems and their vital role in organismal function.

## Quiz

1. What is the main role of the cardiovascular system in animals?

- A. To produce hormones
- B. To transport nutrients, gases, and waste products
- C. To ensure food digestion
- D. To control muscle movements

**Correct answer: B**

2. What is the central organ of the cardiovascular system?

- A. Liver
- B. Lung
- C. Heart
- D. Stomach

**Correct answer: C**

3. How many chambers does the heart have in mammals?

- A. 2
- B. 3
- C. 4
- D. 5

Correct answer: C (4 chambers: 2 atria and 2 ventricles)

4. What is the main difference between an artery and a vein?

A. Arteries always carry oxygen-rich blood, veins do not

B. Arteries have thinner walls than veins

C. Veins carry blood from the heart to the organs

D. Arteries carry blood from the heart to the organs

**Correct answer: D**

**(Note: A is generally true but not always — e.g., pulmonary artery)**

5. Which of the following animals has a three-chambered heart?

A. Dog

B. Cow

C. Frog

D. Pigeon

**Correct answer: C (amphibian)**

6. What type of blood circulation is found in mammals?

A. Single and incomplete

- B. Double and complete
- C. Single and complete
- D. Double and incomplete

**Correct answer: B**

7. What is the primary function of capillaries?

- A. To make blood flow rapidly
- B. To deliver oxygen and nutrients to cells
- C. To store blood
- D. To transport hormones only

**Correct answer: B**

## II. Cardiovascular Physiology

### Note

Cardiovascular physiology is the study of the cardiovascular system, which includes the heart, blood vessels, and blood. It focuses on how these components work together to transport nutrients and oxygen-rich blood to all parts of the body and to carry deoxygenated blood back to the lungs for oxygenation<sup>34</sup>. This field encompasses various aspects, including:

1. Cardiac physiology (the study of heart function),
2. Circulatory physiology (the study of blood flow and blood vessels),
3. Interactions between these components to maintain efficient blood circulation throughout the body.

### II.1. Cardiac physiology (Heart)

- Heart morphology

The morphology of the heart involves its shape, structure, and organization. Here's an overview:

#### II.1.1. External Structure

- **Shape:** The heart resembles an upside-down, **tipped-over pyramid** with **four sides**, a **base** that is mostly posterior, and an **apex** that points anteriorly and slightly to the left.
- **Surfaces:** The heart has five surfaces:
  - **Base** (posterior): Primarily formed by the **left atrium**, with the **right atrium** contributing about one-third.
  - **Diaphragmatic** (inferior): Faces the diaphragm.
  - **Sternocostal** (anterior): Faces the sternum and ribs.
  - **Left and right pulmonary surfaces:** Face the lungs.
- **Margins:**
  - **Right margin:** Formed by the right atrium between the superior and inferior vena cava.

- **Left margin:** Formed by the left ventricle and left auricle.
- **Superior margin:** Formed by both atria and their auricles.
- **Inferior margin:** Marked by the right ventricle.

### II.1.2. Internal Structure

- **Chambers:** The heart is divided into four chambers:
  - **Right Atrium:** Receives deoxygenated blood from systemic veins.
  - **Right Ventricle:** Pumps blood to the lungs.
  - **Left Atrium:** Receives oxygenated blood from the lungs.
  - **Left Ventricle:** Pumps blood to the systemic vessels.
- **Septa:** The heart is divided by three septa:
  - **Interatrial septum:** Separates the right and left atria.
  - **Interventricular septum:** Separates the right and left ventricles.
  - **Atrioventricular septa:** Separate the atria from the ventricles.
- **Valves:** Four valves regulate blood flow:
  - **Tricuspid valve:** Between the right atrium and ventricle.
  - **Pulmonary valve:** Between the right ventricle and pulmonary arteries.
  - **Mitral valve:** Between the left atrium and ventricle.
  - **Aortic valve:** Between the left ventricle and aorta.
- **Layers of the Heart Wall**
  - **Epicardium:** The outermost layer.
  - **Myocardium:** The middle layer, composed of cardiac muscle.
  - **Endocardium:** The innermost layer, lining the heart chambers

The following figure shows the different parts of heart morphology

**Note:** The morphology of the heart varies significantly across different animal species, reflecting adaptations to their specific lifestyles and environments.

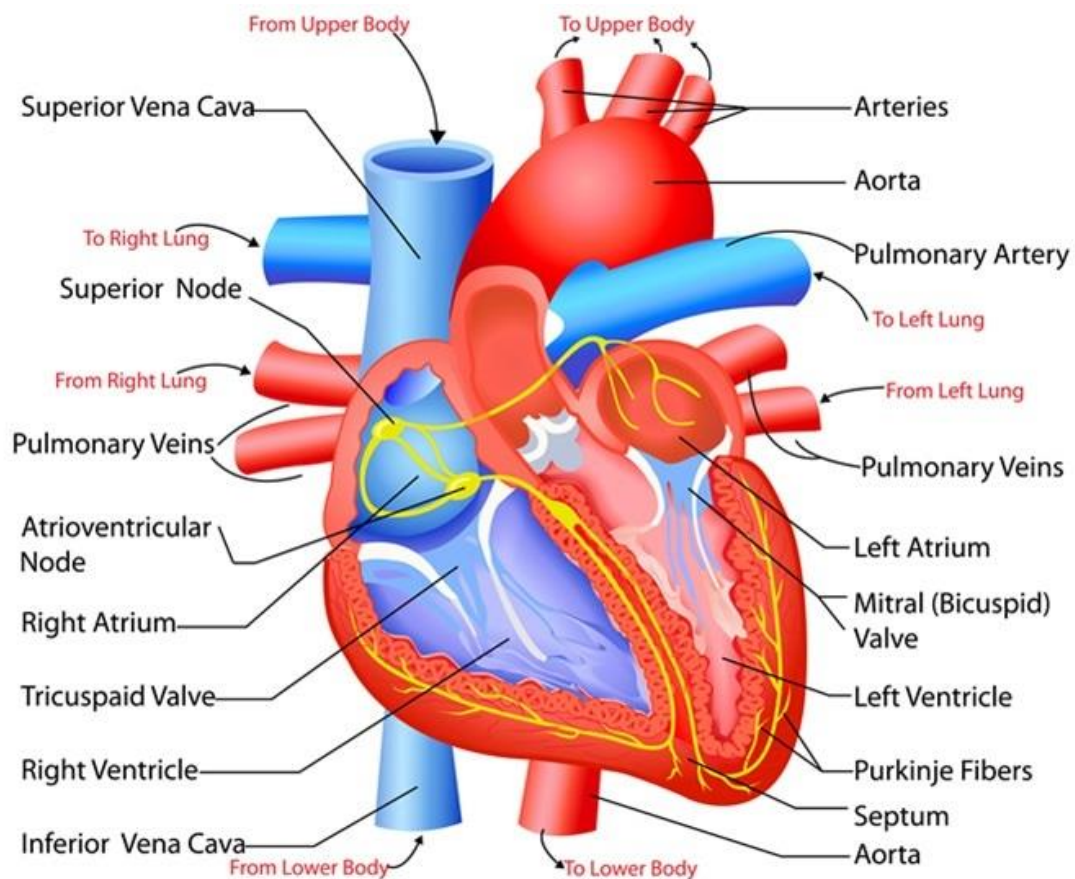
- **Shape and Orientation**

**Quadruped Mammals** (e.g., dogs, pigs, sheep): Hearts are often more elongated and may have a pointed apex. The long axis of the heart is more ventrally tilted compared to humans.

**Dogs:** The heart is ovoid with a blunt apex.

**Pigs:** The heart has a valentine shape with a somewhat blunt apex.

**Sheep:** The heart is more conical with a pronounced apex.



**Figure 1: Heart morphology**

#### - Chamber and Valve Structure

General: All mammals have four-chambered hearts with similar valve structures, but there are differences in valve leaflet numbers and papillary muscle arrangements.

Pigs vs. Humans: The tricuspid valve in pigs typically has three leaflets, similar to humans, but the trabecula septomarginalis (moderator band) is more prominent in pigs.

**Dogs:** Often have a two-leaflet tricuspid valve.

**Fish:** it is typically a two-chambered structure consisting of an atrium and a ventricle. Unlike mammals, which have four-chambered hearts, fish only have a single circuit of blood flow.

- **Pericardium**

**Humans:** The pericardium is thicker (1-3.5 mm) compared to other mammals.

**Other Mammals:** Generally have thinner pericardia (e.g., sheep: 0.32 mm, pigs: 0.20 mm, dogs: 0.19 mm).

- **Atrial Appendages**

**Dogs:** Tubular right and left atrial appendages.

**Pigs and Sheep:** More triangular atrial appendages.

The heart morphology difference between animal species is shown in the following figure

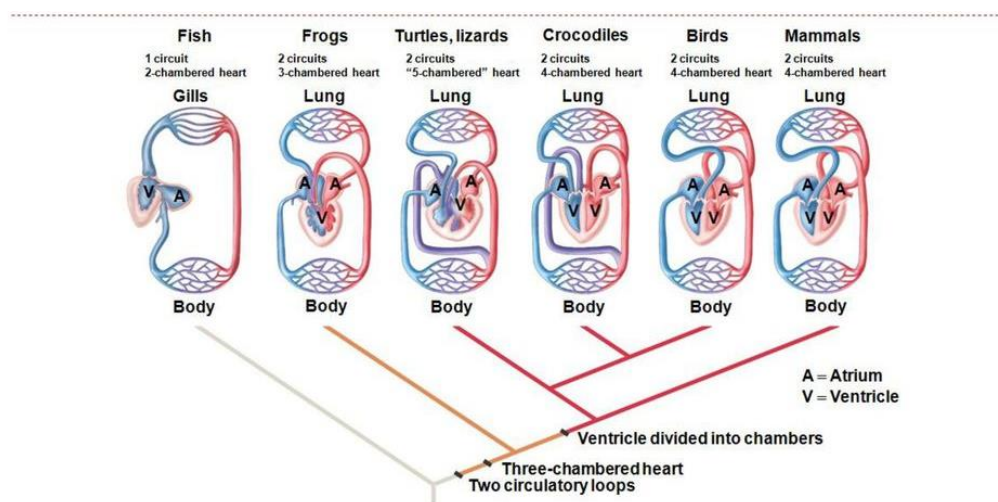


Figure 2 : comparative anatomy of vertebrate hearts

## II.2. Cardiac activity

It refers to the electrical and mechanical functions of the heart that enable it to pump blood throughout the body.

### II.2.1. Mechanical functions

It involves the physical contraction and relaxation of the heart muscle. During **systole**, the ventricles contract to pump blood into the aorta and pulmonary arteries. During **diastole**, the heart relaxes and refills with blood

- **Systole**

**Atrial Systole:** The atria contract, pushing blood into the ventricles. This is the final phase of the cardiac cycle.

**Ventricular Systole:** The ventricles contract, pumping blood into the pulmonary artery (right ventricle) and the aorta (left ventricle).

- **Diastole**

The **heart muscle relaxes**, allowing the chambers to fill with blood.

During ventricular diastole, the **ventricles fill with blood from the atria**, and the **atria also fill with blood from the veins**.

This phase is crucial for ensuring adequate blood volume for the next contraction.

### II.2.2. Heart Sounds

**S1 ("Lub"):** Occurs when the atrioventricular (AV) valves (mitral and tricuspid) close at the start of ventricular systole.

**S2 ("Dub"):** Occurs when the semilunar valves (aortic and pulmonary) close at the end of ventricular systole.

- **Stroke Volume & Cardiac Output:**

**Stroke Volume:** The amount of blood pumped by each ventricle per heartbeat.

**Cardiac Output:** The total volume of blood pumped by the heart per minute, calculated as stroke volume multiplied by heart rate.

- **Pressure Changes:** During systole, pressure in the ventricles rises to overcome the pressure in the arteries to open the semilunar valves.

During diastole, pressure in the ventricles decreases, allowing the AV valves to open and the chambers to refill.

The mechanical activity of the heart is essential for delivering oxygenated blood to tissues and removing waste products, enabling proper organ function and overall body homeostasis.

### II.2.3. Electrical Activity

The electrical activity ensures the heart beats in a coordinated and rhythmic manner.

#### II.2.3.1. The Conduction System of the Heart:

The heart has a specialized network of cells that generate and transmit electrical impulses. The key components are:

**Sinoatrial (SA) Node:** The **natural pacemaker** of the heart located in the right atrium. It **generates electrical impulses** that set the **rhythm** of the heart).

**Atrioventricular (AV) Node:** Located at the junction of the atria and ventricles, it briefly **delays the electrical signal**, allowing the atria to contract and fill the ventricles before they contract.

**Bundle of His:** Transmits the electrical impulse from the AV node to the ventricles.

**Right and Left Bundle Branches:** These branches carry the electrical impulses to the right and left ventricles.

**Purkinje Fibers:** Spread throughout the ventricles, ensuring a **coordinated contraction** of the ventricles.

The following figure shows the **The Conduction System of the Heart**

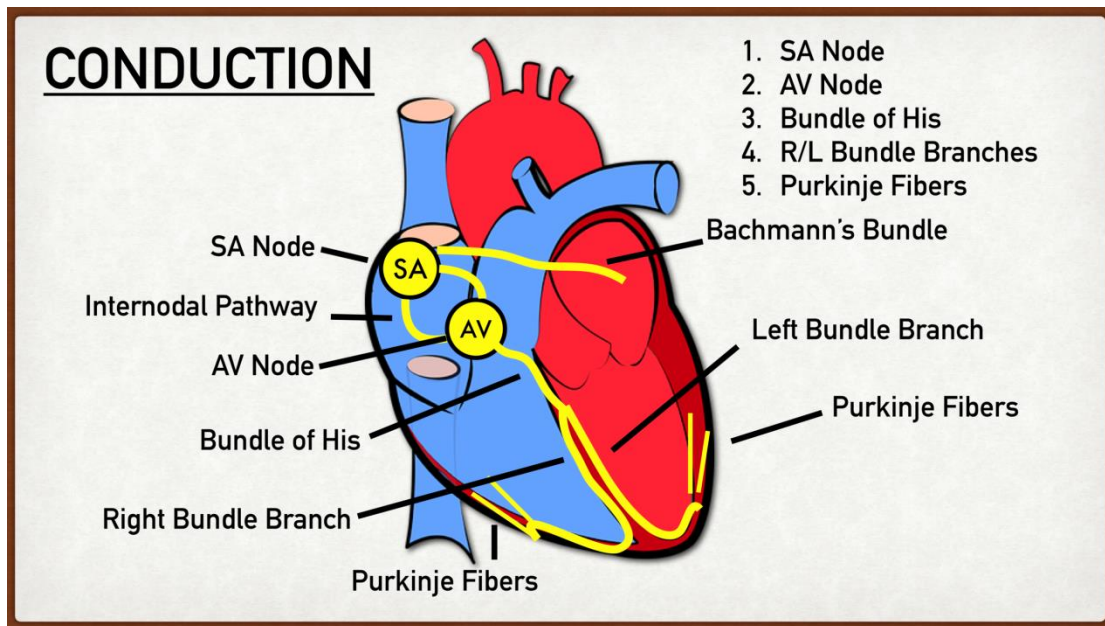


Figure 3: The Conduction System of the Heart

### II.2.3.2. Phases of the Cardiac Action Potential

It is a series of electrical changes that occur in the heart muscle cells, enabling them to contract and pump blood. It consists of five main phases, each characterized by specific ion movements and changes in membrane potential.

#### Phase 0: Depolarization

The electrical impulse causes a rapid influx of sodium ions, leading to a sharp rise in the membrane potential, which triggers the contraction of the heart muscle.

#### Phase 1: Initial Repolarization

Potassium ions move out, and sodium channels close, leading to a brief drop in membrane potential.

#### Phase 2: Plateau

Calcium ions enter the cell, balancing the potassium efflux, which prolongs the action potential and allows for sustained contraction.

#### Phase 3: Repolarization

Potassium ions flow out of the cell, and the membrane potential returns to its resting state.

#### Phase 4: Resting Membrane Potential

The heart cell returns to its resting state, preparing for the next action potential.

The phases of the cardiac Action Potential are summarized in figure 4.

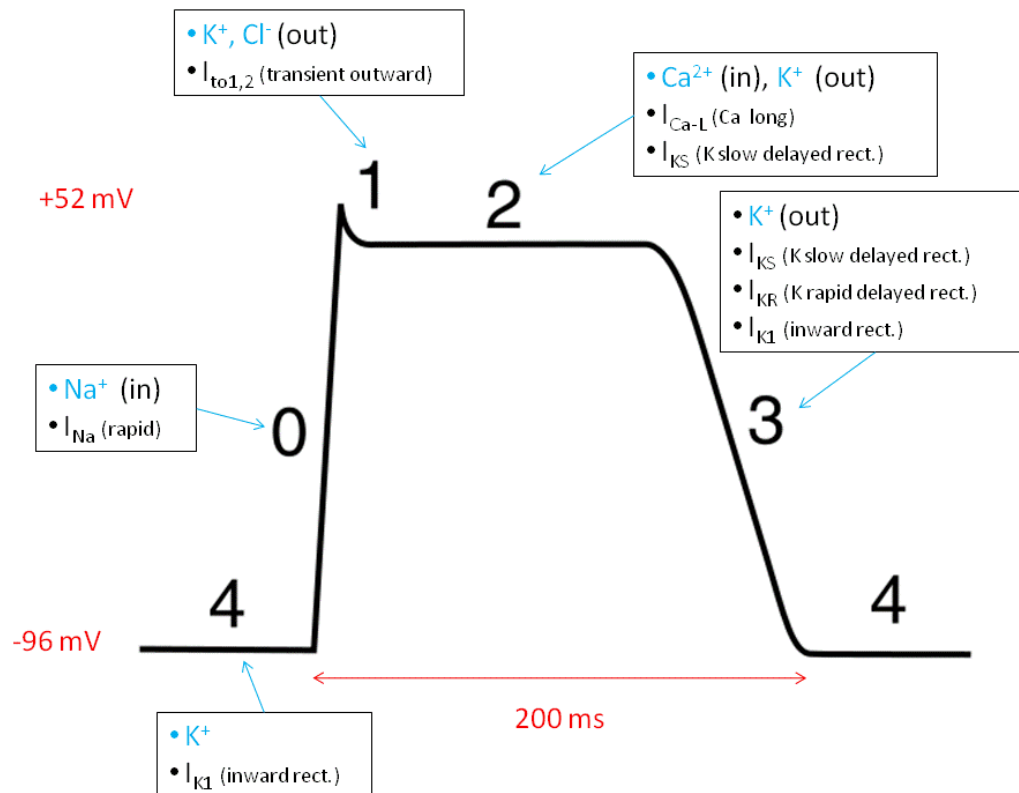


Figure 4 : phases of the cardiac action potential

#### II.2.3.3. Cardiac cycle

The cardiac cycle is the sequence of events that occurs in the heart from the start of one heartbeat to the beginning of the next. It involves the coordinated contraction and relaxation of the heart's chambers to pump blood efficiently throughout the body.

##### - Phases of the Cardiac Cycle:

##### Diastole:

- **Atrial Diastole:** The atria relax and fill with blood.

- **Ventricular Diastole:** The ventricles relax and fill with blood. This phase includes:
  - **Isovolumic Relaxation:** The ventricles relax without a change in volume.
  - Inflow (Rapid Filling): Blood flows into the ventricles.
  - **Diastasis:** A period of slow filling.
- **Atrial Systole:** The atria contract to push more blood into the ventricles.

### Systole:

- **Isovolumic Contraction:** The ventricles contract without ejecting blood, increasing pressure.
- **Ventricular Ejection:** The ventricles contract and pump blood out into the aorta and pulmonary artery.

### Key Events:

Heart Sounds: The closing of the atrioventricular valves during ventricular contraction produces the first heart sound ("lub"), and the closing of the semilunar valves during ventricular relaxation produces the second heart sound ("dub").

Duration: A complete cardiac cycle lasts about 0.8 seconds at a heart rate of 70-75 beats per minute.

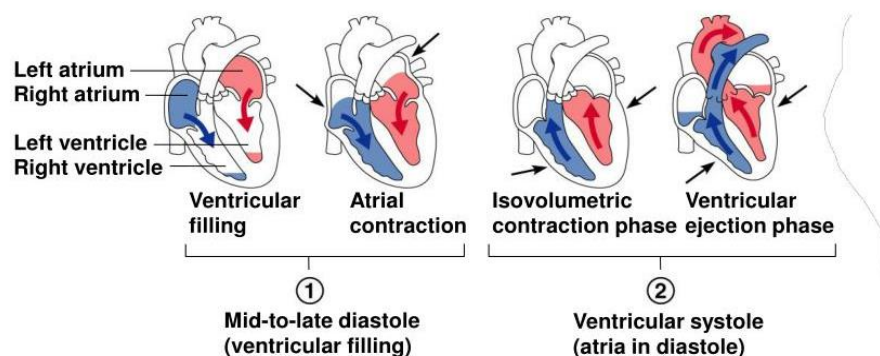


Figure 5: cardiac cycle phases

## II.2.4. Cardiac Electrophysiology

It is the study of the electrical activities of the heart. It focuses on how the heart's electrical signals are generated, propagated, and how they control the heart's rhythm and function.

### II.2.4.1. Electrocardiogram

The ECG records the **electrical impulses generated** by the heart as they travel through the **cardiac conduction system**, starting from the sinoatrial (SA) node, passing through the atrioventricular (AV) node, and spreading through the ventricles via the His bundle and Purkinje fibers.

The resulting ECG trace consists of distinct waves:

P wave (atrial depolarization),

QRS complex (ventricular depolarization)

T wave (ventricular repolarization)

The next figure shows the ECG waves.

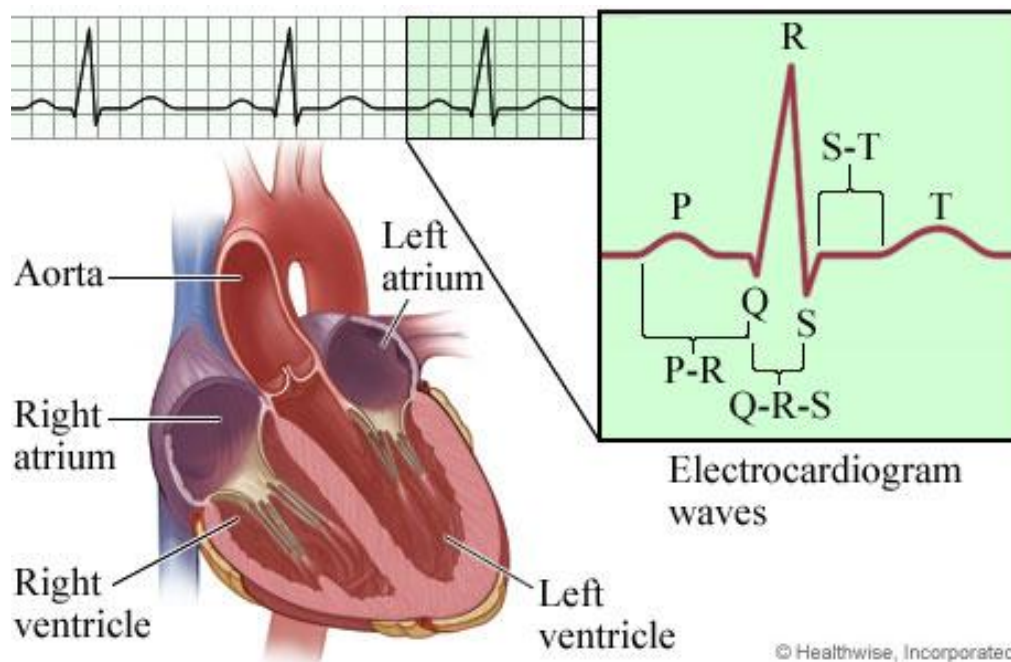


Figure 6: ECG waves

### II.2.5. Regulation of Cardiac Activity

It refers to the mechanisms that control the heart's rhythm, rate, and force of contraction. This regulation involves both intrinsic (internal) and extrinsic (external) factors to ensure the heart pumps blood effectively and maintains homeostasis.

#### II.2.5.1. Intrinsic Regulation (Internal Mechanisms)

##### a. Sinoatrial (SA) Node (The Heart's Pacemaker)

This process is automatic and doesn't require external signals to start, though it can be influenced by factors like hormones and autonomic nervous input.

##### b. Autonomic Nervous System (ANS)

The autonomic nervous system plays a crucial role in modulating heart rate and contractility through two branches:

**Sympathetic Nervous System (SNS):** Increases heart rate and force of contraction (increasing the rate of depolarization in the SA node and increasing the speed of conduction through the AV node).

**Parasympathetic Nervous System (PNS):** Decreases heart rate and contractility. The vagus nerve (cranial nerve X) releases acetylcholine, which slows down the SA node's depolarization, leading to a decrease in heart rate.

##### c. Intrinsic Conduction System

The heart has its own electrical conduction system that ensures the heart beats in a coordinated manner.

#### II.2.5.2. Extrinsic Regulation (External Factors)

##### a. Hormonal Influence

Hormones like adrenaline (epinephrine) and thyroid hormones can influence cardiac activity:

Adrenaline increases heart rate and contractility by stimulating  $\beta$ -adrenergic receptors.

Thyroid hormones (especially thyroxine) increase heart rate and the heart's sensitivity to catecholamines (like adrenaline).

### **b. Baroreceptor Reflex**

The baroreceptors (pressure sensors) in the carotid arteries and aorta detect changes in blood pressure.

If blood pressure rises, baroreceptors send signals to the brain to activate the parasympathetic nervous system, slowing the heart rate to reduce the pressure.

If blood pressure drops, the sympathetic nervous system is activated to increase heart rate and contractility, raising blood pressure back to normal.

### **c. Chemoreceptor Reflex**

Chemoreceptors in the carotid and aortic bodies detect changes in blood levels of oxygen, carbon dioxide, and pH.

Low oxygen (hypoxia) or high carbon dioxide levels (hypercapnia) can increase heart rate to improve blood flow and oxygen delivery.

Acidosis (low pH) or alkalosis (high pH) also influences heart rate, depending on the blood's acid-base balance.

### **Other Factors**

Temperature, Electrolyte Imbalance, Physical Activity and Stress...

## **II.3. Circulation in the vessels**

Blood vessels are essential components of the circulatory system, and they are responsible for transporting blood throughout the body. They can be categorized into three main types: arteries, veins, and capillaries (Figure 7). Each type of blood vessel has distinct characteristics suited to its specific function.

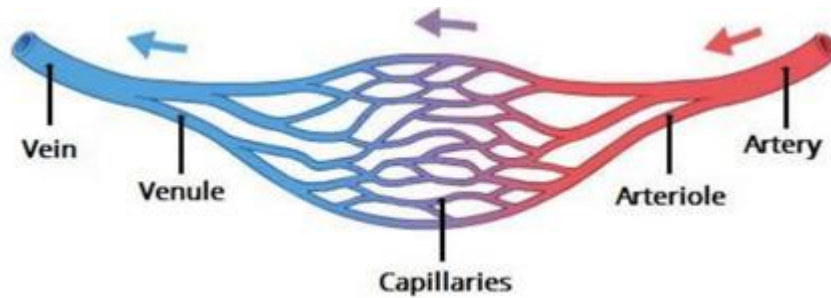


Figure 7: systemic blood circuit

### II.3.1. Arteries

#### - Structure

Arteries have thick, muscular, and elastic walls to withstand the high pressure of blood pumped by the heart.

They consist of three layers, or tunics (Figure 8):

1. **Tunica intima** (innermost layer): This layer includes a lining of endothelial cells in direct contact with the blood flow, along with a fine network of connective tissue and elastic fibers. It has a smooth surface to reduce friction as blood flows through the vessel.
2. **Tunica media** (middle layer): This is the thickest layer in arteries and is composed mainly of smooth muscle cells and elastic fibers arranged in spiral layers. The presence of elastic fibers allows the artery to stretch and recoil as the heart pumps blood, maintaining blood pressure. The smooth muscle enables vasoconstriction (narrowing) and vasodilation (widening) of arteries to regulate blood flow and pressure.
3. **Tunica externa** (outer layer): Also called tunica adventitia, this is a tough layer made primarily of collagen fibers. It provides structural support and protection. Larger arteries also contain small blood vessels called vasa vasorum that supply the artery walls.

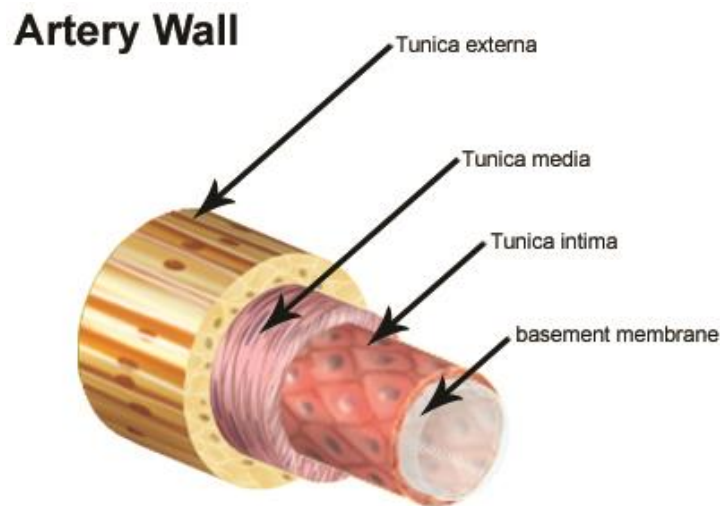


Figure 8: Structure of Artery wall

There are two main types of arteries based on their structure and function:

**Elastic arteries** (e.g., the aorta): Large diameter arteries with abundant elastic fibers allowing them to stretch with the heart's pumping and recoil to maintain blood flow.

**Muscular arteries:** Medium-sized arteries with a thicker tunica media made mostly of smooth muscle, which have a more active role in vasoconstriction to regulate blood distribution.

- **Function**

They carry oxygenated blood away from the heart (except the pulmonary artery, which carries deoxygenated blood to the lungs).

- **Characteristics**

**Thick walls:** To cope with the high pressure of blood flow.

**Elasticity:** Helps maintain blood pressure by expanding and recoiling with each heartbeat.

**Narrow lumen:** The internal diameter is smaller than veins to support high pressure.

**Smooth inner lining (endothelium)** to reduce friction and allow smooth blood flow.

### II.3.2. Veins

#### - Structure

Veins have thinner walls compared to arteries, as the blood pressure in veins is lower.

Veins have three main layers (Figure 9):

1. **Tunica intima** (innermost layer): This is a smooth lining of flat endothelial cells that allows blood to flow easily. Unlike arteries, veins often have valves formed by folds of the tunica intima that prevent backflow and ensure unidirectional blood flow toward the heart.
2. **Tunica media** (middle layer): The middle layer is thinner than in arteries and contains fewer smooth muscle cells and elastic fibers. It is responsible for modest vasoconstriction and vasodilation, controlled by the sympathetic nervous system, which helps regulate blood return to the heart.
3. **Tunica externa or adventitia** (outer layer): This is the thickest layer in veins and is made primarily of connective tissue and elastic fibers. It provides structural support and flexibility. Larger veins depend heavily on this layer for strength.

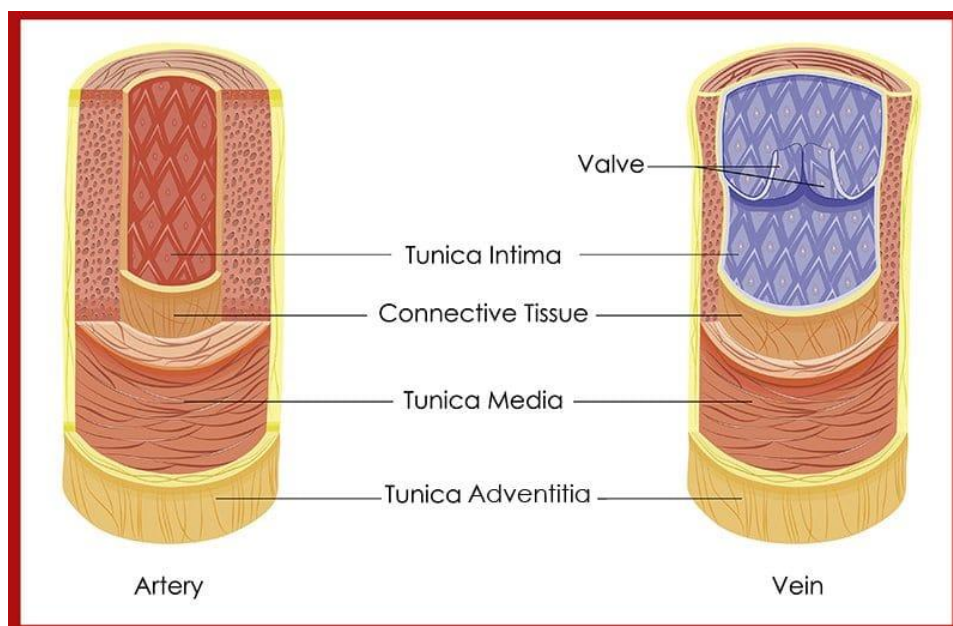


Figure 9: Vein and artery walls structure

- **Function**

Veins carry deoxygenated blood back to the heart (except the pulmonary veins, which carry oxygenated blood from the lungs to the heart).

- **Characteristics**

**Thinner walls:** They don't need to withstand high pressure.

**Wider lumen:** The internal diameter is larger compared to arteries.

**Valves:** Veins, particularly in the limbs, have one-way valves to prevent backflow of blood, helping blood return to the heart against gravity.

**Less elastic tissue:** Veins are not as elastic as arteries because they don't need to accommodate high pressure.

### II.3.3. Capillaries

- **Structure**

Capillaries are tiny, thin-walled blood vessels that connect arteries to veins.

They are the smallest blood vessels in the circulatory system, designed primarily for the exchange of gases, nutrients, and waste between blood and surrounding tissues. Their structure is uniquely simple to facilitate this function.

Capillaries consist of a single layer of endothelial cells (the tunica intima) surrounded by a thin basement membrane. They lack the thicker tunica media and tunica externa found in arteries and veins (Figure 10). This very thin wall, typically only one endothelial cell thick, allows for easy diffusion of oxygen, carbon dioxide, nutrients, and waste products between blood and tissue cells. The diameter of capillaries is about 5 to 10 micrometers, just wide enough for red blood cells to pass through in single file.

There are three main types of capillaries based on their permeability:

1. **Continuous capillaries**, with uninterrupted endothelial cells allowing selective passage of small molecules.

2. **Fenestrated capillaries**, which have small pores to increase permeability to fluids and small molecules, common in kidneys and intestines.
3. **Sinusoidal (discontinuous) capillaries**, with larger openings and a discontinuous basement membrane, allowing passage of larger molecules and cells, found in liver, bone marrow, and spleen.

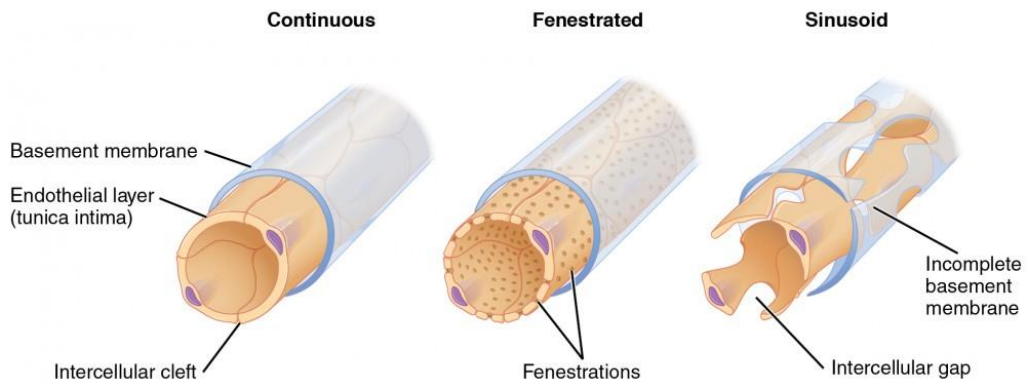


Figure 10: capillaries Types

#### - **Function**

Functionally, capillaries form dense networks called capillary beds in tissues, providing maximal surface area for exchange to support cellular metabolism and homeostasis. They are critical in microcirculation, linking arterioles to venules, and help regulate blood flow and pressure in tissues.

#### - **Characteristics**

**Very thin walls:** Only one cell thick, allowing for easy exchange of substances.

**Extensive network:** Capillaries form a vast network that penetrates tissues, ensuring that every cell is close to a blood vessel.

**Small lumen:** The diameter is so small that red blood cells pass through in single file, maximizing the surface area for exchange.

**Permeable walls:** They allow substances like oxygen, nutrients, and waste products to pass in and out of the blood.

The following image shows the difference between the different systemic blood vessels

	Arteries	Capillaries	Veins
Function	Carry blood <b>away</b> from the heart at <b>high</b> pressure	-Supply all cells with their <b>requirements</b> -Take away <b>waste</b> products	<b>Return</b> blood to the heart at <b>low</b> pressure
Structure of wall	- <b>Thick</b> , strong -Contain <b>muscles</b> , <b>elastic</b> fibres and <b>fibrous</b> tissue	<b>Very thin</b> , only one cell thick	- <b>Thin</b> -Mainly <b>fibrous</b> tissue -Contain far <b>less muscle</b> and <b>elastic</b> tissue than arteries
Lumen	- <b>Narrow</b> -Varies with heartbeat (increases as a pulse of blood passes through)	- <b>Very narrow</b> -Just wide enough for a red blood cell to pass through	<b>Wide</b>
Valves	(-)	(-)	(+) Prevent backflow
How structure fits function	-Strength and elasticity needed to withstand the pulsing of the blood, prevent bursting and maintain pressure wave -Helps to maintain <b>high blood pressure</b> , preventing blood flowing backwards	- No need for strong walls, as most of the blood pressure has been lost -Thin walls and narrow lumen bring blood into close contact with body tissue, allowing <b>diffusion</b> of materials between capillary and surrounding tissues. -White blood cells can squeeze between cells of the wall	- No need for strong walls, as most of the blood pressure has been lost - Wide lumen offers <b>less resistance</b> to blood flow

Figure 11: difference between systemic blood vessels

- **Important**

There are differences in the structure and function of blood vessels among animals that reflect adaptations to their specific physiological needs and environments.

- **General Similarities and Differences**

All animals with a closed circulatory system have arteries, veins, and capillaries, but the structure and thickness of vessel walls vary depending on the species and the blood pressure they maintain.

Arteries typically have thick muscular and elastic walls to withstand high pressure from the heart, while veins have thinner walls with valves to prevent backflow as blood returns under low pressure. The diameter of capillaries is generally constant across mammals (**~5–10 micrometers**) to facilitate efficient exchange of gases and nutrients.

#### - **Specific Adaptations in Animals**

Animals with high blood pressure, like mammals, have arteries with a high proportion of elastic fibers to enable stretching and recoil, supporting continuous blood flow during the cardiac cycle.

Species with low metabolic rates or slow blood flow, such as Greenland sharks, have arteries structured to be more distensible and less elastic, allowing blood vessels to operate effectively under lower pressure.

Large animals with specific mechanical needs show regional variation in arterial structure; for example, giraffes have thick and rigid leg arteries to maintain high pressure against gravity, while their neck arteries are more elastic to accommodate the pulsatile flow.

#### - **Functional Implications**

The mechanics of vessel walls, such as the ratio of collagen to elastin, influence the vessel's compliance and ability to withstand mechanical forces.

The vascular branching patterns and vessel wall compositions are fine-tuned to optimize delivery of nutrients and oxygen based on animal size, activity level, and habitat. Evolution has shaped these variations, ensuring survival by matching vessel structure to environmental and physiological demands.

### II.3.4 Vasomotricity

It is the ability of blood vessels, particularly arteries and arterioles, to constrict or dilate in response to various stimuli.

It plays a crucial role in:

- **Blood pressure regulation:** By adjusting the diameter of blood vessels, vasomotricity helps to maintain consistent blood pressure throughout the body.
- **Thermoregulation:** Blood vessels in the skin dilate or constrict to regulate body temperature.
- **Organ perfusion:** Blood vessels in different organs dilate or constrict to ensure an adequate supply of blood according to the metabolic needs of the tissues.

#### II.3.4. Arterial pressure

Or blood **pressure**, it is the force exerted by circulating blood on the walls of the arteries. It is a critical measure of cardiovascular health and is influenced by the amount of blood the heart pumps and the resistance to blood flow in the arteries.

##### II.3.4.1. Components of Arterial Pressure

- **Systolic Pressure**

This is the higher value in a blood pressure reading and represents the pressure in the arteries when the heart's ventricles contract and pump blood out into the arteries (Figure 12).

- **Diastolic Pressure**

This is the lower value in a blood pressure reading and represents the pressure in the arteries when the heart is at rest between beats. It reflects the resistance in the arteries when the heart is filling with blood (Figure 12).

- **Mean Arterial Pressure (MAP)**

It is the average pressure in an animal's arteries during one cardiac cycle, including both systole and diastole.

$$\text{MAP} \approx \text{diastolic} + \frac{1}{3}(\text{systolic} - \text{diastolic})$$

MAP is critical in managing patients in emergency or intensive care settings, as it better indicates the adequacy of blood flow to organs than just systolic blood

pressure. Maintaining an adequate MAP is essential to avoid organ dysfunction and failure.

Mean Arterial Pressure (MAP) in animals generally averages around 100 mmHg across a wide range of mammalian species regardless of body size, from small mice to large elephants. This consistency in MAP suggests that it is a tightly regulated physiological parameter necessary to sustain adequate organ perfusion in mammals.

Studies have shown:

In mice, MAP averages about 112 mmHg.

In larger mammals, like dogs and horses, the MAP is also close to this range, typically around 90-110 mmHg.

Exceptions exist in animals with specific anatomical challenges; for example, giraffes have a significantly higher MAP (about 230 mmHg) at the heart level to overcome the effects of gravity in pumping blood to their elevated heads.

Variations in MAP among species can also be influenced by stress factors, body position during measurement, and methods used (invasive vs non-invasive).

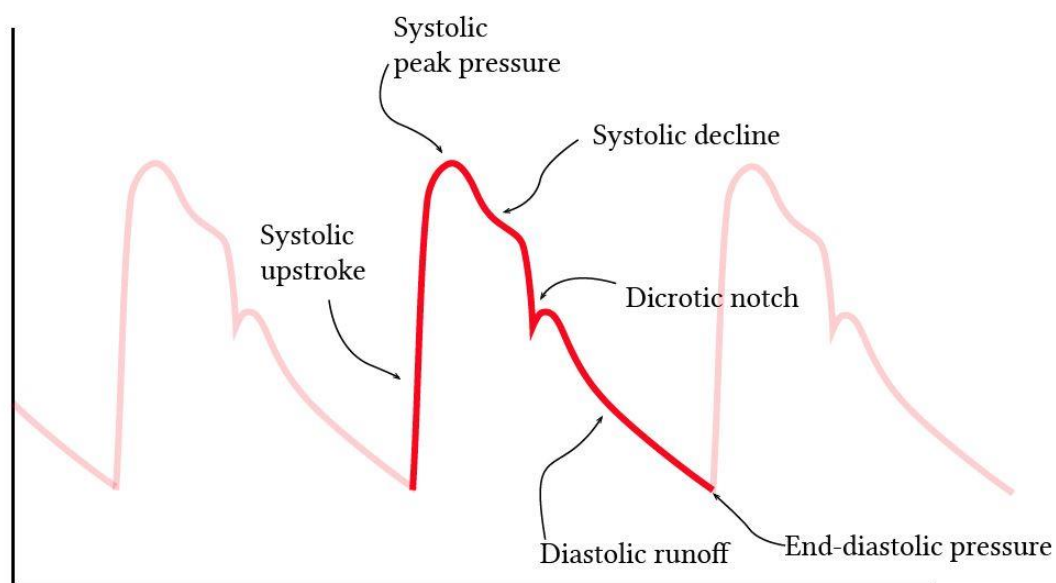


Figure 12: arterial pressure

### II.3.4.2. Factors Affecting Arterial Pressure

#### - **Cardiac Output (CO):**

Cardiac output is the volume of blood the heart pumps per minute. **The greater the cardiac output, the higher the pressure exerted on the arterial walls.** This can be influenced by:

- Heart rate (number of heartbeats per minute)
- Stroke volume (amount of blood pumped per beat)

#### - **Peripheral Resistance (PR)**

This refers to the resistance to blood flow in the smaller arteries and arterioles. The narrower the vessels (due to vasoconstriction, for example), the higher the peripheral resistance, which leads to increased arterial pressure.

Key factors affecting peripheral resistance include:

- Vascular tone (degree of contraction of smooth muscle in the vessel walls)
- Blood viscosity (thickness of the blood)
- The overall diameter of the arteries

#### - **Blood Volume**

An increase in blood volume, as seen in conditions like excessive sodium intake or kidney dysfunction, can lead to higher arterial pressure. Conversely, blood loss (as in hemorrhage) can decrease blood volume and lower pressure.

#### - **Elasticity of Arteries**

Healthy arteries are elastic and can expand to accommodate the surge of blood during systole and recoil during diastole.

#### - **Hormonal Regulation**

Several hormones influence blood pressure regulation:

- Renin-Angiotensin-Aldosterone System (RAAS): This system helps regulate blood pressure by adjusting blood volume and peripheral resistance.

- Antidiuretic hormone (ADH): Helps control blood volume by regulating water retention in the kidneys.
- Aldosterone: Increases sodium retention by the kidneys, which increases blood volume and pressure.

#### - Nervous System Control

The autonomic nervous system (ANS) also plays a role in regulating blood pressure. The sympathetic nervous system (SNS) increases heart rate and vasoconstriction, raising blood pressure, while the parasympathetic nervous system (PNS) tends to lower heart rate and can help lower blood pressure.

#### II.3.4.3. Regulation of Arterial Pressure

The regulation of arterial pressure involves a combination of **short-term** mechanisms that provide quick adjustments to blood pressure and **long-term** mechanisms that maintain blood pressure over hours, days, and even longer. These systems work together to maintain optimal blood pressure, ensuring that the body's organs and tissues receive adequate blood supply while avoiding damage from excessive pressure.

##### 1. Short-term Regulation

- **Baroreceptors**

located in the **aortic arch** and **carotid sinuses**.

- **When blood pressure increases**, the baroreceptors stretch more, sending signals via the **vagus nerve** (carotid sinus) and **glossopharyngeal nerve** (aortic arch) to the brainstem (specifically the medulla oblongata). This stimulates the parasympathetic nervous system and **inhibits the sympathetic** nervous system, leading to:
  - Reduced heart rate (negative chronotropy)
  - Reduced force of contraction (negative inotropy)
  - Vasodilation (widening of blood vessels)

- **When blood pressure decreases**, the baroreceptors detect less stretch and signal to the brainstem to activate the sympathetic nervous system and inhibit parasympathetic activity, resulting in:
  - **Increased heart rate** (positive chronotropy)
  - **Increased force of contraction** (positive inotropy)
  - **Vasoconstriction** (narrowing of blood vessels)

In summary:

- **↑ BP → parasympathetic activation → ↓ HR and vasodilation**
- **↓ BP → sympathetic activation → ↑ HR, contractility, vasoconstriction**

This reflex is a rapid response that helps stabilize blood pressure within seconds to minutes

- **Kidneys:** By controlling blood volume through sodium and water balance, kidneys help regulate long-term blood pressure.
- **Chemoreceptor Reflexes:** Peripheral chemoreceptors in carotid and aortic bodies sense low oxygen, high carbon dioxide, or acidosis and stimulate sympathetic outflow to increase arterial pressure and cardiac output.
- **Other Reflexes**

Low-pressure baroreceptors in the atria and pulmonary vessels detect blood volume changes and contribute to reflexes that adjust heart rate and vascular tone.

- **Central Nervous System Integration:** Cardiovascular centers in the medulla process signals from receptors and coordinate autonomic output to the heart and vessels for rapid pressure adjustments.

### II.3.5. Capillary circulation

Capillary circulation refers to the flow of blood through the capillaries, the smallest and thinnest blood vessels in the circulatory system. Capillaries connect the arterial system to the venous system and are critical sites for the exchange of gases, nutrients, and waste products between blood and tissues.

### II.3.5.1. Blood Flow and Pressure

Blood flow follows a pressure gradient from arteries (high pressure) to veins (low pressure).

Capillary blood pressure is relatively low (about 30-40 mmHg) compared to arterial pressure, enabling controlled exchange of fluid between blood and interstitial fluid.

The movement of fluid across capillary walls is governed by a balance between **hydrostatic pressure** (pushing fluid out) and **osmotic pressure** (pulling fluid in) created mainly by plasma proteins like albumin (Figure 13).

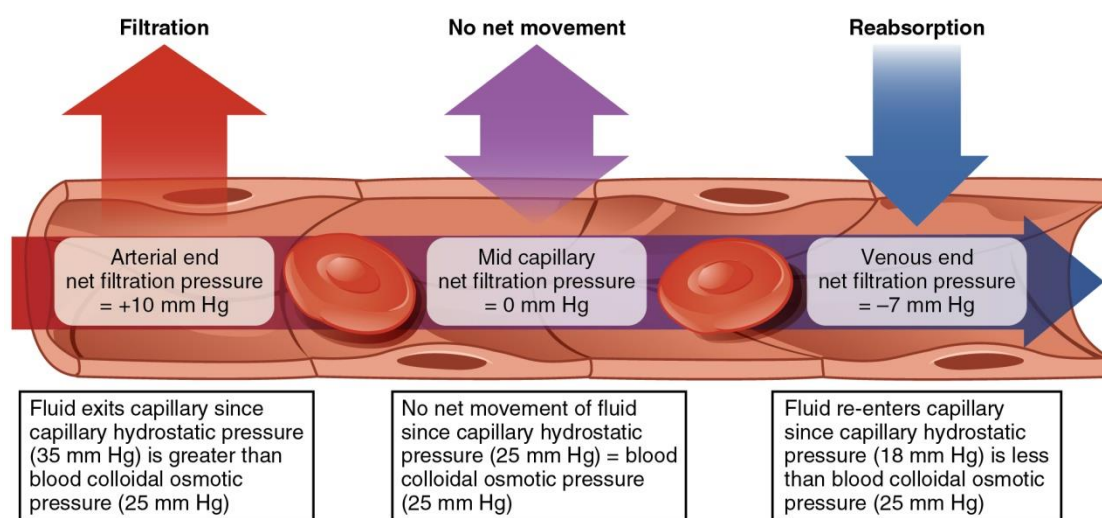


Figure 13: movement of fluid across capillary walls

### II.3.5.1. Regulation

Blood flow into capillary beds is controlled by precapillary sphincters—small muscles that can open or close to regulate which capillaries receive blood based on tissue needs (Figure 14).

For example, during exercise, blood flow to skeletal muscles increases via vasodilation, while flow to the digestive system decreases via vasoconstriction.

About 5-10% of capillary beds are open at any given time, allowing the body to efficiently allocate blood where it is most needed.

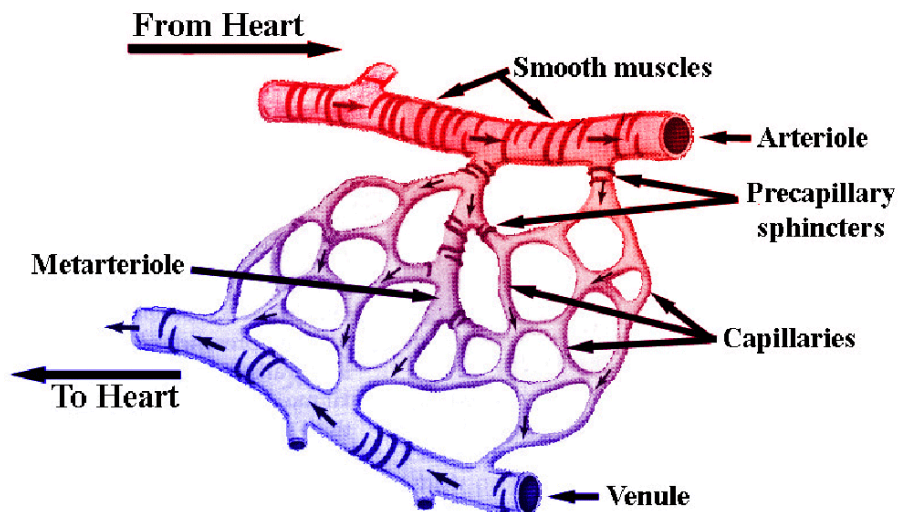


Figure 14: Capillary circulation

### II.3.5.2. Role in Circulation

Capillaries facilitate gas exchange (oxygen and carbon dioxide), nutrient delivery, and removal of metabolic wastes.

Excess plasma fluid that leaves the capillaries is mostly reabsorbed, with the remainder draining into lymphatic vessels to maintain fluid balance.

#### - Exchange Mechanisms

**Diffusion:** Main method for  $O_2$ ,  $CO_2$ , glucose, etc.

**Filtration & Reabsorption:** Driven by pressure differences:

**Hydrostatic pressure ( $P_i$ )** pushes fluid out (from blood to tissue).

**Oncotic pressure ( $\pi$ )** pulls fluid in (due to plasma proteins).

**Bulk Flow:** Net movement of fluid depending on the balance of pressures.

### II.3.5.3. Regulation of Capillary Flow

**Precapillary Sphincters:** These are smooth muscle rings located at the entrance of capillary beds that regulate blood flow into individual capillaries. They can constrict or relax to decrease or increase blood flow respectively. Precapillary sphincters respond to local chemical signals such as oxygen levels, carbon dioxide, pH, and metabolic byproducts like lactic acid.

**Chemical Signals:** Endothelial cells lining the capillaries release vasoactive substances including:

**Nitric oxide (NO):** A potent vasodilator released in response to low oxygen, increased carbon dioxide, and other metabolic signals, which relaxes precapillary sphincters to increase blood flow.

**Endothelins:** Vasoconstrictive peptides that cause sphincter contraction, reducing blood flow during conditions of reduced metabolic need.

**Myogenic Response:** This is an intrinsic mechanism where capillary and arteriole smooth muscle cells contract in response to increased stretch (high pressure) and relax when stretch decreases, helping maintain stable blood flow despite changes in blood pressure.

**Capillary-Arteriole Communication:** Recent research shows capillaries can communicate with upstream arterioles to regulate blood flow dynamically. This involves signaling pathways like pannexin/purinergic signaling and gap junctions adjusted according to local tissue activity and muscle contraction frequency.

**Blood Flow Heterogeneity:** Capillary blood flow can vary between adjacent capillary modules due to differences in driving pressure and resistance, allowing fine-tuning of perfusion at the microvascular level.

## II.4. Venous circulation

Venous circulation is the part of the circulatory system responsible for returning oxygen-depleted blood from the tissues back to the heart.

### II.4.1. Features of venous circulation include

- **Low Pressure System:** Veins operate under much lower blood pressure compared to arteries. This low pressure facilitates blood return to the heart but requires additional mechanisms to aid flow.
- **Large Lumens and Thin Walls:** Veins have larger lumens and thinner, less elastic walls compared to arteries. This allows veins to hold a large volume of

blood and act as capacitance vessels accommodating about 60-70% of the total blood volume.

- **Valves:** Many veins, especially in the limbs, contain one-way valves formed from folds of the tunica intima. These valves prevent backflow of blood and help maintain unidirectional flow toward the heart, crucial.

### II.5. Pulmonary circulation

Pulmonary circulation is the circuit of blood vessels that carries deoxygenated blood from the right side of the heart to the lungs for oxygenation and then returns oxygenated blood to the left side of the heart (Figure 15).

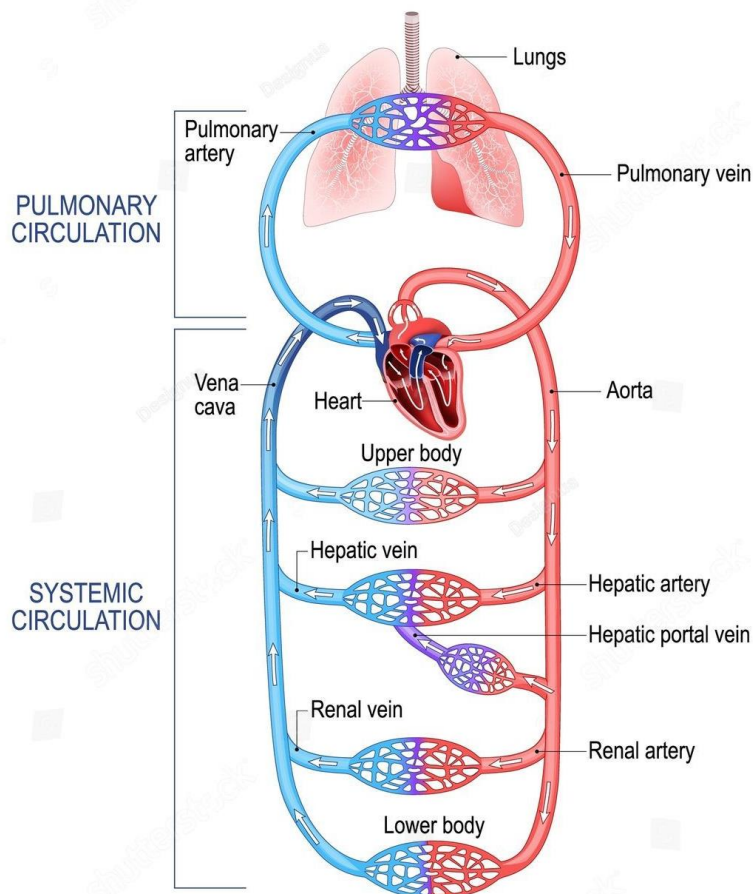


Figure 15: Pulmonary circulation among circulatory system

## - **Structure**

Begins at the right ventricle, which pumps blood into the pulmonary trunk.

The pulmonary trunk splits into the right and left pulmonary arteries that carry deoxygenated blood to the lungs.

Within the lungs, arteries branch into smaller arteries, arterioles, and then into pulmonary capillaries that surround the alveoli where gas exchange occurs.

Oxygenated blood returns via pulmonary venules, merging into larger veins, and eventually into four pulmonary veins that drain into the left atrium.

## - **Function**

The primary function is to exchange gases: remove carbon dioxide from the blood and add oxygen.

Compared to systemic circulation, pulmonary vessels have thinner walls and larger diameters, making pulmonary circulation a low pressure (mean arterial pressure around 15 mmHg) and low resistance system.

The pulmonary circulation accommodates the entire cardiac output and has high compliance to adjust quickly to changes in blood volume.

Pulmonary circulation also supports the bronchial circulation, which supplies oxygenated blood to the lung tissues themselves.

An important regulatory mechanism is hypoxic pulmonary vasoconstriction, where pulmonary arterioles constrict in areas of low oxygen to redirect blood flow to better-ventilated areas of the lung, optimizing gas exchange.

## **Important**

Pulmonary circulation is fundamentally the same in animals and humans in that it transports deoxygenated blood from the heart to the lungs for oxygenation and returns oxygenated blood to the heart. However, there are notable species-specific anatomical and physiological differences.

## **Similarities**

All vertebrates with lungs have a pulmonary circuit carrying blood between the heart and the lungs.

Pulmonary arteries deliver deoxygenated blood to the lungs, and pulmonary veins return oxygenated blood to the heart.

Gas exchange occurs in pulmonary capillaries adjacent to respiratory surfaces.

## **Differences**

**Mammals vs Birds:** Mammals have a respiratory system with large alveoli and reciprocating airflow, whereas birds have a flow-through lung system with small air capillaries allowing for more efficient gas exchange due to cross-current exchange mechanisms. The blood-gas barrier is thinner and more uniform in birds compared to mammals.

**Pulmonary Vascular Structure:** Dogs exhibit more asymmetrical vascular branching than humans, causing differences in blood flow distribution and gravity effects on pulmonary perfusion.

**Pulmonary Arterial Pressure:** Birds like chickens can experience pulmonary hypertension during rapid growth due to differences in pulmonary vascular resistance, while mammals typically do not.

**Adaptations:** Some species show particular adaptations in their pulmonary circulation related to their lifestyle; for example, diving mammals have special adaptations for oxygen conservation.

## **Features of Pulmonary Circulation**

**Low Pressure, Low Resistance System:** Pulmonary circulation operates at a much lower pressure (mean arterial pressure around 5-15 mmHg) than systemic circulation, due to shorter vessel length, larger vessel diameter, and parallel arrangement of capillaries. This minimizes resistance and protects delicate lung tissues.

**High Compliance and Distensibility:** Pulmonary arteries and veins have thinner walls with less smooth muscle, making them highly compliant and able to accommodate the entire cardiac output with less force.

**Gas Exchange Function:** The primary role of pulmonary circulation is to transport deoxygenated blood from the right heart to the lungs, where carbon dioxide is expelled and oxygen is absorbed across the thin alveolar-capillary membrane.

**Extensive Capillary Network:** The lung has a dense capillary network with a vast surface area and very thin barrier (~0.3 micrometers) between air and blood, facilitating rapid gas diffusion.

**Hypoxic Pulmonary Vasoconstriction:** Pulmonary arterioles constrict in response to low oxygen levels in alveoli, diverting blood away from poorly ventilated areas to optimize gas exchange efficiency.

**Zones of Pulmonary Blood Flow:** Due to gravity, blood flow varies in zones within the lung, with the base receiving greater flow than the apex under normal conditions.

**Lymphatic System Role:** Pulmonary lymphatics maintain fluid balance by removing excess interstitial fluid, preventing pulmonary edema and ensuring dry alveoli for efficient gas exchange.

**Overlap with Bronchial Circulation:** The pulmonary circulation primarily oxygenates blood, while bronchial circulation supplies oxygenated blood to lung tissue itself, with some overlap especially near central airways.

These features characterize pulmonary circulation as uniquely adapted for efficient oxygenation of blood while protecting lung structure and function.

## Quiz

1. What structure in the heart initiates the electrical impulse that regulates the heartbeat?

- A. Atrioventricular (AV) node
- B. Sinoatrial (SA) node
- C. Purkinje fibers
- D. Bundle of His

**Correct answer: B**

2. Which of the following best describes systole?

- A. The relaxation of the heart muscle
- B. The filling of the ventricles with blood
- C. The contraction of the heart muscle to pump blood
- D. The closure of the heart valves

Correct answer: C

3. What causes the first heart sound ("lub") heard during auscultation?

- A. Opening of the semilunar valves
- B. Closure of the atrioventricular valves
- C. Closure of the semilunar valves

D. Blood flow into the atria

**Correct answer: B**

4. Which vessel type has the greatest total cross-sectional area and allows for exchange of substances between blood and tissues?

A. Arteries

B. Veins

C. Capillaries

D. Venules

**Correct answer: C**

5. What effect does parasympathetic stimulation have on the heart?

A. Increases heart rate and contractility

B. Decreases heart rate

C. Increases blood pressure

D. No effect on the cardiovascular system

**Correct answer: B**

6. In a normal ECG, what does the QRS complex represent?

- A. Atrial depolarization
- B. Atrial repolarization
- C. Ventricular depolarization
- D. Ventricular repolarization

**Correct answer: C**

7. Which of the following mechanisms contributes most to venous return in animals?

- A. Arterial pressure
- B. Skeletal muscle contractions
- C. Pulmonary ventilation
- D. Capillary action

**Correct answer: B**

8. Why is the left ventricular wall thicker than the right?

- A. It pumps blood to the lungs
- B. It receives blood from the lungs
- C. It pumps blood to the whole body
- D. It stores oxygenated blood

**Correct answer: C**

9. What is the primary function of baroreceptors in the cardiovascular system?

- A. Detect oxygen levels
- B. Measure body temperature
- C. Regulate heart contractions
- D. Monitor blood pressure changes

**Correct answer: D**

10. Which statement best describes cardiac output?

- A. The amount of blood in the heart at rest
- B. The volume of blood pumped by one ventricle per minute
- C. The heart rate multiplied by blood pressure
- D. The pressure exerted by blood on artery walls

**Correct answer: B**

## Conclusion

The cardiovascular system in animals is a highly specialized and dynamic network responsible for the continuous circulation of blood, ensuring the delivery of oxygen, nutrients, hormones, and the removal of metabolic wastes. Across species, the heart and blood vessels exhibit variations in structure and function tailored to meet the diverse metabolic demands and environmental challenges faced by different animals.

Understanding the fundamental principles of cardiac function, vascular dynamics, and regulatory mechanisms provides insight into how animals maintain homeostasis and adapt to physiological stresses such as exercise, dehydration, and pathological conditions. Comparative physiology reveals both conserved and unique features in cardiac anatomy, electrical conduction, and circulation that reflect evolutionary adaptations.

Mastering these concepts equips one with a comprehensive perspective on the integrative nature of the cardiovascular system and its crucial role in overall animal health. This knowledge forms the foundation for advanced studies in veterinary medicine, animal biology, and translational research using animal models.

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