1ST YEAR MEDICAL STUDENTS
GENERAL PHYSIOLOGY
INTRODUCTION TO CARDIAC MUSCLE

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Cardiovascular System (CVS)

- The **cardiovascular (circulatory) system consists of the cardiac muscle (heart), blood vessels and blood.**
- It is a **closed system of vessels** inside which blood circulates continuously by the **pumping action** of the **heart** in **one direction** only by the action of **valves** present in the **heart** and **veins**.

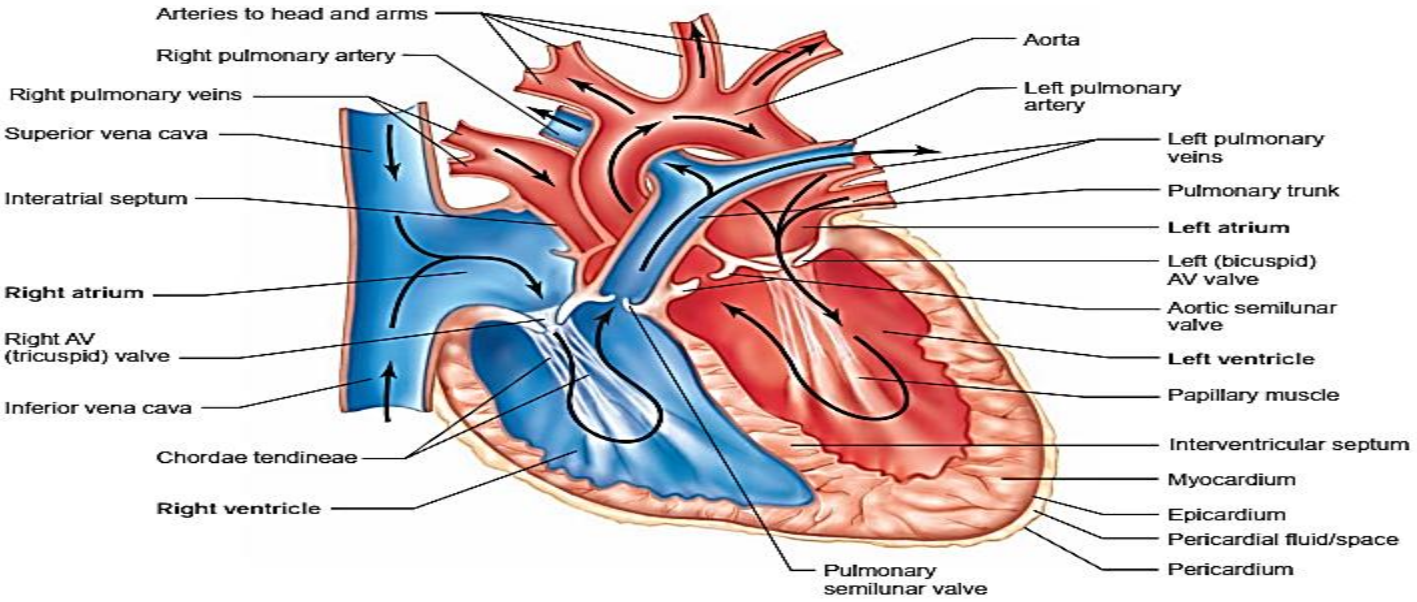


Figure 12.6 AP|R Diagrammatic section of the heart. The arrows indicate the direction of blood flow.

Functions of CVS

- ✓ **The primary function of the cardiovascular system is to deliver blood to the tissues, which provides essential nutrients to the cells for metabolism and removes waste products from the cells.**
- ✓ The **heart serves as the pump**, which, by contracting, generates the pressure to drive blood through a series of blood vessels.
- ✓ The vessels that carry blood from the heart to the tissues are the arteries, which are under high pressure and contain a relatively small percentage of the blood volume.
- ✓ The veins, which carry blood from the tissues back to the heart, are under low pressure and contain the largest percentage of the blood volume.
- ✓ Within the tissues, thin-walled blood vessels, called capillaries, are interposed between arteries and veins. Exchange of nutrients, wastes, and fluid occurs across the capillary walls.
- ✓ The cardiovascular system also is involved in several homeostatic functions: It participates in the **regulation of arterial blood pressure**; it **delivers regulatory hormones from the endocrine glands to their sites of action in target tissues**; it participates in **the regulation of body temperature**; and it is involved in the homeostatic adjustments to altered physiologic states such as hemorrhage, and exercise.

CIRCUITRY OF THE CVS

Left and Right Sides of the Heart

- ✓ Each side of the heart has two chambers, an atrium and a ventricle, connected by one-way valves, called atrioventricular (AV) valves.
- ✓ The AV valves are designed so that blood can flow only in one direction, from the atrium to the ventricle.
- ✓ The left heart and right heart have different functions:
- ○ The left heart and the systemic arteries, capillaries, and veins are collectively called the systemic circulation.
- ○ The left ventricle pumps blood to all organs of the body except the lungs.
- ○ The right heart and the pulmonary arteries, capillaries, and veins are collectively called the pulmonary circulation.
- ○ The right ventricle pumps blood to the lungs.

GENERAL SCHEME OF THE CIRCULATION

- The overall circulation can be characterized as a series circuit in which:
- Oxygenated blood is pumped by the left ventricle into the systemic arterial circulation.
- Deoxygenated blood returns to the right atrium through the systemic veins.
- The right ventricle pumps this blood into the pulmonary circulation.
- Reoxygenated blood subsequently returns to the left atrium through the pulmonary veins.

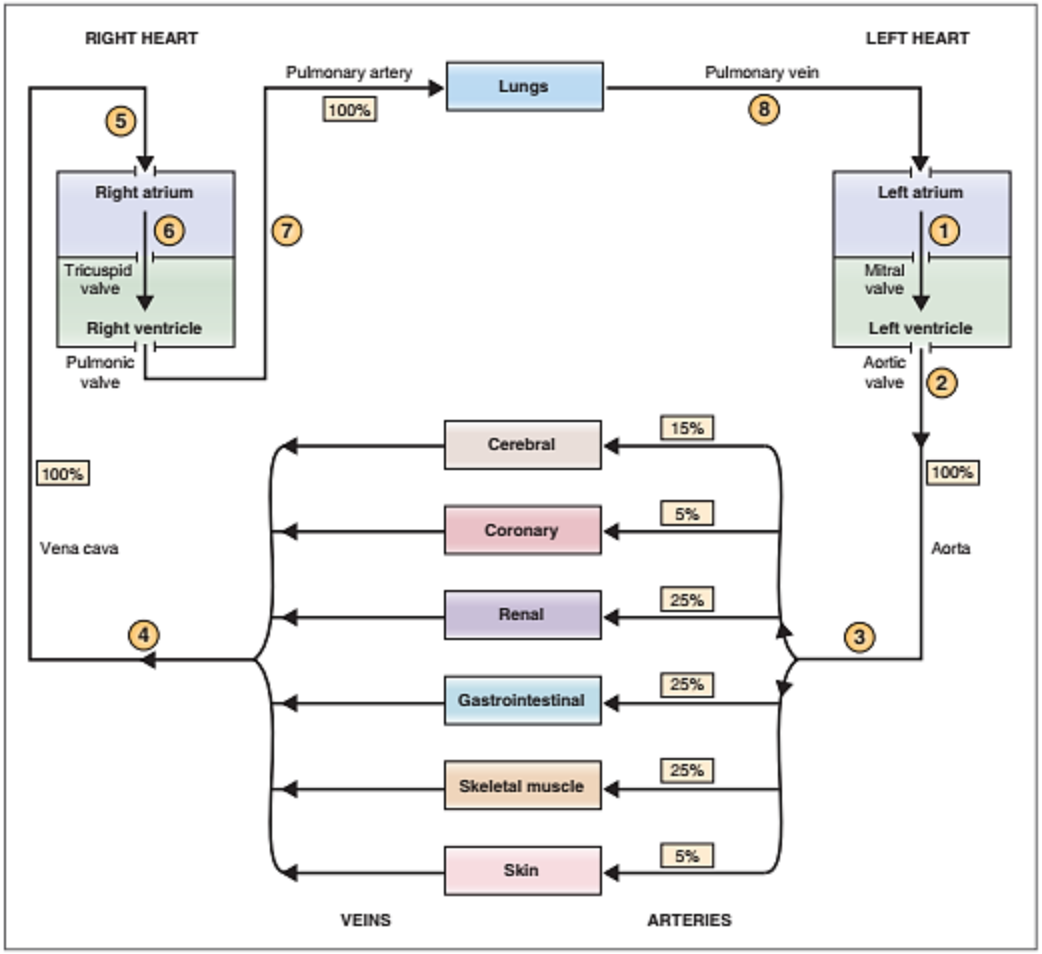


Fig. 4.1 **A schematic diagram showing the circuitry of the cardiovascular system.** The *arrows* show the direction of blood flow. Percentages represent the percent (%) of cardiac output.

- ✓ The rate at which blood is pumped from either ventricle is called the **cardiac output (CO).**
- ✓ **CO: The volume of blood each ventricle pumps as a function of time**, usually expressed in **liters per minute**. It is **about 5 L/minute**.
- ✓ Because the two sides of the heart operate in series, **the cardiac output of the left ventricle equals the cardiac output of the right ventricle** in the steady state.
- ✓ The rate at which blood is returned to the atria from the veins is called the **venous return.**
- ✓ Again, because the left heart and the right heart operate in series, venous return to the left heart equals venous return to the right heart in the steady state.
- ✓ Finally, in the steady state, **cardiac output *from* the heart equals venous return *to* the heart**.

CARDIAC MUSCLE

- Cardiac muscle is a **striated muscle** like the skeletal muscle, but it is **different** from the skeletal muscle in being **involuntary** and **syncytial**.

- **Syncytium:** It means that **cardiac muscle cells are able to excite and contract together** as one unit **due to** the presence of **gap junctions** between adjacent cardiac cells.

- **Both atria** contract together as one unit (**upper syncytium**) and **both ventricles** contract together as one unit (i.e. **lower syncytium**), which are **completely separated** from each other by the **fibrous A-V ring**. So, the excitation waves **cannot be directly transmitted** from one syncytium to the other.

Myocardium of the heart is composed of two types of cardiac muscle cells (fibers):

A. Contractile Cells :

- Form about 98-99% of the cardiac muscle).
- Their action potential (AP) is called **fast AP**.

B. Non-contractile (auto-rhythmic) Cells:

- Form about 1-2 % of the cardiac muscles and are the cells that form **excitatory- conductive system** of the heart).
- Their AP is called **slow or pacemaker AP.**

Physiological Properties of the Cardiac Muscle

Cardiac muscle has four properties, due to which the heart is able to fulfill its function as a pumping organ.

They include:

1. **Automaticity & Rhythmicity (Chronotropism).**
2. **Excitability (Bathmotropism).**
3. **Conductivity (Dromotropism).**
4. **Contractility (Inotropism).**

1. Automaticity and Rhythmicity (Auto-rhythmicity)

Automaticity:

it is the property of self-excitation; the ability of spontaneous generation of action potentials independent of any extrinsic stimuli.

Rhythmicity:

The regular generation of these action potentials (the heart can beat regularly).

Spontaneous automaticity and **rhythmicity (auto-rhythmicity)** of the cardiac muscle is due to the existence of a specialized **excitatory-conductive system**, which is composed of modified **self-exciting**, **non- contractile** cardiac muscle cells called **pacemaker cells**.

Auto-rhythmicity is **myogenic** in origin (i.e. starts from the **muscle** itself **independent** from autonomic nerve supply that **only controls** the heart rate (either ↑ or ↓) **but don't initiate the beat.**

Pacemaker(s) of the heart:

Pacemaker means the part of the heart that has the highest rhythmicity and the whole other parts of the heart follow its rhythm.

They include:

1. Sinoatrial (auricular) (SA) Node (1ry; normal Pacemaker):

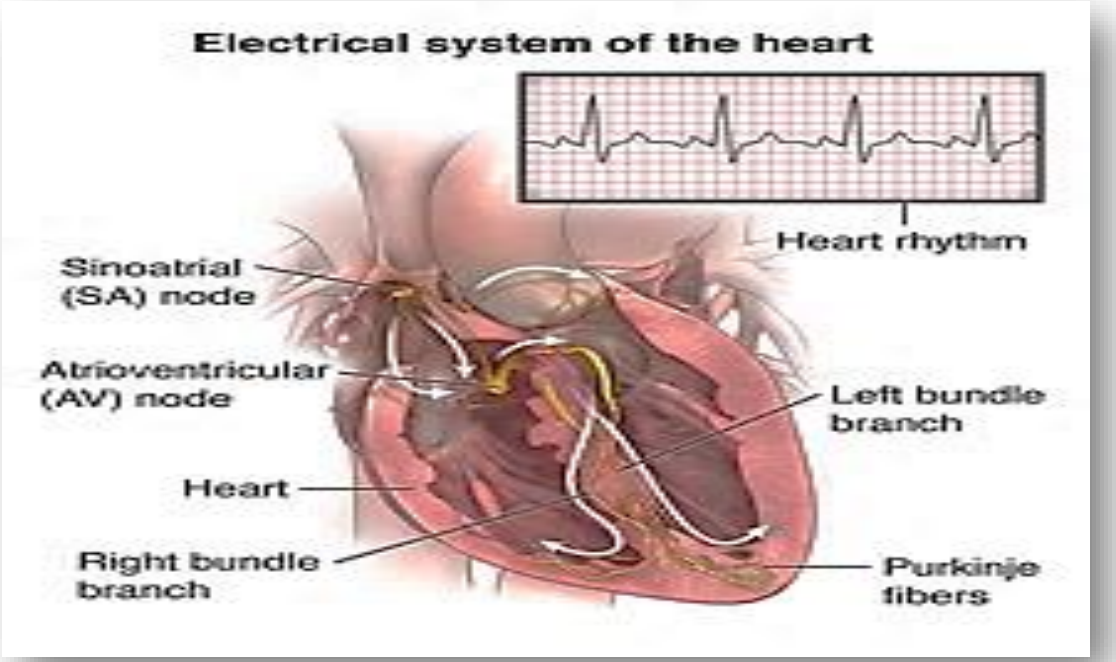
- It has the **highest** rhythm **(90-110; 100/minute)**.
- So, it is called the **normal** or **1ry pacemaker** of the heart.
- Its rhythm is called **sinus rhythm**.

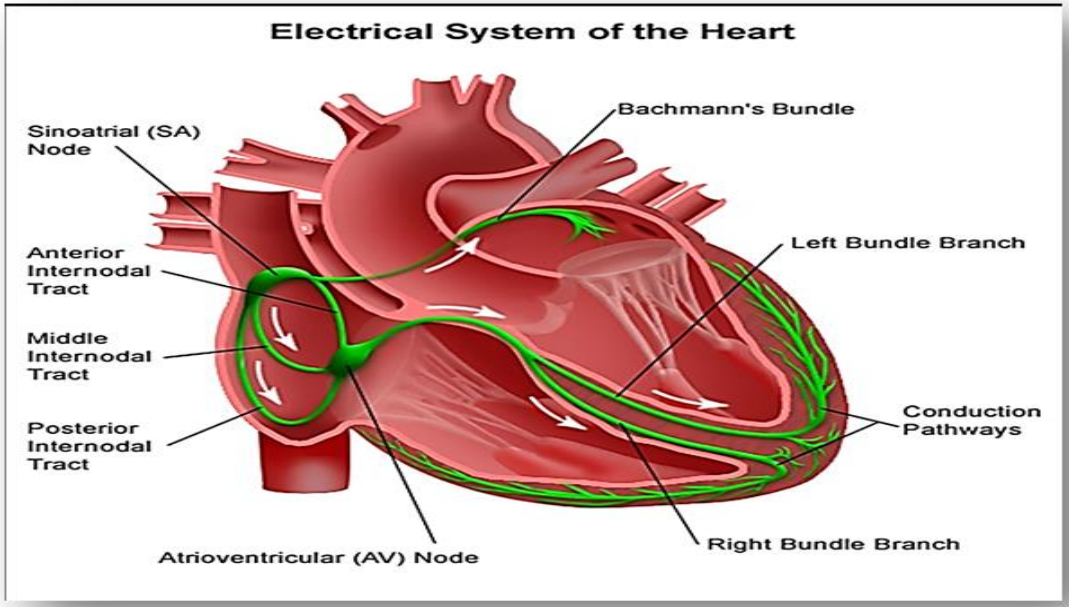
2. Atrioventricular (AV) Node (2ry Pacemaker):

- ✓ Its rate is **45-60 /minute.**
- ✓ It acts **only** if **SA node is damaged or blocked.**
- ✓ Its rhythm is called **nodal rhythm**.

3. Purkinje fibres (3ry Pacemaker):

- Its rate is **25-40 /minute.**
- It takes over **only** if the conduction in **AV node is completely blocked**.
- Its rhythm is called **idioventricular rhythm**.


Electrical system of the heart
Heart rhythm
Sinoatrial (SA) node
Atrioventricular (AV) node
Left bundle branch
Heart
Right bundle branch
Purkinje fibers


Electrical System of the Heart
Bachmann's Bundle
Sinoatrial (SA) Node
Left Bundle Branch
Anterior Internodal Tract
Middle Internodal Tract
Conduction Pathways
Posterior Internodal Tract
Atrioventricular (AV) Node
Right Bundle Branch

N.B.

Although the rhythmicity of the SAN is ~ **100 /min**, the resting heart rate is **only about 75 beat/min**, **why**?

ANSWER:

This is due the **continuous inhibitory discharge** from the vagus nerve on SAN **decreasing** its inherited rhythm from **100 to 75 beat/min**. This called **VAGAL TONE**.

The vagus nerve **supplies** the whole cardiac muscle **except** the **ventricles** (i.e. called **VAGAL ESCAPE PHENOMENON).** This phenomenon **protects** the ventricles from **abnormally high** vagal stimulation (which can cause **cardiac arrest**).

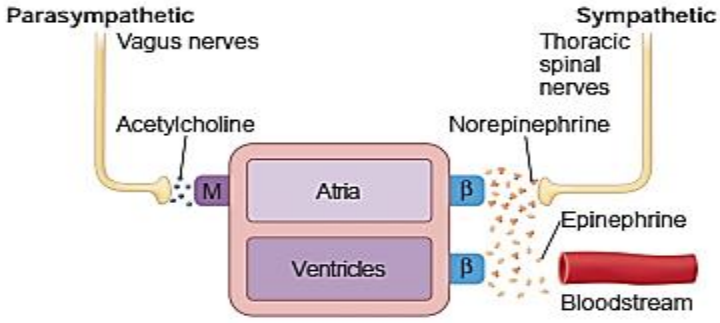


Figure 12.9 Autonomic innervation of heart. Neurons shown represent postganglionic neurons in the pathways. M 5 muscarinic-type ACh receptor; b 5 b-adrenergic receptor.

Factors affecting rhythmicity (Chronotropism)

- The effect of various factors on rhythmicity is called chronotropism.
- The factors that stimulate rhythmicity (accelerating the heart rate) are called + ve chronotropic factors, while factors that inhibit rhythmicity (slowing the heart rate) are called - ve chronotropic factors.

A . Nervous Factors:

1. Parasympathetic (Vagal) stimulation via **acetylcholine (ACh) → (-ve) chronotropic effect.**

So, the rate of SA node discharge is decreased (e.g. bradycardia).

2. Sympathetic stimulation via **noradrenaline (NA) or norepinephrine (NE) → (+ve) chronotropic effect. So, the rate of SA node discharge is increased (e.g. tachycardia).**

B. Chemical Factors:

1. **Catecholamines**: ↑ rhythmicity.
2. **Thyroxine**: ↑ rhythmicity
3. **Acetyl choline (ACh):** ↓ rhythmicity.
4. **Effect of Drugs:**

- **Sympathomimetic drugs → ↑** rhythmicity.
- **Parasympathomimetic drugs (i.e. cholinergic drugs) → ↓** rhythmicity.

C. Physical Factors:

A rise of body temperature (e.g. in muscular exercise or fever)→ ↑ rhythmicity (heart rate; HR) due to increased rate of discharge of SAN.

Hypothermia→ ↓ rhythmicity due to decreased rate of discharge of SAN.

2. Excitability

Excitability: It means the ability of the cardiac muscle to **respond** to **stimulation**.

The cardiac muscle is **self-excited** by signals **generated** in specific **pacemaker cells** and **conducted** via an **excitatory conductive system** to **generate** an action potential **called (i.e. Cardiac muscle or FAST response Action Potential).**

The **RMP** of the cardiac muscle is ~ **(-90 mV)**.
When the cardiac muscle is **stimulated** → an **Action Potential** is generated which is **responsible** for **initiating** cardiac muscle **contraction**.

Factors that affect myocardial excitability

1. Nervous factors:

Sympathetic stimulation increases the excitability.

Parasympathetic stimulation decreases the excitability.

2. Chemical factors:

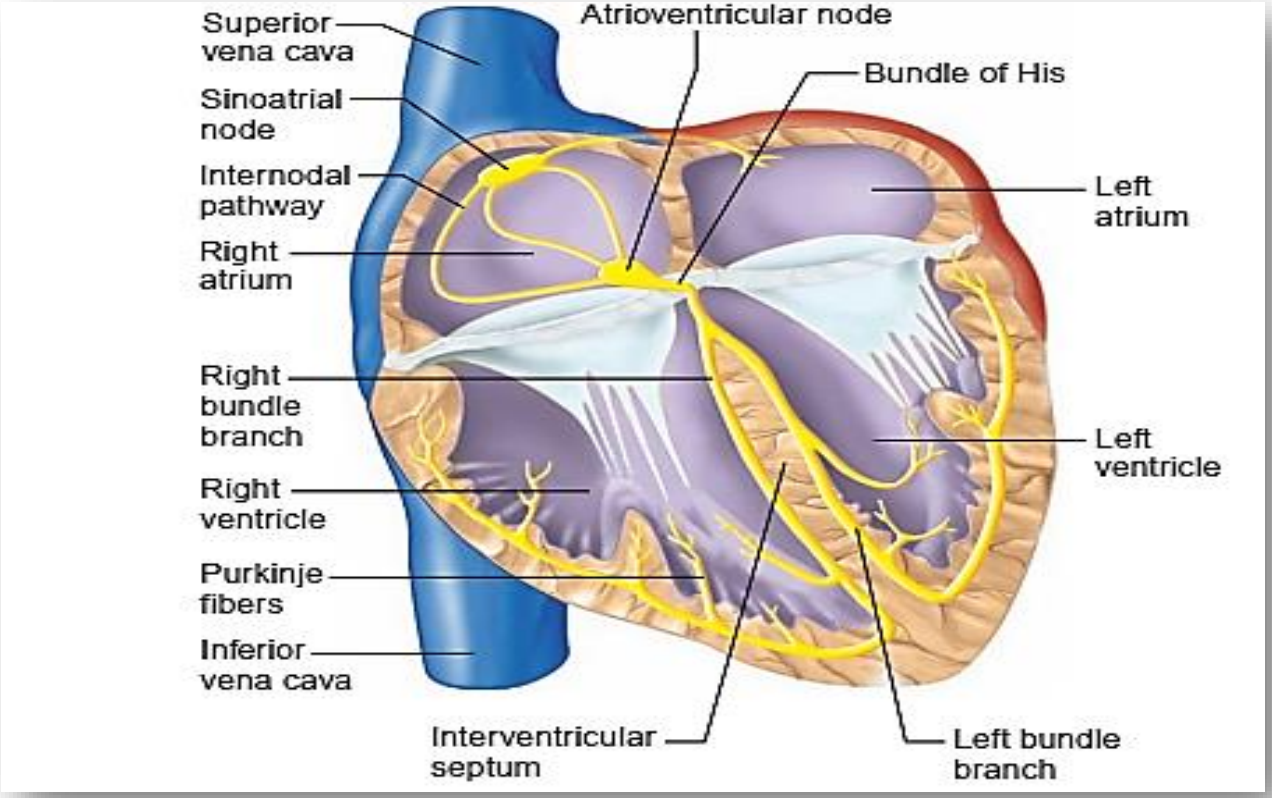
- Hormones: catecholamines and thyroxine increase the myocardial excitability.
- Hypoxia and ischemia: decrease the myocardial excitability.

3. Physical factors:

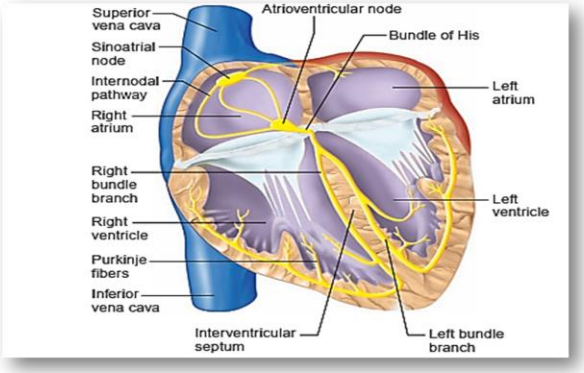
An increase in body temperature increases cardiac excitability and vice versa.

3. Conductivity

It **means** the ability of the cardiac muscle to **transmit** the excitation wave (action potentials) originating in SAN **from** one part of the heart to another **through a highly-specialized conduction system.**



The Cardiac Conduction System



It consists of the following 3 parts

1. The nodal system:

This includes 2 nodes present in the right atrium.

- **The SAN.**
- **The AVN**.

2. The internodal system:

It includes the following 3 tracts (or bundles), which are located in the right atrial wall and consist of:

- The anterior internodal tract: this gives an interatrial bundle to the left atrium (Bachmann's bundle.
- The middle internodal tract.
- The posterior internodal tract.

3. The His-Purkinje System:

It includes the following 3 structures:

- The AV bundle (AVB; bundle of His): It arises from AVN and passes to the ventricles.

It is the only normal muscular connection between the atria and the ventricles.

- The right and left bundle branches.
- The Purkinje fibers: These are fine fibers that arise from both right and left bundle branches.

They convey excitation to the ventricular muscle.

Normal Spread of Cardiac Excitation

1. Sinoatrial (SA) node (NORMAL pacemaker):

Here the initial impulses start → then conducted to the atrial muscle mass **through** the gap junction and to the left atrium **through** the anterior inter-atrial bundle(Bachmann's bundle).

and to → the AVN **through** anterior, middle, and posterior inter-nodal pathways.

The average velocity of conduction in the internodal pathways → one meter/second.

2. Atrioventricular (AV) node (SLOWEST conduction):

There is a DELAY in the conduction occurs in the AV node due to:

- Fewer gap junctions.
- The smaller size of the nodal fiber.

The average velocity of conduction in the AVN → 0.05 meter/second.

Characters of AV nodal conduction

1. One way conduction: the conduction from AVN is a one-way conduction only.

2. AV nodal delay:

Significance:

a. **Allows** atria to empty blood into ventricles during the cardiac cycle **before** the beginning of ventricular contraction.

b. **Protects** the ventricles from the **pathological high atrial rhythm** (to prevent ventricular fibrillation).

N.B.

The **maximum rate of transmission** of impulses through **AV node is about 230 impulse/minute.**

3. AV bundle (Bundle of His)

- It arises from AVN and passes to the ventricles.
- It is **subdivided** into: **Right** and **left** bundles.

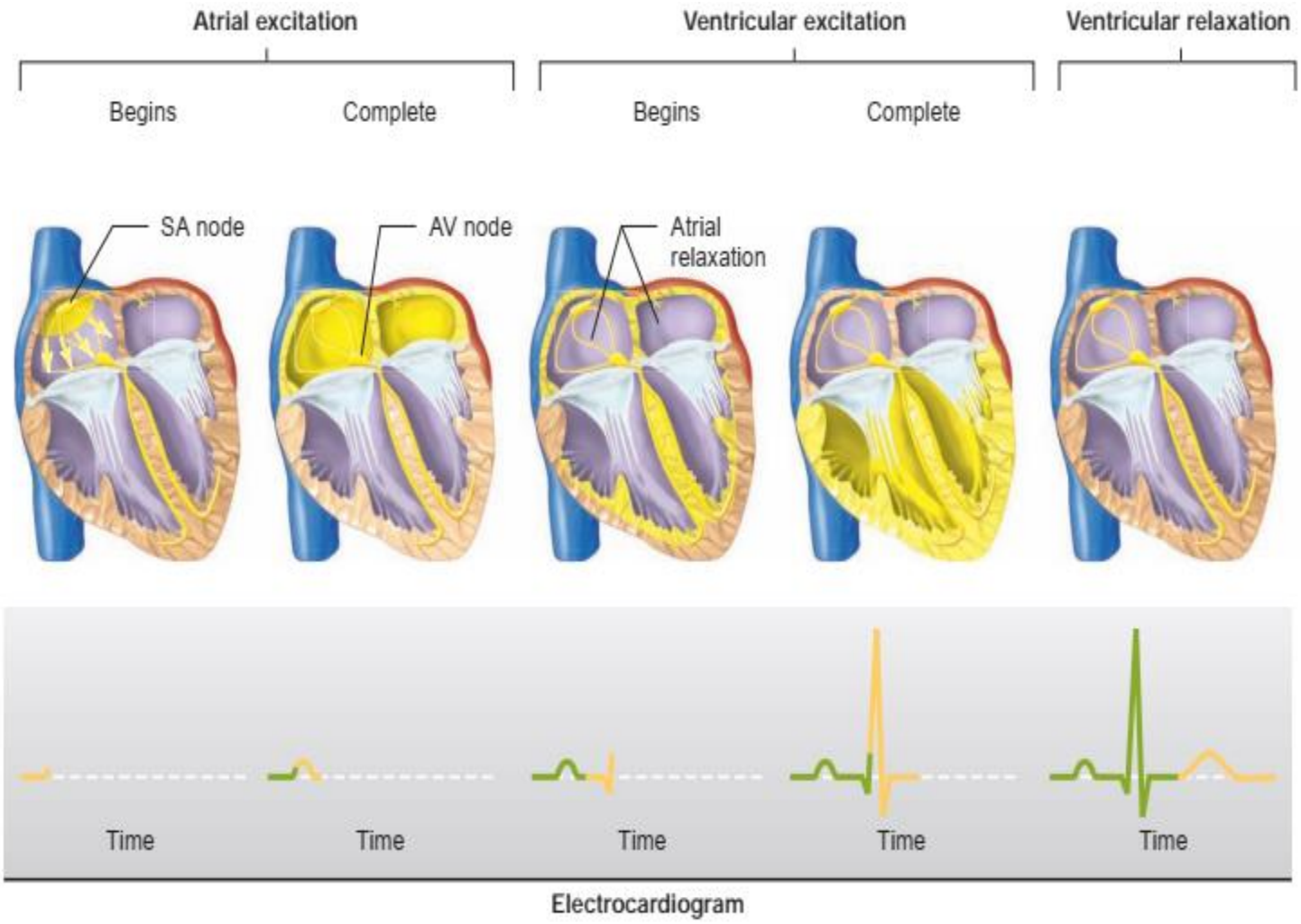
4.Purkinje`s fibers (FASTEST conduction):

- It is formed of fibers that arise from both right and left bundle branches and spread to all parts of **ventricular myocardium**.
- Large fibers with velocity of conduction → **4 meter/second.**
- It **allows** spread of excitation wave to the whole ventricles simultaneously and thus contraction of the both ventricles as **one unit**)

The high conduction velocity of these fibers is due to:

The abundant gap junctions.

Their nature as very large fibers.


Atrial excitation
Ventricular excitation
Ventricular relaxation
Begins
Complete
Begins
Complete
SA node
AV node
Atrial relaxation
Time
Time
Time
Time
Time
Electrocardiogram

Factors affecting cardiac conductivity (i.e. Dromotropism):

I. Positive (+ve) dromotropic factors:

1. Nervous:

Sympathetic stimulation: it accelerates conduction and decreases AV delay.

2. Chemical:

- **Hormones:** e.g. Catecholamines & Thyroxine.
- **Alkalosis.**
- **Drugs**: e.g. Sympathomimetic.

3. Physical: rise of body temperature accelerates conductivity.

II. Negative (-ve) dromotropic factors:

1. Nervous:

Parasympathetic stimulation (vagal): it decreases conduction (atria) and ↑AV nodal delay and may cause heart block.

2. Chemical:

- **Most of electrolyte disturbances** → ↓ conductivity (especially K^+)
- **Acidosis.**
- **Severe ischemia.**
- **Drugs: e.g.** cholinergic drugs.

3. Physical: decreased body temperature.


THANK YOU