Conducting System of the Heart (Junctional Tissue)

Dr.Viral I. Champaneri, MD

Assistant Professor

Department of Physiology

Conducting System of the Heart

- **Heart has→ Special system**
- **That Generates →Electrical impulses**
- **To Cause →Rhythmic Contractions**

Conducting System of the Heart

- **Heart →**
- **Specialized pathway →**
- **Conducts → Electrical impulses**

Electrical impulses

- **Allow the atria to contract**
- **Before ventricles →**
- **Proper filling of the ventricles**
- **Ventricles pumps the**
- **Blood to the various parts of the body**

Conducting System of the Heart

- **This special system which is**
- **Combination of**
- **Specialized *excitable tissues* & *Pathway***
- **Conducting system & Junctional tissue**

Conducting System of the Heart

1. **Sinoatrial node (SA node)**
2. **Atrioventricular node (AV node)**
3. **Bundle of His**
4. **Right & Left Bundle branches (RBB & LBB)**
5. **Purkinje fibers**

SA node (Sinoatrial node)

- **Small**
- **Flattened**
- **Ellipsoid strip of Specialized cardiac tissue**

SA node (Sinoatrial node)

- 3 mm Wide
- 15 mm Long
- 1 mm Thick

SA node → Location

- Superior Posterolateral wall of the Right atrium
- Immediately below and
- Slightly lateral to the
- Opening of the Superior vena cava (SVC)

SA node ➔ Location

- **At the junction of the**
- **Superior vena cava (SVC) and**
- **The Right atrium (RA)**

SA node (Sinoatrial node)

- **Fibers → No contractile muscle filaments**
- **In diameter 3 to 5 micrometers**
- **Diameter of 10 to 15 micrometers**
- **For the surrounding Atrial muscle fibers**

SA node→ Development

- Develops from →

- Right-sided embryonic structure

SA node → Innervation

- The Right Vagus
- Right X^{th} CN → Parasympathetic
- Mainly distributed to → SA node

SA node → Pacemaker

- **Primary (Normal) pacemaker**
- **Generates → Maximum number of impulses**
- **70-80 / minute**
- **Sets the pace of the heartbeat → Pacemaker**

Automatic Electrical Rhythmicity of the Sinus Fibers

- **Some Cardiac fibers have the capability of ➔**
- ***"Self-excitation" ➔***
- ***A process that can cause Automatic***
- ***Rhythmical discharge and contraction***

Automatic Electrical Rhythmicity

- **Capability → *Automatic Rhythmical discharge and contraction***
- **Is especially true of the fibers of**
- **The heart's specialized conducting system**

Automatic Electrical Rhythmicity of the Sinus Fibers

- **The Fibers of the sinus node (SA node)**
- **For this reason...**
- **The sinus node ordinarily**
- **Controls the rate of beat of the entire heart**

Self excitation of SA nodal Fibers

1. **Action potential**
2. **Recovery from the action potential**
3. **Hyperpolarization → After the action potential is over**

Self excitation of SA nodal Fibers

4. **Drift of the "Resting" potential to Threshold**

5. **Finally re-excitation to elicit another cycle**

- ***Process continues throughout a person's life***

Cardiac Muscles 3 membrane Ion Channels

1. ***Fast sodium channels***

2. ***L-type calcium channels***

   (Slow sodium-calcium channels)

3. ***Potassium channels***

Pacemaker Potential

- The cells of the SA node
- Do not maintain a
- Resting Membrane Potential (RMP)
- In the manner of
- Resting neurons or skeletal muscle cells

Pacemaker Potential / Prepotential

- **During the period of Diastole (Relaxation)**
- **The SA node exhibit →**
- ***Slow Spontaneous depolarization***
- ***Called the → Pacemaker potential / Prepotential***

Resting Membrane Potential of SA node

- **“Resting membrane potential”**
- **Of the Sinus nodal (SA) fiber**
- **Between discharges**
- **– 55 mV to – 60 millivolts**

RMP of SA node : – 55 to – 60 mV

- **In comparison with**
- **– 85 to – 90 millivolts**
- **Of the ventricular muscle fiber**

Cause of this Lesser Negativity

- **Cell membranes of the sinus fibers**
- **Naturally leaky to Na^{+} and Ca^{2+} ions**
- **Positive charges of the entering Na^{+} and Ca^{2+} ions**
- **Neutralize some of the intracellular negativity**

Self excitation of Sinus Nodal fibers

- **High sodium ion concentration [Na^+] ➔**
- **In the ECF outside➔ SA nodal fiber**
- **Moderate number of ➔already open Na^+ channels**
- **Na^+ from outside ➔**
- **Normally tend to leak to the Inside (Influx)**

Inherent leakiness to Na^{+} & Ca^{2+}

- **SA nodal fibers**
- **To Na^{+} and Ca^{2+} ions**
- **Causes → *Self-excitation* → *Autorythmicity***

Between Heartbeats

- **Influx of positively charged Na^+ ions**
- **Causes → Slow rise in the RMP**
- **In the Positive direction**
- **Become → Less negative**

Potential Reaches → Threshold voltage

- **−40 millivolts**
- ***L-type calcium channels* become → "Activated"**
- **Causing the action potential**

SA nodal fibers → Not depolarized all the time

- **2 events occur →**
- **During the course of the action potential**
- ***To prevent such a constant state of depolarization***

Cardiac Muscles 3 membrane Ion Channels

1. ***Fast sodium (Na^{+})channels***

2. ***L-type calcium (Ca^{2+})channels***

   [Slow sodium-calcium (Na^{+}-Ca^{2+}) channels]

3. ***Potassium (K^{+}) channels***

1^{st} Event ➔ Closure of L –Type Ca^{2+} channel

- ***Slow sodium-calcium channel***
- **L-type calcium channels become ➔ Inactivated**
- **Closes ➔ Within about 100 to 150 milliseconds**
- **After opening**

1st Event → Closure of L –Type Ca^{2+} channel

- **Influx of**
- **Positive Calcium (Ca^{2+}) and Sodium (Na^{+}) ions**
- **Through the L-type calcium channels → Ceases**

2nd Event → K^+ Channels → Open

- **At about the same time,**
- **Greatly Increased numbers of**
- **Potassium (K^+) channels → Open**

2nd Event → K^+ Channels → Open

- **Potassium (K^+) channels → Open**
- **Large quantities of Positive Potassium ions**
- **Diffuse out → Of the fibre**

2^{nd} Event → K^+ Channels → Open

- **Remain open for another → Few *10^{th} of a second***
- **Temporarily continuing movement of**
- **Positive charges (K^+) out of the cell**

Both these 2 events

- **Reduce intracellular potential**
- **Back to → Negative resting level (-55 to -60 mV)**
- **Terminate → SA nodal action potential**

Hyperpolarization State

- **Excess negativity inside the fiber**
- **Initially carries**
- **The “Resting” membrane potential**
- **Down to about ➔ – 65 mV to – 75 mV**
- **At the termination of the action potential**

Hyperpolarization → Not maintained forever

- **The *next few 10th of a second***
- **After the Action potential is over**
- **Progressively**
- **More and More potassium (K^+) channels → Close**

Inward – Leaking Na^+ and Ca^{2+} ions

- **Once again overbalance ➔**
- **Outward flux of K^+ ions**
- **Causes the "Resting" potential**
- **To drift upward once more**

Again RMP reach Threshold level → – 40 mV

- **Finally reaching the Threshold level**
- **For discharge**
- **At a potential of about – 40 millivolts**

Secondary Pacemaker Regions

- **Two potential or secondary pacemaker regions**
- **The *AV node and Purkinje fibers* are**
- **Normally suppressed by….**
- **Action potentials originating in the SA node potential**

Clinical Physiology
Sick Sinus Syndrome

- **Disease affecting SA-node**
- **Characterized by….**
  - **Bradycardia (Heart rate < 60 bpm)**
  - **Dizziness**
  - **Syncope**

AP From SA node → AV Node

- **Sinus nodal fibers**
- **Connect directly with the atrial muscle fibers**
- **Action potential that begins in the sinus node**
- **Spreads immediately into the Atrial muscle wall**

Internodal & Interatrial Pathways

- Ends of the sinus nodal (SA) fibers
- Connect directly
- With surrounding Atrial muscle fibers

Internodal & Interatrial Pathways

- **Action potentials originating**
- **In the Sinus node (SA node)**
- **Travel outward into Atrial muscle fibers**

Internodal & Interatrial Pathways

- **The Action potential**
- **Spreads through the entire Atrial muscle mass**
- **Eventually → To the A-V node**

Velocity of conduction in Atrial Muscle

- **0.3 m/sec**

Anterior Interatrial Band

- **Passes through → *Anterior walls of the atria***
- ***To the Left atrium***
- **Conduction is *more rapid* → *About 1 m/sec***

3 Internodal Atrial Pathways

- **3 other small bands**
- **Curve through**
- **The Anterior, Lateral, Posterior Atrial walls**
- **Terminate in the → A-V node**

3 Internodal Atrial Pathways

1. **Anterior bundle of Bachmann**
2. **Middle bundle of Wenckebach**
3. **Posterior bundle of Thorel**

3 Internodal Atrial Pathways

- **Fibers are similar to**
- **Even more rapidly conducting**
- **“Purkinje fibers” of the ventricle**

3 Internodal Atrial Pathways

- **Cause of more rapid velocity of conduction in these 3 bands**
- ***Presence of Specialized conduction fibers***

AV node delays impulse : Atria → Ventricles

- **Atrial conductive system is organized such**
- **The cardiac impulse → Does not travel**
- **From the atria into → The ventricles too rapidly**

Importance of A-V nodal delay

- **Allows time → For the atria**
- **To empty their blood into the ventricle**
- **Before → Ventricular contraction begins**

A-V node & Adjacent conductive fibers

- **Delay this transmission into the ventricles**

A-V node → Location

- In the
- Posterior wall of the Right atrium (RA)
- Immediately
- Behind the tricuspid valve (RA → RV)

A-V node → Development

- Develops from→
- Left-sided embryonic structures
- Between Atrium and Ventricle
- Closed to the AV opening

A-V node → Innervation

- **Innervated by →**
- **<u>Left</u> Vagus →Xth CN →Parasympathetic**

A-V node → Produce Impulse

- Can produce impulses at rate →
- 50-60 / min

Penetrating A-V bundle

- **Composed of multiple small fascicles**
- **Passing through → The fibrous tissue**
- **Separating the atria from the ventricles**

Interval of time taken by Cardiac Impulse to travel

Origin of Impulse (From)	Reaches	Time taken (Seconds)	Delay (Seconds)	Total Delay (Seconds)
SA node	A-V node	0.03 sec	0.03 sec	0.03 sec
A-V node	Penetrating Portion of A-V bundle	0.12 sec	0.09 sec	0.12 sec
Penetrating Portion of A-V bundle	Contracting muscles of Ventricles	0.16 sec	0.04 sec	0.16 sec

Cause of Slow Conduction

- **Transitional, Nodal, and Penetrating A-V bundle fibers mainly by...**
- **Diminished numbers of gap junctions**
- **Between → Successive cells**
- **In the conducting pathways**

Cause of Slow Conduction

- **Diminished numbers of gap junctions**
- **In the conducting pathways**
- **So, Great resistance to conduction of**
- **Excitatory ions**
- **From one conducting fibre to the next**

Bundle of His (Hiss)

- **Beginning ➔**
- **At the top of the interventricular septum.**
- **Pierces ➔**
- **The fibrous skeleton of the heart**
- **Continues➔**
- **To descend along the interventricular septum**

Right & Left Bundle Branch

- **The Atrioventricular Bundle of Hiss divides ➔**
- **Into**
- **Right (RBB) and Left (LBB) bundle branches**

One way conduction through A-V bundle

- **A-V bundle → is Unable to travel**
- **Action potentials**
- **Backward from → The Ventricles to → The Atria**
- **Except → In abnormal states**

One way conduction through A-V bundle

- **Prevents re-entry of cardiac impulses ➔**
- **By this route from the ventricles to the atria**
- **Allowing ➔ Only forward conduction**
- **From the atria to the ventricles**

Continuous Fibrous Barrier

- **The Atrial muscle**
- **Is separated from the Ventricular muscle**
- **By a Continuous fibrous barrier**
- **Except ➔ At the A-V bundle**

Continuous Fibrous Barrier ➔Function

- **Normally acts as an ➔ Insulator**
- **To prevent passage of the cardiac impulse**
- **Between atrial and ventricular muscle**
- **Through any other route**

Re-entry of Cardiac impulse → Prevented

1. **Forward conduction through the A-V bundle**

2. **Insulator continuous fibrous barrier**

Rare instances → Abnormal Muscle Bridge

- **Penetrate the fibrous barrier elsewhere**
- **Besides at the A-V bundle**
- **Cardiac impulse can → Re-enter the atria**
- **From the ventricles →**
- **Serious cardiac arrhythmias**

Ventricular Purkinje System

- **Special Purkinje fibers**
- **Lead → from the A-V node**
- **Through → The A-V bundle into → Ventricles**
- **Generate impulse at → 15-40 impulses / min**

Initial Portion of Purkinje System

- **Where → They penetrate the A-V fibrous barrier**
- **They have Functional characteristics**
- **Quite the opposite of those of the A-V nodal fibers**

Purkinje System :1.5 to 4.0 m/sec

- **Very large fibers**
- **Even larger than the normal ventricular muscle fibers**
- **Transmit action potentials at a velocity of**
- **1.5 to 4.0 m/sec**

Purkinje System : Velocity of conduction

- **6 times that in the usual ventricular muscle**
- **150 times that in some of the A-V nodal fibers**
- **Instantaneous transmission of the cardiac impulse**
- **Throughout the entire remainder of the ventricular muscle**

Rapid Transmission of AP by Purkinje fibers

- **Very high level of permeability of the gap junctions**
- **At the intercalated discs**
- **Between the successive cells make Purkinje fibers**

Rapid Transmission of AP by Purkinje fibers

- **High level of permeability of the gap junctions**
- **Ions are transmitted**
- **Easily from one cell to the next**
- **Enhancing the velocity of transmission**

Ventricular Purkinje System

- Contain Very few myofibrils
- They contract little or not at all
- During the course of impulse transmission

Distribution of Purkinje fibers in ventricles

- **After penetrating**
- **The continuous fibrous tissue**
- **Between the Atrial and Ventricular muscle**

Distribution of Purkinje fibers in Ventricles

- **The distal portion of the A-V bundle**
- **Passes downward in the ventricular septum**
- **For 5 to 15 millimeters**
- **Toward the apex of the heart**

Right & Left Bundle Branch

- **The Atrioventricular bundle divides...**
- **Into**
- **Right and Left bundle branches**

Distribution of Purkinje fibers in ventricles

- **The A-V bundle divides**
- **Into Left and Right bundle branches**
- ***Lie beneath* the *Endocardium***
- **On the two respective**
- ***Sides of the ventricular septum***

Left and Right Bundle Branch

- **Each branch spreads**
- ***Downward toward the apex of the ventricle***
- **Progressively dividing ➔ Into smaller branches**

Smaller branches ➔

- **In turn course**
- ***Sidewise* around each ventricular chamber**
- **Left & Right Ventricular Chamber**

Smaller branches ➔

- **Turn**
- **Back**
- **Toward the base of the heart**

End of Purkinje Fibers Penetrate

- **About one third (1/3rd) of the way**
- **Into the muscle mass**
- **And finally become**
- **Continuous with ➔ The cardiac muscle fibers**

Total elapsed Time → Avg. 0.03 sec

- **From → The time the cardiac impulse → Enters**
- **The bundle branches in the ventricular septum**
- **Until**
- **It reaches the terminations of the Purkinje fibers**

Once Cardiac Impulse Enters Purkinje system

- **It spreads → Almost → Immediately**

- **To the *entire* ventricular muscle mass**

Transmission of Cardiac Impulse in Ventricular muscle

- **Once the impulse**
- **Reaches the ends of the Purkinje fibers**
- **It is transmitted through the ventricular muscle mass by the ventricular muscle fibers themselves**

Velocity of Transmission in Ventricular Muscle

- **0.3 to 0.5 m/sec**
- **One sixth (1/6th)**
- **That in the Purkinje fibers**

Cardiac Muscle Wraps the Heart

- **In a double spiral**
- **With Fibrous septa**
- **Between the Spiraling layers**

Cardiac Muscle Wraps the Heart

- **Directly**
- **Outward toward the surface of the heart**

Cardiac Impulse → Angulates

- **Instead Angulates**
- **Toward the surface**
- **Along the directions of the spirals**

Because of Angulation

- **Transmission**
- **From → Endocardial surface**
- **To → Epicardial surface of the ventricle**
- **Requires → Another 0.03 second**

0.03 sec ➔ Approximately equal to the time

- **Required for transmission through**
- **The entire ventricular portion of the purkinje system**

Total time → 0.06 sec

- **For transmission of the cardiac impulse**
- **From → The initial bundle branches**
- **To → The last of the ventricular muscle fibers**
- **In the Normal heart is about *0.06 second***

Summary of Spread of Cardiac Impulse

- **Origin of the cardiac impulse in ➔ Sinus node**
- **Impulse spreads ➔**
- **At moderate velocity through the atria**
- **Atrial depolarization is complete in about 0.1 s**

Summary of Spread of Cardiac Impulse

- **Delayed > 0.1 second in A-V nodal region**
- **Before**
- **Appearing in the ventricular septal A-V bundle**

Summary of Spread of Cardiac Impulse

- **Because conduction in the AV node is ➔ slow**
- **A delay of about 0.1 s (AV nodal delay)**
- **Occurs before excitation spreads to the ventricles**

AV Nodal Delay

- **When there is a lack of contribution of I_{Na}**
- **In the depolarization (phase 0) of the action potential**
- **A marked loss of conduction is observed**

AV Nodal Delay (0.1 s) → Shortened

- **Stimulation of**
- **The sympathetic nerves to the heart**

AV Nodal Delay (0.1 s) → Lengthened

- **Stimulation of**

- **The Vagi (Xth - CN →Parasympathetic**

Impulse enter in Bundle of His

- **Once it has entered this bundle,**
- **It spreads very rapidly**
- **Through the Purkinje fibers**
- **To the entire endocardial surfaces of the ventricles**

Impulse enter in Bundle of His

- **From the top of the septum**
- **The wave of depolarization spreads**
- **In the rapidly conducting → Purkinje fibers**

Purkinje fiber ➔ Ventricles

- **To all parts of ventricles**
- **Impulse spreads ➔ 0.08 – 0.1 sec**

In Humans ➔ Direction of Spread of Impulse

- **Depolarization of the ventricular muscle**
- **Starts ➔**
- **At the Left side of the interventricular septum**

In humans ➔Direction of Spread of Impulse

- **Moves ➔ First to the right**
- **Across the mid portion of the interventricular septum**

In humans ➔ Direction of Spread of Impulse

- **The wave of depolarization then**
- **Spreads down the septum**
- **To the apex of the heart**

In humans → Direction of Spread of Impulse

- **Returns along the ventricular walls →**
- **To the AV groove**
- **Proceeding**
- **From the Endocardial to → the Epicardial surface**

Last portion of Heart to be Depolarized

1. **Posterobasal portion of the left ventricle**
2. **Pulmonary conus**
3. **Uppermost portion of the septum**