

**Heart's Electrical Conduction System**

The heart is primarily made up of muscle tissue. A network of nerve fibers coordinates the contraction and relaxation of the cardiac muscle tissue to obtain an efficient, wave-like pumping action of the heart.

**SA Node:**

- The **sinoatrial node** (abbreviated SA node or SAN, also called the sinus node) is the **impulse generating** (pacemaker) tissue, a group of cells positioned on the wall of the right atrium, near the entrance of the superior vena cava.
- These cells are modified cardiac myocytes. They possess some contractile filaments, though they do not contract. Cells in the SA node will naturally discharge (create action potentials) at about 70-80 times/minute. Because the sinoatrial node is responsible for the rest of the heart's electrical activity, it is sometimes called the primary pacemaker.
- **Although all of the heart's cells possess the ability to generate the electrical impulses** (or action potentials) that trigger cardiac contraction, the sinoatrial node is what normally initiates it, simply because it *generates impulses slightly faster than the other areas* with pacemaker potential. Because cardiac myocytes, like all nerve cells, have refractory periods following contraction during which additional contractions cannot be triggered, their pacemaker potential is overridden by the sinoatrial node.
- The SA node emits a new impulse before either the AV or Purkinje fibers reach threshold.
- If the **SA node doesn't function**, or the impulse generated in the SA node is blocked before it travels down the electrical conduction system, a group of cells further down the heart will become the heart's pacemaker. These cells form the atrioventricular node (AV node), which is an area between the right atrium and ventricle, within the atrial septum.
- The *impulses from the AV node will maintain a slower heart rate* (about 40-60 beats per a minute).
- When there is a pathology in the AV node or Purkinje fibers, an ectopic pacemaker can occur in different parts of the heart. The ectopic pacemaker typically discharges faster than the SA node and causes an abnormal sequence of contraction.

**Note:** An **ectopic pacemaker** or **ectopic focus** is an excitable group of cells that causes a premature heart beat outside the normally functioning [SA node](#) of the human [heart](#)

**AV Node :**

- The **Atrioventricular Node** (abbreviated AV node) is the tissue between the atria and the ventricles of the heart, which *conducts the normal electrical impulse from the atria to the ventricles*.
- The **AV node receives two inputs** from the atria: posteriorly via the crista terminalis, and anteriorly via the interatrial septum.

- The atrioventricular node **delays impulses** for 0.1 second before spreading to the ventricle walls. The **reason** it is so important to **delay the cardiac impulse** is to ensure that **the atria are empty completely before the ventricles contract**.

### **AV Bundle :**

- The **Bundle Of HIS** is a collection of heart muscle cells specialized for electrical conduction that transmits the electrical impulses from the **AV node** (located between the atria and the ventricles) to the point of the **apex of the fascicular branches**.
- The fascicular branches then lead to the **Purkinje fibers** which **innervate** (Supply nerves to (some organ or body part) the ventricles, causing the **cardiac muscle of the ventricles** to contract at a paced interval.
- Cardiac muscle is very specialized, as it is the only type of muscle that has an internal rhythm; i.e., it is myogenic which means that it can naturally contract and relax without receiving electrical impulses from nerves. When a cell of cardiac muscle is placed next to another, they will beat in unison.
- The **fibers of the Bundle of HIS** *allow electrical conduction to occur more easily and quickly than typical cardiac muscle*. They are an **important** part of the electrical conduction system of the heart as they transmit the impulse from the AV node (the ventricular pacemaker) to the rest of the heart.
- The **bundle of HIS** branches into the three bundle branches: the **Right, Left Anterior** and **Left Posterior** Bundle Branches that run along the intraventricular septum.
- The **bundles give rise** to *thin filaments* known as **Purkinje fibers**. These fibers distribute the impulse to the ventricular muscle.
- **Together, the bundle branches and Purkinje network** comprise the ventricular conduction system. It takes about **0.03-0.04s** for the impulse to travel from the bundle of HIS to the ventricular muscle.
- It is extremely important for these nodes to exist as they ensure the correct control and coordination of the heart and cardiac cycle and make sure all the contractions remain within the correct sequence and in sync.

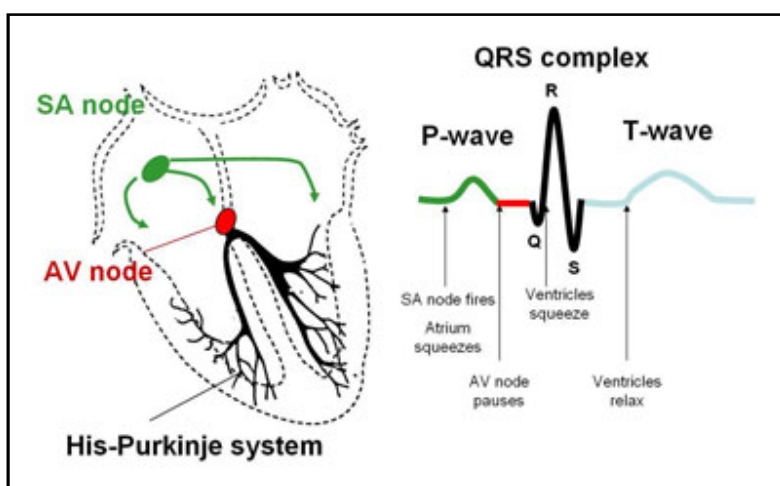
### **Purkinje Fibers:**

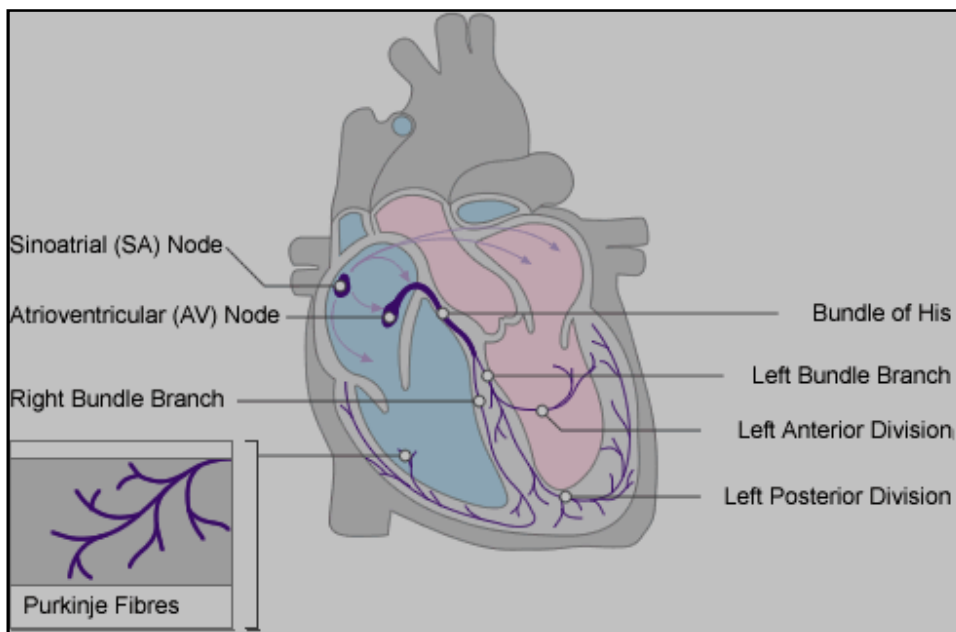
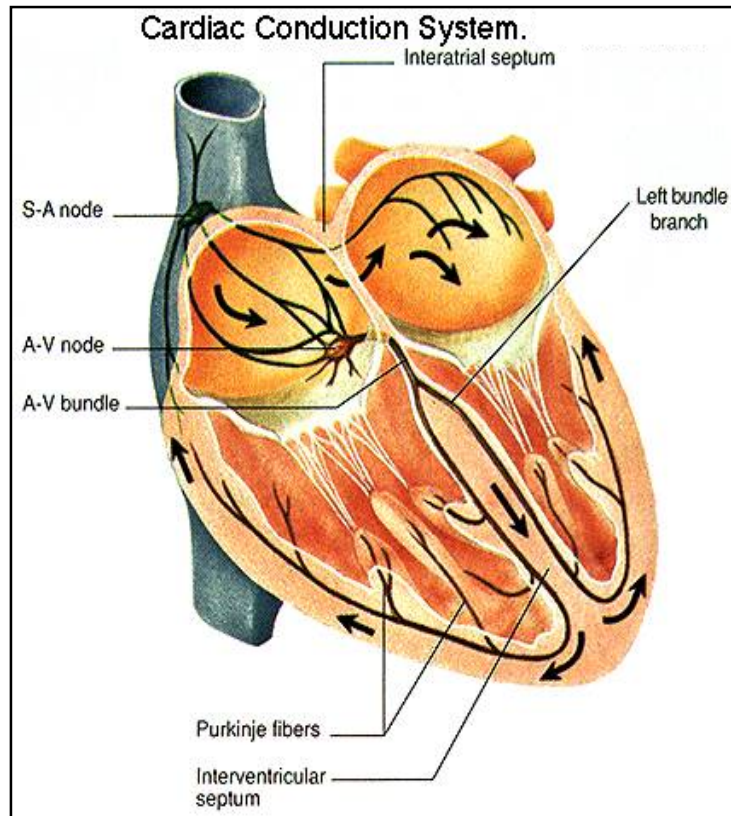
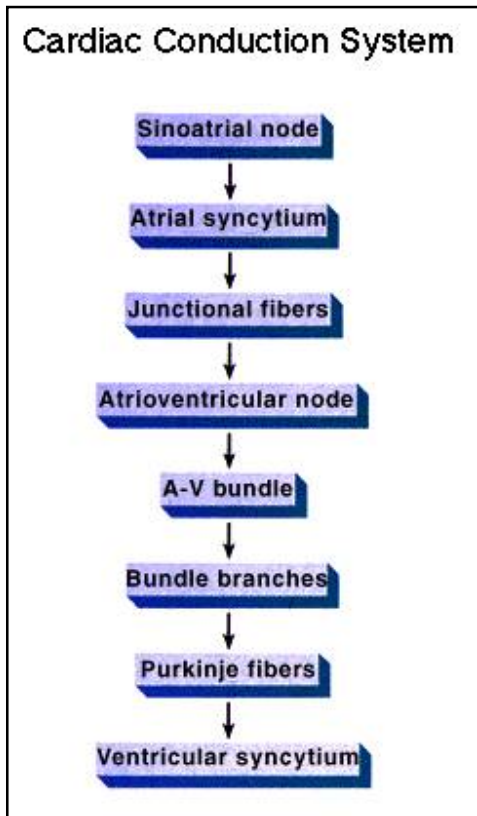
- Purkinje fibers (or Purkyne tissue) are **located** in the **inner ventricular** walls of the heart, just **beneath the endocardium**.
- These fibers are **specialized myocardial fibers** that conduct an electrical stimulus or impulse that *enables the heart to contract in a coordinated fashion*.
- Purkinje fibers work with the sinoatrial node (SA node) and the atrioventricular node (AV node) to control the heart rate.

- During the ventricular contraction portion of the cardiac cycle, the Purkinje fibers carry the contraction impulse from the left and right bundle branches to the myocardium of the ventricles.
- This causes the muscle tissue of the ventricles to contract and force blood out of the heart — either to the pulmonary circulation (from the right ventricle) or to the systemic circulation (from the left ventricle). They were discovered in 1839 by Jan Evangelista Purkinje, who gave them his name.

### **Heart's Electrical Conduction System**

1. **Action Potential** originates in the **sinoatrial (SA) node** and travel across the **wall of the atrium** from the **SA node** to the **atrioventricular (AV) node**.
2. The **SA node** communicates with the **AV node** through something called **junctional fibers**. These junctional fibers are just specialized cardiac muscle cells; they are long and thin, and can carry the action potential from the **SA node** to the **AV node**. However, these junctional fibers are designed to carry the action potential rather slowly. Carrying the action potential slowly is different from firing in a slow rhythm... the rhythm is still fast, but the action potential just takes time running along the junctional fibers. Because they are so slow, that sets up a delay between the activation of the SA node and the activation of the AV node. Since each node's activity leads to contraction of one of the syncytia, the slow characteristics of the junctional fibers is what causes a delay between atrial systole and ventricular systole.
3. AP passes slowly through the **AV node** to give the **atria time to contract**.
4. They then pass rapidly along the **atrioventricular bundle**, which extends from the atrioventricular node through the fibrous skeleton into the **interventricular septum**.
5. The **atrioventricular bundle** divides into **right and left bundle** branches and **action potentials descend** rapidly to the **apex of each ventricle** along the bundle branches.
6. APs are carried by the **Purkinje fibers** from the bundle branches to the **ventricular walls**.
7. The rapid conduction from the **atrio-ventricular bundle** to the ends of the **Purkinje fibers** allows the ventricular muscle cells to contract in unison, providing a strong contraction.





**CONDUCTION SYSTEM OF THE HEART**

- It consists of the sinoatrial (SA) node, the internodal tracts, the atrioventricular (AV) node, the **bundle of His**, the right bundle branch (RBB), the left bundle branch (LBB), and the **Purkinje** network.
- The conduction system of the heart and representative electrical activity from various regions is shown in the figure below.

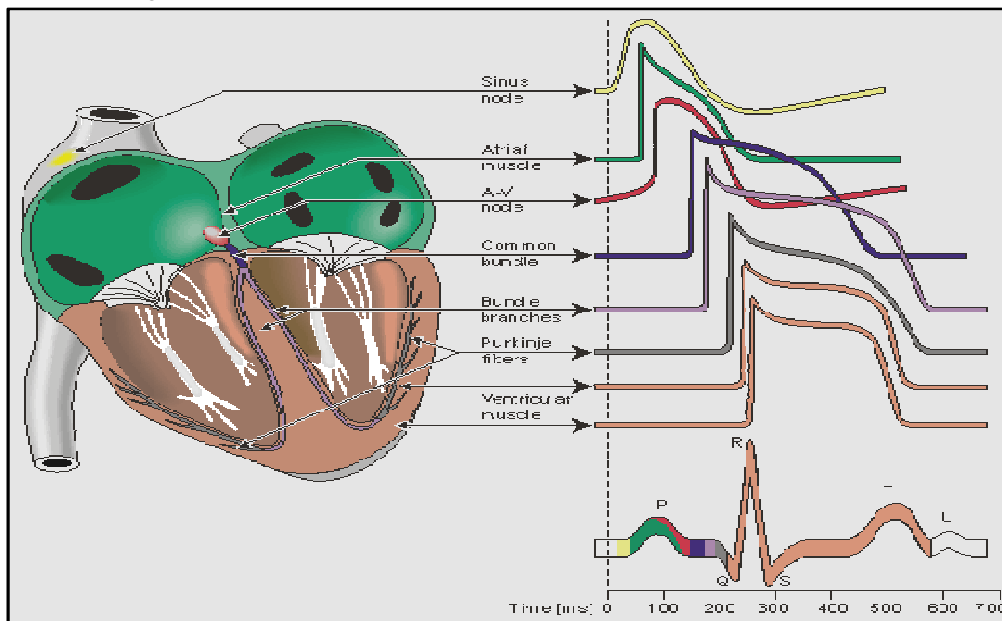


Figure shows: *The contribution of electrical activity of various tissues of the heart in genesis of the ECG signal (the lowest trace)*

- The rhythmic electrical activity of the heart (cardiac impulse) originates in the SA node.
- The impulse then propagates through internodal and interatrial (Buchmans's bundle) tracts.
- As a consequence, the pacemaker activity reaches the AV node by cell-to-cell atrial conduction and activates the right and left atrium in a very organised manner.
- Because atria and ventricles are separated by fibrous tissue, direct conduction of cardiac impulse from the atria to the ventricles can't occur and activation must follow a path that starts in the atrium at the AV node.
- The cardiac impulse is delayed in the AV node for about 100 msec. It then proceeds through the bundle of His, the RBB, the LBB and finally to the terminal Purkinje fibres which arborize and invaginate the endocardial ventricular tissue.
- The delay in the AV node allows enough time for completion of atrial contraction and pumping of blood into the ventricles.
- Once the cardiac impulse reaches the bundle of His, conduction is very rapid, resulting in the initiation of ventricular activation over a wide range.
- The subsequent cell-to-cell propagation of electrical activity is highly sequenced and coordinated resulting in a highly synchronous and efficient pumping action by the ventricles.

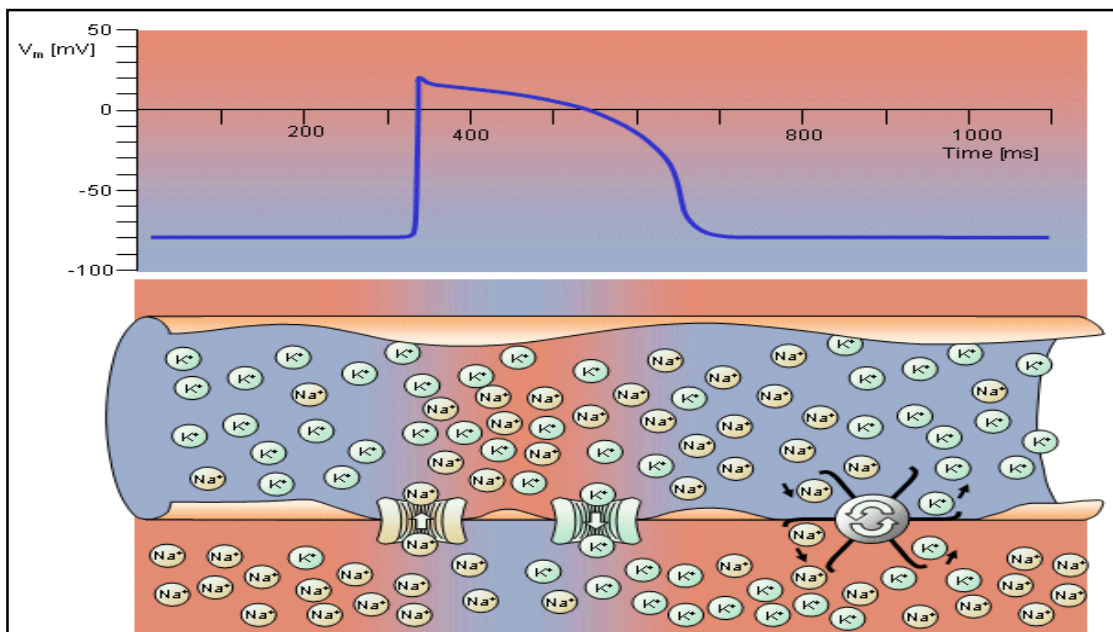
- Essentially, an overall understanding of the genesis of the ECG waveform (cardiac field potentials recorded on the body surface) can be based on a cardiac current dipole placed in an infinite (extensive) volume conductor.

## ELECTRIC ACTIVATION OF THE HEART

In the heart muscle cell, or *myocyte*, electric activation takes place by means of the same mechanism as in the nerve cell - that is, from the inflow of sodium ions across the cell membrane. The amplitude of the action potential is also similar, being about 100 mV for both nerve and muscle. The duration of the cardiac muscle impulse is, however, two orders of magnitude longer than that in either nerve cell or skeletal muscle. A *plateau phase* follows cardiac depolarization, and thereafter repolarization takes place. As in the nerve cell, repolarization is a consequence of the outflow of potassium ions. The duration of the action impulse is about 300 ms, as shown in Figure 6.4 (Netter, 1971).

Associated with the electric activation of cardiac muscle cell is its mechanical contraction, which occurs a little later. For the sake of comparison, Figure 6.5 illustrates the electric activity and mechanical contraction of frog sartorius muscle, frog cardiac muscle, and smooth muscle from the rat uterus (Ruch and Patton, 1982).

An important distinction between cardiac muscle tissue and skeletal muscle is that in cardiac muscle, activation can propagate from one cell to another in any direction. As a result, the activation wavefronts are of rather complex shape. The only exception is the boundary between the atria and ventricles, which the activation wave normally cannot cross except along a special conduction system, since a nonconducting barrier of fibrous tissue is present..



**DEPOLARIZATION REPOLARIZATION RESTORATION OF IONIC BALANCE**

Electrophysiology of the cardiac muscle cell.

## Conduction System of the Heart

Located in the right atrium at the superior vena cava is the *sinus node* (*sinoatrial* or *SA node*) which consists of specialized muscle cells. The sinoatrial node in humans is in the shape of a crescent and is about 15 mm long and 5 mm wide (see Figure 6.6). The SA nodal cells are self-excitatory, *pacemaker cells*. They generate an action potential at the rate of about 70 per minute. From the sinus node, activation propagates throughout the atria, but cannot propagate directly across the boundary between atria and ventricles, as noted above.

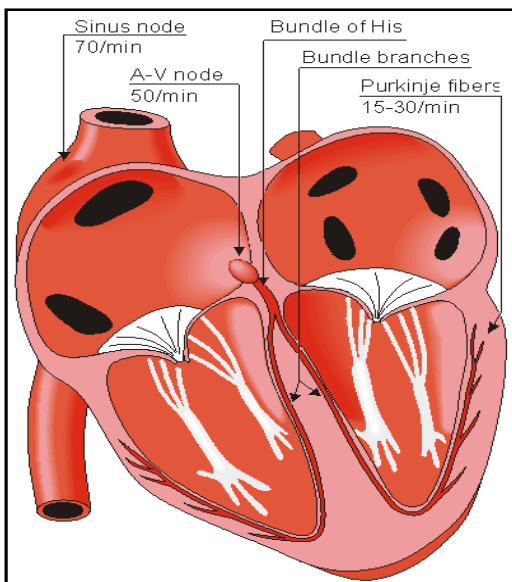
The *atrioventricular node* (AV node) is located at the boundary between the atria and ventricles; it has an intrinsic frequency of about 50 pulses/min. However, if the AV node is triggered with a higher pulse frequency, it follows this higher frequency. In a normal heart, the AV node provides the only



conducting path from the atria to the ventricles. Thus, under normal conditions, the latter can be excited only by pulses that propagate through it.

Propagation from the AV node to the ventricles is provided by a specialized conduction system. Proximally, this system is composed of a common bundle, called the *bundle of His* (named after German physician Wilhelm His, Jr., 1863-1934). More distally, it separates into two *bundle branches* propagating along each side of the septum, constituting the *right* and *left bundle branches*. (The left bundle subsequently divides into an anterior and posterior branch.) Even more distally the bundles ramify into *Purkinje fibers* (named after Jan Evangelista Purkinje (Czech; 1787-1869)) that diverge to the inner sides of the ventricular walls. Propagation along the conduction system takes place at a relatively high speed once it is within the ventricular region, but prior to this (through the AV node) the velocity is extremely slow.

From the inner side of the ventricular wall, the many activation sites cause the formation of a wavefront which propagates through the ventricular mass toward the outer wall. This process results from cell-to-cell activation. After each ventricular muscle region has depolarized, repolarization occurs. Repolarization is not a propagating phenomenon, and because the duration of the action impulse is much shorter at the *epicardium* (the outer side of the cardiac muscle) than at the *endocardium* (the inner side of the cardiac muscle), the termination of activity appears as if it were propagating from epicardium toward the endocardium.



**Fig.** The conduction system of the heart.

Because the intrinsic rate of the sinus node is the greatest, it sets the activation frequency of the whole heart. If the connection from the atria to the AV node fails, the AV node adopts its intrinsic frequency. If the conduction system fails at the bundle of His, the ventricles will beat at the rate determined by their own region that has the highest intrinsic frequency. The electric events in the heart are summarized in Table 6.1. The waveforms of action impulse observed in different specialized cardiac tissue are shown in Figure 6.7.

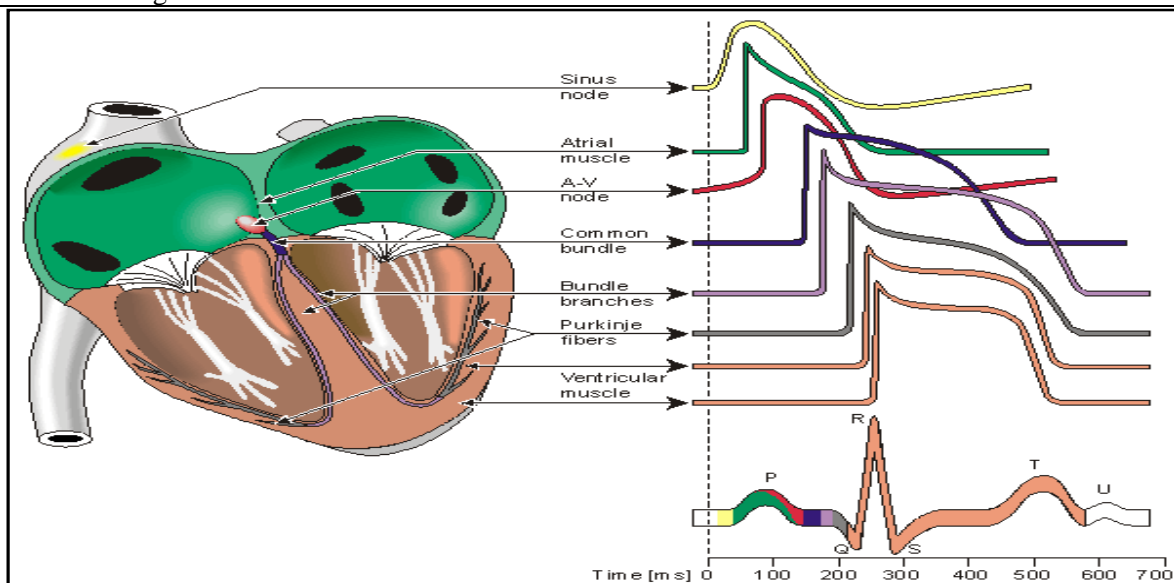
A classical study of the propagation of excitation in human heart was made by Durrer and his co-workers (Durrer et al., 1970). They isolated the heart from a subject who had died of various cerebral conditions and who had no previous history of cardiac diseases. The heart was removed within 30 min post mortem and was perfused. As many as 870 electrodes were placed into the cardiac muscle; the electric activity was then recorded by a tape recorder and played back at a lower speed by the ECG writer; thus the effective paper speed was 960 mm/s, giving a time resolution better than 1 ms.



**Table 6.1.** Electric events in the heart

Location in the heart	Event	Time [ms]	ECG-terminology	Conduction velocity [m/s]	Intrinsic frequency [1/min]
SA node	impulse generated	0		0.05	70-80
atrium, Right	depolarization *)	5	P	0.8-1.0	
Left	depolarization	85	P	0.8-1.0	
AV node	arrival of impulse	50	P-Q interval	0.02-0.05	
	departure of	125			
bundle of His	impulse activated	130	QRS	1.0-1.5	
bundle branches	activated	145		1.0-1.5	
Purkinje fibers	activated	150		3.0-3.5	
endocardium	activated	175		0.3 (axial)	
Septum		190		-	
Left ventricle	depolarization	190	0.8 (transverse)	20-40	
epicardium	depolarization	225			
Left ventricle	depolarization	250			
Right ventricle	depolarization				
epicardium					
Left ventricle	repolarization	400	T		0.5
Right ventricle	repolarization				
endocardium					
Left ventricle	repolarization	600			

\*) Atrial repolarization occurs during the ventricular depolarization; therefore, it is not normally seen in the electrocardiogram.



**Fig. 6.7.** Electrophysiology of the heart. The different waveforms for each of the specialized cells found in the heart are shown. The latency shown approximates that normally found in the healthy heart.

## ELECTRICAL STIMULATION OF THE HEART

Normally the signal for cardiac electrical stimulation starts in the sinus node (also called the sinoatrial or SA node). The sinus node is located in the right atrium near the opening of the superior vena cava. It is a small collection of specialized cells capable of spontaneously generating electrical stimuli (signals). From the sinus node, this electrical stimulus spreads first through the right atrium and then into the left atrium. In this way the sinus node functions as the normal pacemaker of the heart.

The first phase of cardiac activation consists of the electrical stimulation of the **right and left atria**, electrical stimulation, in turn, signals the atria to contract and to pump blood simultaneously through the tricuspid and mitral valves into the right and left ventricles respectively. The electrical stimulus then spreads to specialized conduction tissues in the **atrioventricular (AV) junction** (which includes the AV node and bundle of His) and then into the left and right bundle branches, which carry the stimulus to the ventricular muscle cells.

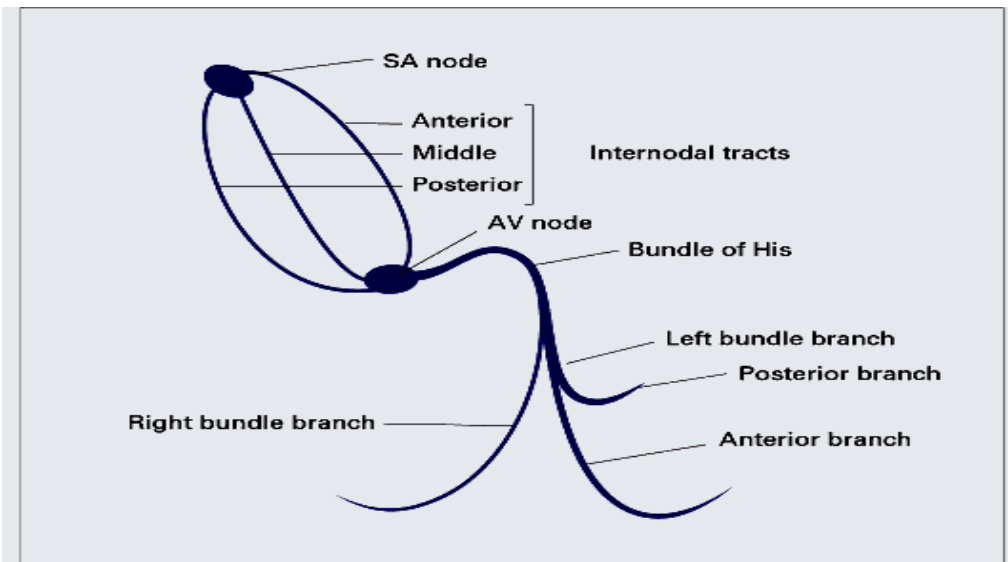
The AV junction, which functions as an electrical “bridge” connecting the atria and ventricles, is located at the base of the interatrial septum and extends into the ventricular septum. It has two subdivisions; the upper (proximal) part is the AV node. (in older texts the terms “AV node” and “AV junction” are used synonymously.) the lower (distal) segment of the AV junction is called the bundle of His, after the physiologist who described it. The **bundle of His** then divides into two main branches; the right bundle branch, which brings the electrical stimulus to the right ventricle, and the left bundle branch, which brings the electrical stimulus to the left ventricle.

The electrical stimulus spreads simultaneously down the left and right bundle branches into the ventricular muscle itself (ventricular myocardium). The stimulus spreads itself into the ventricular myocardium by way of specialized conducting cells, called Purkinje fibers, located in the ventricular muscle.

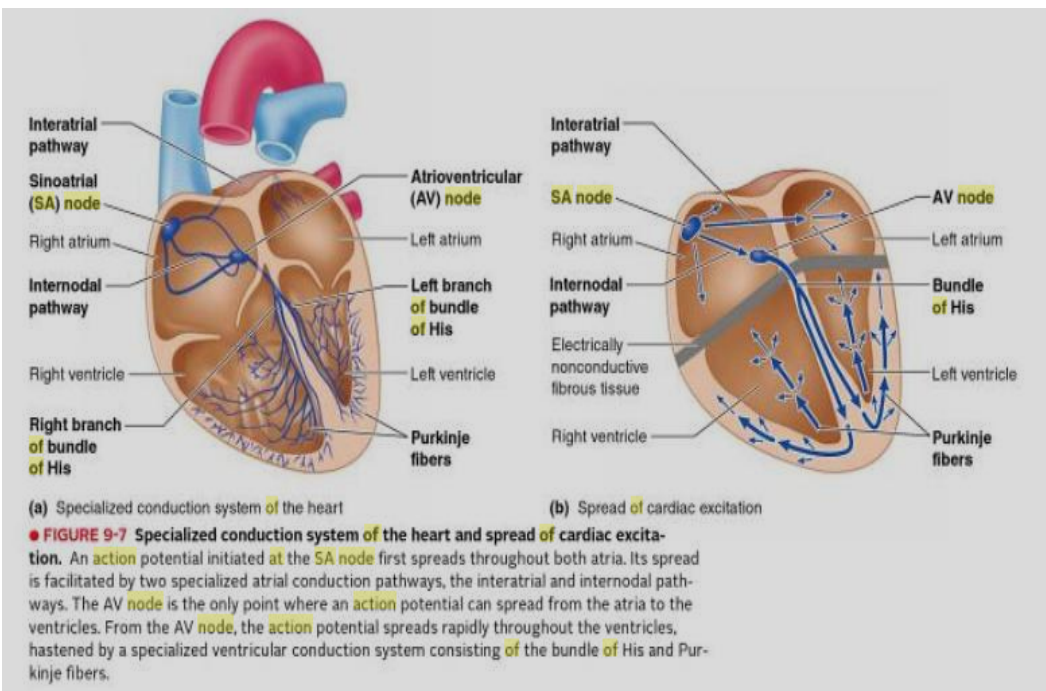
Under normal circumstances, when the sinus node is pacing the heart (normal sinus rhythm), the AV junction appears to function primarily as a shuttle, directing the electrical stimulus into the ventricles. However, under some circumstances the AV junction can also function as an independent pacemaker of the heart. For example, if the sinus node fails to function properly, the AV junction may act as an escape pacemaker. In such cases an AV junctional rhythm (and not sinus rhythm) is present. This produces a distinct ECG pattern Just as the spread of electrical stimuli through the atria leads to atrial contraction, so the spread of the electrical stimuli through the ventricles leads to ventricular contraction with pumping of blood to the lungs and into the general circulation.

**In summary**, the electrical stimulation of the heart normally follows a repetitive sequence of five steps:

1. Production of a stimulus from pacemaker cells in the sinus node (in the right atrium)
2. stimulation of the right and left atria
3. spread of the stimulus to the AV junction AV node and bundle of His)
4. spread of the stimulus simultaneously through the left and right bundle branches
5. stimulation of the left and right ventricular myocardium



8 The conducting system of the heart.



**Spread of action potential through cardiac muscle**

The A.P. spreads through the cardiac muscle very rapidly. It is because of the presence of gap junctions in the cardiac muscle fibers. The gap junctions are permeable junctions and allow free movement of ions. Due to this, the action potential spread rapidly from one muscle fiber to another fiber. The action potential is transmitted from atria to ventricles through the fibers of specialized conductive system.

**Spread of Impulses from SA NODE**

The mammalian heart has got a specialized conductive system by which, the impulses from SA node spread to other parts of the heart. The conductive system is formed by modified cardiac muscle fibers. It includes five components:-

- |   |                              |
|---|------------------------------|
| 1. Internodal pathway – Between sinoatrial node and atrioventricular node | 3. Bundle of his             |
| 2. Atrioventricular node (AV node)  | 4. Branches of bundle of his |
|   | 5. Purkinje fibers           |

**Rhythmicity of other parts of the heart**

Though SA node is the pacemaker in the mammalian heart, the other parts of the heart also have property of the rhythmicity. The rhythmicity of different parts:-

- |                  |   |            |                       |   |            |
|------------------|---|------------|-----------------------|---|------------|
| 1. SA NODE       | - | 70-80/mins | 4. Purkinje fiber     | - | 35-40/mins |
| 2. AV NODE       | - | 40-60/mins | 5. Ventricular muscle | - | 20-40/mins |
| 3. Atrial Muscle | - | 40-60/mins |                       |   |            |

**Conductive system in human heart**

Human heart has a specialized conductive system through which the impulses from SA node are transmitted to all other parts of the heart. The conductive system in human heart comprises:

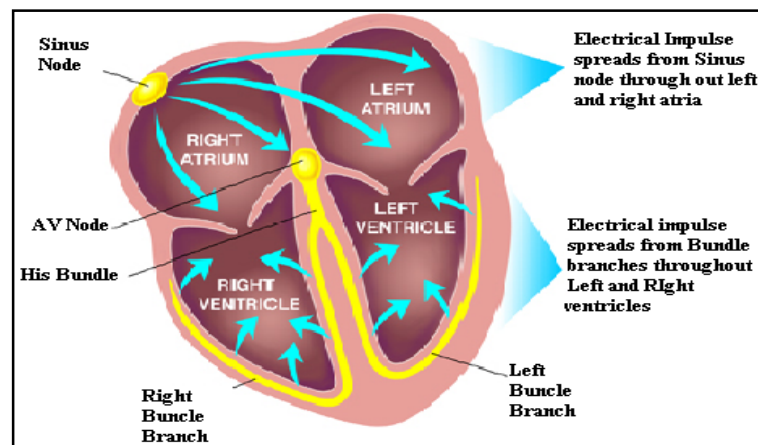
1. AV node
2. Bundle of his
3. Right and left bundle branches
4. Purkinje fibers.

## **BIOELECTRICITY**

SA node is situated in right atrium just below the opening of superior venacava. AV node is situated in the right posterior portion of intra-atrial septum. The impulses from SA node are conducted AV node by three types of internodal fibers.

1. Anterior internodal fibers of Bachman
2. Middle internodal fibers of Wenckebach
3. Posterior internodal fibers of Thorel.

All these fibers from SA node converge on AV node and interdigitate with fibers of AV node. From AV node, the bundle of His arises. It divides into right and left branches which run on either side of the interventricular septum. From each branch of Bundle of His, many Purkinje fibers arise and spread all over the ventricular myocardium.



The biopotentials are acquired with the help of specialized electrodes that interface to the organ or the body and transduce low-noise, artifact-free signals. The basic design of a biopotential amplifier consists of an instrumentation amplifier. The amplifier should possess several characteristics, including high amplification, input impedance, and the ability to reject electrical interference, all of which are needed for the measurement of these biopotentials. Ancillary useful circuits are filters for attenuating electric interference, electrical isolation, and defibrillate on shock protection. Practical considerations in biopotential measurement involve electrode placement and skin preparation, shielding from interference, and other good measurement practices.