CARDIAC ELECTROPHYSIOLOGY*

Summary: In this class we will descriptively review the electrical events that trigger a contraction. In addition, we will look at how the heart is able to adjust its stroke volume as a result of the Frank-Starling Phenomenon and the influence of the sympathetic nervous system. We will also see how to found cardiac output using the Fick principle and finally, we will look at the control of cardiac output and work of the heart.

I. The Initiation and Coordination of a Heart Beat

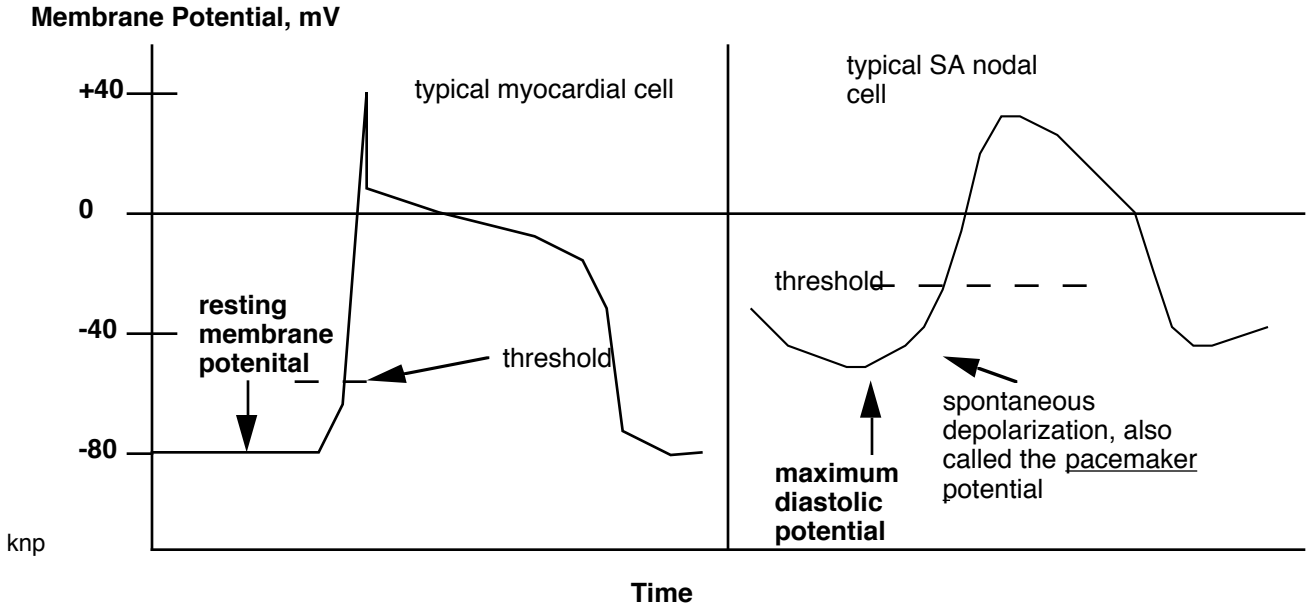
A. The **purpose of the heart's electrical system is to initiate and coordinate the heartbeat.**

1. We say that the origin of the coordinating signal for the heartbeat is **myogenic** since it comes from within modified muscle cells and does not come from the nervous system. Likewise, we can say that the production of the signal responsible for the heartbeat is an **intrinsic** feature of the heart/

2. For the heart to be an effective pump it is very important that different parts of the muscle contract in an orderly manner for certain periods of time (relative to other parts).

B**. Initiation of Heartbeats -- Pacemaking**: The initiation is normally in the specialized (myocardially-derived) tissue of the sinoatrial node.

1. The cells of the SA node exhibit a property called **AUTOMATICITY**. This means that they tend to spontaneously discharge until their thresholds are reached at which time they fire an action potential (AP). Other cardiac cells, will under appropriate conditions, also show automaticity, some more easily than others. Usually this is a bad thing since it is related to a breakdown in coordination.



2. All of the muscle and muscle-derived cells in the heart are joined into an **electrical syncytium**.

(a) The cause of this is that the synapses between cardiac cells are present in structures known as gap-junctions.

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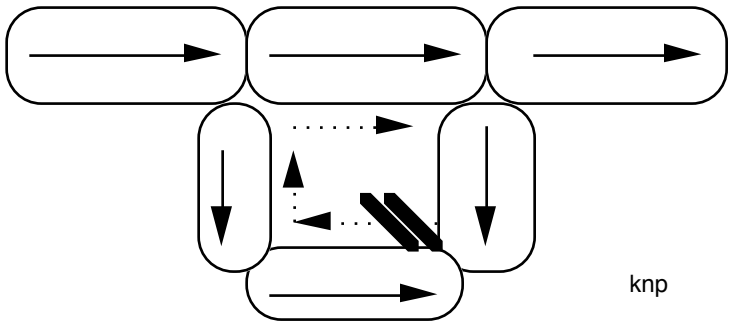
(b) **Gap-junctions** are essentially channels that connect the sarcoplasm of adjacent cells; electrical potentials are transmitted through the gap junctions in a manner very similar to their transmission along a cell.

(c) therefore, the gap junction between cardiac cells acts functionally as **electrical synapses**. Unlike chemical synapses, signals at electrical synapses can move in both directions.

! At chemical synapses, signals move in only one direction because the chemical transmitters are released only from one side of the synapse. And, for our purposes we can assume that the receptors for these chemical transmitters are only found on the other side.

! The only thing that prevents signals from moving in both directions in the heart or from reversing themselves is that the cells have a property common to all excitable cells called a **refractory period.** This is a period of time just after a cell has fired when no normal stimulus will cause the cell to fire. Thus, in a normal heart if an AP (for some reason) managed to follow a circle back around to a cell that had just conducted it, it would stop when it got to that cell since the cell would be in its refractory period:

All of thse nearby cells are linked together electrically. Solid arrows in cells show normal x-mission; arrows outside of cells show the possible circular pathway that is blocked by refractory periods



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This prevents signals from moving in circles and destroying coordination; in pathological situations sometimes signals do move in circles and the result is a potentially fatal situation called fibrillation.

(d) Thus, the entire heart is interconnected to form one big cell, electrically speaking.

(e) Within the SA node, the AP from the first cell to fire will quickly propagate to other cells in the SA node and cause them to fire. Thus, the first cell to fire, **the cell with the highest intrinsic rate of discharge, will act as the pacemaker for the entire SA node and the entire heart.**

! In mammals, the initiation and conduction of the signal that coordinates the heartbeat is **intrinsic** to the heart itself. Since this signal comes from modified muscle tissue, we say that it is **Myogenic**. By contrast, in some animals (such as most arthropods) the signal comes from a group of nerve cells located on the heart (**"cardiac ganglion"**) these cells directly active the muscle cells. Such hearts (where the beat originates in and is largely distributed by nervous tissue) are called **neurogenic**.

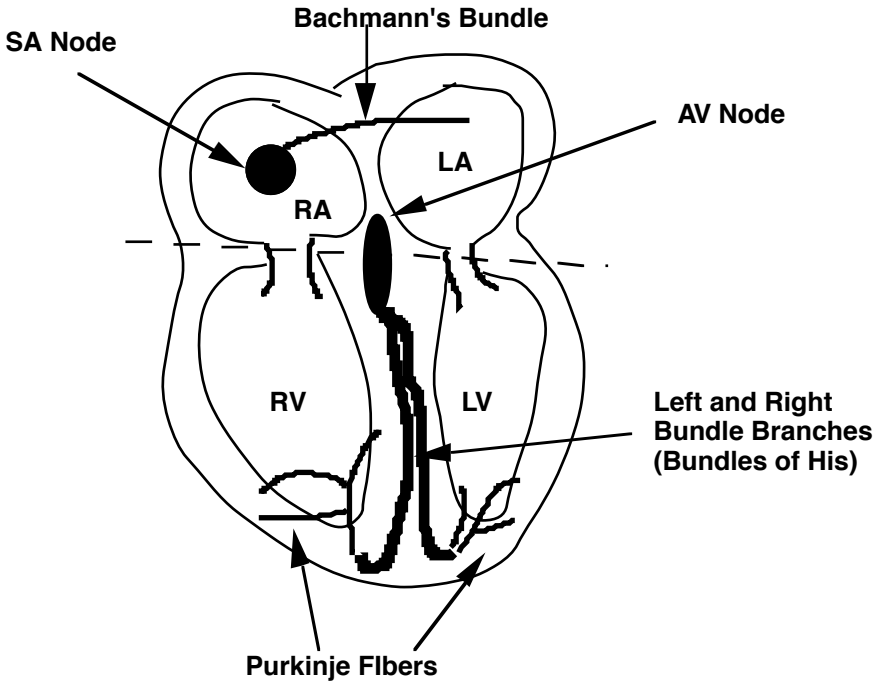
C. Transmission of the Action Potential Throughout the Heart:

1. The Atria:

a. The AP will generally spread from the pacemaker like a wave in a pond.

b. However, there are also certain specialized areas where AP conduction is more rapid **(Facilitated Pathways)**. In the atria, the tissues known as **Bachmann's Bundles** that consist

of elongated cells that run across the top of the atrium are believed to produce rapid conduction along the top of the atria.



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c. Once the AP leaves the SA node or Bachmann's bundles, it is transmitted from myocardial cell to myocardial cell via electrical synapses

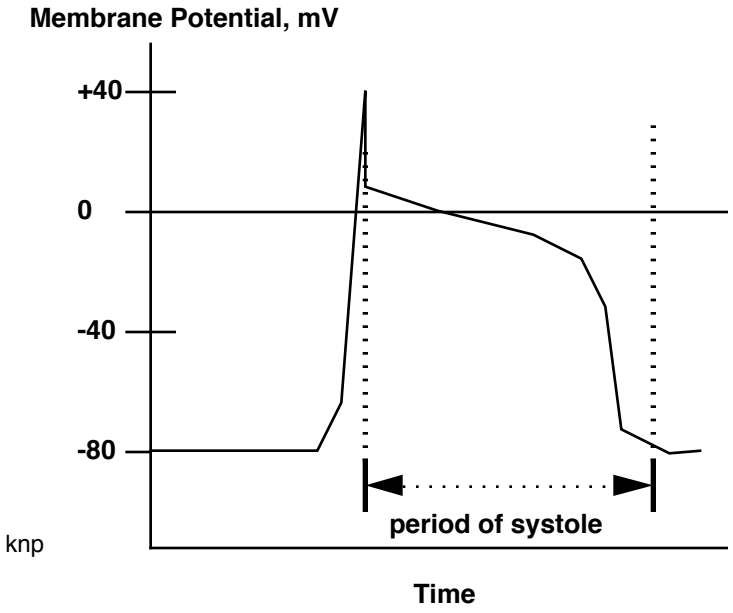
i. The **action potential** in these **myocardial cells** (and the **ventricular myocardium, Purkinje fibers, and Bundles**) is rather unusual when compared to those of either smooth or skeletal muscle cells.

(a) It is very long in duration -- often several hundred milliseconds.

(b) During most of the duration of the AP, Ca^{++} enters the cytoplasm via extracellular, SR, and mitochondrial pools.

(c) This extended period of depolarization corresponds with an extended active state called **systole**.

(d) The active state, as with other types of muscles is maintained for a short time after the AP dies out since it takes time to lower intracellular concentrations of calcium:



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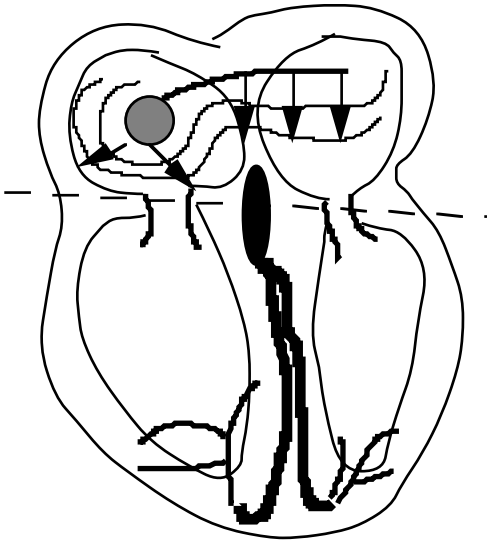
ii. The contraction starts at the top of the atria and moves downward towards the A-V valve system:



The curved lines and arrows show the propogation of the AP from the SA node and Bachmann's bundle through the atrial myocardium towards the ventricles and AV node.

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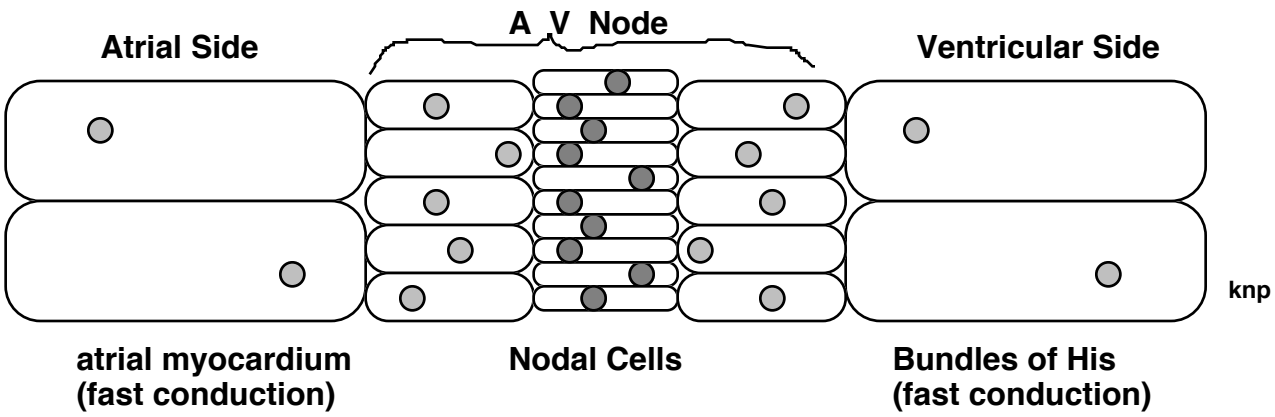
2. A-V transmission: In a normal heart, the only place where the AP can pass from the atria to the ventricles is through the **AV node**. All of the other cells are connective tissue and act as an insulator.

a. The AV node has a special property in that it conducts APs very slowly when compared to the myocardial cells.

b. It performs this trick by being composed of very small diameter cells. In excitable cells, the smaller the diameter, the slower the conduction velocity.



c. Thus, while most cells in the heart are very large and conduct signals at high velocity, the **central AV cells** (called "nodal" cells) and the cells of the SA node (which are also small) **both conduct at slow rates.**

d. The result is that the AV node delays the "leading edge" and the rest of the AP for some time. This **gives the atria a chance to complete their contractions before the ventricles (which are much stronger) can start to contract.**

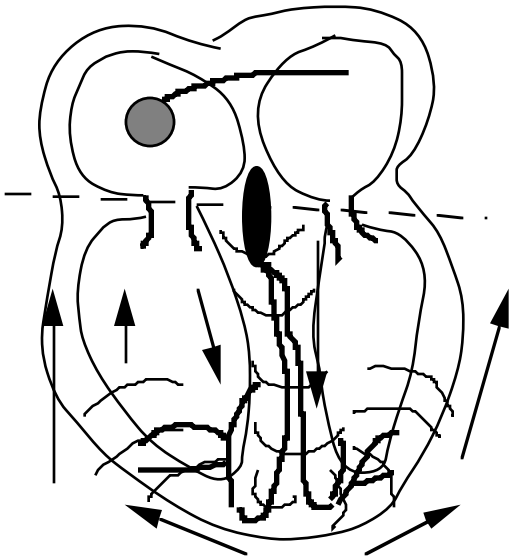
3. Ventricular Transmission: The AP emerges from the AV node and moves down the intra-ventricular septum through the **right and left bundle branches (Bundles of His).**

a. The **Bundles of His are preferred conduction pathways**, much like Bachmann's bundles. They rapidly move the AP from the AV node to the apex (really the bottom) of the heart. Along the way they activate the septal myocardial cells causing the septum to contract (it essentially becomes a rigid wall).

b. At the end, the bundles divide into individual specialized conducting cells called **Purkinje fibers.**

c. The **Purkinje fibers** terminate at various points on the ventricular myocardium. Generally these points are near the apex of ventricles.

d. The **AP and wave of contraction therefore starts at the apex and moves towards the valves**. This action tends to **squeeze blood upwards towards the semilunar valves and out of the heart**. (please see next page)



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e. **When the AP reaches the connective tissue** region between the ventricles and atria, **it dies out**. The reason that it does not move backwards or re-enter the AV node is because these tissues are in their refractory period.

? Review: What is the name of the process that links electrical systole (the transmission of an AP) with mechanical systole (contraction)? Think about skeletal muscle.