MEDICINE
KING SAUD UNIVERSITY

Physiology Team 436

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Cardiac Electrical Activity

CVS BLOCK

Red: very important.
Green: Doctor's notes.
Pink: formulas.
Yellow: numbers.
Gray: notes and explanation.

Physiology Team 436 – Cardiovascular Block Lecture 2

Lecture: If work is intended for initial studying.
Review: If work is intended for revision.

Objectives

Study Smart: focus on mutual topics.

In this lecture we will first give an introduction to the AP –adding to lecture 1- and then we will talk about these electrophysiological properties in detail.

FEMALES' OBJECTIVES

- Discuss the cardiac conductive system and its function.
- Describe the action potential of the cardiac muscle and its components.
- Define the refractory period and the excitation contraction coupling.
- Discuss the control of excitation and conduction of the heart.

MALES' OBJECTIVES

- State and define the main electrical and mechanical properties of the heart.
- Explain the genesis of the resting membrane potential in the cardiac muscle cell and identify the ionic currents during the different phases of the fast-response and slow-response action potentials in the cardiac muscle cell.
- Discuss pacemaker electrical activity.
- Define ectopic pacemaker and explain the mechanisms of ectopic pacemakers.
- Summarize the function of the different parts of the conducting system of the heart and describe the sequence of normal conduction in the heart.
- Describe the effects of sympathetic and parasympathetic stimulation on the electrophysiological properties of the heart.

ONLY IN MALES' SLIDES

How the Heart Performs its Function as the Central Pump of The CVS (Recall lecture 1)

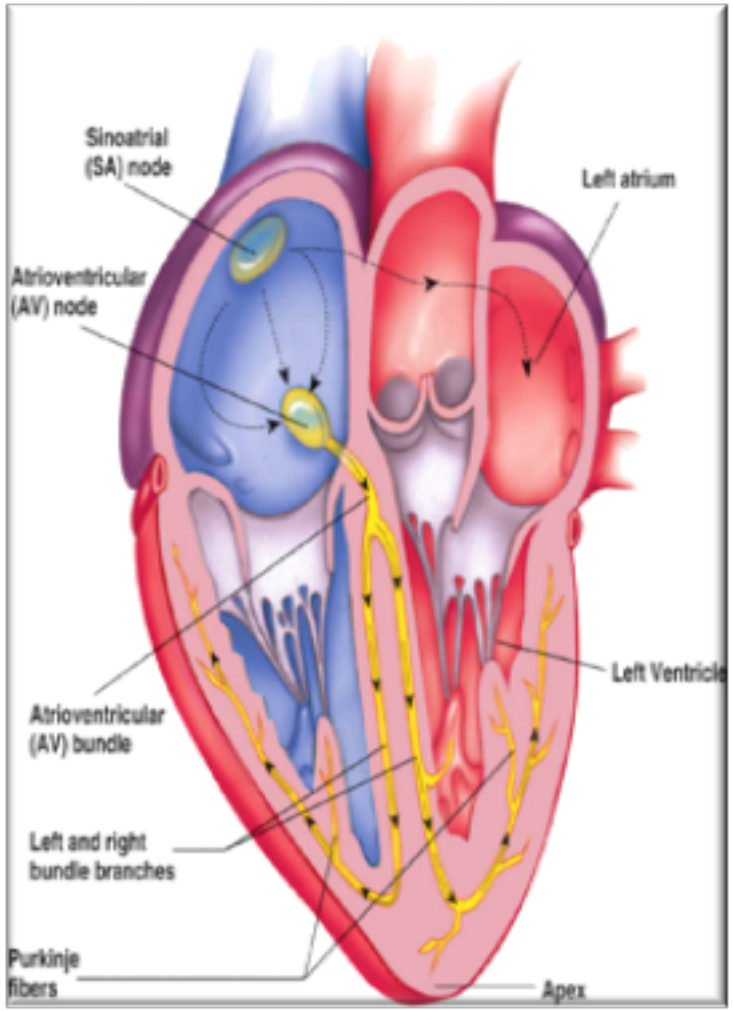
The 2 main types of cells in the heart:

1. Cells of the specialized conduction system: non-contractile cardiac cells (but they initiate action potential by: constitute the tissue of SAN, the atrial internodal tract, AVN, the bundle of His, and the purkinje system) - they are called autorhythmic cells- we will talk about it in slide #5

2. Contractile cells (myocytes; working cells) (contract - don't initiate their own action potential)

Primary difference between these 2 cells (the specialized conduction system cells and the myocytes):

Is the absence of myofibrils in specialized conduction system cells; thus, little or no contraction is seen.



Essential Heart Properties for its Functioning as the Central Pump of the CVS

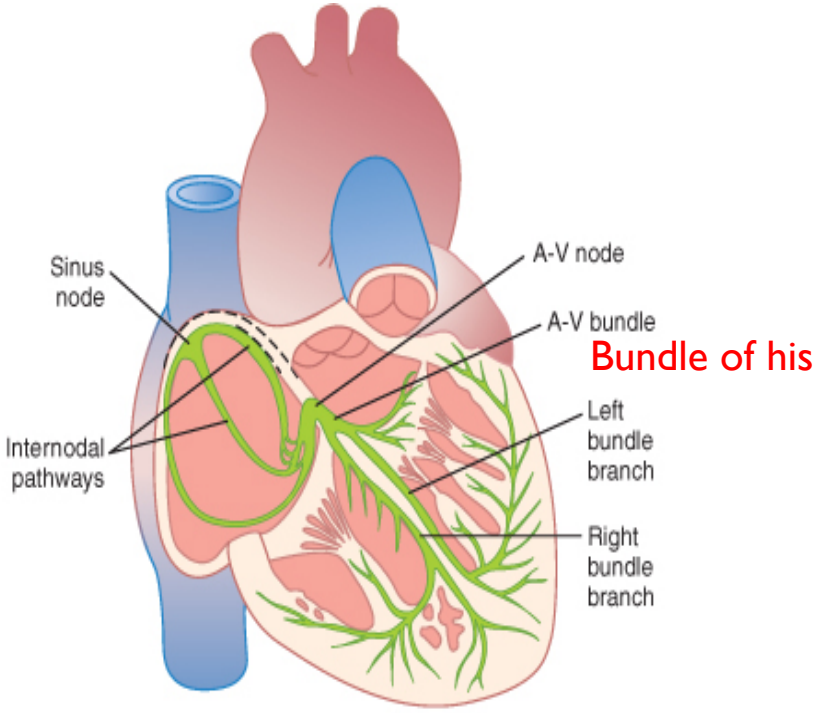
Electrophysiological properties of the heart	**1- Autorhythmicity (automaticity and rhythmicity)**	**- Generating rhythmical electrical impulses (cardiac impulse) independent of any extrinsic stimulation .** **- Impulse generate in SA node** (pacemaker of the heart).
	2- Conductivity	-The conduction system specialized cells of the heart carry cardiac impulses rapidly to the myocytes in the atria, and after a pause, to the myocytes in the ventricles.
	3- Excitability	
Mechanical property of the heart (mechanical response to excitation)	**4- Contractility**	The atria contract about one sixth (1/6) of a second ahead (before) of ventricular contraction. (Why?) To allow filling of the ventricles before they pump the blood into the circulation (AV NODE) (if they contract simultaneously the ventricles will not fill adequately and will pump less blood than needed and air)

Another special importance of the system is that it allows all portions of the ventricles to contract simultaneously, which is essential for the most effective pressure generation in the ventricular chambers. (On slide #24)

The Specialized Excitatory and Conductive System of the Heart

The cells of the specialized conductive system are found in:

- The sinoatrial (S-A node): in right atrium
- Bachmann's Bundle (interatrial bundle)
- The internodal pathway (anterior, middle, and posterior)
- The atrioventricular (A-V node): between right atria and ventricle
- The atrioventricular bundle (Bundle of His)
- Left and right bundle branches
- Purkinje fibers: transports signals to all cells



Remember!

They do not have myofibrils (actin & myosin) so they will not contract.

Video of (SA Node)
Duration: (0,59 secs)

Resting Membrane Potential (RMP)

- **Resting membrane potential:** is an intracellular potential of the resting myocyte and is found to be –80 mV to –90 mV (80 to 90 mV lower than the extra cellular potential).
- **In atrial and ventricular cells:** this RMP is stable until external stimulation (excitation) is applied.
- **In sino-atrial node cells** (in particular) **and many conduction fibers:** the RMP is not stable, drifting towards zero at times.

(this is because the SAN is never at rest as it doesn't require a stimulus)

- **Electrical potentials arise from:**
  1. Differences in the concentrations of ions across the membrane.
  2. The presence of selective ion-conducting channels spanning the membrane, namely K^+, Na^+, and Ca^{2+}.

Resting Ventricular Myocytes	
Intracellular concentration	***Extracellular concentration***
Na+: 10 mM/L	Na+: 140 mM/L
K+: 140 mM/L	K+: 4 mM/L
Ca++: 0.0001 mM/L	Ca++: 1.2 mM/L

- In resting conditions: membrane is permeable to K^+ only.
- K^+ diffuses out of cell (efflux) down a concentration gradient.
- Negatively charged ions (phosphate and proteins) cannot leave cell creating negative intracellular charge
- RMP is due to K^+ efflux

Ion pumps and exchangers establish differences in ions concentration across the cell membrane.

Potassium Equilibrium Potential

- **Potassium :** is the generator of the resting membrane potential
- In resting conditions : membrane is permeable to K^+ only.
- Intracellular concentration of K^+ is 140 and extracellular concentration is 4 → efflux of K^+ down concentration gradient.
- This causes the intracellular charge to be negative due to :
  1. K^+ efflux
  2. negative intracellular ions (mainly organic phosphates and intracellular proteins) not being able to accompany the K^+ ions.
- As potassium is being diffused out of the cell, a point is reached where The number of K^+ ions diffusing out of cell down concentration gradient = number of K^+ ions pulled into cell by the negative intracellular charge. This point is called "potassium equilibrium potential*".
- *Extra explanation: في وضع الراحة، تسمح الخلية فقط بمرور ايون واحد في الخلية وهذا الايون هو البوتاسيوم. زي ما نعرف انه تركيز البوتاسيوم أعلى جوا الخلية فهذا بيخلي البوتاسيوم (الي شحنته موجبة) يطلع برى الخلية. الحين صارت الشحنة الداخلية للخلية سالبة لأن البوتاسيوم طلع ولأن جوا الخلية بروتينات وفوسفات شحنتهم سالبة. والشحنة الخارجية للخلية موجبة لان البوتاسيوم طلع ولان أصلا في تركيز عالي من الصوديوم مرة(موجب الشحنة).

طيب الحين الي جوا سالب والي برا موجب والبوتاسيوم لسا قاعد يطلع لان في فرق في التركيز بس في جزء من البوتاسيوم قاعد يدخل لأن البوتاسيوم موجب وداخل الخلية سالب.

فالنقطة الي يصير فيها كمية البوتاسيوم الي يطلع نفس كمية الي يدخل نسميها Potassium equilibrium potential.

The Nernst Equation

It describes: the balance of electrical and chemical forces across a cell membrane

We can use Nernst equation to calculate the Potassium Equilibrium Potential

$$Em = 61.5 \log 10 \frac{[X]e}{[X]i}$$

Note the subscript 'e' is usually replaced by 'o'.

Em = (equilibrium potential for particular ion)
[X]e = concentration of ion in ECF
[X]i = concentration of ion in ICF

According to Nernst equation:

Membrane permeable to potassium:

- $E_K = 61.5 \log_{10} \frac{4}{140}$

  = -95 mV

Membrane permeable to sodium:

- $E_{Na} = 61.5 \log_{10} \frac{140}{10}$

  = +71 mV

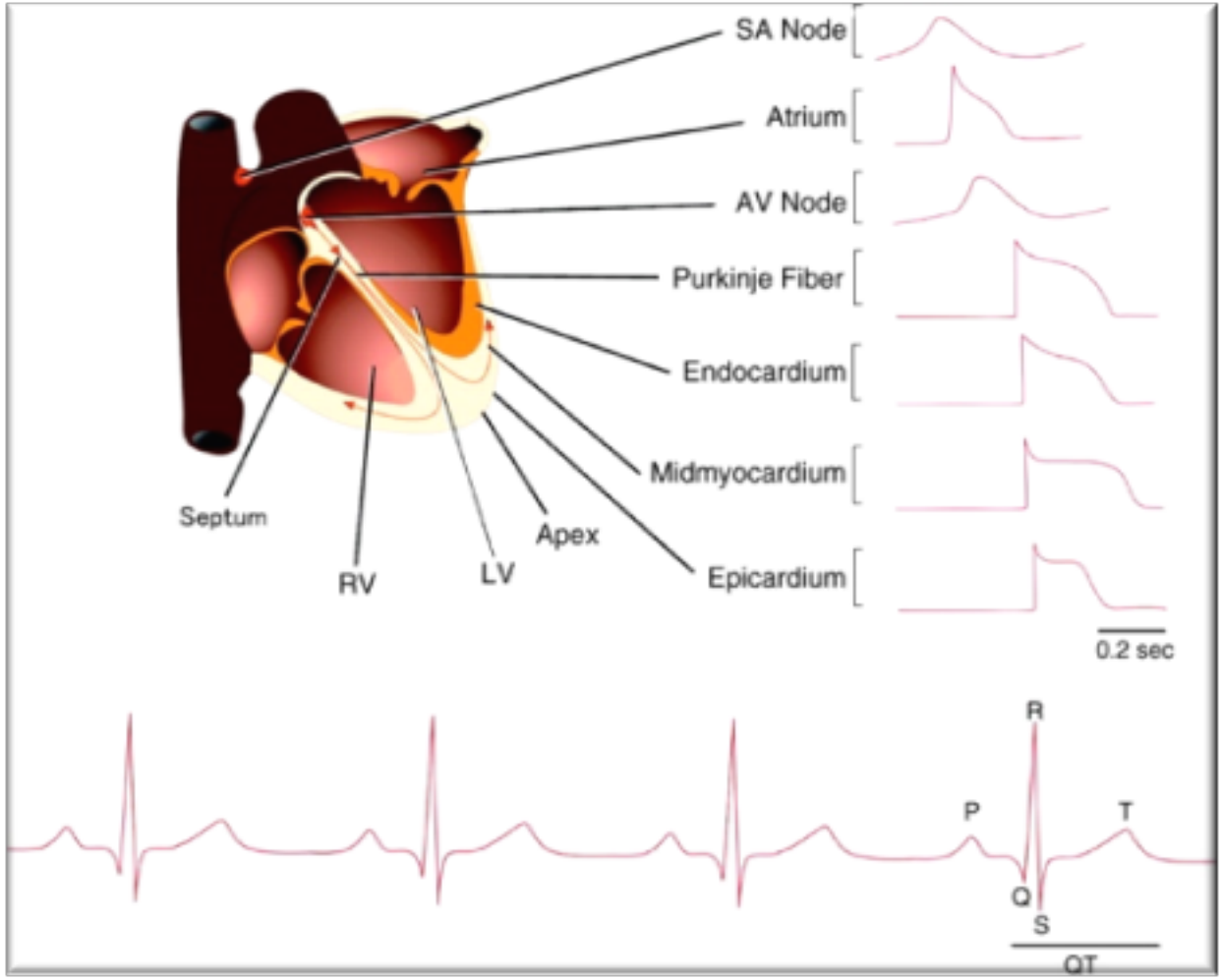
Ion	Extracellular concentrations (mM)	Intracellular concentrations (mM)*	Equilibrium potential (mV)
Na^+	145	10	70
K^+	4	135	−94
Ca^{++}	2	10^{-4}	132

- E_K to K+ = -95 mV
- RMP = -90 mV
- We can conclude from the values that the RMP is mainly due to potassium efflux and not sodium influx.
- **But if RMP is caused by K efflux, why aren't they equal?**
  RMP increased because small amounts of Na diffused into cell. The diffusion of Na is called background currents

Cardiac Action Potentials: **Excitability**

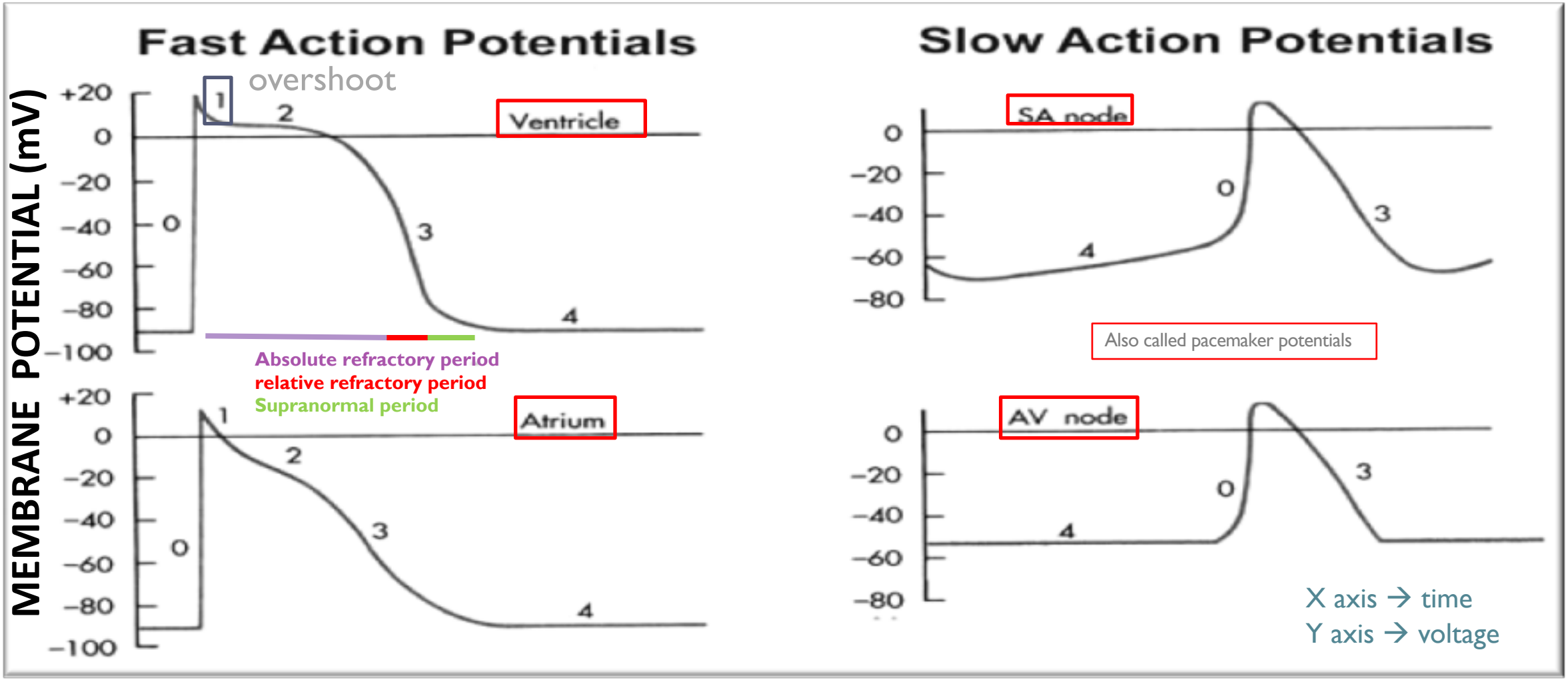
- Excitability : is the electrical response to excitation (stimulation).
- When an excitable tissue is excited, it responds by generating action potentials.
- Cardiac action potentials can be broadly classified into two types, termed:

1. **Fast-response.**
2. **Slow-response potentials**.



Action Potentials from Different Areas of the Heart

(This slide is an explanation for the next slide)



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Major Differences Between Fast-Response and Slow-Response Action Potentials

	Fast Response Action Potential	Slow Action Potential
Found in	1. Atrial 2. Ventricular 3. His-Purkinje cells	1. Sinus node 2. Atrioventricular (AV) node
Phases found	All phases of action potential are present (0/1/2/3/4) (phases will be explained in next slide)	Phases 1 & 2 are absent (phase 0/3/4 are found)
Resting membrane potential (Phase 4)	Stable; voltage is constant (unless stimulus applied)	Unstable; voltage slowly decreases (decreases negativity) (drifting towards zero with time) (there is spontaneous depolarization)
Phase 0	Rapid depolarization with a substantial overshoot (positive inside voltage)	Slower initial depolarization, lower amplitude overshoot
Phase 1	- Early partial repolarization - A rapid reversal of the overshoot potential	Absent
Phase 2	Long plateau	Absent
Phase 3	Repolarization	Repolarization
Phase 4	Stable , resting membrane potential	Slowly depolarizing "resting" potential
Conduction Velocity	Rapid	Slow

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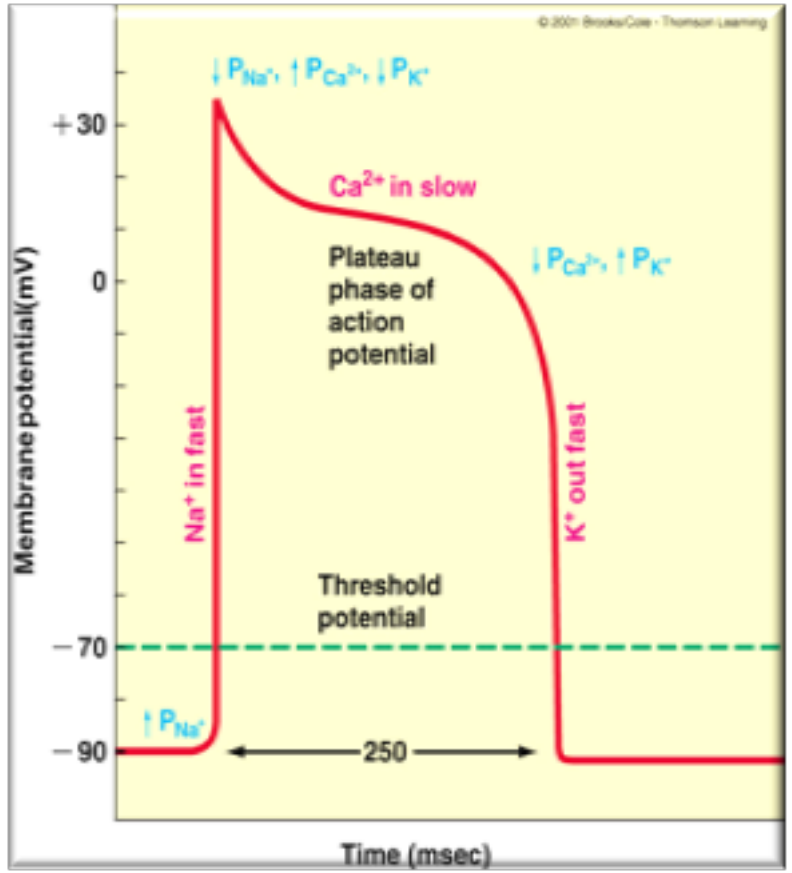
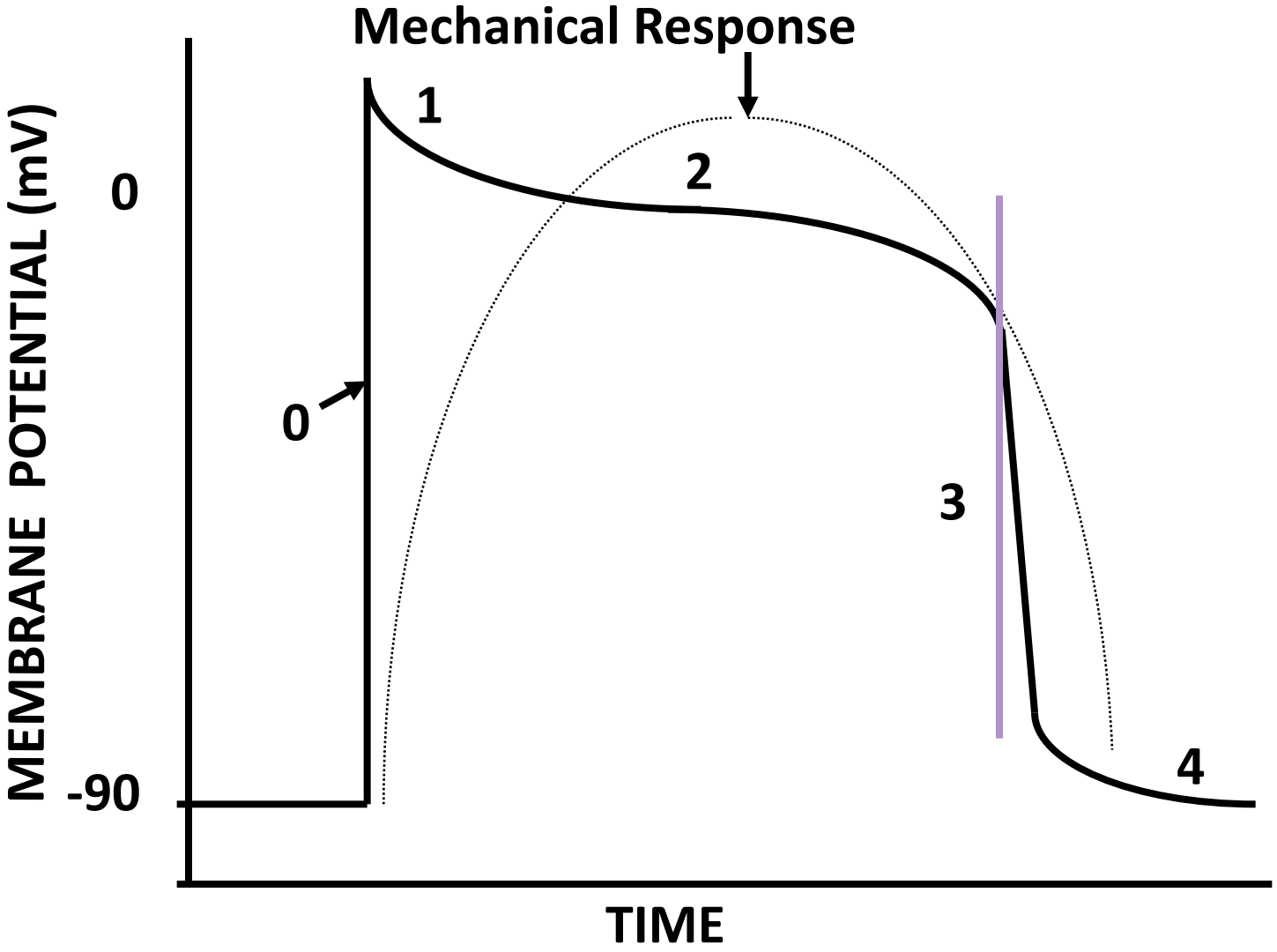
Fast-Response Action Potential

Phase	Due to
Phase 0 – Very rapid depolarization	Na^+ influx through voltage-gated (fast) Na^+ channels
Phase 1 – Early partial repolarization	• Inactivation of (fast) Na^+ channels • K^+ begins to move out of cell
Phase 2 – Plateau Around 0 mV	➢ Permeability of slow (ca+2) channels • L-type calcium channels ➢ Chemical & Electrical forces of K^+ & Ca^{2+} balanced; • K^+ out of cell = Ca^{2+} into cell
Phase 3 - Repolarization	➢ Inactivation of slow (Ca^{2+}) channels ➢ ↑ conductance of K^+ out of cell • Polarity of the cell interior becomes more (-)
Phase 4	Resting state; RMP established



Video of (AP of Cardiac Muscle) Duration: (15 mins)

Fast-Response Action Potential



When AP reaches myocyte; calcium is released → mechanical response (contraction due to calcium release)

During Phase 2 - plateau:
Catecholamines → ↑ inward current of Ca (by phosphorylating DHPR)

Ca^{2+} channel blocker drugs → ↓ inward current

Electrical Activity of The Pacemaker: Auto-rhythmicity

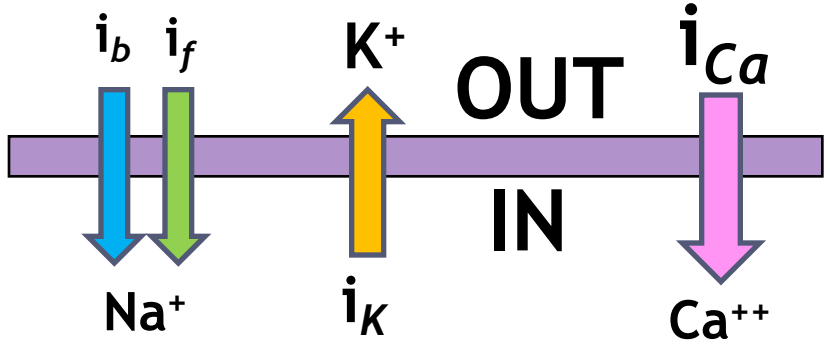
The decay (decreased negativity) of pacemaker potential with time is caused by:

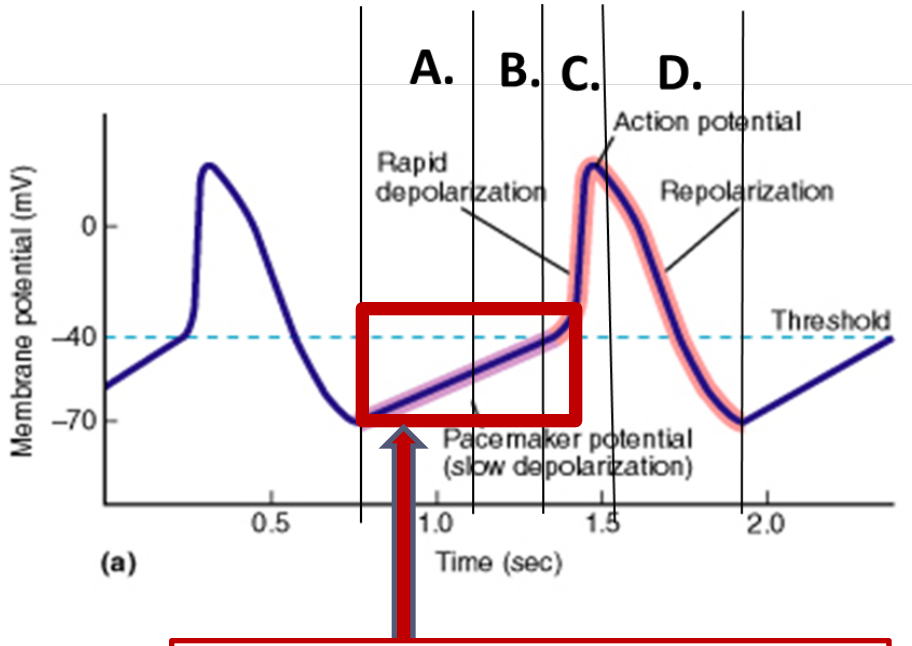
Early stage		Later stage
A small current of Na^+ flow into the cell. This current can be (i_f and i_b):	Membrane permeability to K^+ gradually falls. As a result the outward background current i_k falls progressively. This will allow the inward currents (i_f **and** i_b) to dominate increasingly.	Ca^{2+} current in the later part.

I_f a specialized pace maker current termed

I_b the inward background current

f= funny channels: channels for sodium on SA membrane)

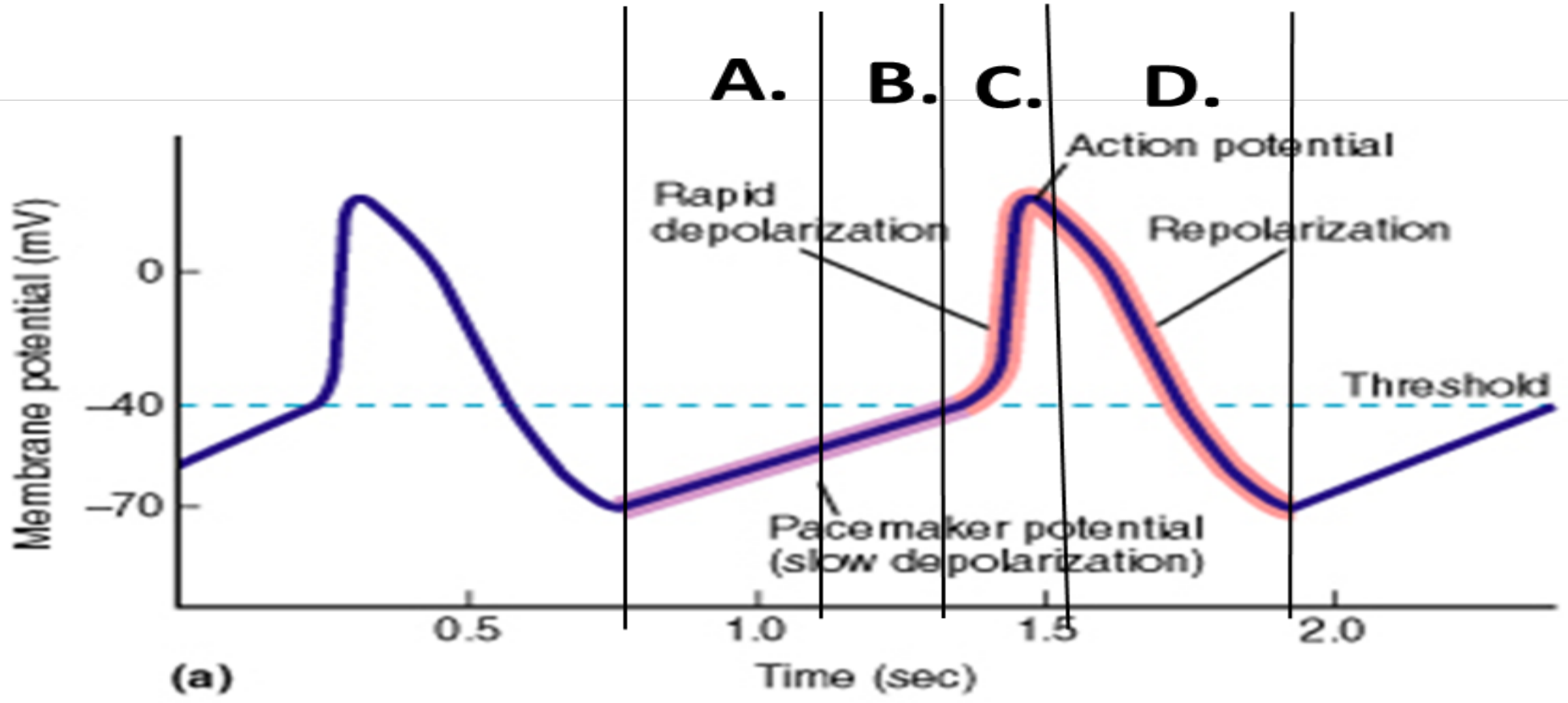




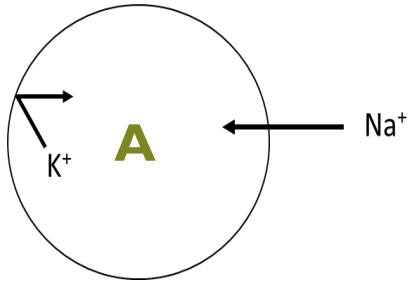
As time passes, pacemaker potential decays (decreases in negativity)

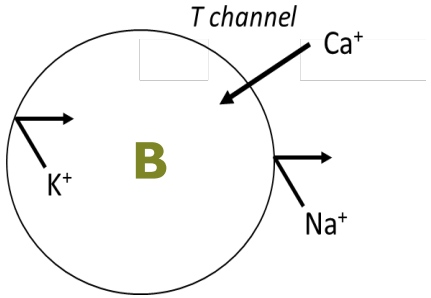
Autorythmicity: ability of SA node to generate its own impulse
The decay of SA node potential is the basis of autorythmicity

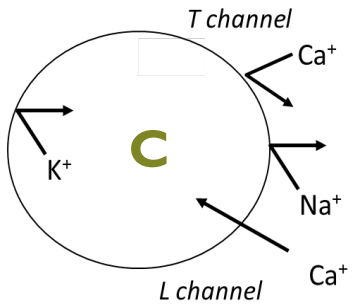
The next slide will explain this diaphragm

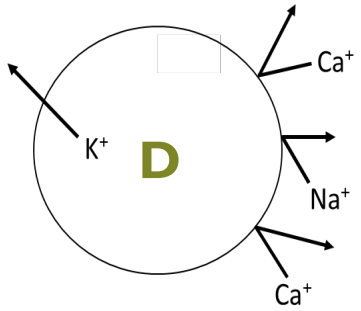


Pacemaker Potential









A. ↓ P_K ; ↑ P_{Na}
- Closure of K^+ channels.
- Opening of "funny" channels (Na+)

f= funny channels: channels for sodium on SA membrane)

B. ↑ P_{Ca}
- Opening of voltage-gated Ca^{++} channels (**T**-type channels)
- Closure of funny channels

C. ↑↑ P_{Ca}
- Opening of voltage-gated Ca^{++} channels (**L**-type channels)
- Closure of **T**- type Ca^{++} channels

D. ↑ P_K ; ↓ P_{Ca}
- Opening of voltage- gated K^+ channels
- Closure of voltage dependent Ca^{++} channels (**L**-type)

Notice the differences between Slow action potential (pacemaker potential) and fast response action potential.
For example: in Slow AP → rapid depolarization is caused by Ca influx
Fast AP → rapid depolarization is caused by Na influx

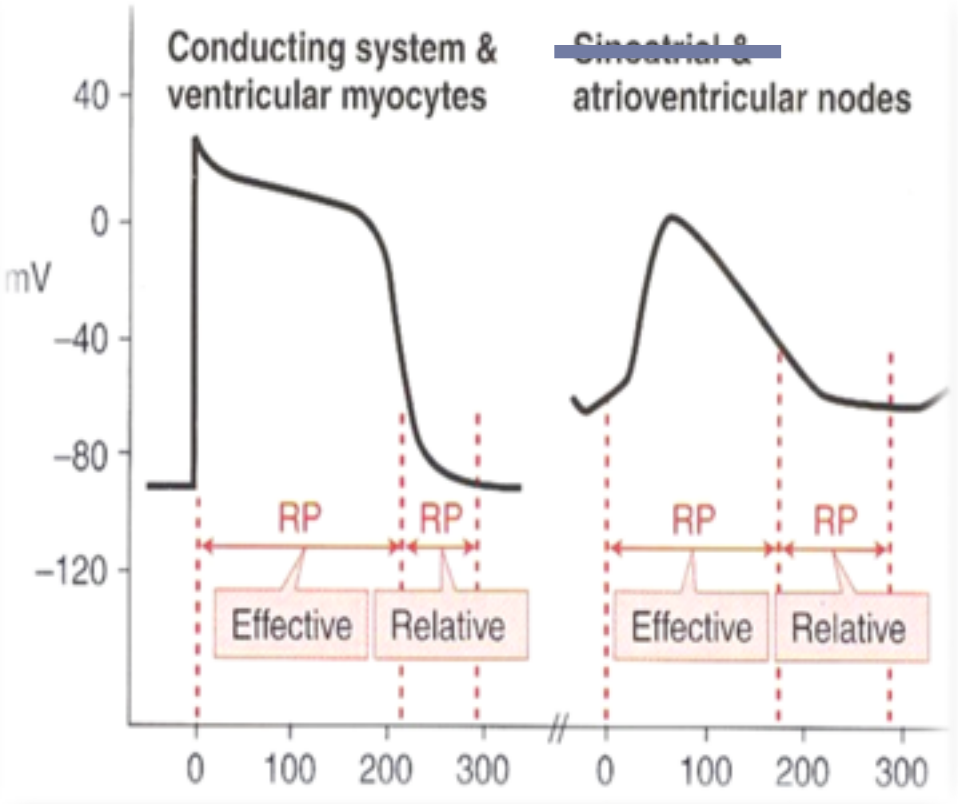
A+B = slow depolarization = phase 4
C= Rapid depolarization = Phase 0
D= Repolarization = Phase 3

P: permeability

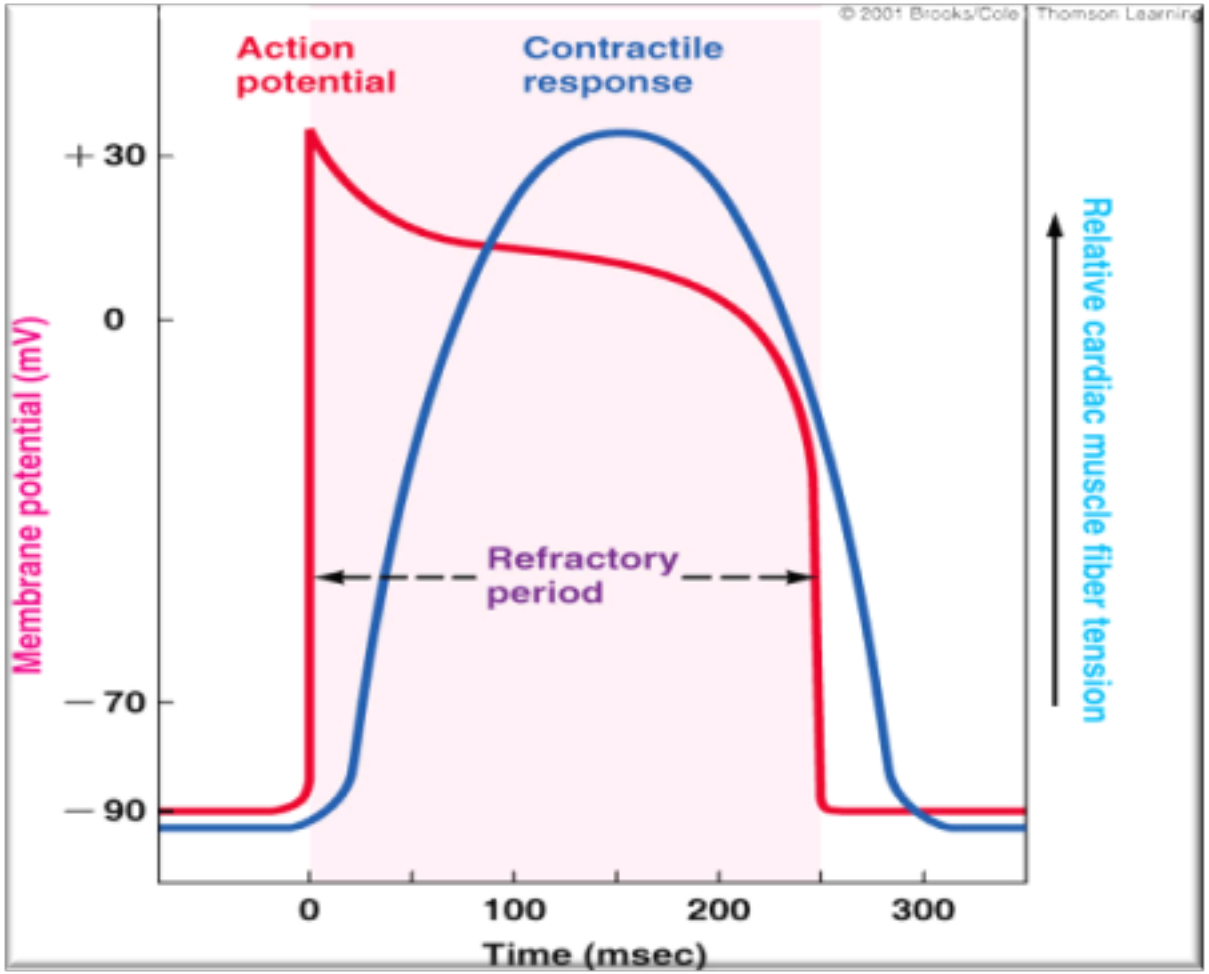
Refractory Period

Effective (absolute) Refractory Period (ERP)	Relative Refractory Period (RRP)
The cell is unable to be depolarized	Follows ERP
	Depolarization possible with supra-normal stimulus
Phase 0 to portion of Phase 3	Phase 3 to Phase 4

- In SA node there is no refractory period because SA node does not respond to stimuli (since it generates its own impulse).
- In AV node there is a refractory period because AV node responds to stimuli from SA node.



Refractory Periods: Importance of the Long Plateau



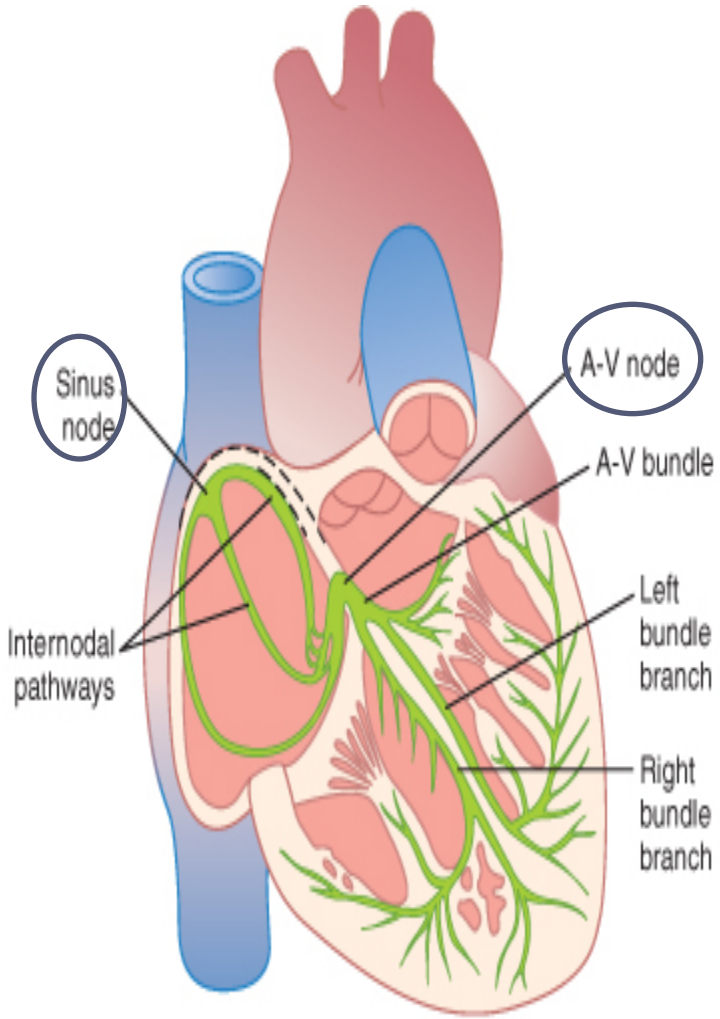
- Long absolute (effective) refractory period will prevent cardiac muscles from being tetanized.(انقباض مستمر)
- The duration of the effective refractory period is approximately equal to the duration of the mechanical event.

الخط الأحمر: الاكشن بوتنشل
الخط الأزرق: رد فعل القلب للاكشن بوتنشل. من بداية الخط الأزرق الى القمة ← انقباض القلب (سيستولي)
من القمة إلى نهاية الخط الأزرق ← انبساط القلب (دياستولي)

باين من الرسمة إنه الريفراكتوري بيريود (الإفيكتف) بادية من بداية الخط الأزرق الى ما بعد القمة بشوي. معنى هذا الكلام ان مستحيل يبدا اكشن بوتنشل جديد في السيستولي

Extra Information:

- Sometimes when there is an ischemia in the blood supply to the atria there will be fibrosis and this will affect the function of S-A node making it not functioning properly so, to solve this problem doctors will use artificial pacemaker for the patient.
- The impulses spread from the S-A node to the A-V node through the internodal pathway which is found in the right atrium.
- Atrioventricular node and delay of impulses conduction from the atria to the ventricles: The atrial conductive system is organized so that the cardiac impulse does not travel from the atria to into the ventricles too rapidly; this delay allow time for the atria to empty the blood into the ventricular before ventricular contraction begins. It is primarily the A-V node and its adjacent conductive fibers that delay this transmission into the ventricles.
- Causes of the slow conduction A-V node : The slow conduction in the transitional , nodal , and penetrating A-V bundle fibers is caused mainly by diminished number of gab junction between successive cells in the conducting pathway , so there is a great resistant to conducting of excitatory ions from one conducting fibers to the next. Therefore, it is easy to see why each succeeding cell is slow to be excited.



Conduction of Impulses: Conductivity

1. Sinoatrial / Sinus Node (SA Node)	2. Atrioventricular Node (AV Node)
All slow response tissues have the ability to auto-activate (automaticity). **Location:** in the superior lateral wall of the right atrium near the opening of the superior vena cava. **Functions:** Pacemaker of the heart • Its rate of rhythmic discharge is greater than any other part in the heart. • Highest frequency compared to other conduction parts and suppresses other pacemaker. • [Frequency]: the number of heartbeats per minute. - SA Node Is capable of originating action potentials. - The AP is characterized by: diastolic depolarization - Slow depolarization of phase 4 - The impulses normally arise in it. - It controls excitation and conduction in the heart.	**Location:** in the posterior wall of the right atrium. **Function:** delay (stopping) in the conduction of impulses (0.1 sec). This allows time for the atria to empty the blood into the ventricles before ventricular contraction begin. So the atria contracts before the ventricle. Now it enters the atrio ventricular bundle to the perkinje fibers.

What is a pacemaker? A pacemaker the part of an organ or of the body that controls any rhythmic physiological activity. Commonly being the sinus node in the human heart, and the resultant rhythm is a sinus rhythm.

Conduction of Impulses

3. The Purkinje system*

Purkinje fibers are very large fibers.

Transmit action potentials at a very high velocity (1.5-4.0 m/sec).

Highest speed of conduction.

- Very high permeability of gap junctions
- → ions are transmitted easily from one cell to the next
- → enhance the velocity of transmission

Ventricular muscle contract at almost the same time.

The Purkinje System

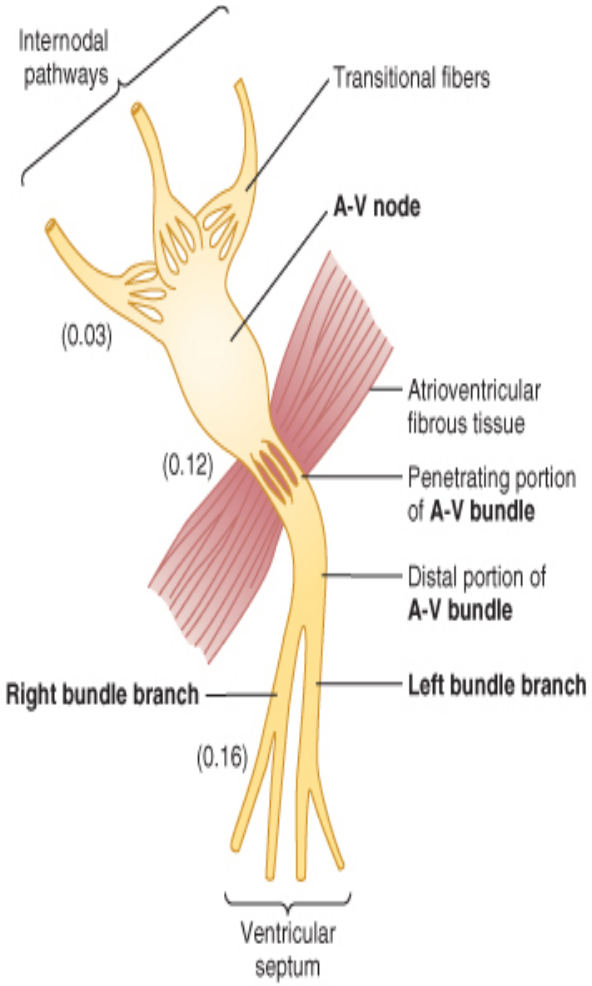
Penetrates atrioventricular fibrous tissue (AV Bundle)

→ divides into right and left bundle branches

→ each branch spread toward the apex of the heart

→ divide into small branches

→ penetrate and become continuous with cardiac muscle fibers



*They are very large fibers, even larger than the normal ventricular muscle fibers, and they transmit action potentials at a velocity of 1.5 to 4.0 m/sec, a velocity about six times that in the usual ventricular muscle.

Spread of the Cardiac Impulse through the Heart

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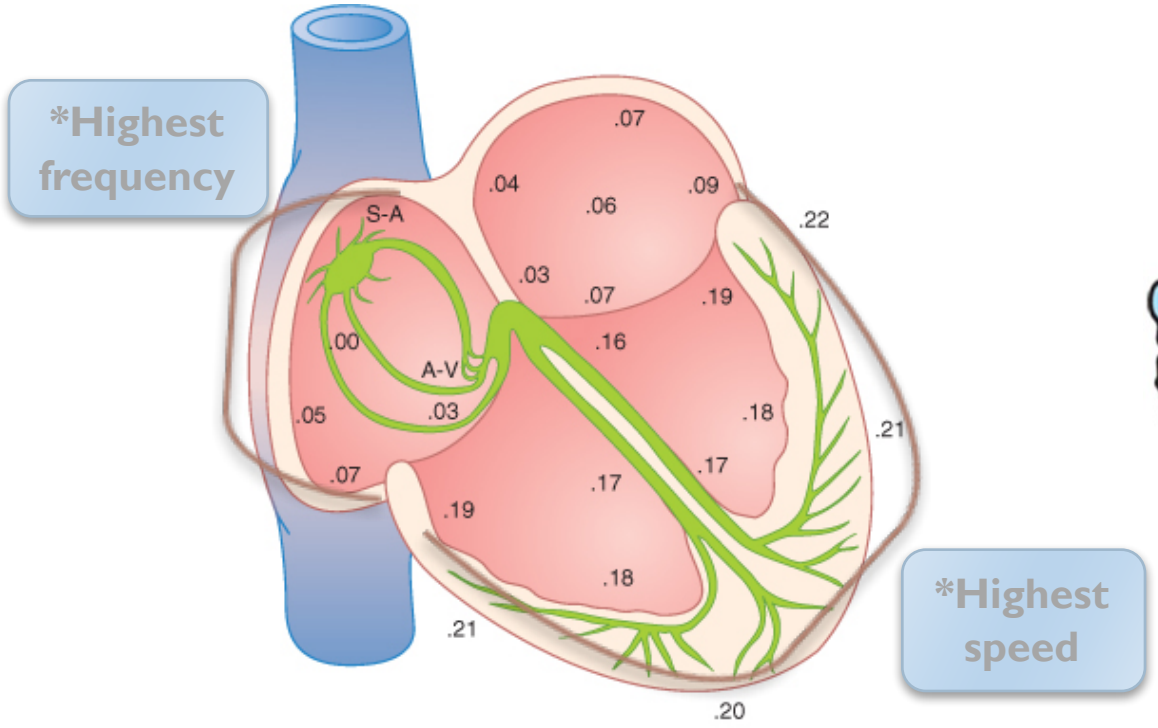

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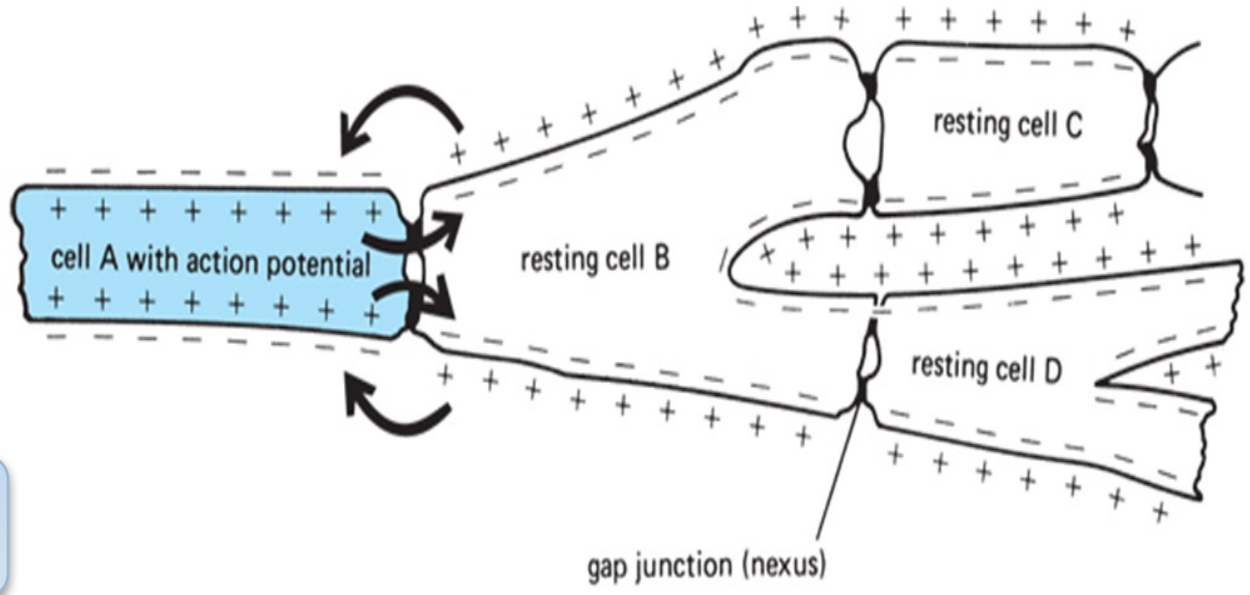

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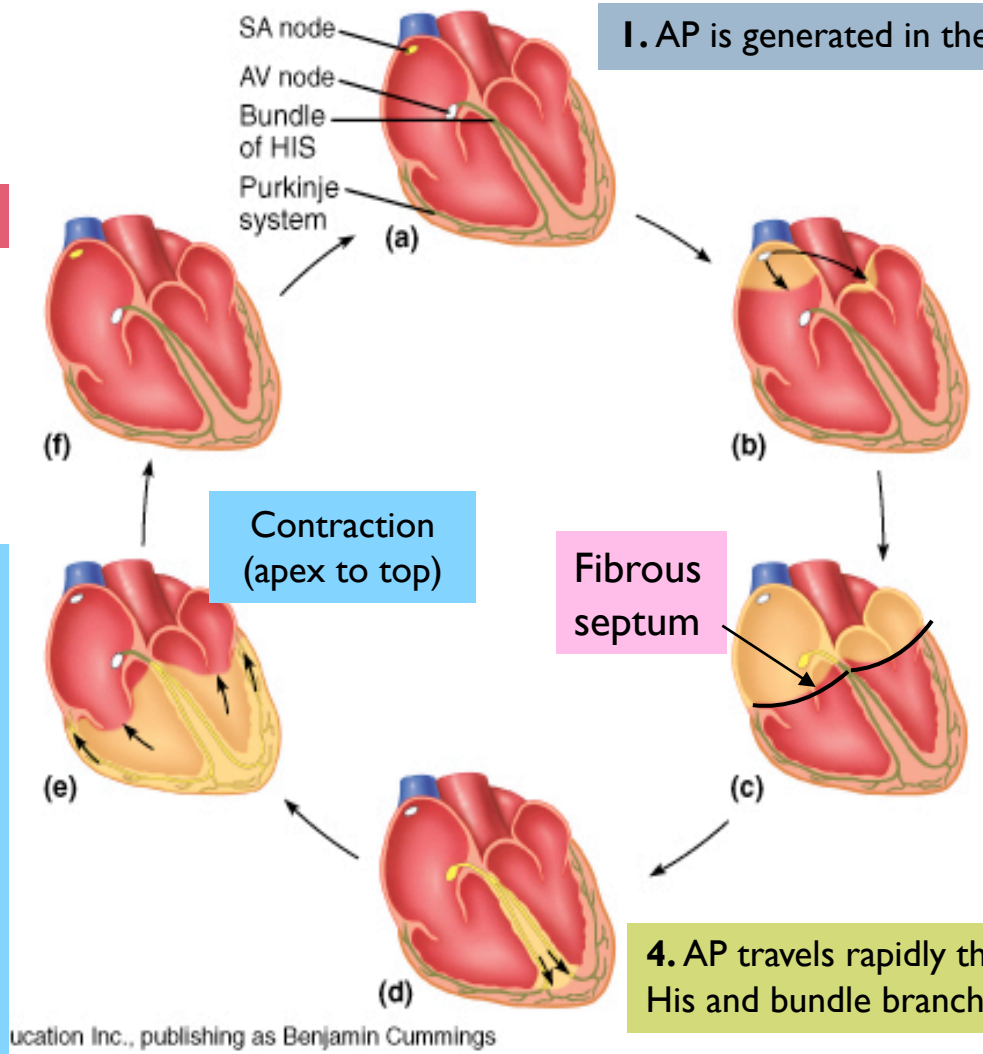
Normal Conduction of the Action Potential in the Heart



1. AP is generated in the SA node

2. AP is conducted through the atria.

-Conduction Very rapid.

-Atrial cells are large.

3. Conduction slows at the AV node.

-Small cells.

3.

- Why AV node delays impulse for 0.1 – 0.15 seconds? to allow time for the atria to empty the blood into the ventricles before ventricular contraction begin
- What controls the AV node conductivity? Sympathetic and parasympathetic stimulation

4. AP travels rapidly through the bundle of His and bundle branches

5. AP spreads through the ventricles (bottom/apex to top)

- Ventricular cells are electrically coupled through gap junctions.
  - Depolarization begins in Interventricular septum
  - Spreads to right and left endocardial surfaces
  - Spreads from endocardium to epicardium

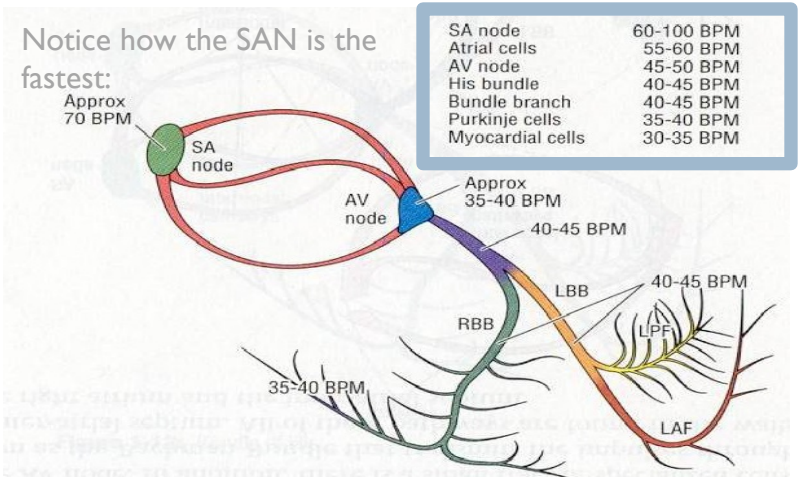
6. Rest

AV nodal delay's function is to keep ventricles in diastole while atria is in systole

Conduction Velocity (CV) in heart

- CV depends on: current spread (عبور التيار), hence, diameter and number of gap junctions between cells (larger diameter, more gap junctions → faster conduction).
- Purkinje fibers: have **very large diameter** and **more gap junctions** with high permeability.
- AV node and bundle (Bundle of His): have small diameter and few gap junctions.
- Approximate CV:

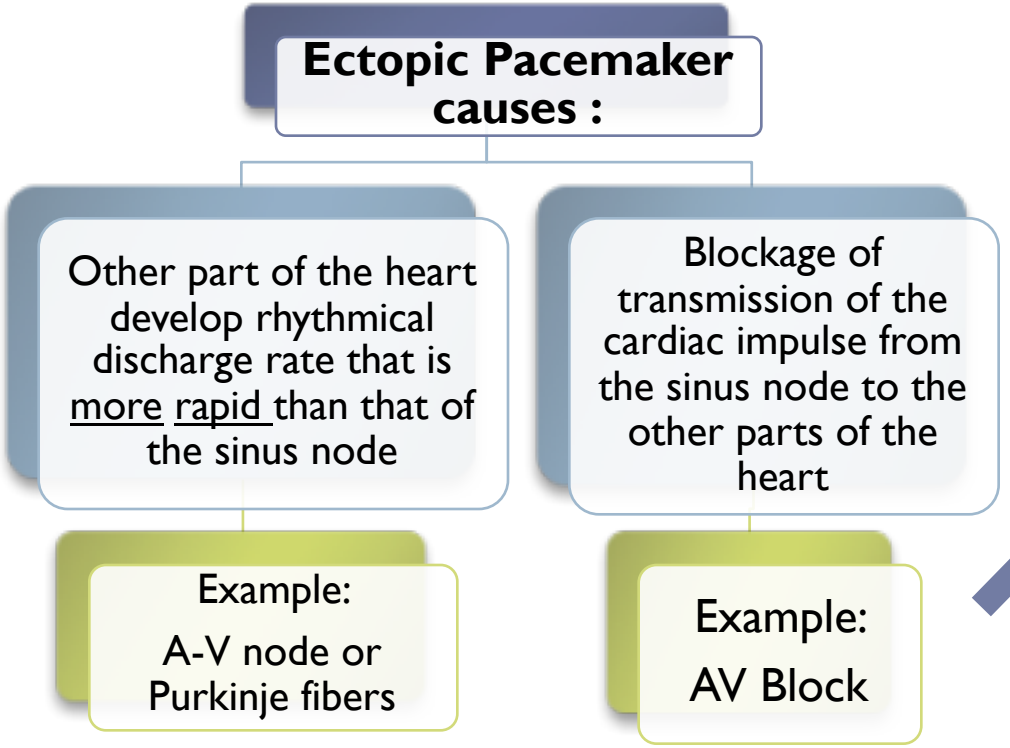
SA node	0.05 m/sec
Atria	0.3m/sec (internodal pathway 1.0m/sec)
AV node	0.05m/sec
Bundle of His	1 m/sec
Purkinje system	4 m/sec
Ventricular muscle	1 m/sec



- The **high conduction** velocity of Purkinje fibers is to ensure that the ventricular myocytes contract at almost the same time.

Abnormal Pacemakers (Ectopic -out of place- Pacemakers)

Ectopic beat: A beat generated outside the normal pacemaker (S-A node).
Ectopic focus (foci pl.) or Ectopic pacemaker.
The site that generates an ectopic beat.



Example:
A- V node (atrioventricular node) block:
The cardiac impulse fails to pass from atria into the ventricles

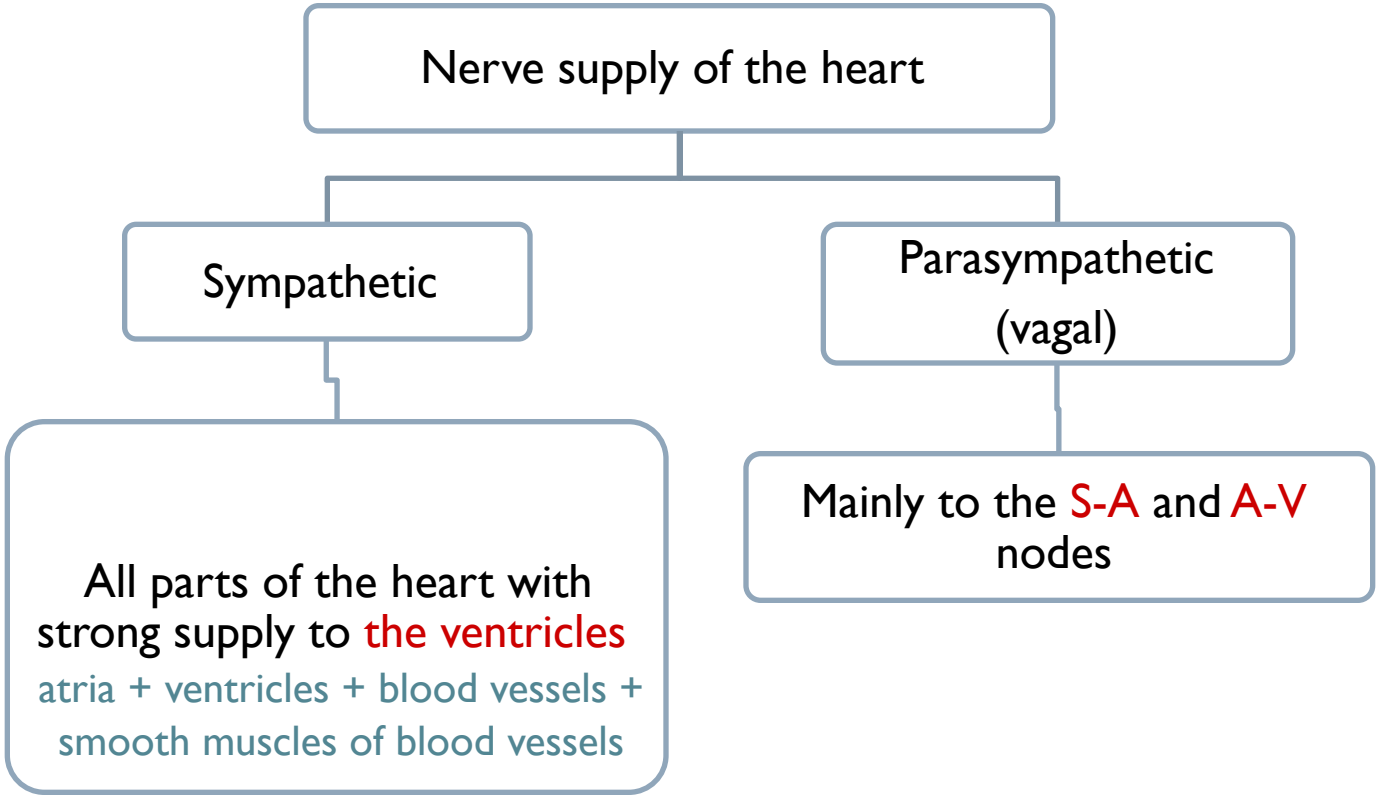
The atria continues to beat at the normal rate of rhythm of the S-A node

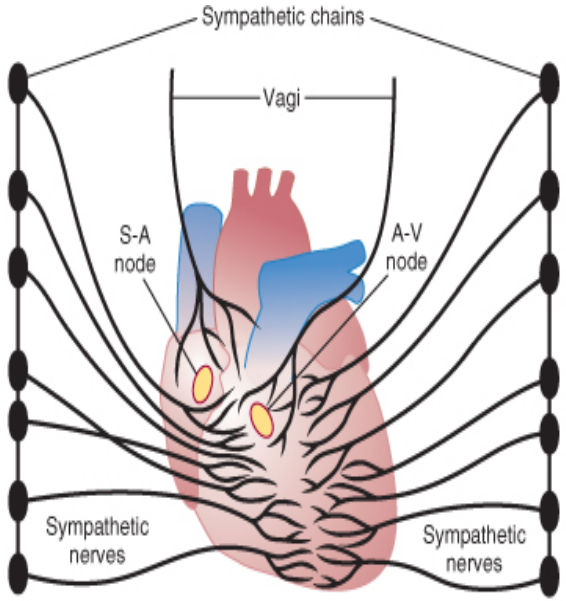
A new pacemaker develops in the Purkinje system with new rate.(ventricular escape)

In AV block:
Atria still have SA node as pace maker
Ventricles develop new pacemaker

Control of the heart Rhythmicity and impulse conduction by the cardiac nerves

- The heart is supplied with both sympathetic and parasympathetic nerves (which are controlled by cardiac center in the medulla oblongata).





Video of (Autonomic Innervation of the Heart) Duration: (4 mins)

Cont.

Parasympathetic (vagal) stimulation of the heart	Sympathetic Stimulation of the heart
• ↓ Rate of rhythm of the S-A node (↓ heart rate). • ↓ Transmission (conduction) of impulses to the A-V node. Strong stimulation of the vagi: • Stop the rhythmical excitation completely by the S-A node. • Block transmission of cardiac impulses completely from the atria to the ventricle. • **Ventricular Escape:** some point in the Purkinje fibers develops a rhythm of its own. ⟹ الفنتركل هربت من تاثير الفايقس	• ↑ Rate of rhythm of the S-A node (↑ heart rate). • ↑ Transmission (conduction) of the impulses to the A-V node. • ↑ Force of contraction (+ ionotropic).

- Parasympathetic stimulation has no effect on the force of contraction because it does not supply the ventricles .The sympathetic stimulation has a crucial effect on the contraction because it supplies the ventricles.
- In strong stimulation of vagi (vagus nerve, vagal stimulation) the ventricles may stop beating for 5-20 sec, but then some small area in the purkinje fibers develop a rhythm of its own and causes ventricular contraction at 15-20 beats per minute , that's called VENTICULAR ESCAPE.

Quiz

- https://www.onlineexambuilder.com/cardiac-electrical-activity/exam-136804

Link to Editing File

(Please be sure to check this file frequently for any edits or updates on all of our lectures.)

References:

- Girls' and boys' slides.
- Guyton and Hall Textbook of Medical Physiology (Thirteenth Edition.)

Thank you!

اعمل لترسم بسمة، اعمل لتمسح دمعة، اعمل و أنت تعلم أن الله لا يضيع أجر من أحسن عملا.

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