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مُبارك عليكم شهر رمضان

Cardiac electric activity

Editing File

Main text Female's slide Male's slide Important text Doctor's note Extra

Objectives:

- Know the components of the conducting system of the heart, the conduction velocities & spread of cardiac impulse through the heart
- Understand control of excitation and conduction in the heart
- Identify the action potential of the pacemaker and the differences between pacemaker potential & action potential of myocardial cells
- Describe the control of heart rhythmicity and impulse conduction by the cardiac nerves, what is latent and abnormal pacemakers

Dr. nagy

ادعوا له :)

Click the button to get 10 billion$!!

Dr: In general numbers are Very important!

Female's slide

What's so special about the heart ?

سُبْحَانَ رَبِّكَ رَبِّ الْعِزَّةِ

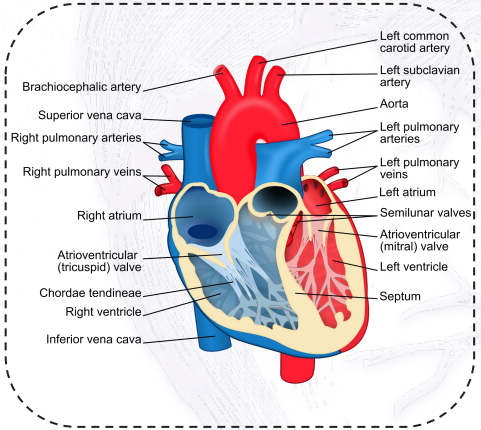
A quick review of heart anatomy :)

1. The heart has the ability to intrinsically depolarize(contract) itself. It doesn't really depend on the central nervous system for that.
   (Unlike skeletal muscles which have to be stimulated by nervous system, the heart generates its own electrical stimulation. That is why it can beat even if it's taken of the body. The CNS can make the heart go faster or slower.) Thx439

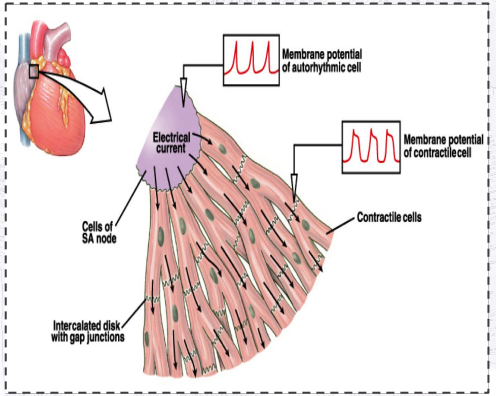
It has many different cells that can generate action potentials by themselves (will be mentioned in details later on)

2. The heart is innervated by nerves influencing HR (increase or decrease) , contractility and cardiac output. So, the nervous system DOESN'T generate cardiac impulses, it only influences impulse rate; and hence, contractility and cardiac output during the process as well.
   CO: the volume of blood that is squeezed per min
   SV: the volume of blood that is squeezed for one beat

3. The heart has automaticity: Which is the intrinsic ability to spontaneously(ذاتيًا) depolarize itself and send action potential to all myocardium (nodal and contractile cells) to trigger the heart muscle to contract.



Heart Rhythmicity and the Myocardium:



1 Rhythmical Excitation system of the Heart :

- The heart is endowed with a special system for:
  1. Responsible of generating rhythmical electrical impulses to cause rhythmical contraction of the heart muscle.
  2. Functions in conducting impulses rapidly through heart.

2 To understand the conduction system of the heart it is important to learn about the myocardium, which is divided into two major types:

Nodal Cells	Contractile Cells
Generate action potentials but are NOT contractile and these include: 1. SA node 2. AV node 3. AV bundle (bundle of His) 4. Bundle branches (left and right) 5. Purkinje fibers	1. Consist of contractile proteins (actin, myosin, troponin, tropomyosin). 2. contain a sarcoplasmic reticulum. 3. they generate the force that push blood out of the heart.

3 Note that nodal cells are responsible of generating the rhythm and pace.

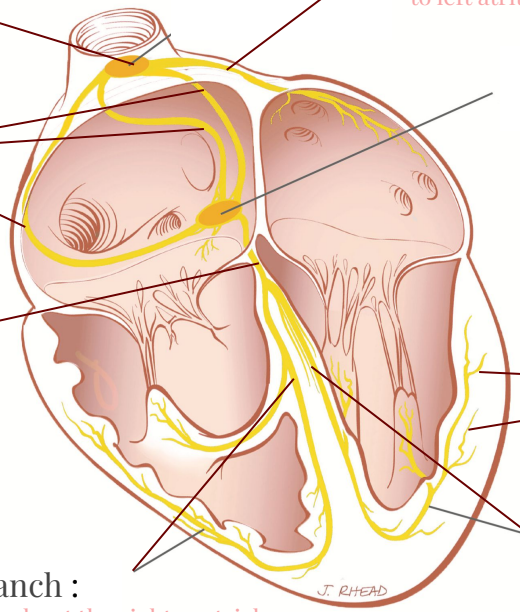
Specialized Excitatory and Conductive system of the Heart:

Sinus (sinoatrial) node :
Generate rhythmic impulses (main pacemaker).

Bachmann's Bundle :
Conduct impulses from sinus node(located in right atrium) to left atrium.

Internodal pathways :
Conduct impulses from sinus node to atrioventricular (A-V) node.

AV (atrioventricular) node :
Receive impulses from both atria are then delayed before passing into ventricles. (why it's delayed? Will be discussed later)



Ventricular syncytium : The contractile cells

A-V bundle :
Conducts impulses from both atria to ventricles (also called bundle of His).

Purkinje fibers :
Conduct cardiac impulses to all parts of ventricles connecting with the smaller units in muscle.

Right Bundle branch :
Spreads impulse throughout the right ventricle.

Left Bundle branch :
Spreads impulse throughout the left ventricle.

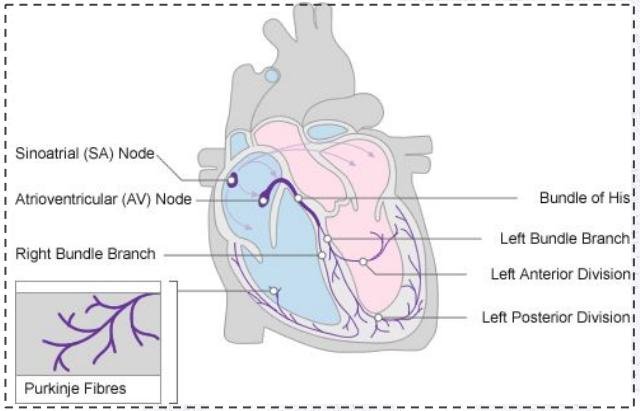
وَفِي أَنْفُسِكُمْ أَفَلا تُبْصِرُونَ

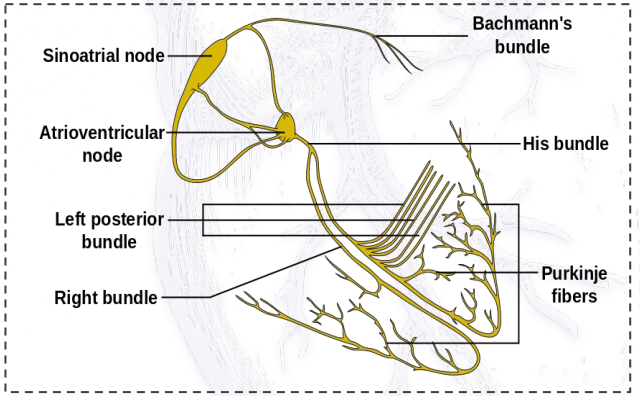
Important slide

Excitation Sequence:

كيف تبدأ العملية و تسلسلها

1. SA node fires to the **Bachmann's bundle** so the left atrium contracts then the internodal pathways across the left and right atrium, eventually all these impulses will propagate to the AV node where it's delayed.
2. After that, the action potential (impulse) goes to the interventricular septum, and then reaches the AV bundle or bundle of His, which branches to right bundle that allows for the action potential to travel across the right ventricle and left bundle for the left ventricle.
3. Then it goes to breaking units called the Purkinje fibers fibers that connect to smaller units in ventricles.





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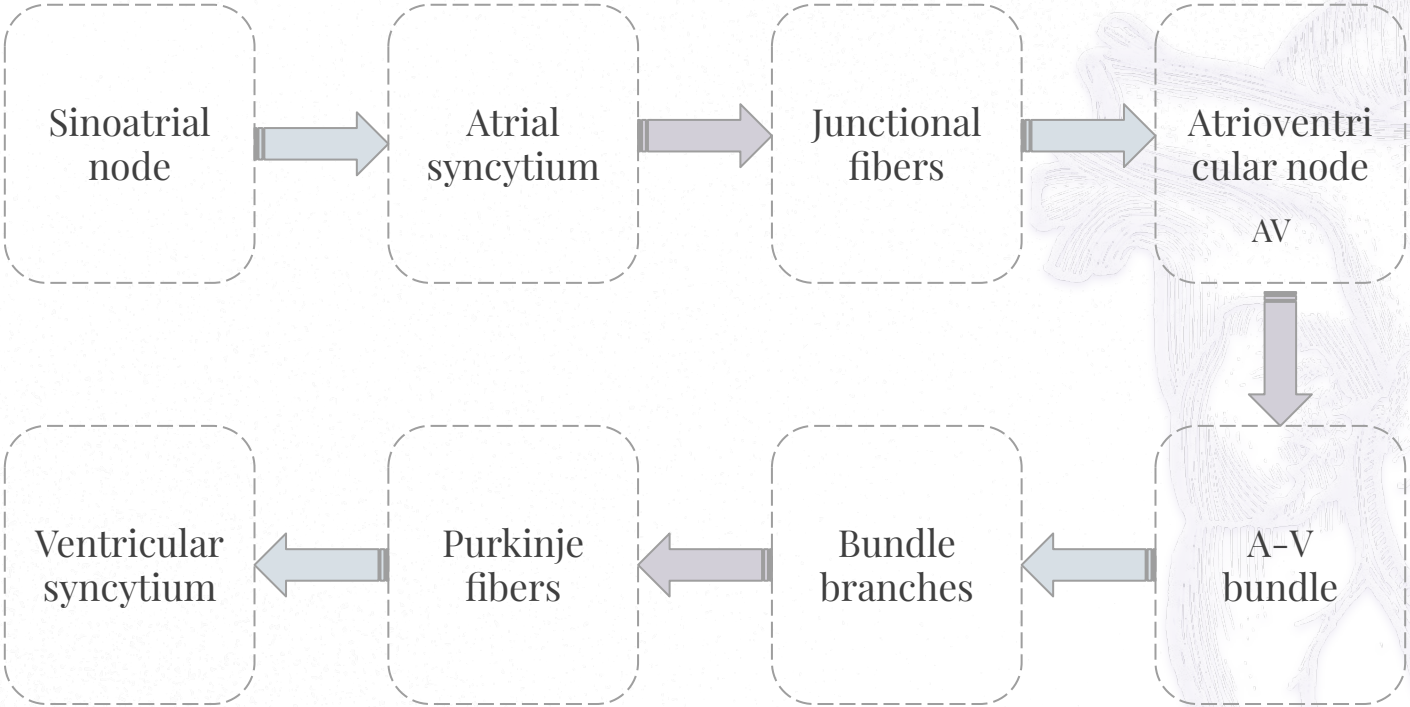

Sinoatrial node
Atrial syncytium
Junctional fibers
Atrioventricular node
AV
A-V bundle
Bundle branches
Purkinje fibers
Ventricular syncytium

SA node:

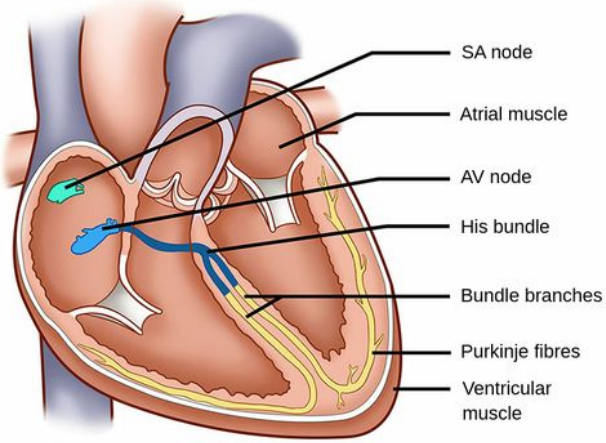
1. The SA node, also known as the pacemaker, is a specialized ellipsoid strip of cardiac muscle that is flat and small in size and is directly linked to the right atrium.

2. The sinus rhythm(normal heart rate) is established by the SA node, which is located on the superior posterolateral wall of the right atrium, just below the superior vena cava. It has no contractile fibers.

3. The SA node, which has the fastest (highest) rate of auto-rhythmicity, is responsible for regulating the heart rate

4. Sinus rhythm(refers to the natural heart rate range) is 60-80(100) beats per minute (bpm) which is generated without aid of central nervous system: no sympathetic or parasympathetic nervous system effect in generating impulse ..this nervous influence is an extrinsic influence not intrinsic to heart and only affects HR(Heart rate) and factors linked to it like CO (cardiac output), SV (stroke volume), BP (blood pressure).

5. SA node is responsible for producing the electrical signals that initiate the mechanical activity, which leads to the contraction of the heart.



Cardiac impulse from SA node to atrial muscle :

The cardiac impulse after it's origin in the SA node spreads throughout the atrial muscle by two routes:

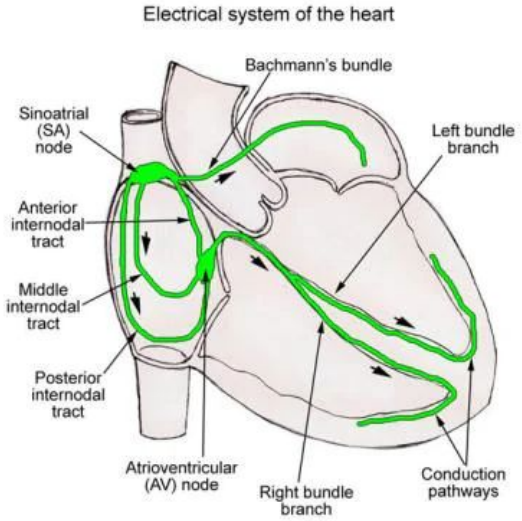
Anterior, middle and posterior conducting bundles
(internodal bundles)

1. Anterior internodal, bundle of Bachman

2. Middle internodal, bundle of Wenkebach

3. Posterior internodal, bundle of Thoral

4. These inter nodal pathways conduct the impulses at a faster rate than atrial muscle fibers, because of specialized conduction fibers.



Ordinary Atrial muscle fibers

- The velocity of conduction in most atrial muscle is about 0.3 m/sec.(slow)

- In the specialized internodal pathways the conduction velocity may reach upto 1 m/sec.(fast)

- The impulse after leaving SA node takes 0.03 sec to reach the AV node (considered a delay).

Extra slide
Thx 443

Cardiac impulse from SA node to atrial muscle :

What is the difference between the atrial muscle fibers and the internodal pathways ?

atrial muscle fibers

- The ordinary atrial muscle fibers are located throughout the walls of the atria and are responsible for carrying electrical impulses that coordinate the contraction of the atria.

- These impulses travel from the sinoatrial (SA) node, which is the natural pacemaker of the heart, through the ordinary atrial muscle fibers and stimulate the atrial muscle cells to contract.

- Primary function is to <u>contract.</u>

internodal pathways

- The internodal pathways, are a series of specialized conduction fibers that connect the SA node with the (AV) node, which is the next stage in the electrical conduction pathway.

- The internodal pathways are located in the walls of the right atrium and carry electrical impulses from the SA node to the AV node.

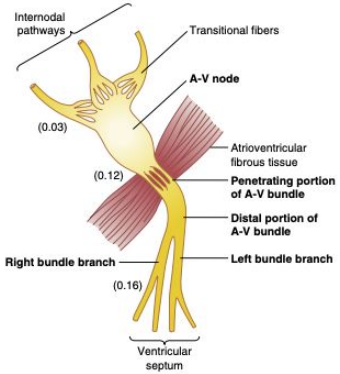
- primary function is to rapidly <u>conduct</u> the electrical impulse.

Atrioventricular (AV) Node:

Location: A-V node is in the posterior wall of the right atrium immediately behind the tricuspid valve (underneath the pulmonary trunk).

Delay of Impulse Conduction from the Atria to the Ventricle:

1	Impulse originates in SA node
2	Reach AV node 0.03 sec after its origin
3	Delay of 0.09 sec in A-V node
4	Enters A-V bundle, passes into ventricles
5	Delays of **0.04** sec occurs in A-V bundle (bundle of His)



Total delay is **0.16** sec

Note that the Slow Conduction in penetration A-V bundle fibers is caused by **diminished**(قلة) **number of gap junctions** (between the successive cells in the conductive pathways).

Atrioventricular (AV) Node:

What is the importance of the 0.09 (0.1) delay at the AV node?

1. The cardiac impulse does not travel from the atria to the ventricles too rapidly.

2. This delay allows time for the atria to empty their blood into the ventricles before ventricular contraction begins, ventricles are able to effectively collect the blood from the atria and then Push it into the aorta and pulmonary circulation.

3. increasing the efficiency of pumping action of the heart.

Two microscopic (histological) reasons for this delay:

1. Nodal cells contain numerous gap junctions, which enhance the speed of action potentials and facilitate the transfer of ions from one cell to another. However, the AV node, comprising many of these nodal cells, has significantly **fewer gap junctions** compared to other nodal cells.

2. The AV node exhibits **smaller fiber diameter**, which leads to a reduction in conduction velocity. As a general rule, the velocity of conduction is influenced by the diameter of the fibers, (where larger diameters promote faster conduction, and smaller diameters result in slower conduction).⟶ resistance!

One-Way Conduction Through A-V Bundle:

تمنع ال electrical impulses يجون من ال ventricle الى ال atrium

1. It is a characteristic of the A-V bundle, it's the inability of action potentials to travel backward from the ventricles to the atria.

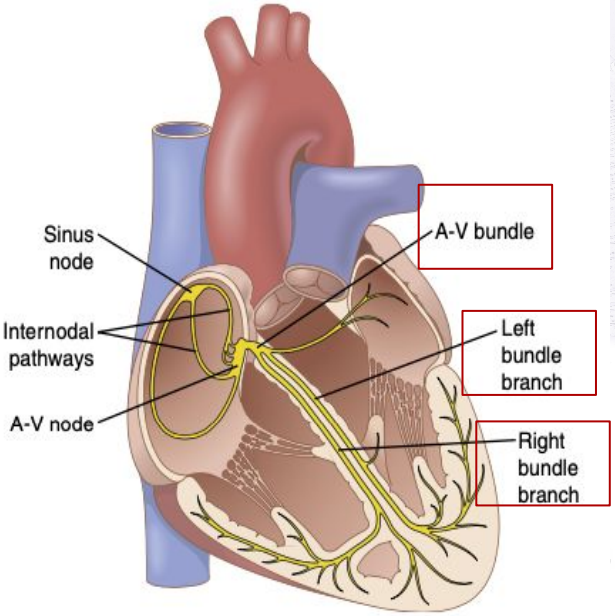
2. Allows only forward conduction from atria to ventricles. This prevents re-entry of cardiac impulse by this route from the ventricles to the atria.

3. Atrial muscle is separated from ventricular muscle by a continuous fibrous barrier which acts as an insulator to prevent the passage of cardiac impulse between the atrial and ventricular muscle except at AV bundle, allowing only forward conduction through the A-V bundle itself.

Right and left bundle branches :

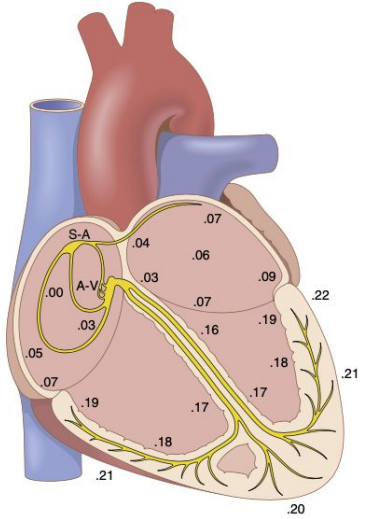
1. Bundle of His (AV bundle)splits into two branches which are called right and left bundle branches present on the respective sides of the ventricular septum.

2. From the time the cardiac impulse enters the bundle branches until it reaches the terminations of Purkinje fibers , the total time averages only 0.03 sec.



Transmission in Ventricular Purkinje System:

- very large fibers that transmit APs at a velocity of 1.5 - 4.0 m/sec (6 times that of ventricular muscle).
- Rapid transmission through Purkinje fibers is caused by very high level of permeability of gap junctions at the intercalated discs between the successive cells of Purkinje fibers.
- Allows instant transmission of cardiac impulse throughout entire ventricular muscle.
- The rapid conduction through the purkinje fibers ensures that different parts of ventricles are excited almost simultaneously; this greatly increases the efficiency of heart as a pump.



Transmission of the Cardiac Impulse in the Ventricular Muscle :

Once impulse reaches ends of Purkinje fibers, it is transmitted through ventricular muscle mass by ventricular muscle fibers themselves.

Conduction velocity is not the same in all myocardial tissues: It is slowest in the AV node and fastest in the Purkinje fibers

Note that eventually the ventricular contraction begins 0.1 - 0.2 sec, after the contraction of atria.

(بسبب التأخير في الAV node)

	Conduction rate m/s	Importance
1	SA node (0.05)	
2	Atrial pathways (0.3 - 1)	
3	AV node (0.01 - 0.05) (slowest)	Allow filling of ventricles
4	Bundle of His (1 - 2)	
5	Purkinje system (2 - 4) (fastest)	To allow efficient ejection of blood
6	Ventricular muscles (1)	

Female's slide

Important slide

Mechanism of Sinus Nodal Rhythmicity

Cardiac muscle has 3 types of membrane ion channels that play an important roles in causing voltage changes of AP:

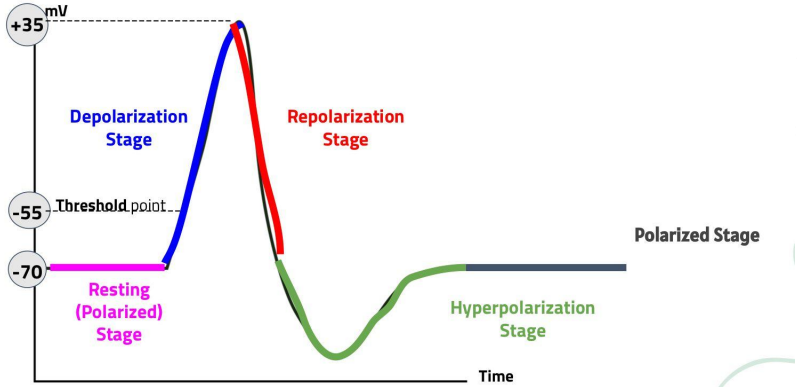
- Fast Na+ channels
- Slow Ca+2 channels
- K+ channels

Just a reminder of the action potential :)

MSK remember?

Stages of Action Potential

- **Resting**/Polarized
- **De**polarization
- **Re**polarization
- **Hyper**polarization



Female's slide

Mechanism of Sinus Nodal Rhythmicity

How does this self-action potential take place?

We look at a nodal cell and a contractile cell. The nodal cell needs to have gap junctions that allows ions to flow from the nodal cells to contractile cell so it can contracts.

1. The resting membrane potential of the SA node is destabilized by the presence of leaky Na+ channels that permit a gradual entry of Na+ ions into the cell's lumen. Additionally, Ca+2 channels are activated, which further elevates the positive charge within the cell.

2. As a result, the resting membrane potential of the SA node becomes less negative than the ventricular cells (contractile cells), ranging from -55 to -60 mv(because of leak Na Channel).
This is in contrast to the normal resting membrane potential of other cells, which typically falls between -70 to -75 mv.

Female's slide

cont..

When the membrane potential reaches -40 mV, an additional channel becomes activated, leading to a sudden influx of Ca+2 ions and resulting in a sharp rise in the graph. These channels, known as L- type Ca+2 channels, sensitive to changes in voltage and are capable of generating depolarization by increasing the positive charge up to +40 mV.

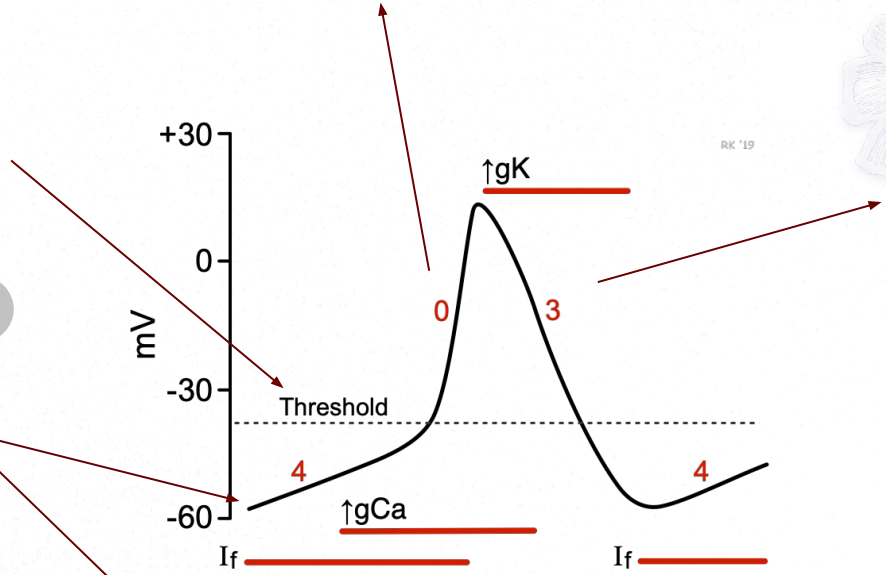
3

L stands for : long lasting or better call it lazy :)

Threshold potential for SA node?
-40mv

When the positive charge builds up, it reaches a threshold potential. While the threshold potential is typically -55mV in most cells, it is -40mV in nodal cells.

2



At approximately +40 mv caused by voltage-gated Ca+2 channels, these channels deactivate (shut off)

After the deactivation of Ca+2 channels, a K+ channel opens, allowing K+ ions to exit, resulting in the loss of positive charge and repolarization of the membrane potential to approximately the resting membrane potential (-50mv*). When the membrane potential reaches -60mv, the K+ channel closes and the Na+ channel opens, starting the cycle again.

4

Na+ will get into the SA cell which will lead to the elevation of charge to -55

At -55, T - type ca2+ channels will start opening and Ca2+ start to move into the cell slowly making the membrane potential even more positive.

1

It should be noted that Na+ channels exhibit high sensitivity to a charge of -60 mv. As a result, upon reaching this charge level, the Na+ channels will begin to open. That's why the RMP is -60 and not -70 mv like other type of cells in our body.

AP in Pacemaker (SA node):

Female's slide

Important slide
SAQ,MCQs

Phase 0:

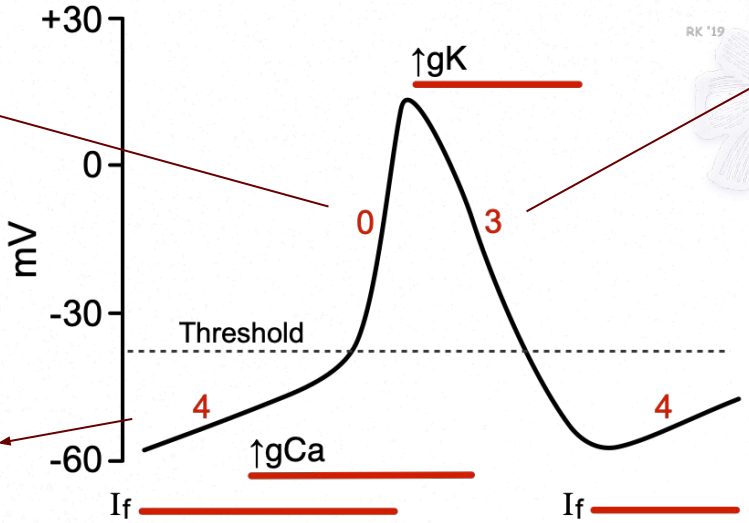
Depolarization is caused by increased Ca++ through L-type Ca++ channels that began to open toward the end of Phase 4

2

Phase 4:

- Slow Na+ "funny" currents enter and cause depolarization, initiating Phase 4 when the membrane potential is at -60 mV.
- When the membrane potential reaches -50 mV, Ca++ enters through transient or T-type channels, leading to further depolarization of the cell.
- This causes more Ca++ to enter, resulting in depolarization until the action potential threshold is reached, typically between -40 and -30 mV.
- At this point, long-lasting or L-type Ca++ channels open at -40 mv.

1



RK '19

General info..

Unlike the ventricular action potential, the opening of Ca2+ channels is not sustained, and there is no "plateau" stage. Therefore, the action potential is triangular in shape

Explained later on..

Phase 3:

K+ channels opening results in an increase in outward-directed K+ currents, leading to hyperpolarization, which is known as repolarization.

3

General info..

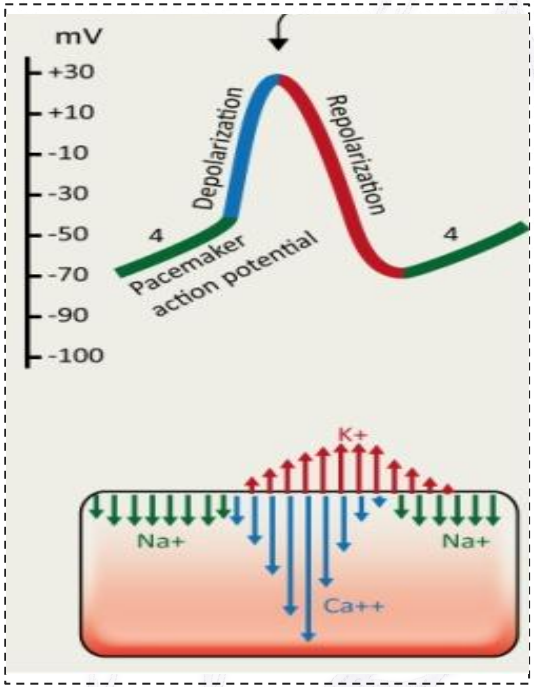
- Gap Junctions are responsible for spreading the cations(موجبة) within the cell to neighboring nodal or contractile cells.

- These junctions connect the nodal cells to each other and to contractile cells through the protein desmosome,
(made of catherns and attachment blocks like desmoplakin), and keratin is attached to that, connecting the nodal to the contractile cells
The Gap Junction is composed of a family of proteins called connexons.

Gap junctions(مرور الايونات) + desmosomes(تربط بين الخلايا) = intercalated discs.

Mechanism of Sinus Nodal Rhythmicity

- Return of AP to its negative state occurs slowly, rather than the abrupt return that occurs for ventricular fiber.
- A hyperpolarized (super negative) state is necessary for pacemaker channels to become activated.
- Without the membrane voltage becoming very negative at the end of phase 3, pacemaker channels remain inactivated, which suppresses pacemaker currents and decreases the slope of phase 4.
- K+ channels remain open continuing movement of positive charges out of cell, with resultant excess negativity inside the fiber; this is called **hyperpolarization.**
- The hyperpolarization state carries the "resting" membrane potential down to about −55 to −60 mv at the termination of the AP



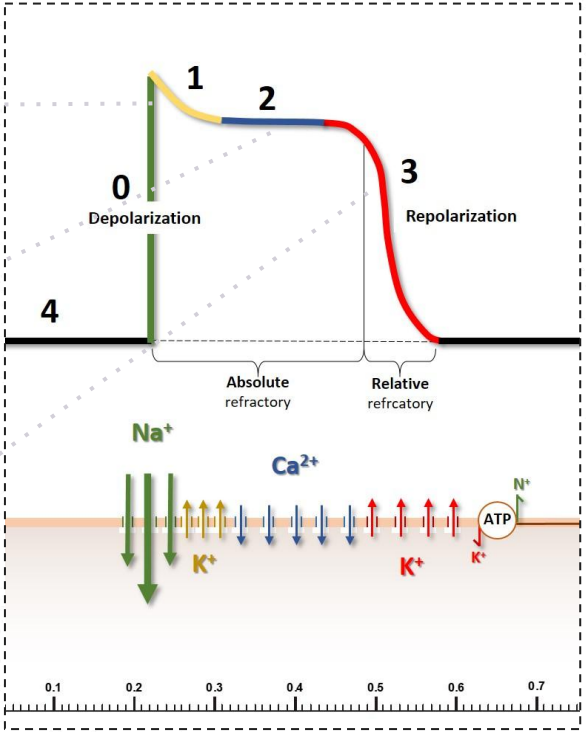
Action Potential In The Cardiac Muscle

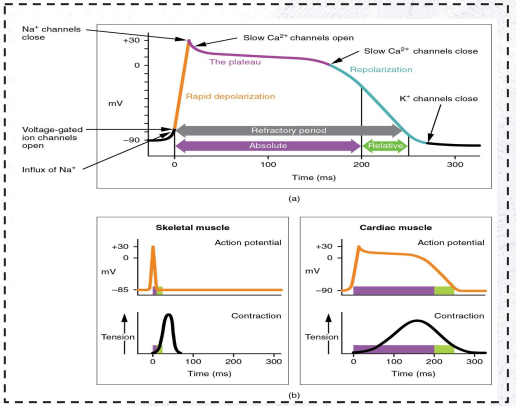
The cardiac action potential is made of 3 phases:

Depolarization: Caused by the opening of fast Na channels & slow Ca channels

Plateau: remaining of slow Ca channels open for several m second, drawing large amount of Ca inside wich prolong depolarization

Repolarization : Opening of potassium channels



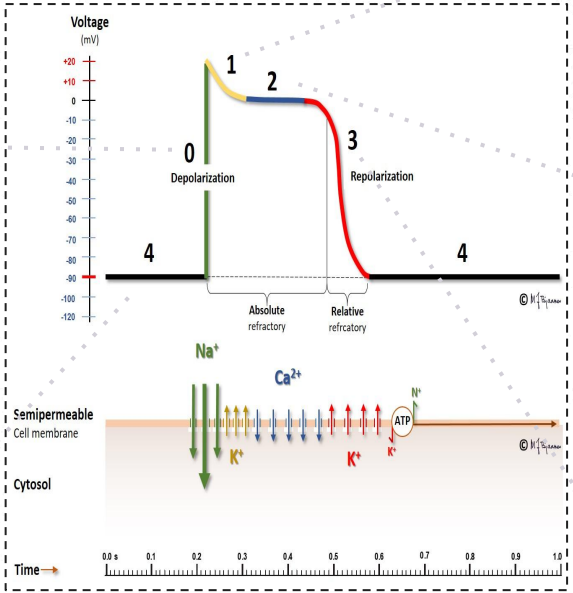


The presence of Plateau in the action potential causes ventricular contraction to last as much as 15 times as long in cardiac muscle as in skeletal muscle

Action Potential In The Cardiac Muscle

Phase 0 (depolarization):
Fast sodium channels open.
Voltage gated sodium channels (fast sodium channels) open and cell depolarize. Membrane potential reaches about +20 millivolts before the sodium channels close.

Phase 4 (resting membrane potential): averages about −90 millivolts.



Phase 1 (initial repolarization):
fast sodium channels close. Cell begins to repolarize, and potassium ions leave the cell through open potassium channels.

Phase 2 (Plateau) :
calcium channels open and fast potassium channels close.
Initial repolarization Occurs. Potassium ion efflux decreases and increased calcium ion influx causes the action potential to plateau.

Phase 3 (rapid repolarization):
calcium channels close
and slow potassium channels open. The closure of calcium ion channels and increased potassium ion permeability, permitting potassium ions to rapidly exit the cell

Guyton and hall pp 111

Female's slide

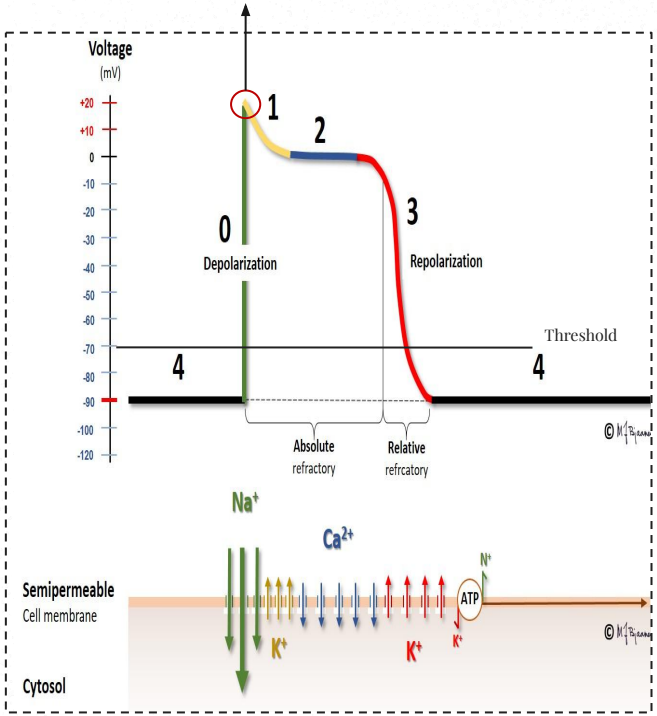
Action Potential In The Cardiac Muscle

Threshold potential for contractile cells?
-70mv

Phase 0 (depolarization): At -70mv, specialized voltage gated Na+ blast open
Then Na+ flows in very fast this causes the inside of the cell to become very positive. This positive charge starts moving across the cell membrane (Sarcolemma) in a wave motion
Charge reaches +10mv as some other channels start opening up allowing for some Ca+2 to trickle in... slowly this causes along side Na+ to reach +10mv.
It is actually in range +10 to +20

Phase 4 (resting membrane potential): Resting membrane potential for the contractile cells are -85—90 mv. Ions leaking via gap junctions charge rises to reach threshold potential which is around -70mv

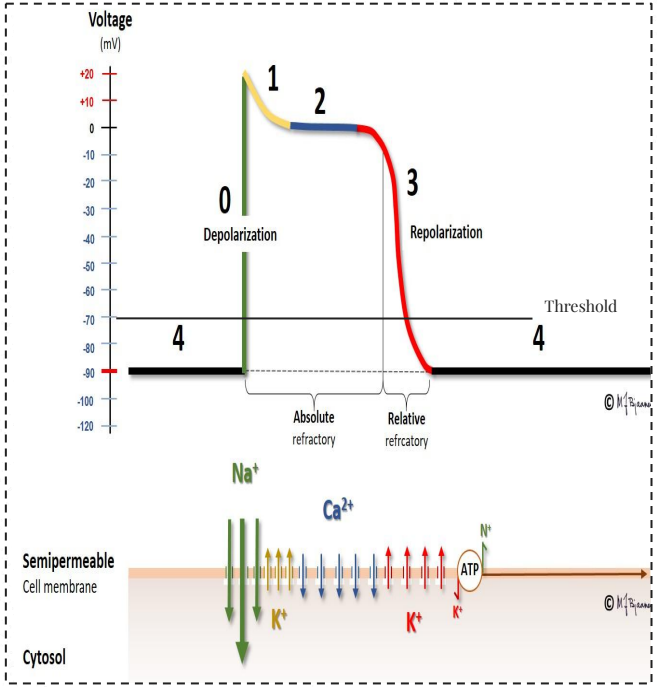
Inactivation of Na channel



Phase 1 (initial repolarization):
At +10mv, Na+ channels inactivate but little of Ca+2 are still opened but some other channels open at this time. K+ channels open now bcus charge is very positive (+10mv) so K+ leave to adjust charge K+ coming out more than the quality of Ca+2 slowly trickling in. this makes charge drops down a little bit in graph drop is from 10mv to around omv.

Action Potential In The Cardiac Muscle

Phase 2 (Plateau) : At omv, Ca+2 become a little bit more active so L type Ca+2 channels open more but don't forget that K+ ions are still leaving the cell. So + leaving and + coming in leaving no space to change membrane potential. This causes plateau for a little bit in the graph (duration of plateau is 250ms).
In atrial fiber the plateau is shorter than in ventricular fibers



Phase 0 : where voltage gated Na+ open causing Na+ influx which results in depolarization (sharp rise in graph).
phase 1 : little dip is noted in the graph were the K+ open as charge is taken from +10 to.
Phase 2 : is plateau where Ca+2 is in and K+ is leaving cell.
Phase 3 : is just K+ channels.
Phase 4: is resting K+ slow leaking out until ions take potential to resting membrane potential

Linda costanzo

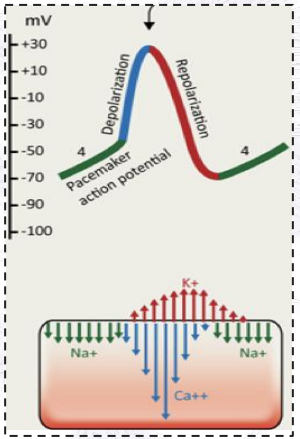
How is such a balance of inward and outward currents achieved during the plateau? There is an increase in calcium (Ca 2+) conductance which results in an inward Ca 2+ current which called slow inward current, reflecting the slower kinetics of these channels (compared with the fast Na + channels of the upstroke). The Ca 2+ channels that open during the plateau are L-type channels To balance the inward Ca 2+ current, there is an outward K + current,
The significance of the inward Ca 2+ current extends beyond its effect on membrane potential. This Ca 2+ entry during the plateau of the action potential initiates the release of more Ca 2+ from intracellular stores for excitation-contraction coupling. This process of so-called Ca 2+ -induced Ca 2+ release is discussed in the section on cardiac muscle contraction.

How do we get this nodal cell to rest?

When about +40mv is reached due to voltage gated Ca+2 channels, these channels actually shut off at +40mv.

When they shut off, other channels open: K+ channel. So K+ ions exit a lot so + is lost and become –ve and potential is repolarization until around resting membrane potential -50mv, but when membrane potential reaches -60mv, K+ channels close and Na+ channels open by -60mv and cycle repeats.

Dr: Note that k+ still flow which cause hyperpolarization but Na+ leak cause the cycle to start again



Important slide

Why Plateau Occurs?

Plateau = موجب يدخل (Ca++) وموجب يطلع (K+)

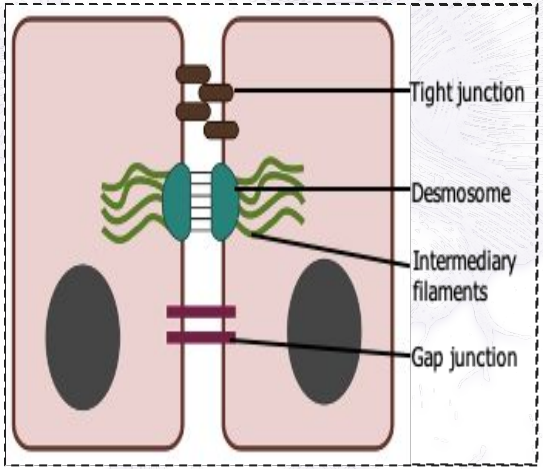
1. Voltage activated sodium channels, called fast channels
2. Voltage-activated calcium-sodium channels (L-type calcium), slow to open, called slow channels. (Prolonged)
3. Opening of fast channels causes spike of AP
4. Prolonged opening of the slow calcium-sodium channels allows calcium to enter, cause plateau.
5. Moreover, voltage-gated potassium channels are slower to open. This delays the return of the membrane potential to −80 to −90 millivolts.

What is the significance of plateau?
-To prevent tetanization
-efficient ejection of blood
-for synchronization
-prolongation of refractory
-periods(preventing tetanus)

Functional Syncytium

You should remember that due to gap junctions between cells the nodal and contractile, this means they are inter-connected and influence each other. So they depolarize by the same time and they synchronize (متزامن) their action to contract as a unit and this unit is called **functional syncytium**.

Nodal cells send action potentials through gap junctions to the myocardium and so they contract as a unit. This contraction of a unit is due to the functional **Syncytium**. This also allows for the top and bottom of the heart to function in their own unique way



Important slide

Refractory Periods

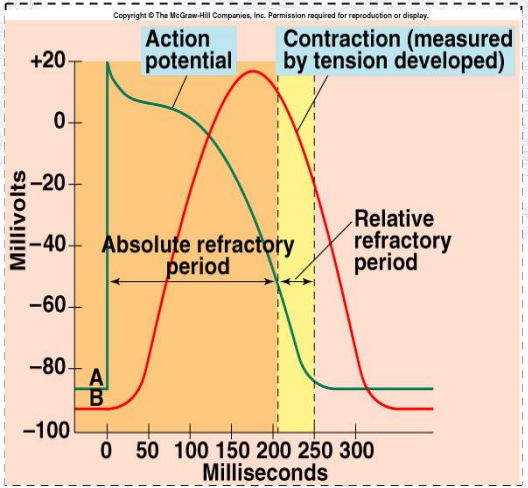
Heart contracts as syncytium, Contraction lasts almost 300 msec.

Refractory periods last almost as long as contraction, So:

1. Myocardial muscle cannot be stimulated to contract again until it has relaxed.
2. Summation and tetanus of cardiac muscle is impossible.
(Because long refractory period occurs in conjunction with prolonged plateau phase)

Long refractory period prevent ventricles from contracting at too high rates so that enough time is allowed for refill of the ventricles

Ensures alternate periods of contraction and relaxation which are essential for pumping blood.



Important slide

Refractory Periods

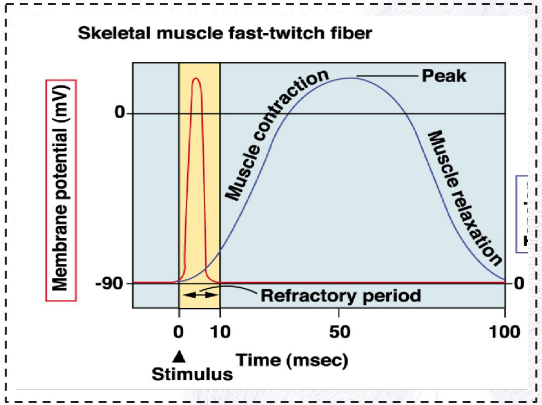
The refractory period is short in skeletal muscle,but **very long** in cardiac muscle.

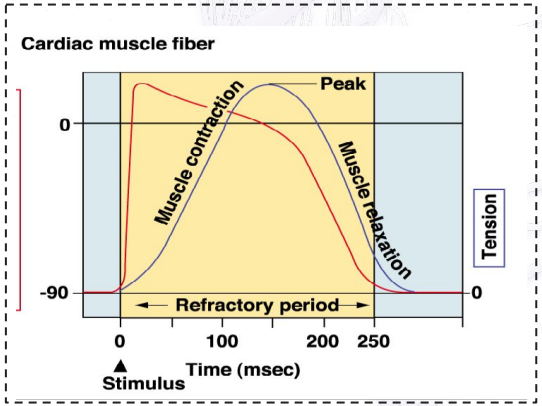
This means that skeletal muscle can undergo summation and tetanus, via repeated stimulation

Cardiac muscle **CAN NOT** undergo sum action potentials or contractions and can't be tetanized

- Summation occurs when a muscle fiber is stimulated repeatedly with a short interval between stimuli.
- tetanus occurs when the frequency of stimulation is so high that the muscle fiber does not have time to relax between stimuli, it's sustained.

You can't have an action potential while an action potential is going,
The cardiac muscle AP takes as long as the contraction, so you basically can't sum or being tetanized.
But in skeletal muscles, the AP is a alot less than the period of contraction, thus summation can occur with a greater stimulus before getting into the relaxation phase :)





Pathology: Latent "ectopic" Pacemaker

- A pacemaker elsewhere than the sinus node is called an "ectopic" pacemaker.
- An ectopic pacemaker causes an abnormal sequence of contraction of the different parts of the heart and can cause significant disability of heart pumping.
- The cause of shift of the pacemaker is blockage of transmission of the cardiac impulse from the sinus node to the other parts of the heart.

Sometimes the electrical impulses do not originate in the SA node, but in another
part of the heart, which is called an **ectopic pacemaker**.
An ectopic pacemaker is a small cluster of cells that spontaneously generates electrical signals, which can
interfere with the normal rhythm of the heart.

Location	Intrinsic Firing Rate (impulse/min)
Sinoatrial Node	70-80
Atrioventricular Node	40-60
Bundle of HIS	40
Purkinje fibers	15-20

If the SA node is damaged, AV node will become the pacemaker cell and so on

Mechanism of Sympathetic and Parasympathetic effect

Female's slide

Important slide

Sympathetic effect

1. Stimulation of the sympathetic nerves releases the hormone norepinephrine
2. Norepinephrine stimulates beta-1 adrenergic receptors
3. Increases permeability to Na+ and Ca+2 causing a more positive resting potential and increased excitability
4. increases rate of sinus nodal discharge

Parasympathetic effect (Vagal)

1. Parasympathetic Stimulation releases acetylcholine
2. Acetylcholine increases permeability to K+ allowing rapid leakage of K+ out of conductive fibers.
3. Causes increased negativity inside fibers (hyperpolarization) making tissue less excitable
4. Decreases rate of rhythm of the sinus node and A-V junctional fibers.

سُبْحَانَ رَبِّكَ رَبِّ الْعِزَّةِ

Female's slide

Effect of parasympathetic (ACH) Stimulation on Cardiac Rhythm

1

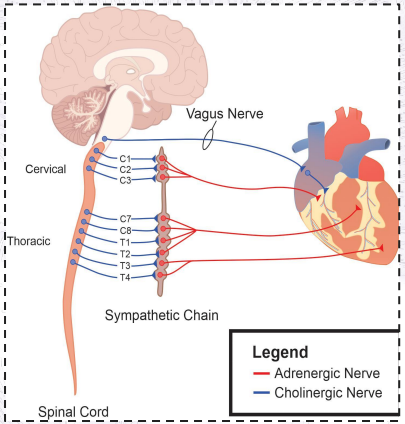
It decreases rate of sinus nodal discharge.

2

It reduces rate of conduction

3

Strong stimulation of vagus stops rhythmical excitation by SA node or blocks transmission of cardiac impulse from atria into ventricles.



Autonomic Nervous System Effect

	Sympathetic	Parasympathetic
Heart rate	↑	↓
Conduction velocity	↑	↓
Contractility	↑	↓ Atrial only
AP frequency	↑	↓

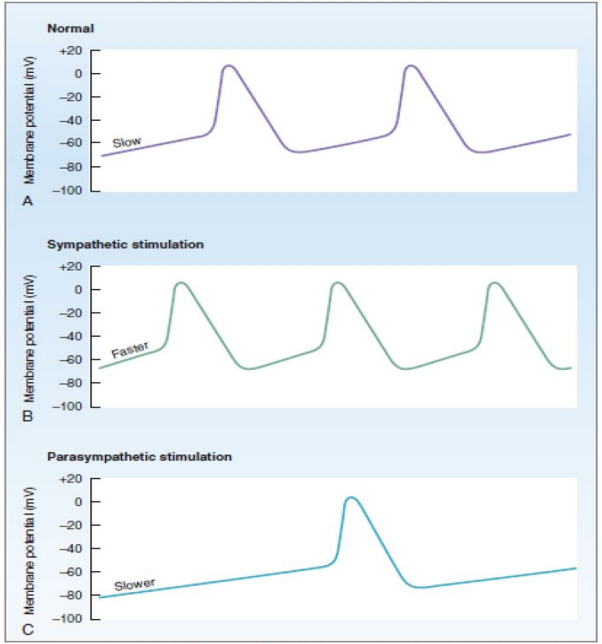


Figure 4–16 **Effect of sympathetic and parasympathetic stimulation on the SA node action potential. A,** The normal firing pattern of the SA node is shown. **B,** Sympathetic stimulation increases the rate of phase 4 depolarization and increases the frequency of action potentials. **C,** Parasympathetic stimulation decreases the rate of phase 4 depolarization and hyperpolarizes the maximum diastolic potential to decrease the frequency of action potentials.

Comparison of AP in skeletal muscle vs. Cardiac Muscle :

TABLE 14-3 Comparison of Action Potentials in Cardiac and Skeletal Muscle

	SKELETAL MUSCLE	CONTRACTILE MYOCARDIUM	AUTORHYTHMIC MYOCARDIUM
Membrane potential	Stable at −70 mV	Stable at −90 mV	Unstable pacemaker potential; usually starts at −60 mV
Events leading to threshold potential	Net Na^+ entry through ACh-operated channels	Depolarization enters via gap junctions	Net Na^+ entry through I_f channels; reinforced by Ca^{2+} entry
Rising phase of action potential	Na^+ entry	Na^+ entry	Ca^{2+} entry
Repolarization phase	Rapid; caused by K^+ efflux	Extended plateau caused by Ca^{2+} entry; rapid phase caused by K^+ efflux	Rapid; caused by K^+ efflux
Hyperpolarization	Due to excessive K^+ efflux at high K^+ permeability when K^+ channels close; leak of K^+ and Na^+ restores potential to resting state	None; resting potential is −90 mV, the equilibrium potential for K^+	Normally none; when repolarization hits −60 mV, the I_f channels open again. ACh can hyperpolarize the cell.
Duration of action potential	Short: 1–2 msec	Extended: 200+ msec	Variable; generally 150+ msec
Refractory period	Generally brief	Long because resetting of Na^+ channel gates delayed until end of action potential	None

Male's slide

Conduction System Defects

Male's Dr: not important, just for your knowledge.

Gene	Protein	Conduction Defect	Associated Conditions	Mechanism
Ion channels				
SCN5A	Nav1.5	AV conduction defect, sick sinus syndrome, bundle branch block	Brugada syndrome 1, LQTS 3, AF 3, dilated cardiomyopathy, multifocal ectopic Purkinje-related premature contractions	Slowing of conduction velocity and pacemaking rate, tissue degeneration via TGF-b1
TRPM4	TRPM4	AV conduction defect		Possibly elevated density of TRPM4 channels disables action potential propagation down the Purkinje fibers.
SCN1B	Scn1b	Bundle branch block	Brugada syndrome 5	Slowing of conduction velocity mainly in Purkinje fibers
KCNJ2	Kir2.1	AV block, bundle branch block	Andersen-Tawil syndrome (LQTS 7)	Prolongation of action potential and slowing of pacemaking rate
HCN4	HCN4	Sick sinus syndrome		Reduction of pacemaker current I_f
Structural proteins				
GJA5	Connexin40	AV block, bradycardia	Ventricular arrhythmias	Defective coupling of conducting myocytes
ANK2	Ankyrin-B	Sick sinus syndrome	LQTS 4, AF, CPVT	Abnormal sinoatrial electrical activity due to dysfunction in Ankyrin B-based trafficking pathways
DES	Desmin	AV block	VT/VF, cardiomyopathy Skeletal myopathy	Desmin-positive aggregates and inability of mutated desmin to interact with cellular structures. Mitochondrial dysfunction
Protein kinases				
PRKAG2	γ-2 subunit of AMP-activated protein kinase (AMPK)	Sinus bradycardia, AV block	Wolff-Parkinson-White syndrome Glycogen storage cardiomyopathy	Disruption of annulus fibrosus by glycogen-filled myocytes

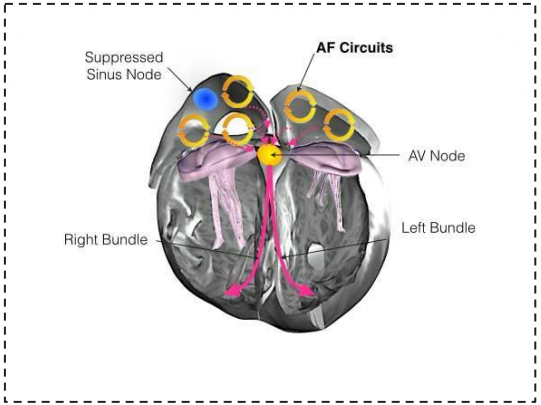
Atrial Fibrillation: Pacemaker and AV Node Ablation

1

During Atrial fibrillation the atria are activated by multiple AF circuits in rapid (>300 bpm) and irregular manner,this rapid activity suppresses the normal pacemaker cell to the heart, the Sinus node.

2

During AF the AV node is bombarded with rapid irregular impulses from fibrillating atria. This rapid electrical activity conducts through the AV node to ventricle resulting in rapid and irregular activation and contraction of the ventricles, this is why patient with AF feel a rapid irregular pulse.



Action Potential in Cardiac Muscle vs SA Node a Comparison

very useful to differentiate

	SA node	Contractile muscle
RMP	-60 mV	-90 mV
Phase 0	Less steep	More steep
Plateau	No plateau	Plateau
Repolarization	Gradual	steep
threshold	-40mv	-70mv

IN SA node less negative because of NA+ and Ca+ leaky channels

In SA node the responsible channel is slow Na and Ca channel while in contractile cell it is Fast Na channel

Check here for our summary
Highly recommended !!!!!

Sorry but if you will not cheack it راحت عليك المليون

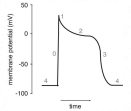
MCQs:

Answers

For more question check our summary file!

1/D
2/C
3/C

1 During which phase of the ventricular action potential is the membrane potential closest to the K+ equilibrium potential?



A	Phase 1	B	Phase 2	C	Phase 3	D	Phase 4

2 During which phase of the ventricular action potential is the conductance to Ca2+ highest?

A	Phase 0	B	Phase 1	C	Phase 2	D	Phase 3

3 In which phase of the ventricular muscle action potential is the potassium permeability the highest?

A	Phase 1	B	Phase 2	C	Phase 3	D	Phase 4

MCQs:

Answers

For more question check our summary file!

4/C
5/D
6/A

4 **Sinoatrial node is the pacemaker of the heart because of**

A	Location in the right atrium	B	Neural control	C	Natural leakiness to Na	D	Natural leakiness of K+

5 **Which of the following best explains how sympathetic stimulation affect the heart ?**

A	Permeability of the S-A node to sodium decreases	B	Permeability of the A-V node to sodium decreases	C	Permeability of the S-A node to potassium increases	D	There is an increased rate of upward drift of the resting membrane potential of the S-A node

6 **Which one of the structures has the highest rate of rhythmic discharge compared to other part in the heart:**

A	(SA) node.	B	Atrial muscle.	C	Purkinje fibers.	D	(AV) node.

SAQ

Briefly explain the excitation sequence?	Slide 6
Describe the Effect of parasympathetic Stimulation?	Slide 27: Effect of parasympathetic Stimulation
Why does the plateau occur in contractile myocardium?	Slide 21
What are the channels that plays an important role in causing voltage changes in APs?	Slide 17

Finally you have arrived , we have been waiting for you !!

Meet our team !

Team leaders

Rimaz Alhammad

Noreen Almaraba

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Did you like the lecture ? we mean our work :)

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