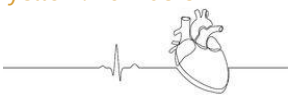
جامعة الملك سعود
King Saud University

Please remember that is very important to completely understand physiology.
You may contact the physiology leader for any questions.

Cardiac Electrical Activity

Index:
Red: important Grey: extra information Green: doctor's notes yellow: numbers
Purple: only in female slides Blue: only in male slides

Physiology Team437



MED437 KING SAUD UNIVERSITY

OBJECTIVES

By the end of this lecture you will be able to:

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

ONLY in female slides

Cardiac Electrical Activity

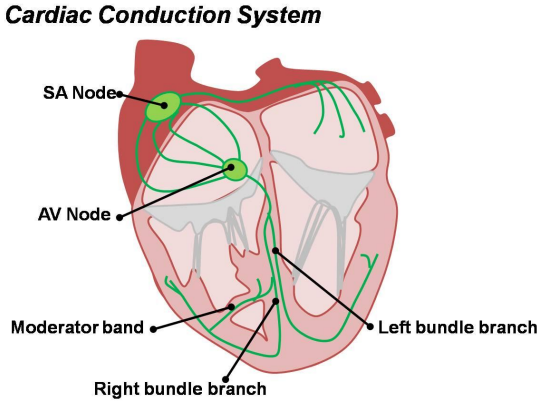
Automaticity of the heart: the heart is capable of:

- Generating rhythmical electrical impulses.
- Conduct the impulses rapidly through the heart in a specialized conducting system formed of specialized muscle fibers (Not nerve fibers).

The atria contract about one sixth of a second a head of ventricular contraction:

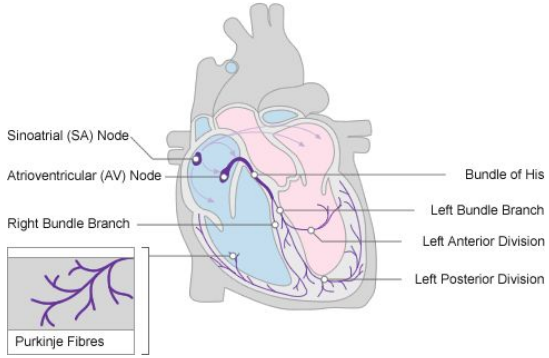
Why?

To allows filling of the ventricles before they pump the blood into the circulation.

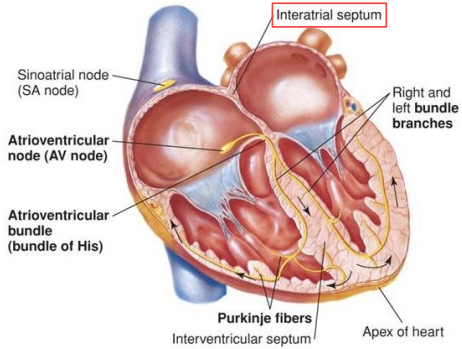


Components of the Conducting System

- S-A node.
- Internodal pathway.
- A-V node.
- A-V bundle (Bundle of Hiss).
- Left & right bundle branches.
- Purkinje fibers.



Heart has a special system for generating rhythmical electrical impulses to cause rhythmical contraction of the heart muscle.



Sequence of Excitation

Sinus-Atrial node (SA node)

↓

Atria

↓

Atrial-ventricular node (AV node)

↓

Ventricles

Sinoatrial node

↓

Atrial syncytium

↓

Junctional fibers

↓

Atrioventricular node

↓

A-V bundle

↓

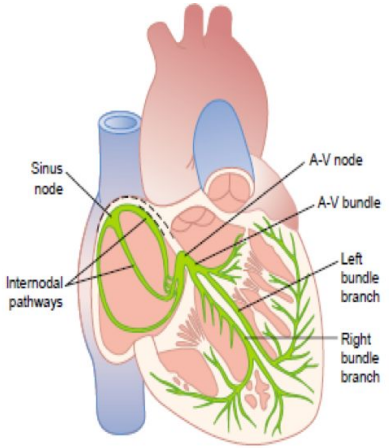
Bundle branches

↓

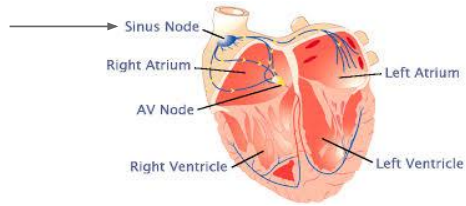
Purkinje fibers

↓

Ventricular syncytium



SA "sinoatrial" Node:



- SA node is the pacemaker of the heart, because it's rhythmic discharge is greater than any other part of the heart (highest frequency) .
- It is located in the superior posterio-lateral wall of the right atrium, It's fibers are continuous with atrial fibers, it is made of modified cardiac muscles, and velocity of conduction between the fibers is 0.05 m\s.
- Responsible for generating the electrical impulses that bring about the mechanical activity, i.e contraction of the heart.
- SA node has the fastest rate of autorhythmicity.
- It's membrane potential is unstable. so, it's capable of originating action potential.

S.A node determine the heart rate

Spread of Cardiac Impulse from SA node to Atrial muscle

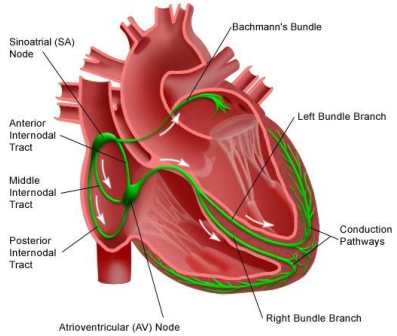
The cardiac impulse after it's origin in the SA node spreads throughout the atrial muscle through two routes:

Specialized anterior, middle and posterior conducting bundles

- Anterior internodal bundle of Bachman
- Middle internodal bundle of Wenkebach
- Posterior internodal bundle of Thoral

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 spread of cardiac impulse from SA node to atrial muscle:

- The velocity of conduction in most atrial muscle is about 0.3m/sec.
- In the specialized internodal pathways the conduction velocity may reach up to 1 m/sec.
- The impulse after leaving SA node takes 0.03 sec to reach the AV node.

AV "atrioventricular" Node:

- The AV node is located in the posterior wall of the right atrium immediately behind the tricuspid valve.
- It receives impulses from S-A node & transmits it to ventricles through A-V bundle.
- A-V bundle conducts impulses to A-V bundle branch at velocity of 1 m/s.

What is the cause of slow conduction in the A-V node?

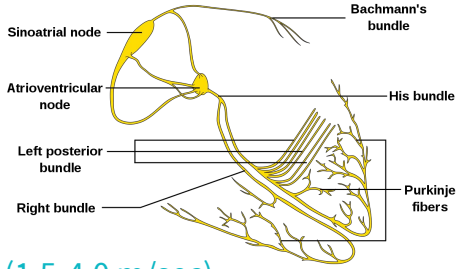
The cause of slow conduction is mainly diminished number of gap junctions between the successive cells in the conducting pathways.

The total delay in the A-V nodal and A-V bundle system is about 0.13s. This delay, in addition to the initial conduction delay of 0.03s from the sinus node to the A-V node, makes a total delay of 0.16s before the excitatory signal finally reaches the contracting muscle of the ventricles.

Significance of AV nodal delay:

- The cardiac impulse does not travel from the atria to the ventricles too rapidly.
- This delay allows time for the atria to empty their blood into the ventricles before ventricular contraction begins and also allows the coronary blood to supply the heart.الزبدة
- This increases the efficiency of the pumping action of the heart.
- To protects ventricles from pathological high atrial rhythm.

The Purkinje System (Purkinje Fibers)



- Purkinje fibers are very large fibers.
- Transmit action potentials at a very high velocity (0.1-4.0 m/sec) (1.5-4.0 m/sec).
- **The rapid transmission is caused by:**
  - Very high level of permeability of gap junctions at the intercalated discs between the successive cells of Purkinje fibers.
  - → Ions are transmitted easily from one cell to the next.
  - → Enhance the velocity of transmission.
- **Significance:**
  - 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.
  - allows ventricular muscle to contract at almost the same time for their effective pumping (synchronous contraction).

Right and Left Bundle Branches

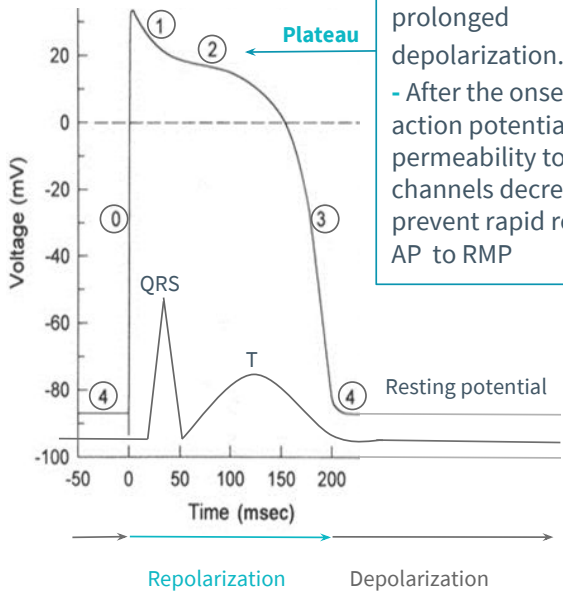
- Bundle of His splits into two branches which are called right and left bundle branches that lie on the respective sides of the ventricular septum.
- From the time the cardiac impulse enters the bundle branches until it reaches the terminations of Purkinje fibers, the total time averages only 0.03 sec.

One- way Conduction through AV bundle

- A special characteristic of the A-V bundle is its inability of action potentials to travel backward from the ventricles to the atria.
- This prevents re-entry of cardiac impulse by this route from the ventricles to the atria.
- The atrial muscle is separated from the 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.

Action Potential of The Cardiac Muscles

The cardiac action potential is made of 3 phases:		
Depolarization:	**Plateau:**	**Repolarization:**
Caused by the opening of Fast Na channels & slow Ca channels	Remaining of slow Ca channels open for several seconds, drawing large amount of Ca inside which prolong depolarization	Opening of potassium channels



- Opening of the slow Ca channel cause prolonged depolarization.
- After the onset of action potential the permeability to K channels decreases to prevent rapid return of AP to RMP

- Phase (0) - Depolarization - Na Enters the cell
- Phase (2) - Initiate contraction - Ca Enters the cell
- Phase (3) - Repolarization - K Exits the cell

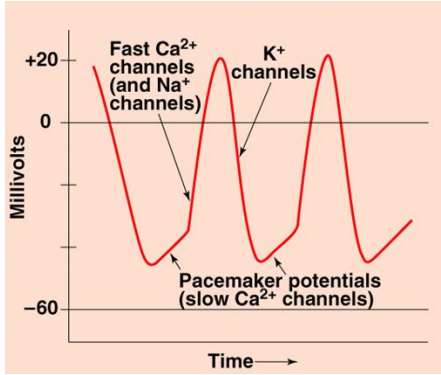
Electrical Activity of the Heart

SA node: SinoAtrial node Demonstrates automaticity, so it function as the pacemaker.

- The Electrical pulse starts with spontaneous depolarization, giving us (pacemaker potential).
- This event caused by spontaneous diffusion of Ca^{2+} through slow Ca^{2+} channels.
- Keep in mind that cells do not maintain a stable RMP.

Pacemaker Action Potentials:

- Depolarization:
  - Voltage Gated fast Ca^{2+} channels open. **SO** Ca^{2+} diffuses inward.
  - Opening of Voltage Gated Na^{+} channels may also contribute to the upshoot phase of the AP.
- Repolarization:
  - Voltage Gated K^{+} channels open. **SO** K^{+} diffuses outward

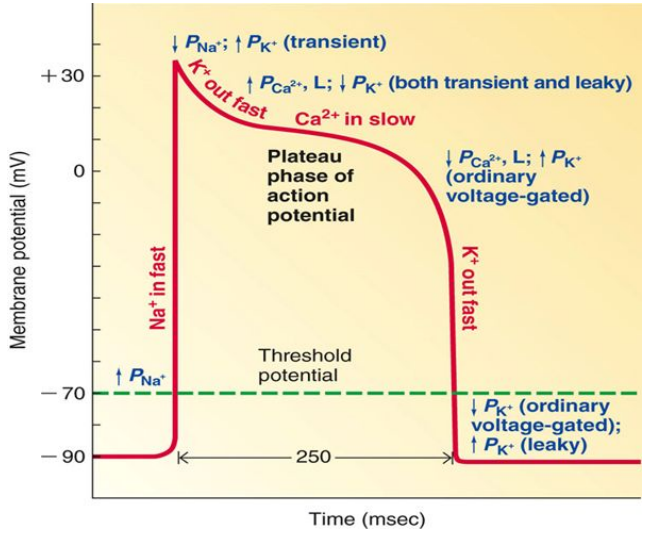


تعمل الـ SA node كمولد ذاتي للنبضات الكهربائية، ومنها ينطلق الـ AP لعضلة القلب.
تبدأ بدخول بطيء للكالسيوم "Pacemaker Potential" يرتفع فيه الجهد قليلاً ثم ينطلق الـ AP مع الدخول السريع للكالسيوم والصوديوم
وينتهي بإعادة فرق الجهد للـ RMP عن طريق خروج البوتاسيوم
كما حين نقوم بتشغيل السيارة !
نعطيها دفعة بسيطة من البنزين للتشغيل ، ثم ندعس اللي بالشارع .

ONLY in male slides

Myocardial APs

- Majority of myocardial cells have a RMP of –90 mV.
- SA node spreads APs to myocardial cells.
  - When myocardial cell reaches threshold, these cells depolarize.
- Rapid upshoot occurs:
  - VG Na^+ channels open.
    - Inward diffusion of Na^+.
- Plateau phase:
  - Rapid reversal in membrane polarity to –15 mV.
    - VG slow Ca^{2+} channels open.
      - Slow inward flow of Ca^{2+} balances outflow of K^+.
- Rapid repolarization:
  - VG K^+ channels open.
  - Rapid outward diffusion of K+.



Don't get confused !!
Plateau phase will prolong the depolarization,, how?? after the depolarization, the K will begin to leak out, so the calcium will get inside to balance the decrease in positivity inside , therefore, the plateau will occur and depolarization will be prolonged.

Conduction of Impulse

- APs from SA node spread quickly at rate of 0.8 - 1.0 m/sec.
- Time delay occurs as impulses pass through AV node.
  - Slow conduction of 0.03 – 0.05 m/sec.
- Impulse conduction increases as spread to Purkinje fibers at a velocity of 4.0 m/sec.
  - Ventricular contraction begins 0.1–0.2 sec. after contraction of the atria.

Conduction Speed in Cardiac Tissue

Tissue	Conduction Rate (m/s)
SA node	**0.05**
Atrial pathways	**1**
AV node	**0.05 (0.01)** (Slowest)
Bundle of His	**1**
Purkinje system	**4** (Fastest)
Atrial & Ventricular muscle	**1 (0.3-0.4)**

Mentioned on females' first lecture and on males' second lecture

Refractory Periods

Cardiac muscle has 2 refractory periods

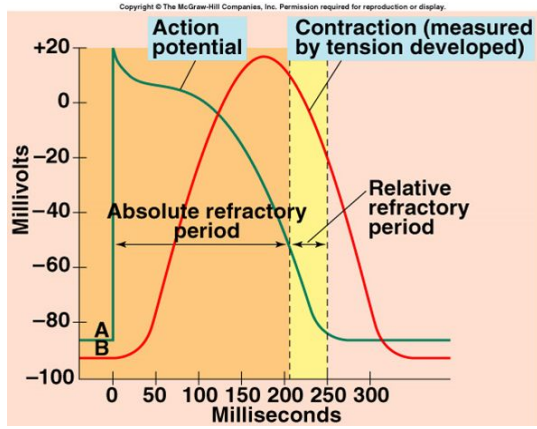
Recall : refractory period of the heart means, the interval of time during which a normal cardiac impulse **cannot** re-excite an already excited area of cardiac muscle.

Absolute Cardiac muscles cannot be excited

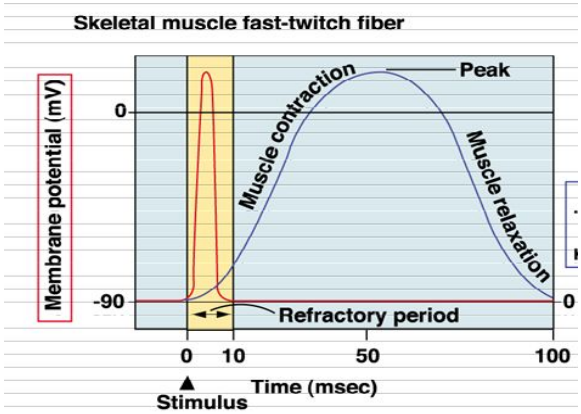
Relative Cardiac muscles can be excited by strong stimulus

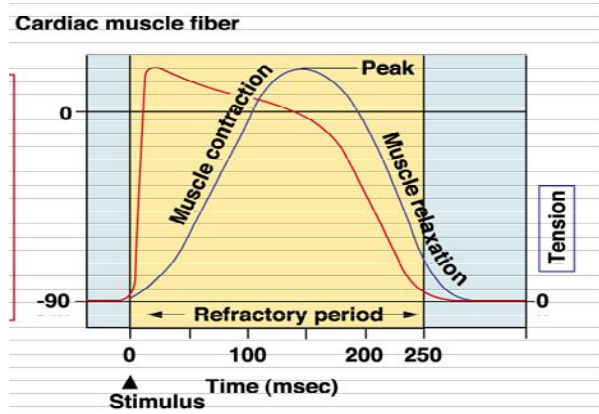
- Heart contracts as syncytium.
- Heart contraction lasts almost 300 msec.

That's why the cardiac muscle doesn't get fatigue. It has more time to relax than the skeletal muscle, because the contraction in skeletal muscle last just 10 milliseconds



- In cardiac muscle fiber, the refractory period lasts almost as long as the entire muscle contraction.
- Myocardial muscle cannot be stimulated to contract again until it has relaxed (summation cannot occur).





- 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 **CANNOT** undergo summation action potentials or contractions and can't be tetanized.

Significance:

- Long refractory period prevent ventricles from contracting at too high rates so that enough time is allowed for refill of the ventricles.
- Because long refractory period occurs in conjunction with prolonged plateau phase, **summation and tetanus of cardiac muscle is impossible.**
- Ensures alternate periods of contraction and relaxation which are essential for pumping blood.

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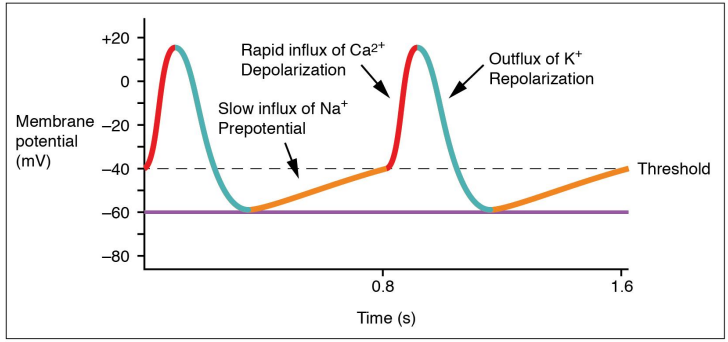
Action Potential of the Pacemaker (Pacemaker Potential)



- The cell membrane of pacemaker cells is leaky to Na^+. This decreases gradually MP.
- Then Ca^{++} influx d.t opening of transient Ca^{++} channels decreases MP from -60 mv to a firing level of -40 mv.
- This gradual depolarization is called pacemaker potential or pre-potential.
- At firing level, long lasting Ca^{++} channels open & Ca^{++} influx occurs causing fast change of MP from -40 to +10 mv. (depolarization).
- At peak, K^+ outflux begins & MP returns to -60 mv. (repolarization). Then the cycle is repeated by self excitation.

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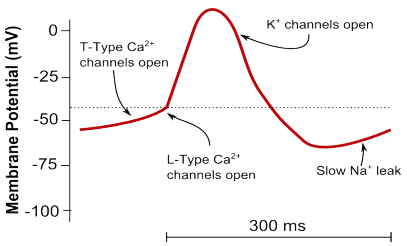
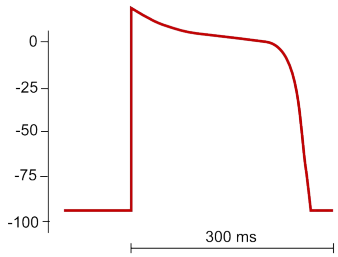
Pacemaker AP



Ventricular AP



Pacemaker Action Potential	Ventricular Action Potential
Does not need a stimulus	Needs a stimulus
RMP is -60 mv.	RMP is -90 mv.
Max. depolarization is +10 mv.	Is +20 mv.
Is of smaller magnitude	Larger magnitude
Has pre-potential stage	No pre-potential stage
Depolarization is gradual	Is rapid
Depolarization is due to Ca^{++}	Is due to Na^{+}
It has spike, no plateau	Has plateau, no spike

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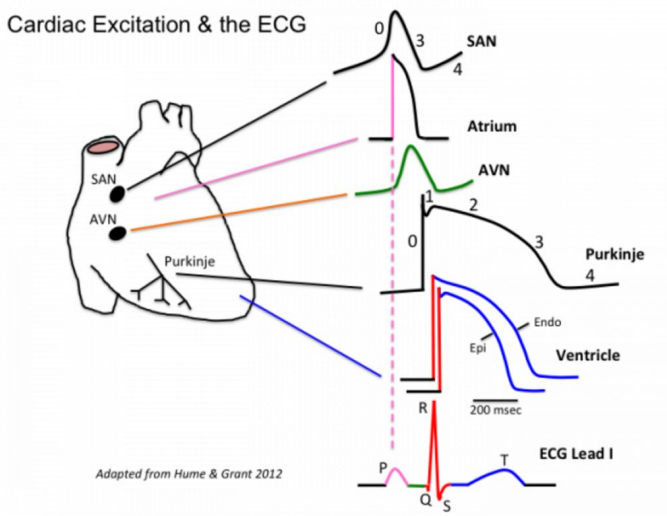

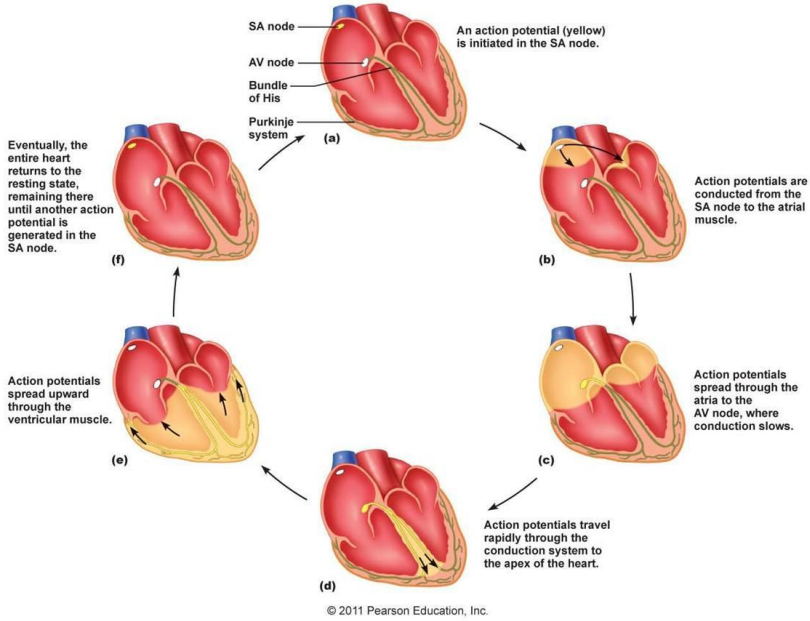

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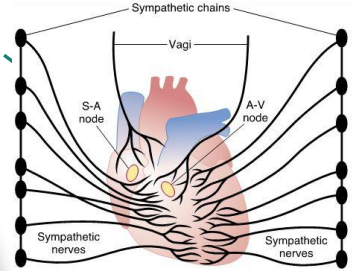
Control of Heart Rhythmicity and Impulse Conduction by the Cardiac Nerves

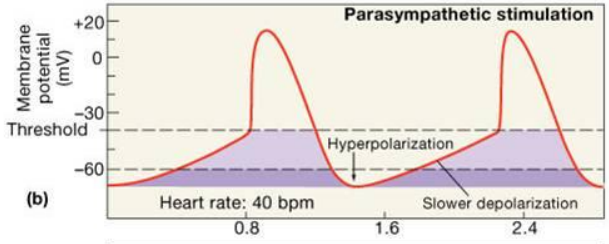
Parasympathetic nerves (vagi): mainly to the S-A and A-V nodes

The heart is supplied with both sympathetic and parasympathetic nerves

Sympathetic nerves: all parts of the heart with strong supply to the ventricles



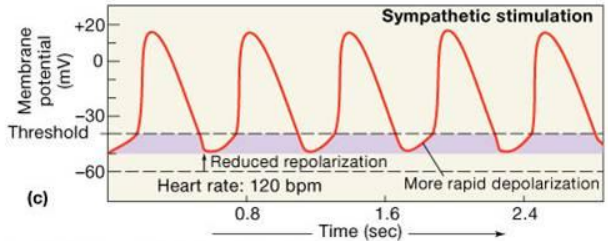
Parasympathetic Stimulation of the Heart



- ↓ The slope of pre-potential of S-A node due to increase the permeability to K^+ (i.e ↓ rhythm of the S-A node, so slow the heart rate).
- ↓ Transmission of impulses to the A-V node.
- Strong stimulation of the vagi:
  - Stop completely the rhythmical excitation by the S-A node.
  - Block completely transmission of cardiac impulses from the atria to the ventricle.
  - Some point in the Purkinje fibers develops a rhythm of its own.

"Ventricular Escape"

Sympathetic Stimulation of the Heart



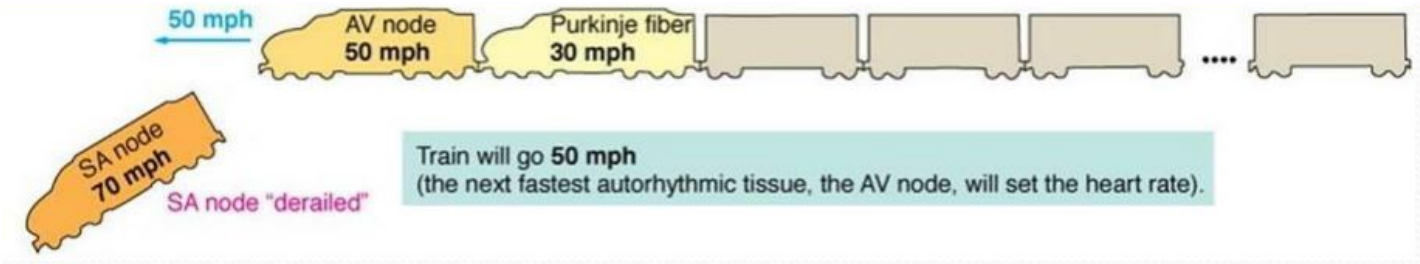
- ↑ The slope of pre-potential of S-A node (i.e ↑ rhythm of the S-A node) due to increase the permeability to Na^+ & Ca^{++}, so accelerate the heart rate.
- Increase transmission of impulses to the A-V node.
- increase force of myocardial contraction.

ONLY in female slides

ONLY in female slides

Latent Pacemaker

- S-A node is the normal pacemaker of heart, i.e. it initiates the excitation wave, drive whole heart and makes the pace (speed) of heart at a rate of 105 impulse/min, inhibited by right vagus nerve to be 70 impulse/min (vagal tone).
- A-V node, His bundle & Purkinje fibers have also intrinsic automaticity & ability to set a pace. They are called **latent Pacemakers.**
- Latent Pacemakers are normally suppressed & function only if the S-A node is damaged, or its impulse is blocked, or if the rate of firing of the latent pacemakers increases.
- If S-A node is damaged, A-V node becomes the new pacemaker and heart follow it but at a slower rate (50-60 impulse/min) **(A-V nodal rhythm**).



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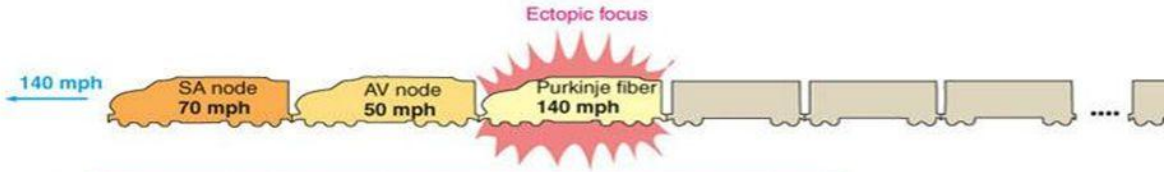
Latent Pacemaker... Cont

- If S-N node or A-V node are damaged, His bundle & Purkinje fibers become the pacemaker with a rhythm of 20-40 impulse/min (**idioventricular rhythm**).
- Rhythmicity is high in S-A node > A-V node > His bundle & Purkinje fibers.
- In some cases, the normally slowest Purkinje fibers can become over excited = ectopic focus and cause premature ventricular contraction.
- It can occurs upon excess caffeine, lack of sleep, anxiety, stress or some organic conditions.



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Abnormal (Ectopic) Pacemaker

- **Ectopic pacemaker**: a pacemaker elsewhere than the sinus node.
- The causes:
- 1- Any other part of the heart develops a rhythmical discharge rate that is more rapid than that of the sinus node.
- 2- Blockage of transmission of the cardiac impulse from the sinus node to the other parts of the heart.

Example: A-V block

→ Cardiac impulses 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 a new rate.

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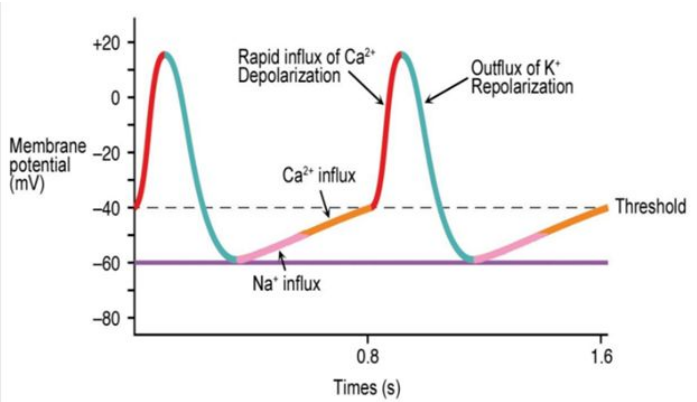
Action potential of the pace maker (pace maker potential)

- cell membrane of pace maker cells is leaky to Na^+. This decreases gradually MP.
- Then Ca^{++} influx d.t opening of transient Ca^{++} channels decreases MP from -60 mv to a firing level of -40 mv.
- This gradual depolarization is called pace maker potential or pre-potential.
- At firing level, long lasting Ca^{++} channels open & Ca^{++} influx occurs causing fast change of MP from -40 to +10 mv. (depolarization).
- At peak, K^+ outflux begins & MP returns to -60 mv. (repolarization). Then the cycle is repeated by self excitation.



Differences between pace maker P & AP of myocardial cells

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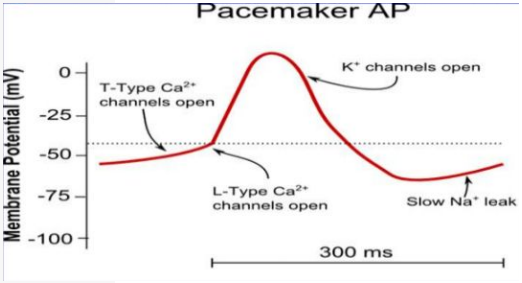

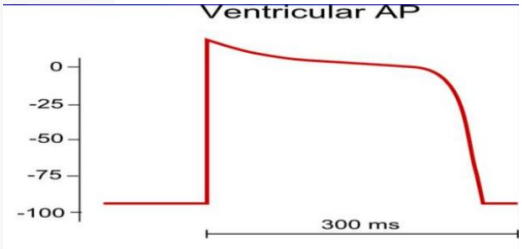

Pace Maker Action Potential	Ventricular Action Potential.
Does not need a stimulus	Needs a stimulus
RMP is -60 mv.	RMP is -90 mv.
Max. depolarization is +10 mv	is +20 mv
Is of smaller magnitude	larger magnitude.
Has pre-potential stage	no pre-potential stage
Depolarization is gradual.	is rapid.
Depolarization is due to Ca^{++}	is due to Na^{+}.
It has spike, no plateau.	has plateau, no spike

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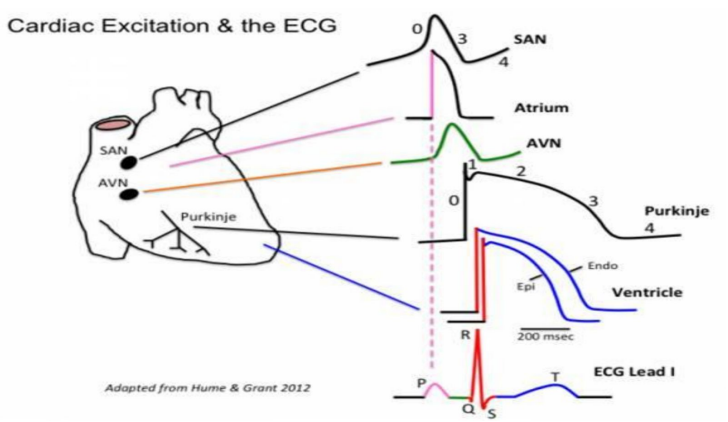

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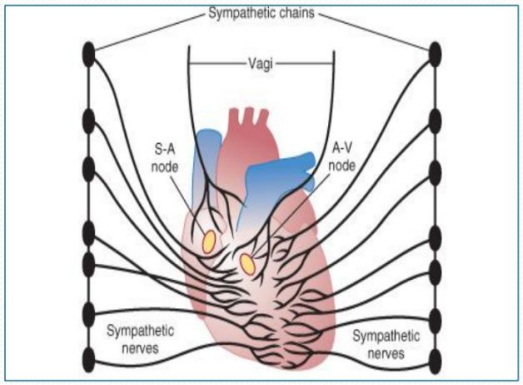
- The heart is supplied with both sympathetic and parasympathetic nerves.
- Parasympathetic nerves (vagi): mainly to the S-A and A-V nodes.
- Sympathetic nerves: all parts of the heart with strong supply to the ventricles

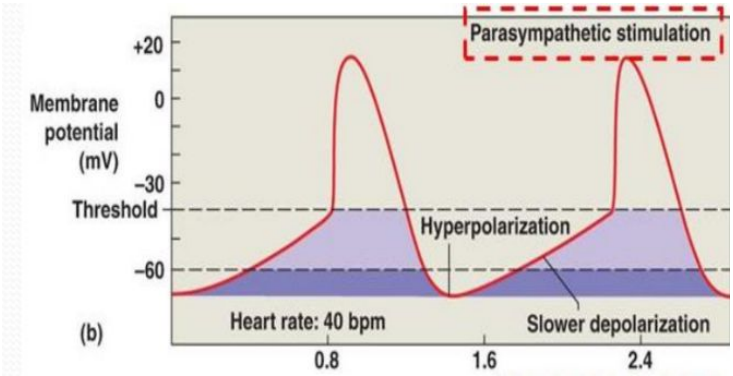


ONLY in female slides

Parasympathetic stimulation of the heart

- ⬇ the slope of pre-potential of S-A node due to increase the permeability to K^+ (i.e rhythm of the S-A node, so slow the heart rate).
- ⬇ transmission of impulses to the A-V node.
- Strong stimulation of the vagi:
  - Stop completely the rhythmical excitation by the S-A node.
  - Block completely transmission of cardiac impulses from the atria to the ventricle .
  - Some point in the Purkinje fibers develops a rhythm of its own.

<u>"Ventricular Escape"</u>



Summary

- Nerves supply the heart > parasympathetic (vagus nerve) to S.A and A.V node & sympathetic to all parts of the heart with strong supply to the ventricles.
- The cardiac conduction system is a group of specialized cardiac muscle cells in the walls of the heart that send signals to the heart muscle causing it to contract.
- The components of cardiac conduction system : SA and AV node,Internodal pathway, A-V bundle, Left & right bundle branches & Purkinje fibers.

S-A node	Superior posterio-lateral wall of the right atrium	Pacemaker + originating action potentials by itself.
A-V node	Posterior wall of the right atrium	Delay in the conduction of impulses
Purkinje fibers	Penetrate atrioventricular fibrous tissue	Transmit action potentials at a very high velocity > because it has very high permeability of gap junction so ions are transmitted easily.

Quiz

1- S-A node is located in the superior lateral wall of:

A. Right atrium **B.** Left atrium

C. Right ventricle **D.** Left ventricle

2- Action potential travels from S-A node to A-V node through:

A. Purkinje fibers **B.** Atrial fibers

C. Internodal pathways **D.** Bundle of his

3- The delay in the conduction impulse at A-V node is:

A. 0.05 sec **B.** 0.13 sec

C. 1 sec **D.** 0.3 sec

4- Which of the following has the fastest conduction:

A. S-A Node **B.** A-V Node

C. Purkinje Fibers **D.** Atrial and Ventricular Muscles

5- The resting membrane potential in pacemaker action potential is:

A. -90 **B.** -60

C. +10 **D.** +20

6- The sympathetic nerves supply all part of the heart with strong supply to the:

A. Ventricles **B.** Atria

C. Purkinje System **D.** Bundle of his

Answers:
1- A
2- C
3- B
4- C
5- B
6- A

Thank you for checking our work

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العنود سلمان

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عمر الفوزان
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نايف المطيري
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روان مشعل
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ليلى الصباغ
فلوة السعوي
نورة بن حسن
نورة الحربي
نورة العثيم
مجد البراك
لينا العوهلي
عهد القرين
مها النهدي
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Any questions?

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