Electrocardiogram

Physiology Team 439

MED439
KING SAUD UNIVERSITY

Black: in male / female slides
Red : important
Pink: in female slides only
Blue: in male slides only
Green: notes
Gray: extra information

Editing File

Objectives

- Identify waves, intervals & segments of the normal ECG trace and the physiological cause of each wave.
- Determine the bipolar, unipolar and chest leads.
- Know what is Einthoven's triangle and Einthoven's law.
- Describe the practical use of the ECG.

The Electrocardiogram (ECG)

Definition

- ECG is the record of the algebraic sum of electrical activity i.e. action potentials generated by the heart during cardiac cycle.
- **Monophasic** action potentials recorded from microelectrode inserted in a single fiber.

راح ياخذ محصلة كل اكشن بوتنشل يطلع من كل فايبر في عضلة القلب

Principle

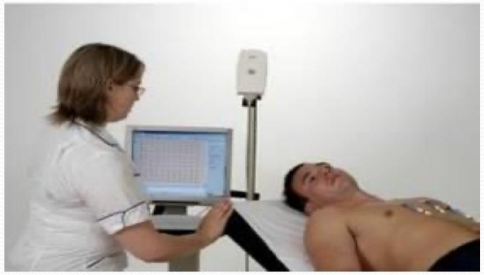
- When the depolarization wave spreads through heart, electrical currents pass into the surrounding tissue.
- Part of the current reaches the surface of the body (body fluids are good conductors).*
- The electrical potentials generated by these currents can be recorded from surface electrodes.
- How ECG can be recorded? By electrodes placed on the skin opposite to the heart. (We have 3 main ways: **bipolar**, **unipolar**, and **chest** leads)

*القلب حوله fluids ويوصل الكهرباء، فالbody fluids توصل الكهرباء لل electrodes بعدين للجهاز.

Practical Uses of ECG

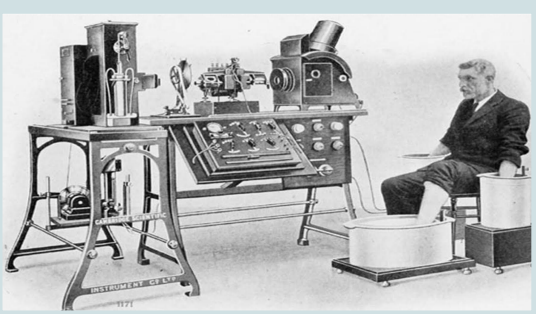
1. Electrical cardiac (Heart) Axis
2. Heart rate (remember RR interval)
3. Heart Rhythm
4. Myopathies
5. Chamber Hypertrophy
6. Myocardial Ischemia/MI
7. Drug toxicity (eg; digoxin) (Ex:u wave)
8. Electrolyte disturbances
9. Carditis
10. Conduction defects

machines for recording ECG



Computer-based and electronic display

Pen recorder and a moving sheet.



-Photograph of a complete electrocardiograph, showing the manner in which the electrodes are attached to the patients, in this case the hands and one foot being immersed in jars or salt solution.
-Einthoven's Original Machine weighed 500 pounds and needed five operators.

ECG Principle

When the depolarization wave spreads through the heart, electrical current pass into the surrounding tissue and be recorded from surface electrodes.

Repolarization starts with the same point that Depolarization started with, except in the Heart. Which means:

- **In the heart** the part that Depolarize first Repolarize last.
- And the part that Depolarize last Repolarize first.

So, Depolarization spreads from the base to the Apex of the heart, and repolarization is the opposite direction.
ARE YOU GETTING MY POINT!!!

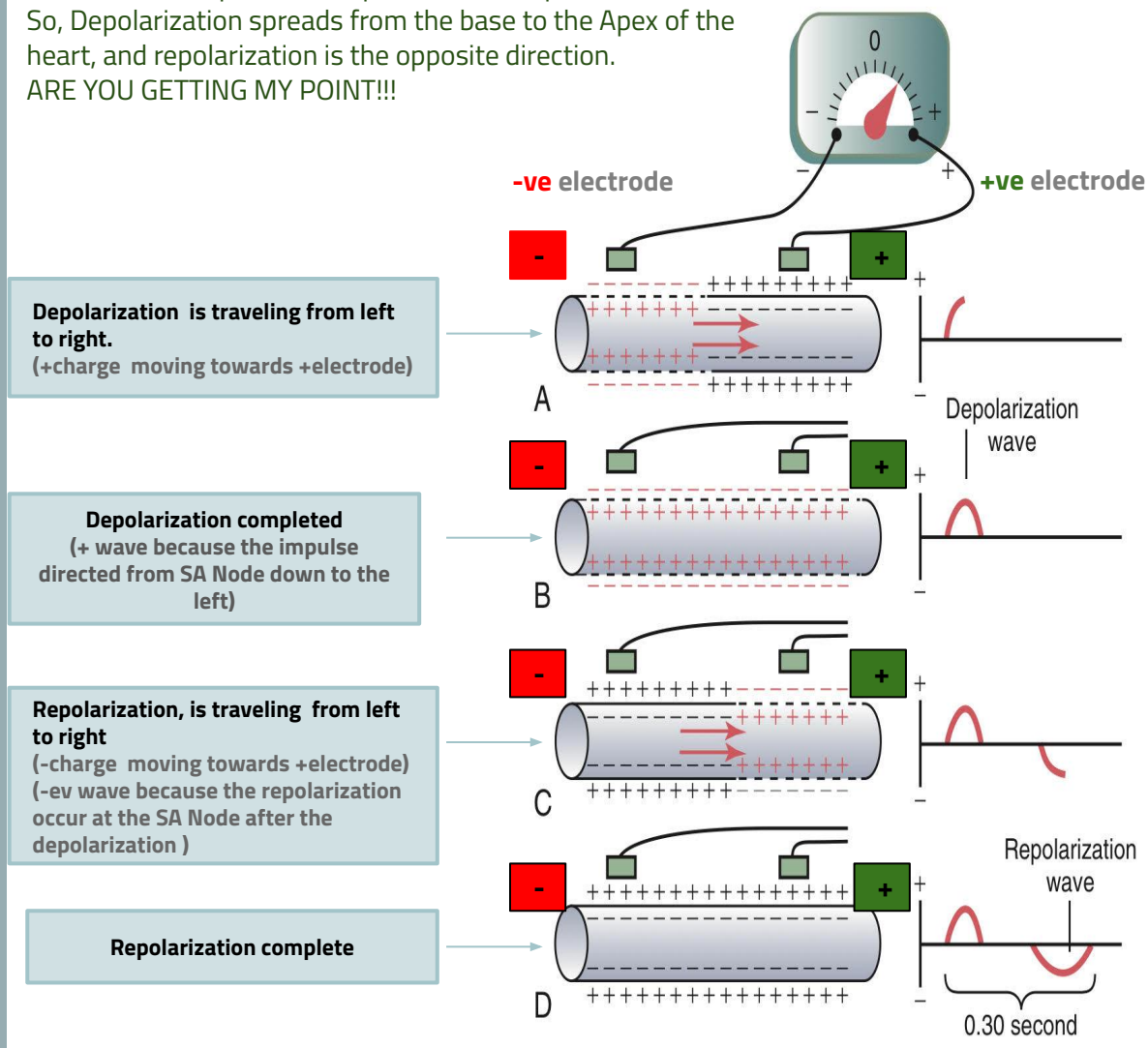


Figure 11-2. Recording the depolarization wave (**A** and **B**) and the repolarization wave (**C** and **D**) from a cardiac muscle fiber.

Basic concepts

Depolarization means positive charges are flowing into cells. depolarization of one cell stimulates the depolarization of the adjacent cell through gap junctions (syncytium, remember?)

Repolarization means negative charges are flowing in.

In ECG you need to know 4 main concepts :)

1. Two electrodes are placed on the body (one positive, one negative)

2. A positive/upwards deflection on the ECG is made by:
   a) Positive charges moving (depolarization) towards a positive electrode or
   b) Negative charges moving (repolarization) towards a negative electrode

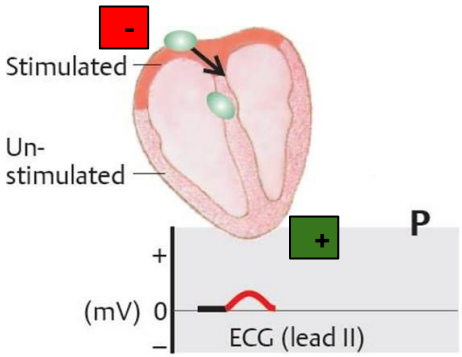
3. A negative/downwards deflection on the ECG is made by:
   c) Positive charges moving towards a negative electrode or
   d) Negative charges moving towards a positive electrode

4. An isoelectric (straight) line is made by no movement of charges (ex: AV node delay)

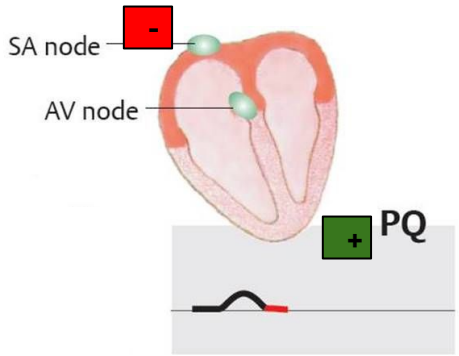
Sequence of Cardiac Excitation

- ## Atrial Excitation/Depolarization:

Anatomical position of electrical activity with Corresponding ECG waveforms

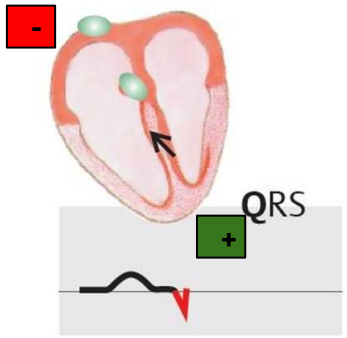


Depolarization(+) moves towards +, so upwards deflection.

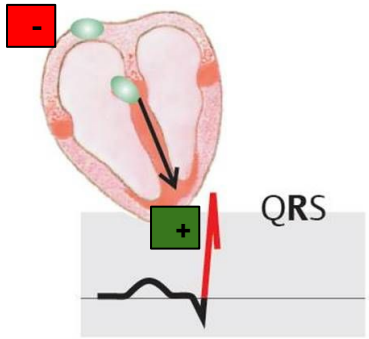


No movement of charges AV nodal delay, so isoelectric line.

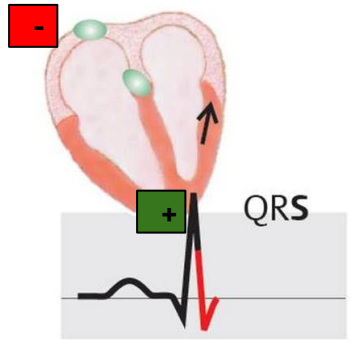
- ## Ventricular Excitation/Depolarization:



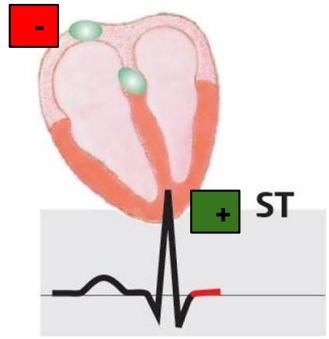
Septal depolarization: (+) moves towards (-), so downward deflection.



Major ventricular depolarization: (+) moves towards (+), so upward deflection.



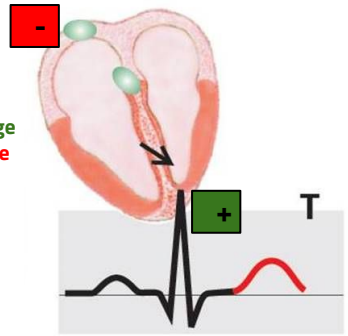
Basal depolarization: (+) moves towards (-), so downward deflection.



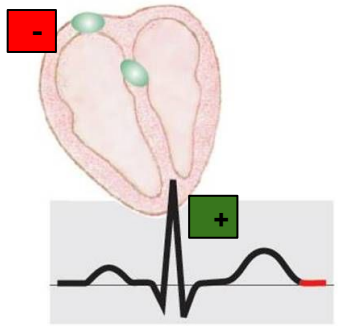
Ventricles are completely depolarized= no movement of charges, so isoelectric line.

- ## Ventricular Relaxation/Repolarization:

Note:
arrowhead=positive charge
arrow tail: negative charge
(repolarization)



Ventricular repolarization: (-) moves towards (-) so upward deflection.



Ventricles are completely repolarized= no movement of charges, so isoelectric line.

3 Waves (Deflections)

- P wave
- QRS complex
- T wave

-P, R & T- waves are positive فوق
- Q & S- waves are negative تحت

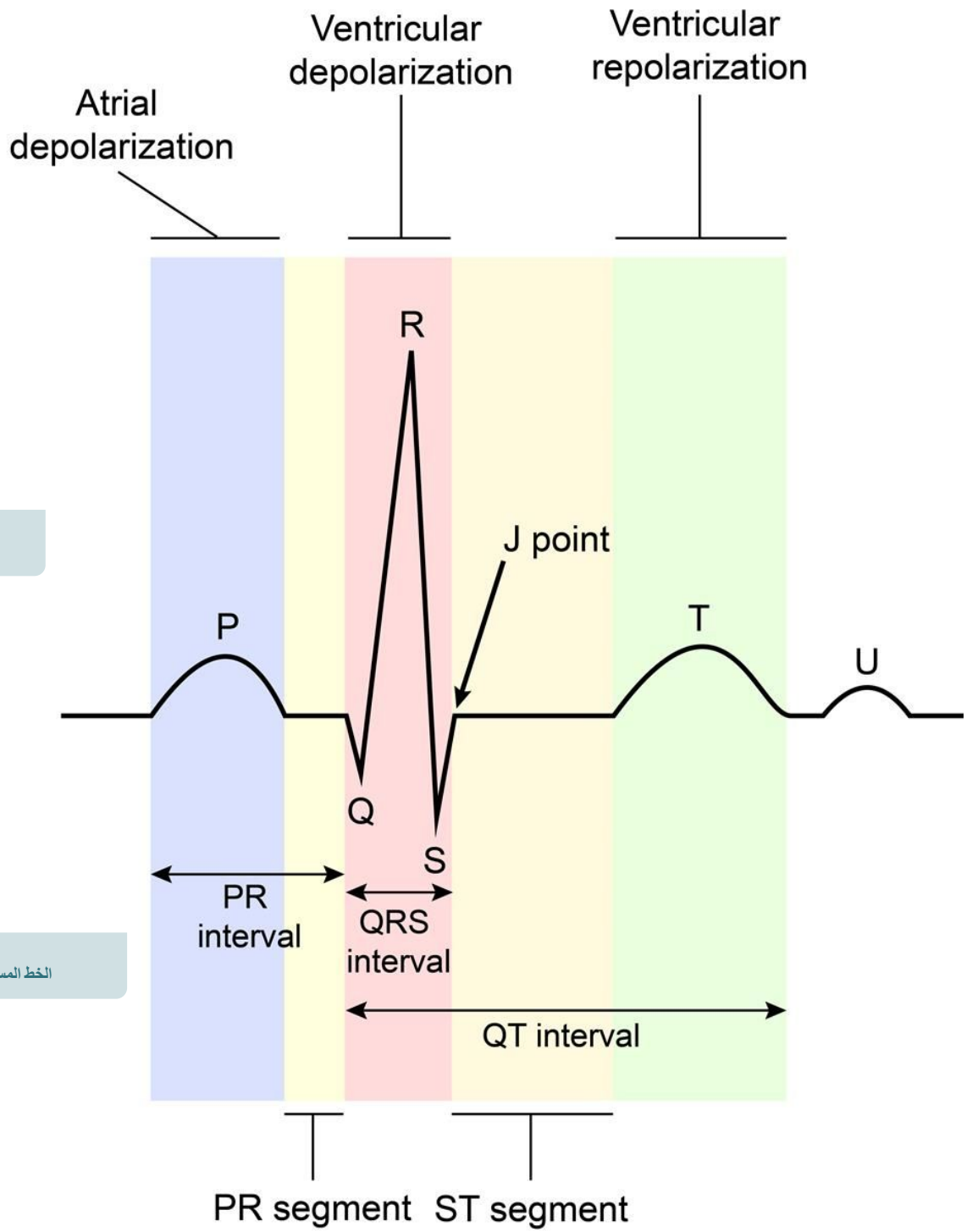
3 Time intervals (include waves+Isoelectric)

Interval: combination of a wave and a segment
- **PR interval***
- **QT interval**
- **RR interval**

*ليه قلنا PR مو QR رغم أن Q قبل R؟
لأن الQ ما تكون ظاهرة على الكيرف بشكل واضح

3 Segments (isoelectric, no waves included) الخط المستقيم

- PR- segment
- ST- segment
- TP- segment



الPR هنا تمثل انتقال الشحنة من ال Atrium إلى الVentricle عن طريق AV node
PR segment represent AV nodal delay

Analysis of normal ECG waves:

P wave

Due to atrial depolarization

P-wave Precedes atrial contraction by: 0.02 sec

Atrial repolarization occurs at the same time with ventricular depolarization. But, since ventricular depolarization wave is giant, it masks the atrial repolarization wave.

QRS Complex

Due to ventricular depolarization

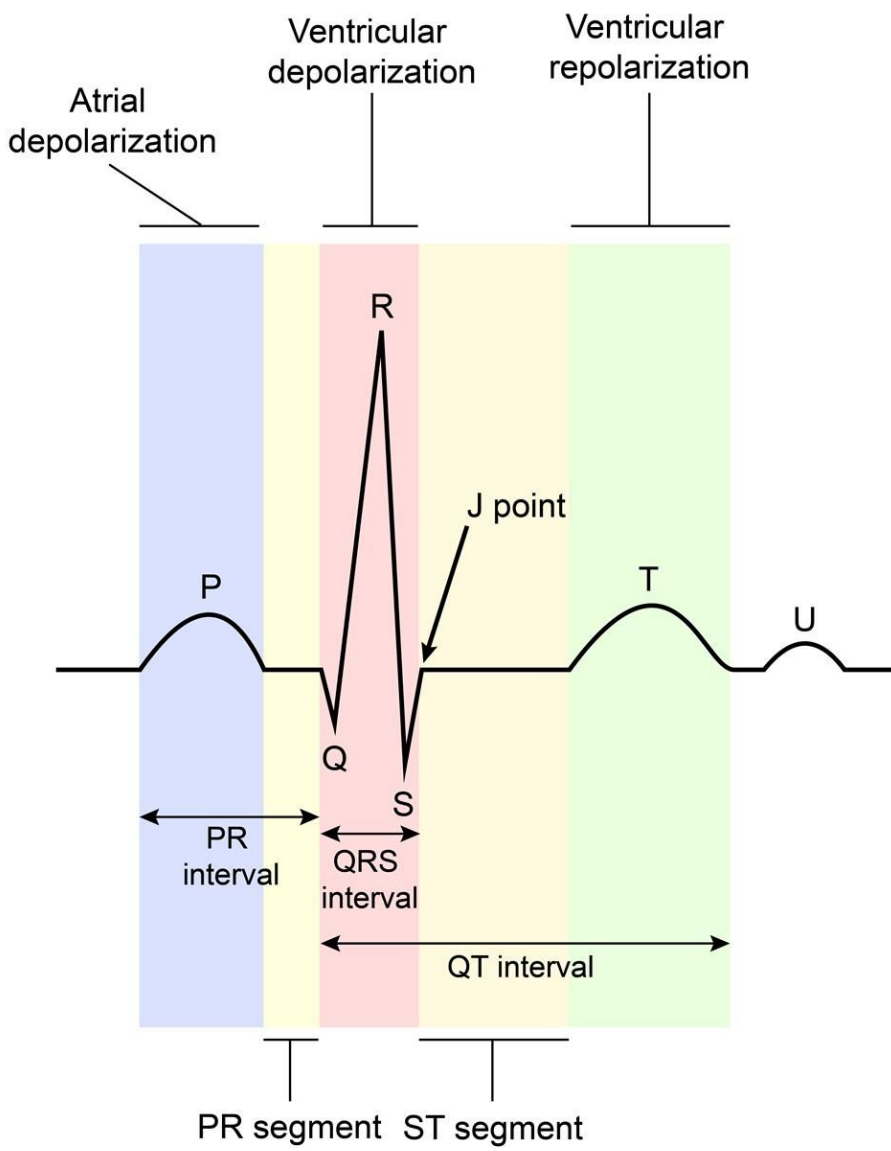
Q wave: due to depolarization of interventricular septum.
R wave: due to depolarization of most ventricular wall.
S wave: due to depolarization of base of the heart.
QRS complex is recorded before the onset of ventricular systole.

T-wave

Due to ventricular repolarization

T-wave occurs during latter part of systole, before the onset of diastole

is recorded before the onset of ventricular diastole.



Why is the T wave not equal to the QRS complex? the depolarization in the heart is very fast -> QRS is narrow while the repolarization is slow, therefore T-wave is wide and it takes time. So the amount of current is the same but the duration is different.

U-wave:

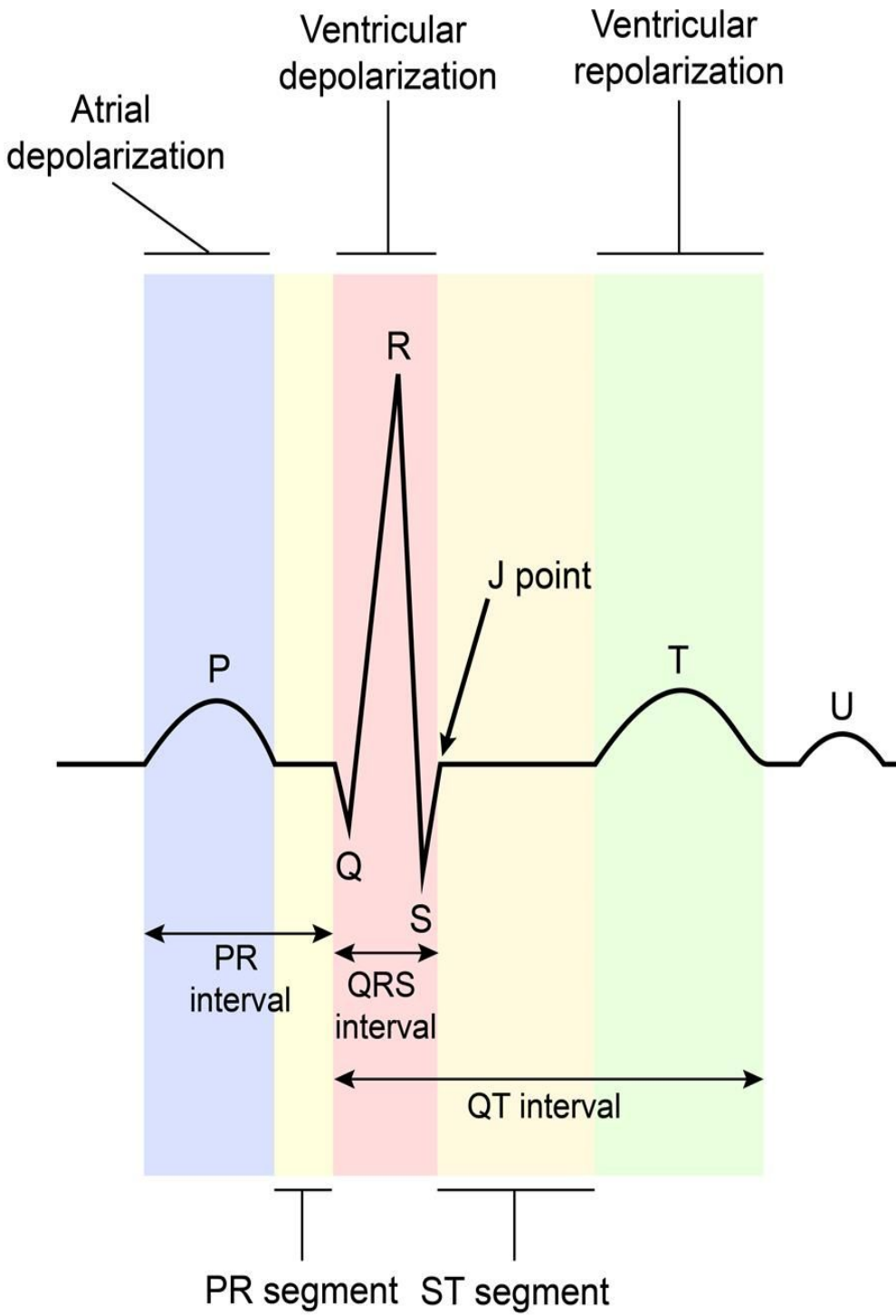
Normal U-wave

- The U wave is a wave on an ECG that is not always seen.
- It follows and is the same direction as T wave.
- It is typically small, round, symmetrical and positive in **lead II**
- (U) waves are thought to represent repolarization of the papillary muscles or Purkinje fibers.

Non-normal U-wave

When they become **prominent or inverted.**

- Prominent U waves are most often seen in hypokalemia, but may be present in hypercalcemia, thyrotoxicosis, exposure to digitalis, epinephrine or Class 1A and 3 antiarrhythmics, congenital long QT syndrome (a defect in the ion channels) and in the setting of intracranial hemorrhage.
- An inverted U wave may represent myocardial ischemia or left ventricular volume overload.



Normal ECG intervals

PR interval

Time period measured From the start of P wave (initial atrial depolarization) → to the start of QRS complex (Initial ventricular depolarization)

PR interval = 0.12 - 0.2 sec

Includes P wave (which denotes atrial depolarization) & PR segment (which denotes AV delay)

An increase in conduction velocity through AV node will decrease P-R interval (sympathetic stimulation) & vice versa.

QT interval

From the **beginning of Q wave** (ventricular depolarization) → **end of the T wave** (ventricular repolarization).

0.35 – 0.45 sec.

It includes :QRS complex, ST segment & T-wave

It represents the **ventricles contraction** (the total time needed to depolarize and repolarize) and the approximate refractory period

RR interval

Between two successive R-waves

Used to measure **Heart rate** & cardiac cycle length.

Heart rate:
can be measured by counting the number of R-waves per minute.
If the interval between 2 beats is 1 second , the heart rate is 60 beats per minute

Summary

ECG Waves & Causes

ECG Wave	cause	Represent
P- wave	Atrial depolarization	* Time of electrical impulse from SA node *precedes atrial contraction by = 0.02 sec.
QRS-complex Measured from beginning of Q wave till end Of S wave.	ventricular depolarization	Consists of 3 waves : • Q wave (-ve) =produced by depolarization of interventricular septum . • R wave (+ve)= produced by depolarize of the ventricular wall. • S wave (-ve)= produced by depolarization of the base of the heart. • Precedes ventricular contraction by 0.02 sec. • Occurs after P-wave by 0.12-0.2 sec = PR interval
T- Wave	ventricular repolarization	Occurs during latter part of systole

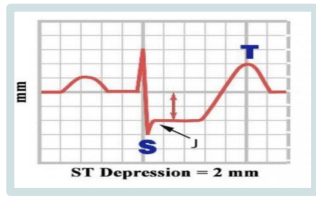
Normal ECG segments

TP segment

- Calculated from end of T- wave to beginning of P- wave.
- Time interval from end of ventricular repolarization till - next atrial depolarization.
- It represents **ventricular filling.**

ST segment

- **It is segment of ECG from end of S wave to beginning of T wave**.
- During this segment all ventricular muscles are completely depolarized, i.e. no potential difference between areas of myocardium at this stage.
- It roughly corresponds to the plateau phase of the ventricular action potential.
- A normal ST segment is on isoelectric line.
- If it is deviated up or down, it indicates diseased fibers. Depression indicates Ischemia, and Elevation indicates MI



- The criteria for a ST elevation myocardial infarction (**STEMI**) is ST segment elevation and inverted T wave in two or more contiguous leads.

Summary: Duration of ECG waves & intervals

Interval	Normal duration		events in the heart during interval
	Average	Range	
PR interval *	0.18*	0.12-0.2	Atrioventricular conduction
QRS duration	0.08	to 0.1	ventricular depolarization
QT interval	0.4 *	to 0.43	ventricular action potential
ST interval (QT minus QRS)	0.32	...	plateau portion of the ventricular action potential

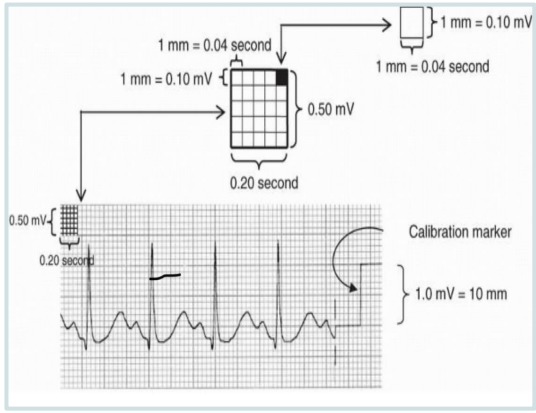
* **Measured From the beginning pf the P wave to the beginning of the QRS complex**

* **Shortens as heart rate increases from average of 0.18 s at a rate of 70 beats / min to 0.14 s at a rate of 130 beats / min.**

* **Can be lower (0.35) depending on heart rate**

ECG paper calibration

- ECG is displayed on a graph paper as waves.
- **Speed:** ECG machine runs at 25 mm/sec.



Time (X-axis):
1mm square = 0.04 sec
5 small squares = 0.2 sec
25 small squares (5 big squares) = 1 sec

Voltage (y-axis):

1mm square = 0.1 mV
10 small lines = 1mV

How to calculate Heart rate from ECG paper calibration ?

$$\text{Heart Rate} = \frac{1500}{\textit{Small}\text{ squares between R-R}}$$

$$\text{Heart rate} = \frac{300}{\textit{Number}\text{ of large squares between two QRS complexes}}$$

The ECG leads

- Leads are electrodes which measure the difference in electrical potential between either:
  1. Two exploring (Active) electrodes attached to the surface of body (bipolar leads)

  2. One point on the body (Exploring) and a virtual reference point (Indifferent) electrode with zero electrical potential (unipolar leads)

- An ECG lead is a pair of electrodes and their wires to make a complete circuit. They are applied to particular parts of the body.

ECG leads are 12 leads:-

1- 3 Standard **Bipolar** Limb Leads:
(I, II, III)

2- 3 Augmented **Unipolar** Limb Leads:
(aVR, aVL, aVF)

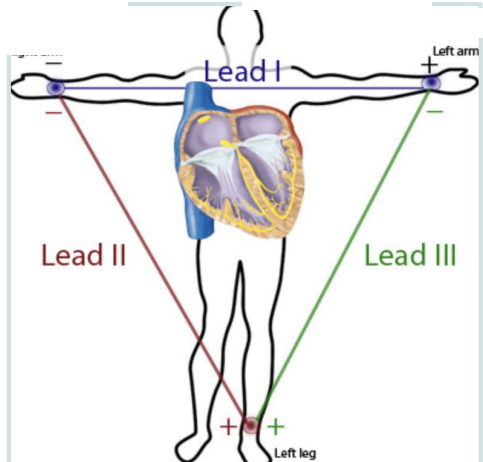
3- 6 **Unipolar (precordial)** chest Leads:
(V1, V2, V3, V4, V5, V6)

The axis of a particular lead represents the viewpoint from which it looks at the heart.

The Bipolar (Standard) Limb Leads

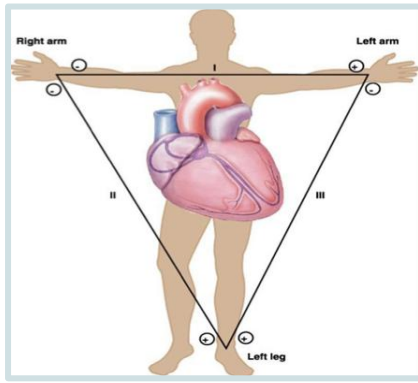
Bipolar: Two exploring (active) electrodes attached to the surface of body.

Lead I	Connects right arm (-ve) & left arm (+ve)
Lead II	Connects right arm (-ve) & left leg (+ve)
Lead III	Connects left arm (-ve) & left leg (+ve)



Einthoven Triangle and Law

Einthoven's triangle: The standard limb leads can be represented by Einthoven triangle. The heart is considered to lie in the center.



- The lower apex is the point at which the left leg connects.
- The two apices at the upper part of the triangle represent the points at which the two arms connect electrically.

Einthoven's law:

States that if the ECGs are recorded simultaneously with the three limb leads, the sum of the potentials recorded in leads I and III will equal the potential in lead II.

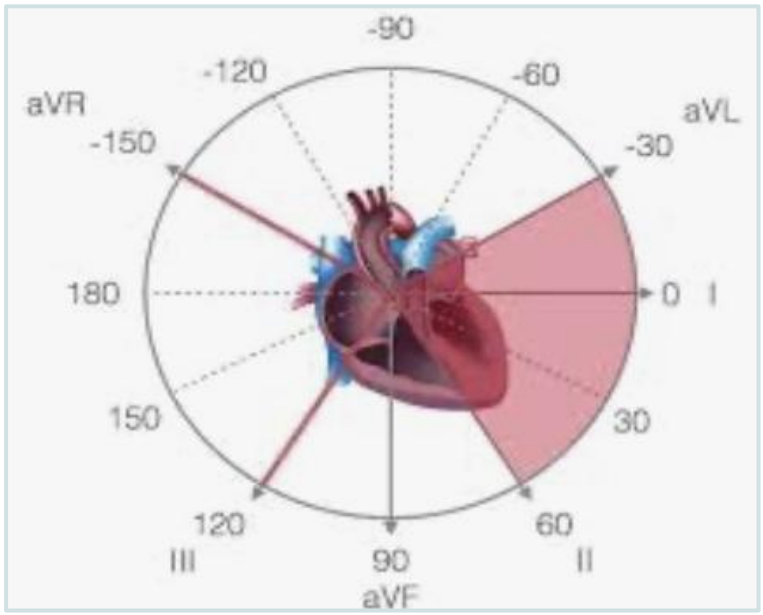
Lead I + Lead III = Lead II

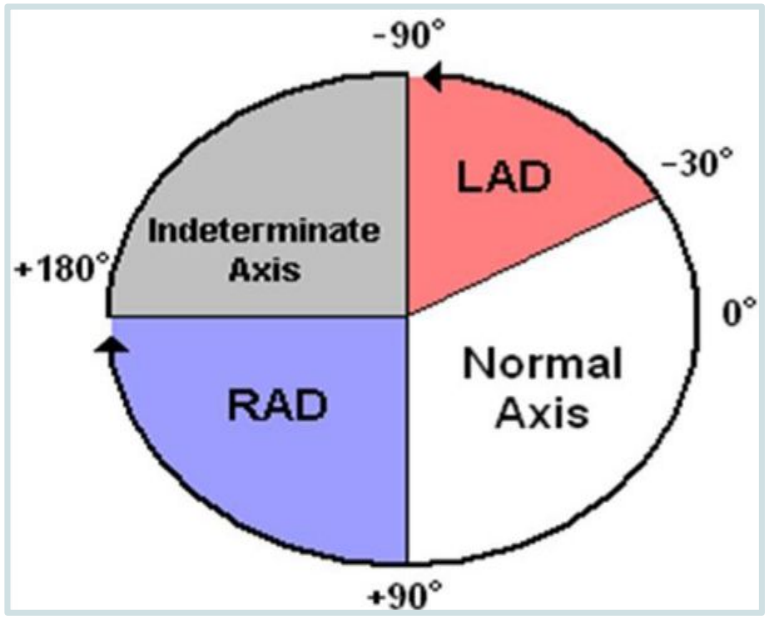
Hexagonal reference system

Another name :HEXA AXIAL

- The direction of axis of 3 standard limb leads can be represented by 3 intersecting lines:-

The axis of lead I is **0 degree**
The axis of lead II is **60 degree**
The axis of lead III is **120 degree**.





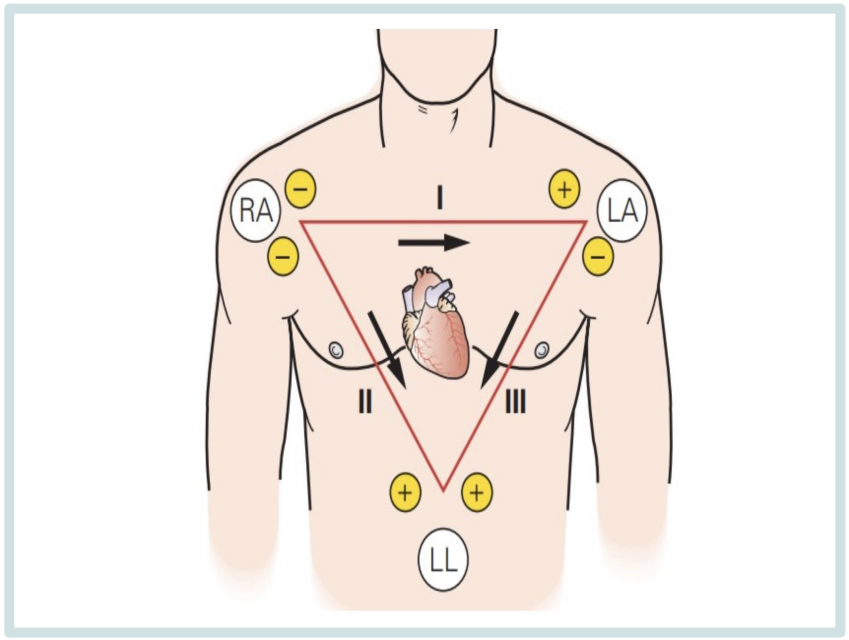
النورمل axis تمثل الاتجاه الطبيعي للكهرباء : -٣٠ إلى +٩٠

Female slide ONLY

Augmented Unipolar Leads

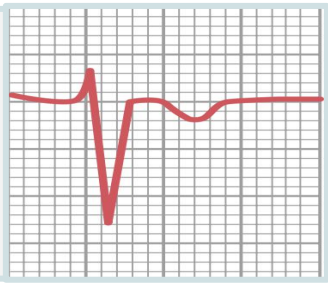
- ECG record is by using an active or exploring electrode a virtual reference point connected to an indifferent electrode at zero electrical potential.
- One limb is connected to the positive terminal of the ECG. The other two limbs are connected to the negative terminal of the ECG.
- These are aVR, aVL, aVF "a=stands for augmented, V=voltage, R=right arm, L=left arm, F=left foot".
- All are similar to the standard limb leads except aVR lead is inverted.
- Letter (a) means augmentation i.e. ↑ magnitude of recording 1.5 times.

They are labeled according to limb to which the exploring (positive) terminal of machine is connected into:



When the positive terminal is on the right arm, the lead is known as the aVR lead; when on the left arm, it is known as the aVL lead; and when on the left leg, it is known as the aVF lead.

Augmented voltage Right arm
When the positive terminal is connected to right arm and other electrode is connected to other 2 limbs =**aVR**.



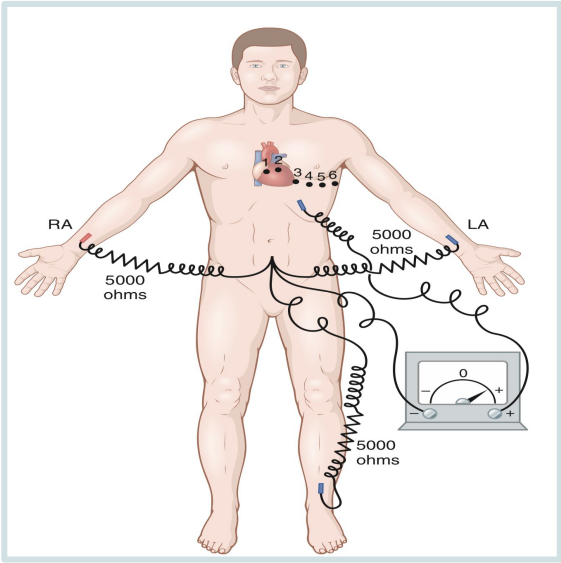
Augmented voltage left arm When the positive terminal is connected to left arm and other electrode is connected to other 2 limbs = **aVL**.

Augmented voltage left foot
When the positive terminal is connected to left foot and other electrode is connected to other 2 limbs = **aVF**.

*Female slide ONLY

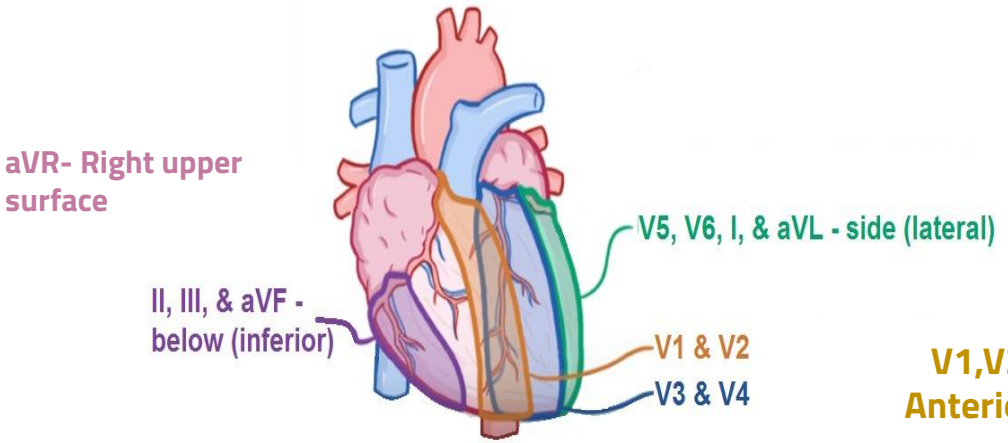
*Chest Leads

- Exploring (positive) electrode is placed on chest, the indifferent (negative) electrode is connected to the 3 limbs **:-** the right arm, left arm, and left leg.
- They include leads V 1-6.
- V1 & V2: QRS are mainly negative because the chest leads are nearer to the base of the heart (electronegative).
- V3, V4, V5 & V6: are mainly positive because the chest electrode are nearer to the apex (electropositive).



Anatomical relations of leads in a standard 12 lead ECG

Two Leads of the same anatomical Group are "Anatomically contiguous"



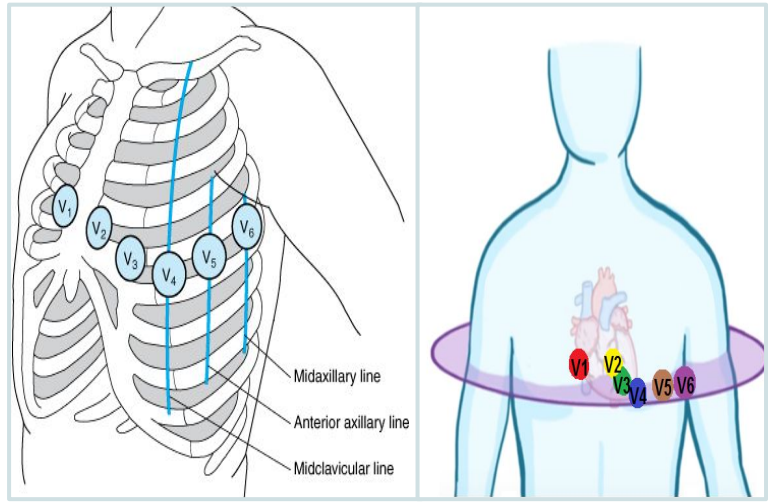
V1,V2,V3,V4. Anterior surface

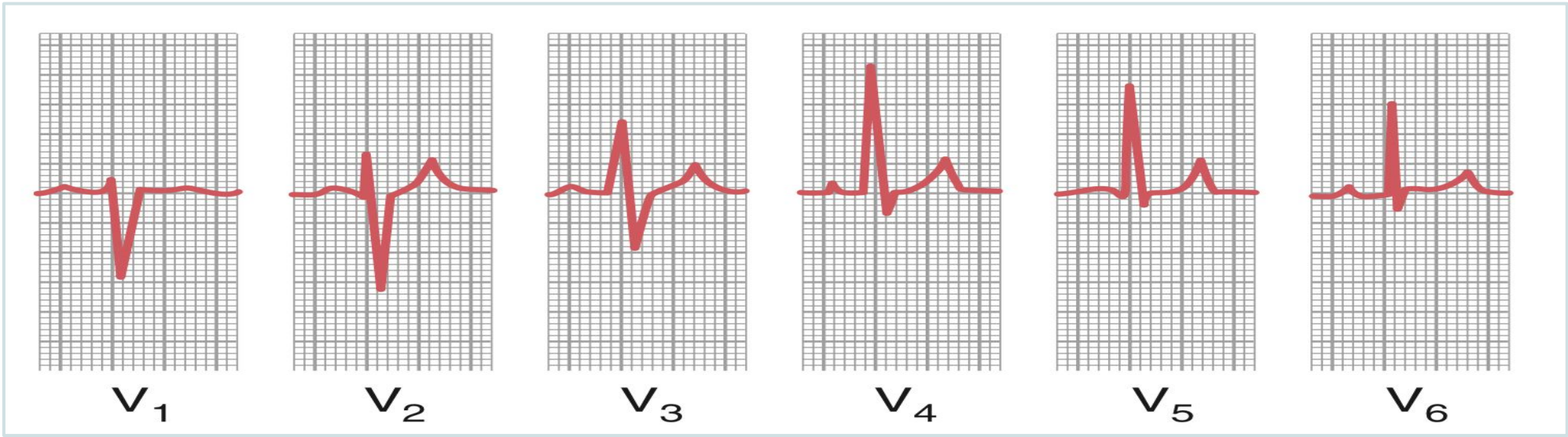
The criteria for a ST elevation myocardial infarction (STEMI) is ST segment elevation in two or more contiguous Leads

Female slide ONLY

Chest Leads

V1	At **right 4th** intercostal space near sternum.	**V4**	At **left 5th** intercostal space at midclavicular line.
V2	At **left 4th** intercostal space near sternum.	**V5**	At **left 5th** intercostal space at anterior axillary line.
V3	Midway between **V2 & V4.**	**V6**	At **left 5th** intercostal space at mid axillary line.

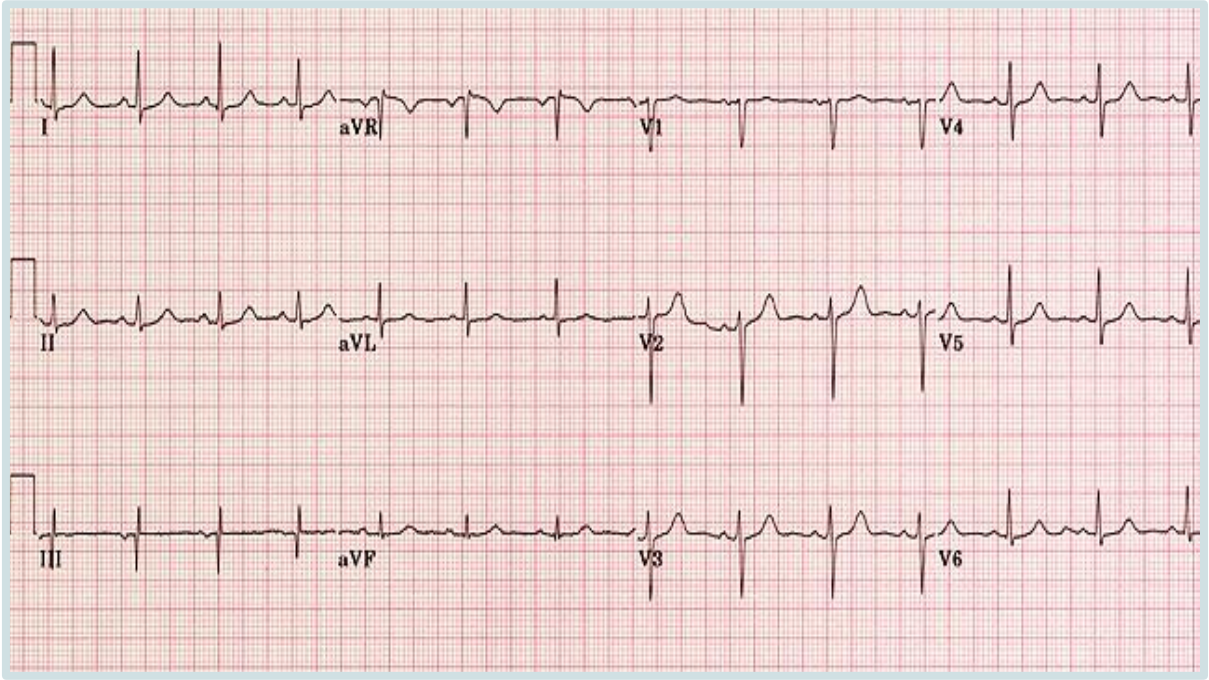




Summary of ECG Leads

	Limb leads	Precordial leads
Bipolar leads	I,II,III (Standard limb leads)	-
Unipolar leads	aVR, aVL, aVF (Augmented limb leads)	V1-V6

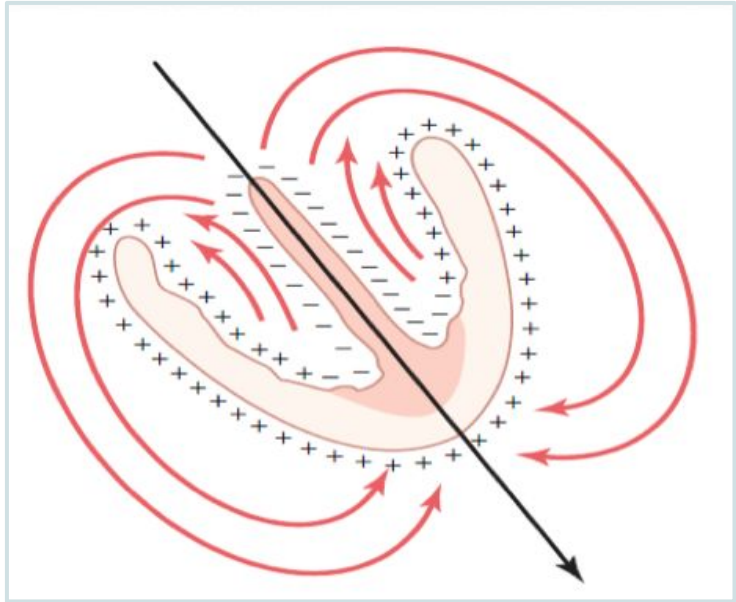
This is normal ECG
ECG helps to define a lot of diseases, you can read more for your own knowledge :
Click here



Cardiac Vectors

- Electrical forces can be represented in the form of **vectors**. (قوة موجهة)
- A vector is an arrow that points in the direction of the electrical potential generated by the current flow, with the arrowhead in the positive direction.
- The length of the arrow is proportional to the voltage of the potential .

Extra information from Guyton :
The shaded area and the minus signs in Figure 12-1 show depolarization of the ventricular septum and of parts of the apical endocardial walls of the two ventricles. At the instant of heart excitation, electrical current flows between the depolarized areas inside the heart and the non depolarized areas on the outside of the heart, as indicated by the long elliptical arrows. Some current also flows inside the heart chambers directly from the depolarized areas toward the still polarized areas. Overall, considerably more current flows downward from the base of the ventricles toward the apex than in the upward direction. Therefore, the summated vector of the generated potential at this particular instant, called the instantaneous mean vector, is represented by the long black arrow drawn through the center of the ventricles in a direction
from the base toward the apex. Furthermore, because the summated current is considerable in quantity, the potential is large and the vector is long



- **Mean vector through the partially depolarized ventricles. The length of the arrow is proportional to the voltage the potential.**

The vector is always directed towards the positive electrode

اتجاه الكهرباء بناءً على المحصلة downward and to the left وكل ماكان
vector طويل كل ماكان مقدار الكهرباء اكبر .

The Vectors That Occur at The Atria During Depolarization & Repolarization: The P Wave

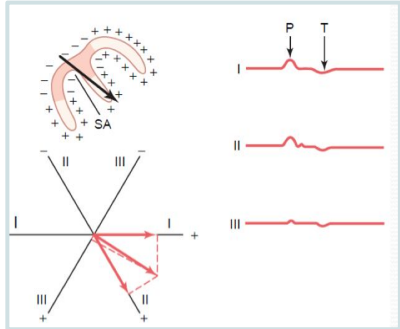
-The area in the atria that becomes depolarized first is the sinus nodal region. (discussed in slide 5 "ECG principles") spreads in all directions over the atria. Therefore, the point of original electronegativity in the atria is about at the point of entry of the superior vena cava where the sinus node lies, and the direction of initial depolarization is denoted by the black vector

-The area in the atria that becomes repolarized first is the sinus nodal region. It became positive instead of negative

Therefore, the atrial repolarization vector is backward to the vector of depolarization.

-In a normal ECG, the atrial T wave appears at about the same time that the QRS complex of the ventricles appears. Therefore, it is almost always totally obscured by the large ventricular QRS complex

-Depolarization of the atria and generation of the P wave, showing the maximum vector through the atria and the resultant vector in the three standard leads.

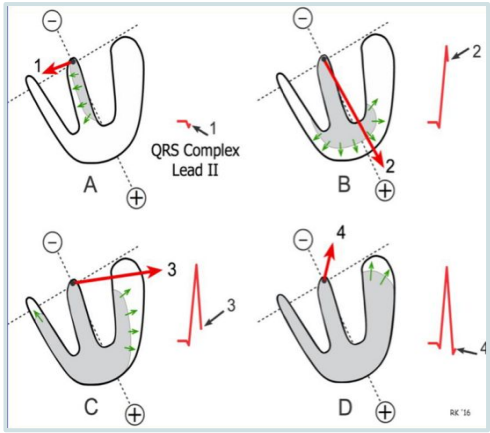


Vectors That Occur at Successive Intervals During Depolarization of The Ventricles-the QRS Complex

- When the cardiac impulse enters the ventricles through the A-V bundle, the first part of the ventricles to become depolarized is the left endocardial surface of the septum.

- It spreads through the ventricular muscle to the outside of the heart.

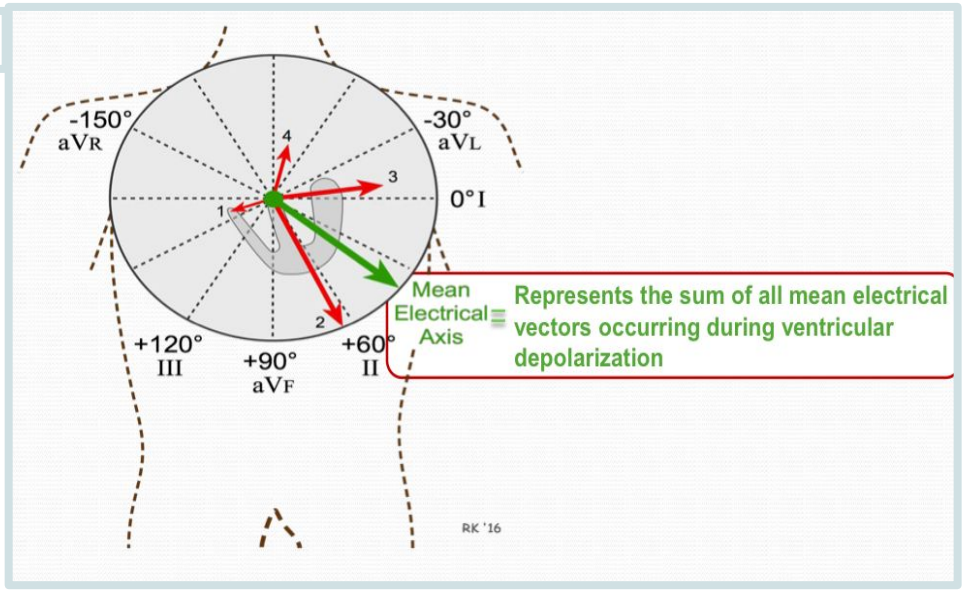
- Q wave is caused by initial depolarization of the left side of the septum before the right side, which creates a weak vector from left to right for a fraction of a second before the usual base-to-apex vector occurs thats why Q wave is downward (away from the apex)



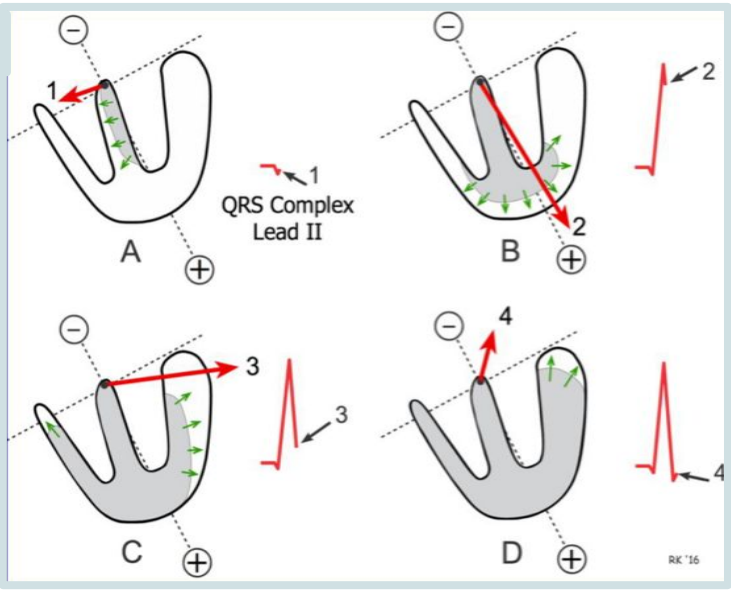
More explanations in next slide

Vectors That Occur During Ventricular Depolarization

1



2



Time for Explanation:

First u need to know that :

- The red arrows represent a vector which is the net direction of current flow, which is the the sum of the 5 Green arrows (in picture number2)
- The positive electron is down while the Negative is up, and if the current flows away from the positive we will have a downward deflection.
- The length of the arrow is proportional to the voltage of the potential
- QRS: Represent ventricular depolarization,
- Q wave: due to depolarization of interventricular septum.
- R wave: due to depolarization of most ventricular wall.
- S wave: due to depolarization of base of the heart.

1- The impulse pases from the av-node to the left septum, when the left side of the septum depolarize the current flows from the depolarized aera to the non depolarized area which is the right septum, So the net direction of the current will be from left to right, as u can see in the picture the current is going away from the positive electron, and this is why we get a negative Q wave (a downward deflection) but it's just a small deflection, Why? Because the red Arrow is short, but Why? because the voltage of potential is weak.

2- Now the whole septum is depolarized, so now the current is moving from the septum to the Apex, so the net direction of the current (which is the red arrow) is going toward the the positive electron, so we will get a big positive deflection.

3- More of the Apex and the outer portions will depolarize, and the red arrow will be facing away the positive electron, so you will get a downward deflection.
4-Now the last part of the ventricle will get depolarized, which is the base of the heart, the most upward left portion of the left ventricle, so when this last portion depolarize the current will go away from the positive electron.

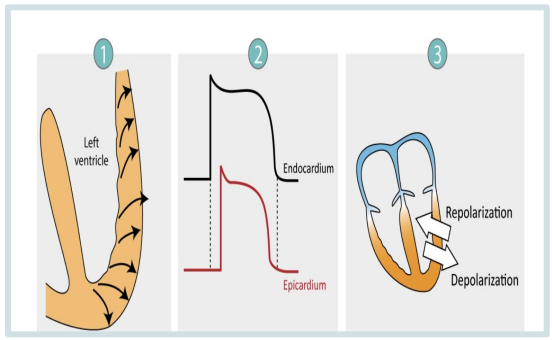
Electrocardiogram During Ventricular Repolarization The T Wave

Because the septum and endocardial areas of the ventricular muscle depolarize first, it seems logical that these areas should repolarize first as well, but actually it is NOT so!

- The greatest portion of ventricular muscle mass to repolarize first is the entire outer surface of the ventricles, especially near the apex of the heart because the septum and other endocardial areas have a longer period of contraction than do most of the external surfaces of the heart so endocardial areas, conversely, normally repolarize last.

- Therefore, the positive end of the overall ventricular vector during repolarization is toward the apex of the T wave heart. As a result, the normal T wave in all three bipolar limb leads is positive, which is also the polarity of most of the normal QRS complex.

Note That:



Depolarization is directed from the endocardium to the epicardium. The electrical vector has the same direction,
The duration of the action potential is shorter in epicardial cells, which is why repolarization starts there. The repolarization is therefore directed from the epicardium to the endocardium.
To conclude, the direction of the vectors during de- and re- polarization are opposite , but so is the flux of ions and therefore there in no net difference in the direction of the electrical vector. The electrical vector has the same direction during de- and re- polaraztion.

Quiz:

1- Which one of the following is an Inferior lead ? A) II
B) I
C) V3
D) aVL

2- Which one of the following is Time interval from ventricular repolarization till - next atrial depolarization.
A) TP segment
B) QT segment
C) PR segment
D) ST segment

3-ECG records electrical changes in which of the following layers of the heart .
A) pericardium
B) epicardium
C) Endocardium
D) Myocardium

4-which of these represents the ventricular filling?
A) QT segment
B) PR interval
C) QT interval
D) TP segment

5-which of the following is a chest lead that is placed on the anterior axillary line?
A) V3
B) V5
C) V6
D) V1

Answer Key: 1A - 2A- 3D - 4D - 5B

Quiz:

1- What are the physiological importance of P-R Interval ?

2- Why is S-T segment Isoelectric ?

3- Describe why each wave of QRS complex happen?

4- What does the QT interval contain?

A1: Denotes atrial depolarization & AV delay.

A2: Because the heart has completely depolarized, and repolarization has not started yet.

A3: slide (8)

A4: QRS complex, ST segment & T-wave

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