جامعة الملك سعود
King Saud University

The Electrocardiogram ECG

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:

- Define ECG & list uses of ECG.
- Explain basic ECG principles.
- Describe ECG leads and their application.
- Recognize ECG waves, Intervals and, segments.
- Determine rate and normal heart rhythm.
- Have some idea about ECG abnormalities in common clinical conditions.
- Determine the bipolar, unipolar and chest leads.
- Know what is Einthoven’s triangle and Einthoven’s law.

History of ECG (just read it)

The invention of the capillary electrometer in the early 1870s by Gabriel Lippmann led to the first recording of a human electrocardiogram by Augustus D. Waller. Without exposing the heart Einthoven presented his idea of applying the galvanometer to the recording of the cardiac electrical activity in 1903. He also coined the term elektrokardiogramm in German (the dominant language at the time for scientific publications) and labeled the recorded waveforms P, Q, R, S, T, and U to differentiate them from the original— but incomplete—A, B, C, and D described by Waller Waller was nominated for the Nobel Prize along with Einthoven but died before it could be presented, so Einthoven alone received it. (Waller AD J Phys 1917)

DEFINITION

"ECG is a graphical representation of the sum of all the electrical activities of the heart usually recorded from the body surfaces".ECG can help the doctor see if you have heart muscle damage or electrical problems in the heart.

ECG helps in diagnosis of...

- Abnormal rhythm
- Conduction defect
- Electrolytes imbalance
- Abnormal heart rates
- Myocardial damage
- Chamber hypertrophy

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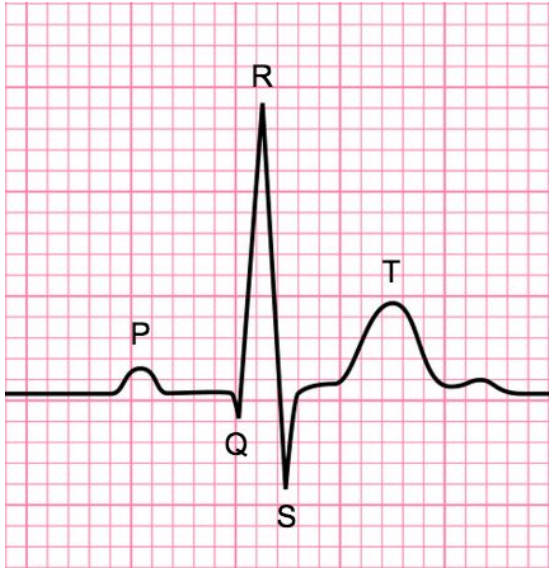
What types of information can we obtain from an ECG?

- Heart rate.
- Normal Intervals.
- Heart Rhythm:
  - Regular.
  - Single P-wave precedes every QRS complex.
  - P-r interval is constant and within normal range.
- Cardiac axis.
- Myopathies:
  - Helps in diagnosis of chest pain.
  - Proper use of thrombolysis in treatment of MI depend upon it.
- Electrolyte disturbances (i.e. hyperkalemia, hypokalemia).
- Drug toxicity (i.e. digoxin and drugs which prolong the QT interval).

Principle of ECG

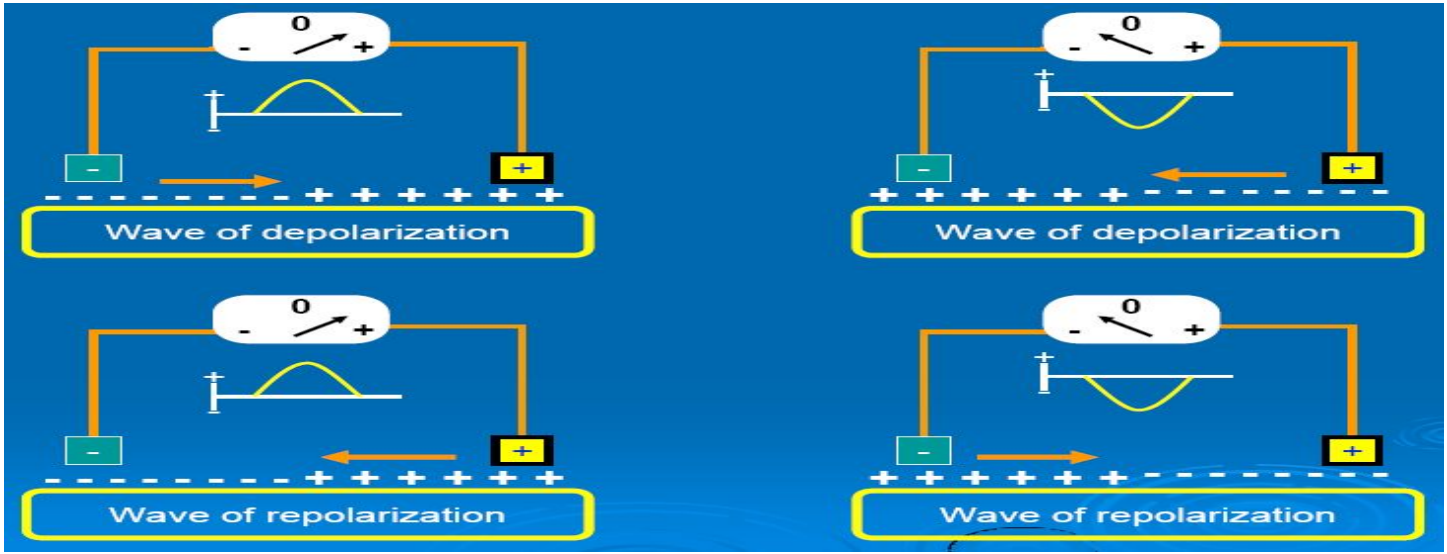
- ECG can be recorded by placing electrodes on body surface on opposite sides of the heart.

- When the depolarization wave spread 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 electrodes placed on the skin opposite the heart.
- The record is the ECG.



Electrode and ECG principles

Drs Note:
When it goes to the positive electrode, it shows upward deflection.
When it goes to the negative electrode, it shows downward deflection.



Explanation of the diagram from gyton page 131

In Figure 11-2A, depolarization, demonstrated by red positive charges inside and red negative charges outside, is traveling from left to right. The first half of the fiber has already depolarized, while the remaining half is still polarized. Therefore, the left electrode on the outside of the fiber is in an area of negativity, and the right electrode is in an area of positivity, which causes the meter to record positively. Note that when depolarization has reached the halfway mark in Figure 11-2A, the record has risen to a maximum positive value.

In Figure 11-2B, depolarization has extended over the entire muscle fiber, and the recording to the right has returned to the zero baseline because both electrodes are now in areas of equal negativity. The completed wave is a depolarization wave because it results from spread of depolarization along the muscle fiber membrane.

Figure 11-2C shows halfway repolarization of the same muscle fiber, with positivity returning to the outside of the fiber. At this point, the left electrode is in an area of positivity, and the right electrode is in an area of negativity. This polarity is opposite to the polarity in Figure 11 2A. Consequently, the recording, as shown to the right, becomes negative.

In Figure 11-2D, the muscle fiber has completely repolarized, and both electrodes are now in areas of positivity so that no potential difference is recorded between them. Thus, in the recording to the right, the potential returns once more to zero. This completed negative wave is a repolarization wave because it results from spread of repolarization along the muscle fiber membrane.

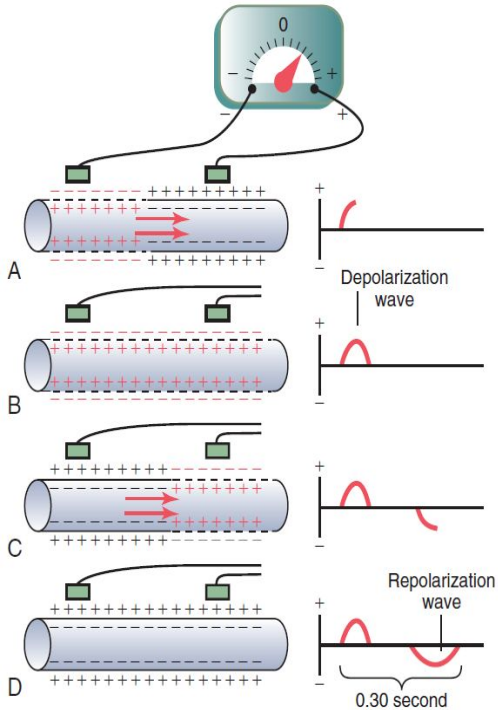


Figure 11-2. Recording the depolarization wave (**A** and **B**) and the repolarization wave (**C** and **D**) from a cardiac muscle fiber.

The one on the center:

Both electrodes are in positive area so no action potential change will occur and therefore it will be 0

The one on the left :

The negative electrode is in the positive area and the positive electrode is in the negative area so the result will be negative

The one on the right:

The negative electrode is in the negative area and the positive electrode is in the positive area so the result will be positive

طيب ليش اللي عاليسار بيطلع سالب واللي عاليمين بيطلع موجب ؟؟؟؟
بكل بساطة إذا كانت معكوسة راح تكون سالب واذا كانت مضبوطة راح تكون موجبة لأن التيار يمشي في الاتجاه الصحيح

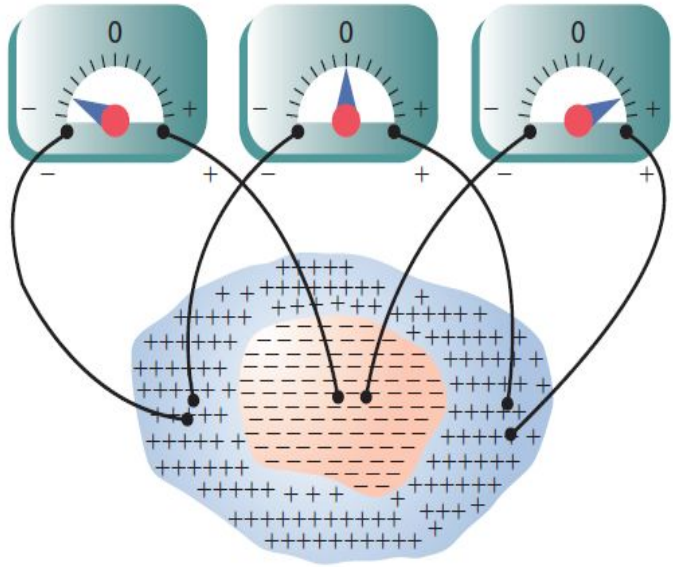
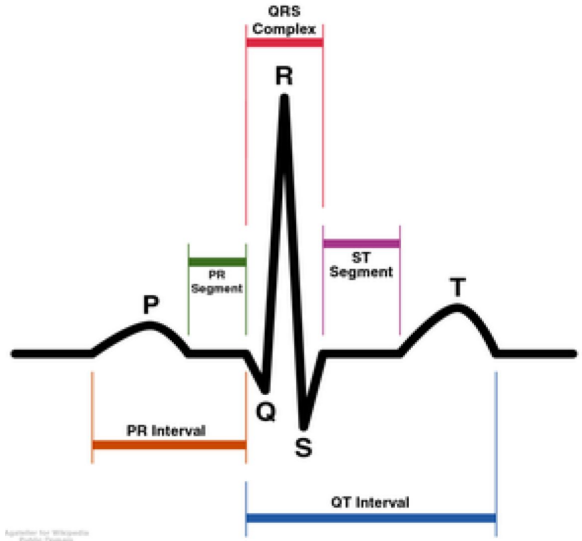


Figure 11-4. Instantaneous potentials develop on the surface of a cardiac muscle mass that has been depolarized in its center.

ECG Waveforms, Intervals & Segemens

- 3 waves: (depolarize & repolarize)
  - P-wave
  - QRS complex (ventricular depolarization)
  - T- wave
  - P, R & T are positive waves.
  - Q & S are negative waves.
- 3 time intervals: (include waves)
  - P-R interval
  - Q-T interval
  - R-R interval (a whole cycle)
- 3 segments “part of repolarization”: (isoelectric, doesn’t include waves*)
  - ST segment
  - TP segment
  - PR segment



*لاتطلع ولاتنزل

Analysis of Normal ECG "Waves"

P-wave

- Due to atrial depolarization.
- P-wave is recorded before the onset of atrial systole.
- 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 is recorded before the onset of ventricular diastole.
- usually same direction as QRS

- PR Interval = impulse from atria to ventricles (wave+segment+AVN delay).
- QT Interval = This interval spans the onset of depolarization to the completion of repolarization of the ventricles.

Causes of ECG Waves

ECG Wave	Cause	Represent
P- wave	Atrial depolarization	Time of electrical impulse from SA node to spread through atrial muscle. Duration = 0.08 –0.1 sec Precedes atrial contraction by ≈ 0.01 - 0.02 sec
QRS complex	Ventricular depolarization	Measured from beginning of Q wave till end of S wave. Consists of 3 waves: **Q wave: (-ve):** Produced by depolarization of interventricular septum. **R wave: (+ve):** Produced by depolarization of ventricular wall. **S wave: (-ve):** Produced by depolarization of the base of the heart. Duration ≤ 0.1 sec. 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, before the onset of diastole. Ventricular repolarization progresses from apex to the base of the heart. Duration = 0.27 sec.

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

Analysis of Normal ECG "Intervals"

P-R interval

- Time period measured from start of P- wave to start of QRS complex; thus P-R interval includes P- wave & PR segment.
- P-R interval is the time from the initial depolarization of atria to the initial depolarization of ventricles.
- P-R interval range = 0.12-0.2 sec.
- An increase in conduction velocity through AV node will decrease P-R interval (sympathetic stimulation) & vice versa.
- (wave+segment+AVN delay)

Q-T interval

- Q-T interval is the time from the beginning of the Q wave to the end of the T wave.
- The QT interval represents total time taken by ventricle to depolarize & repolarize [contraction of ventricles].
- The Q-T interval includes the QRS complex, ST segment & T- wave.
- Q-T interval range = 0.35 – 0.45 sec.
- Approximate refractory period of ventricle.

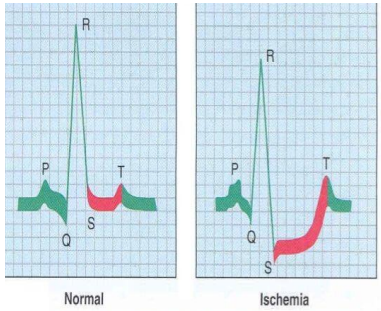
R-R interval

- The interval between two successive R- waves.
- It determines the heart rate & cardiac cycle length.
- Heart rate can be measured by counting the number of R- waves per minute.

Analysis of Normal ECG "Segments"

S-T segment

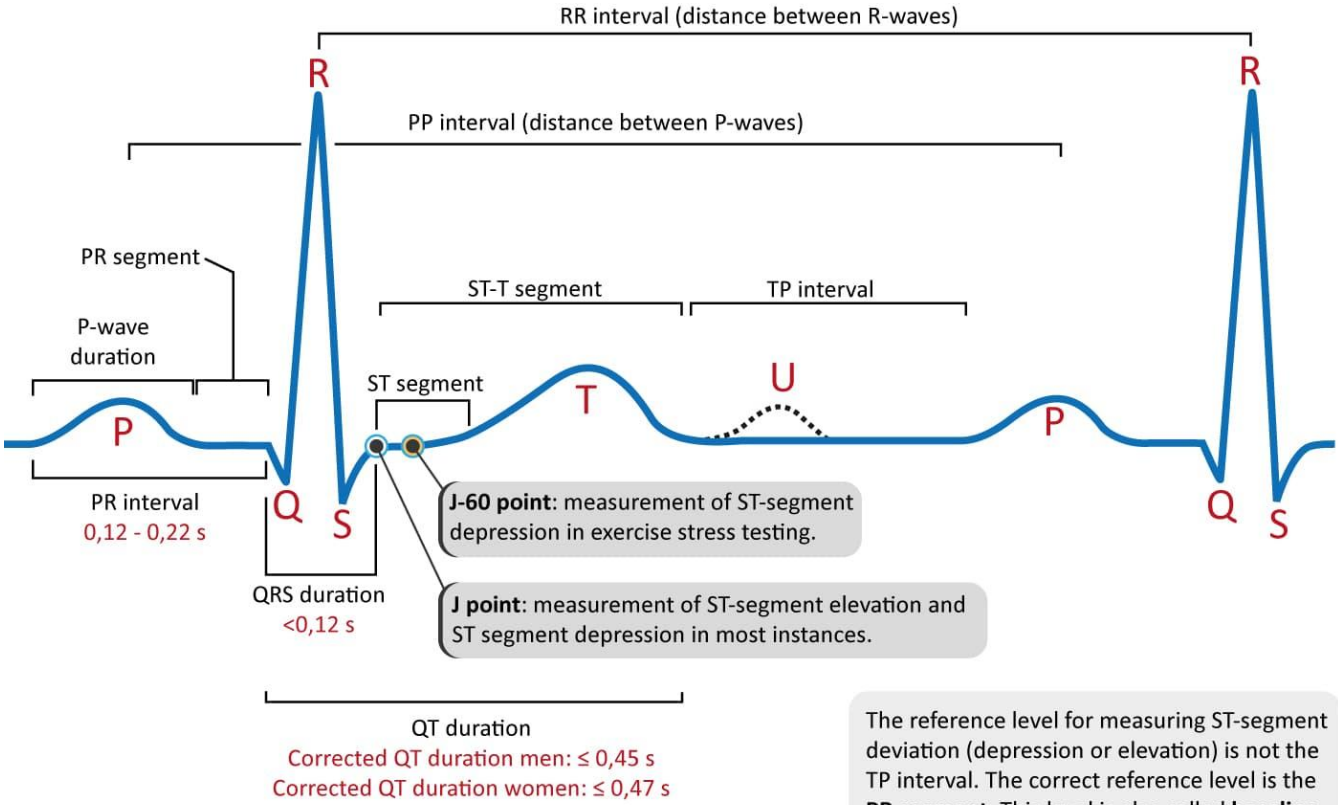
- It is segment of ECG from end of S wave to beginning of T wave.
- During this segment all ventricular muscles are completely depolarized, showing that there is no potential difference between areas of myocardium at this stage.
- It roughly corresponds to the plateau phase of the ventricular action potential.
- A normal S-T segment is on isoelectric line.
- If it is deviated up or down, it indicates diseased fibers.
- e.g. myocardial infarction.



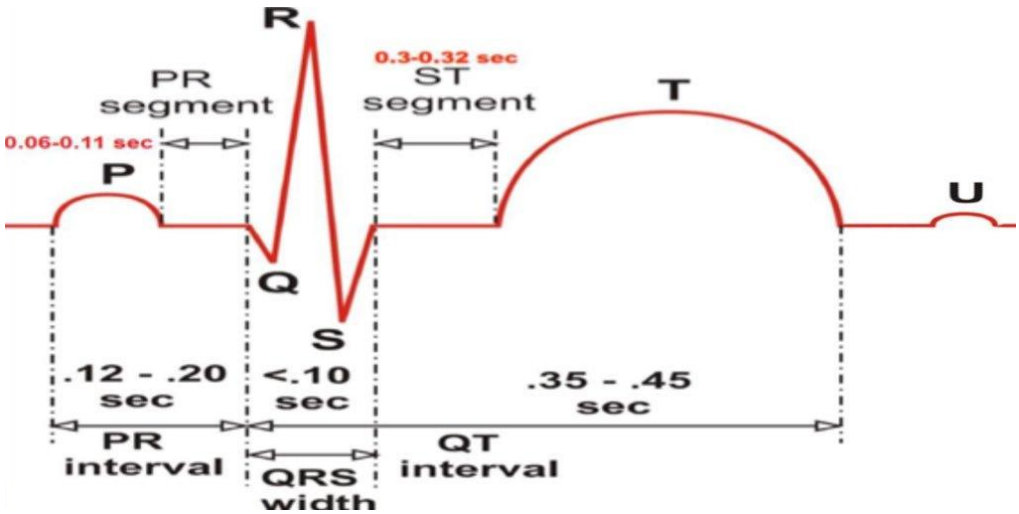
Depression of the S-T segment as a result of myocardial ischemia

T-P segment

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

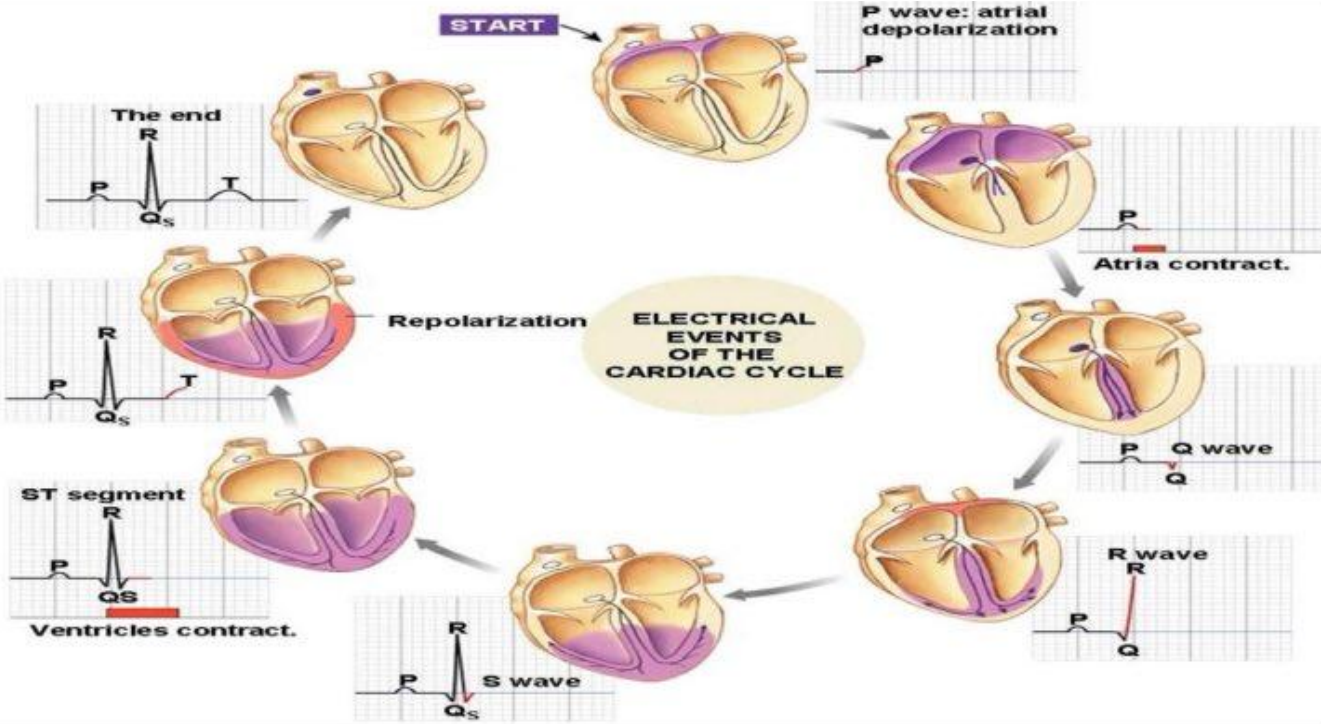


The reference level for measuring ST-segment deviation (depression or elevation) is not the TP interval. The correct reference level is the **PR segment**. This level is also called **baseline** level or **isoelectric level**.



Heart Rate:

- The heart rate is the repetition of the time interval between two successive heart beat.
- If the interval between 3 beats is 1 second, the heart rate is 60 beats per minute.


START
P wave: atrial depolarization
P
Atria contract.
P
Q wave
P
Q
R wave
R
P
Q
S wave
R
P
Qs
Ventricles contract.
ST segment
R
P
QS
Repolarization
R
P
T
Qs
The end
R
P
T
Qs
ELECTRICAL EVENTS OF THE CARDIAC CYCLE

Take a break

& Remember to drink some water 

”

CARDIAC VECTORS

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

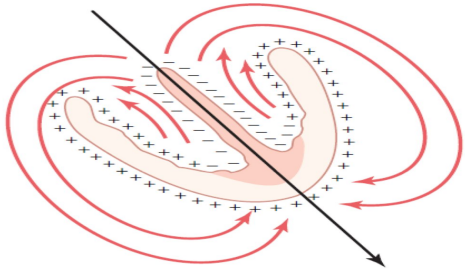


Figure 12–1

Mean vector through the partially depolarized ventricles.

DEPOLARIZATION OF THE ATRIA—THE P WAVE

- ★ The area in the atria that also becomes repolarized first is the sinus nodal region, the area that had originally become depolarized First . 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

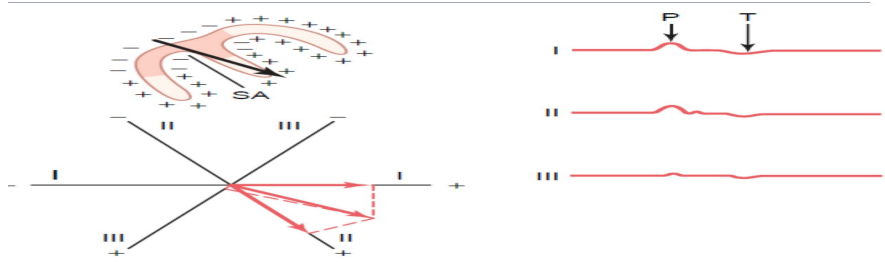


Figure 12–9

Depolarization of the atria and generation of the P wave, showing the maximum vector through the atria and the resultant vectors in the three standard leads. At the right are the atrial P and T waves. SA, sinoatrial node.

VECTORS THAT OCCUR AT SUCCESSIVE INTERVALS DURING DEPOLARIZATION OF THE VENTRICLES—THE QRS COMPLEX

- When the cardiac impulse enters the ventricles through the atrioventricular 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.

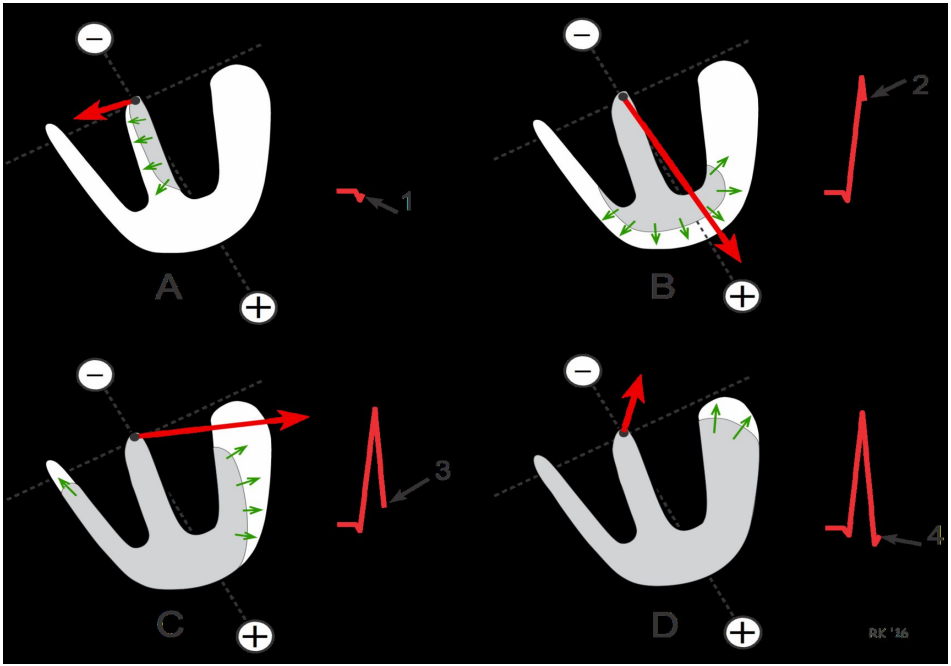
ELECTROCARDIOGRAM DURING REPOLARIZATION—THE T WAVE

- 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 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.

Flow of Electrical current in the Heart

- In normal ventricles, current flows from negative to positive, from the base of the heart toward the apex.
- The first area that depolarizes is the ventricular septum
- Current flows from the electronegative inner surface (from the base of the heart to the apex)
- An electrode placed near the base of the heart is electronegative, and near the apex is electropositive.

Patterns of excitation of ventricles to produce QRS complex in ECG



Explanations for the image:

A: negative Q wave produced by depolarization of interventricular septum (why negative ?? because it is away from the positive)

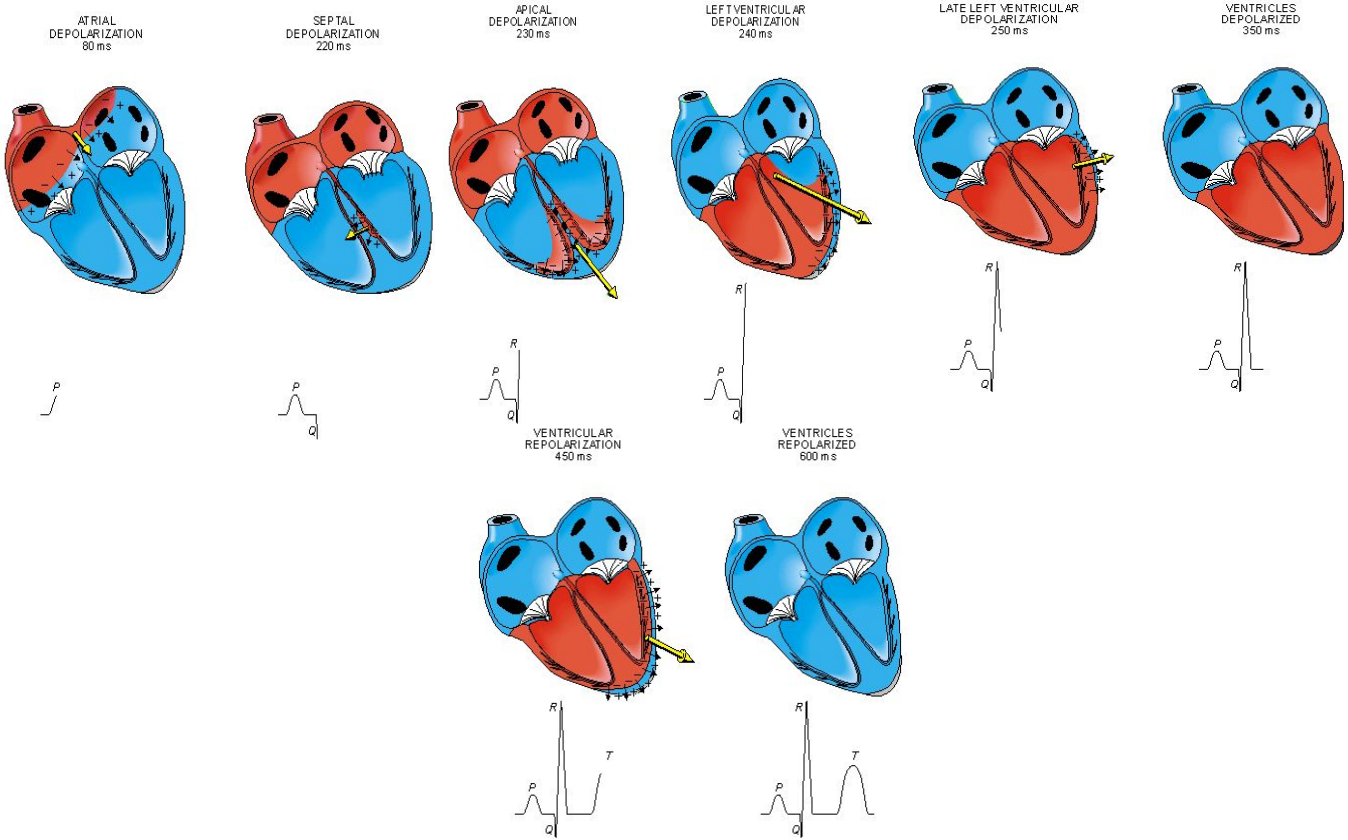
B: positive R wave produced by (apical) depolarization of ventricle wall

C: positive R wave produced by (late) depolarization of ventricle wall

D: negative S wave produced by depolarization of the base of heart

(it is absent in some people)

Pattern of excitation of Heart and ECG



ECG Intervals

Intervals in ECG mean : Wave + Segment

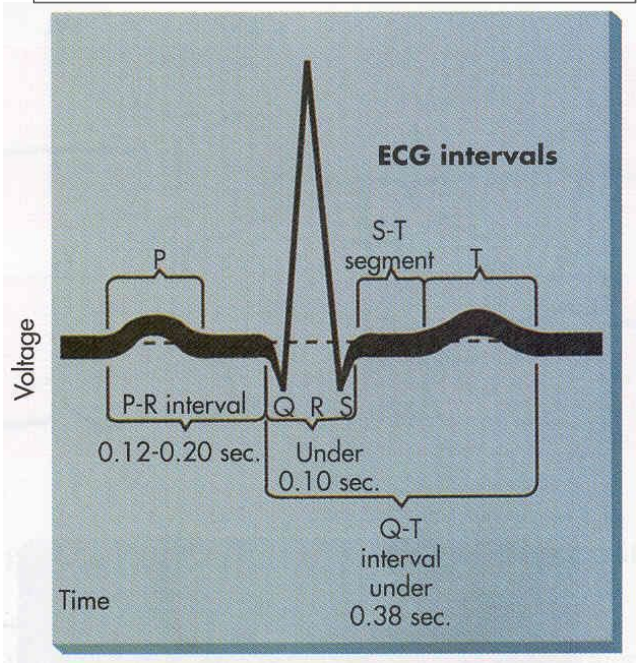
TABLE 29–2 ECG intervals.

Intervals	Normal Durations		Events in the Heart during Interval
	Average	Range	
PR interval[a]	0.18[b]	0.12–0.20	Atrioventricular conduction
QRS duration	0.08	to 0.10	Ventricular depolarization
QT interval	0.40[c]	to 0.43	Ventricular action potential
ST interval (QT minus QRS)	0.32	…	Plateau portion of the ventricular action potential

[a]Measured from the beginning of the P wave to the beginning of the QRS complex.

[b]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.

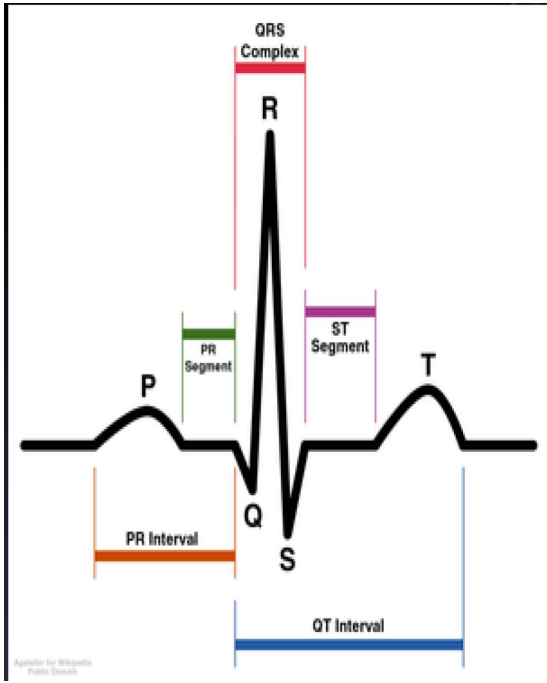
[c]Can be lower (0.35) depending on the heart rate



More explanation about T wave

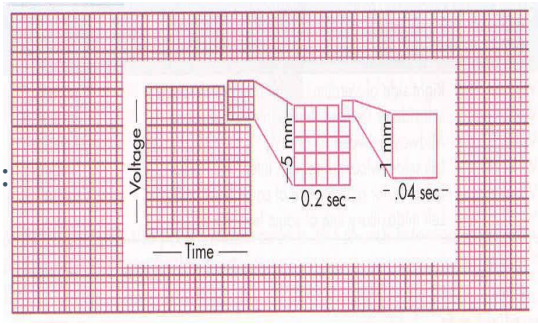
The ventricles remain contracted until after repolarization has occurred, that is, until after the end of the T wave.

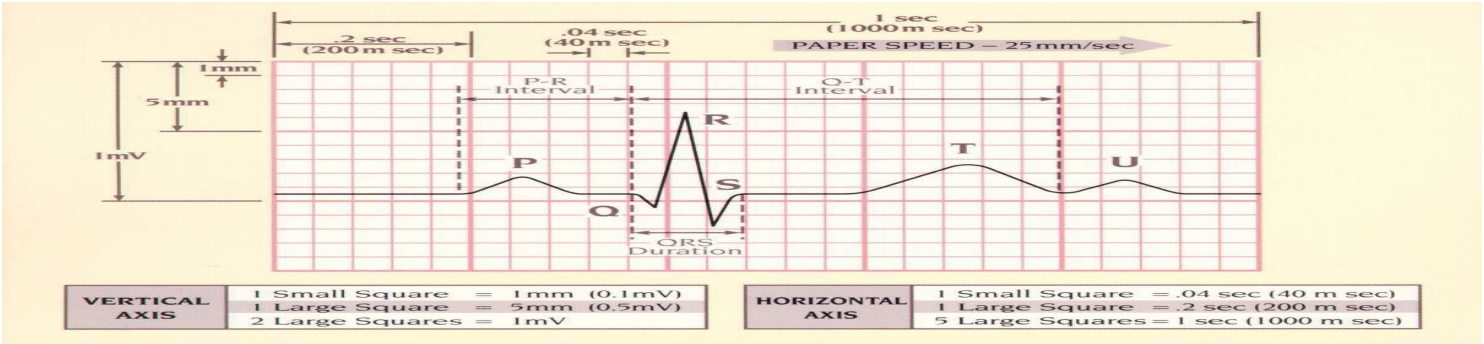
The ventricular repolarization wave is the T wave of the normal ECG. Ordinarily, ventricular muscle begins to repolarize in some fibers about 0.20 second after the beginning of the depolarization wave (the QRS complex),but in many other fibers, it takes as long as 0.35 second. Tus, the process of ventricular repolarization extends over a long period, about 0.15 second. For this reason, the T wave in the normal ECG is a prolonged wave, but the voltage of the T wave is considerably less than the voltage of the QRS complex, partly because of its prolonged length.



The ECG paper

- ECG is displayed on a graph paper as waves
- Speed :ECG machine runs at 25mm/sec
- Voltage (millivolt) is calibrated on the vertical line
  - 1mm square = 0.1mV
  - -10mm square = 1mV
- Time(seconds) is calibrated on the horizontal lines (X-axis):
  - 1mm square = 0.04 second
  - 5 small lines= 0.2 second
  - 25 small lines= 1 second





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) electrodes with zero electrical potential (unipolar leads)

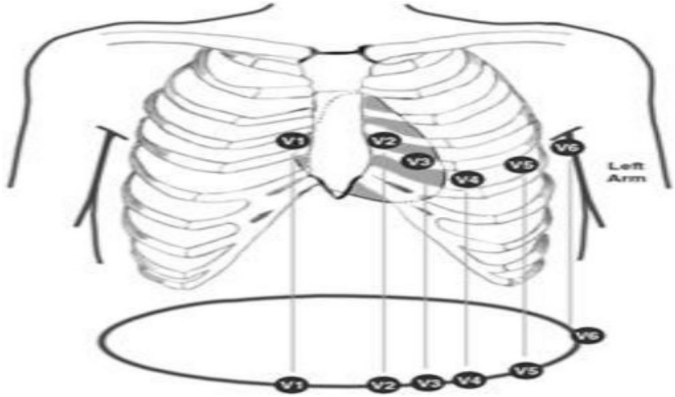
	Limb leads	**Precordial leads**
Bipolar	I: connects right arm (-ve) & left arm (+ve) II: connects right arm (-ve) & left leg (+ve) III: connects left arm (-ve) & left leg (+ve) (Standard limb leads)	–
Unipolar (V leads)	aVR,aVF,aVL (augmented limb leads)	V1- V6

Lead Placement

- There are 12 leads:
- 3 Standard Limb Leads (Bipolar)
- 3 Augmented Limb Leads (Unipolar)
- 6 Precordial (chest) Leads (Unipolar)
- Colors are linked to the table shown beside

Septal	Anterior	Lateral	Inferior	Special
		aVL	aVF	aVR
V1	V3	I	II	
V2	V4	V5 V6	III	

All chest leads are to the left of the sternum except V1 is to the right of the sternum.
V1 = 4th intercostal space right sternum
V2 = 4th intercostal space left sternum
V3 = midway between V2 and V4
V4 = 5th intercostal space midclavicular
V5 = between V4 and V6 anterior axillary line
V6 = midaxillary line lateral to V4 and V5



Einthoven's law

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.

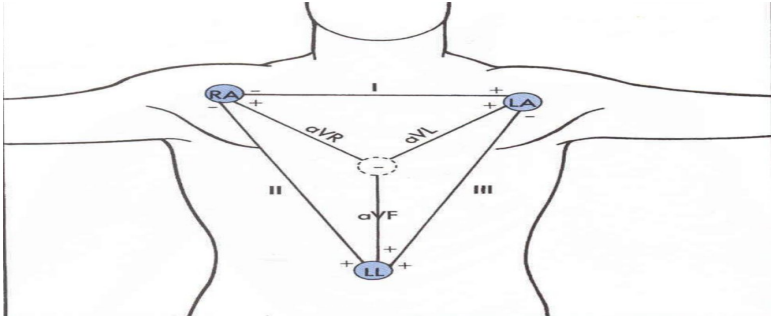
(The sum of the voltage in Lead I + Lead III = Lead II)

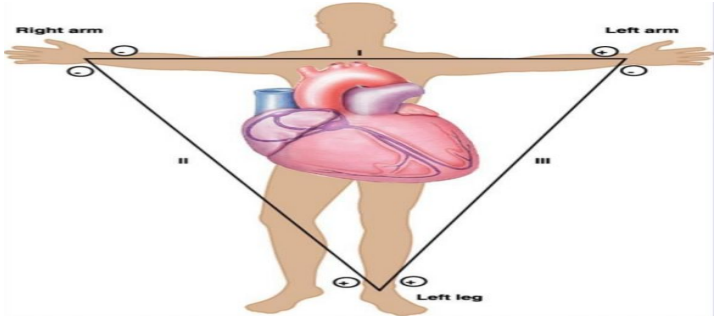
The standard limb leads can be represented by Einthoven triangle.

The heart is considered to lie in center (the triangle is drawn around the area of the heart).

The two apices at the upper part of the triangle represent the points at which the two arms connected electrically

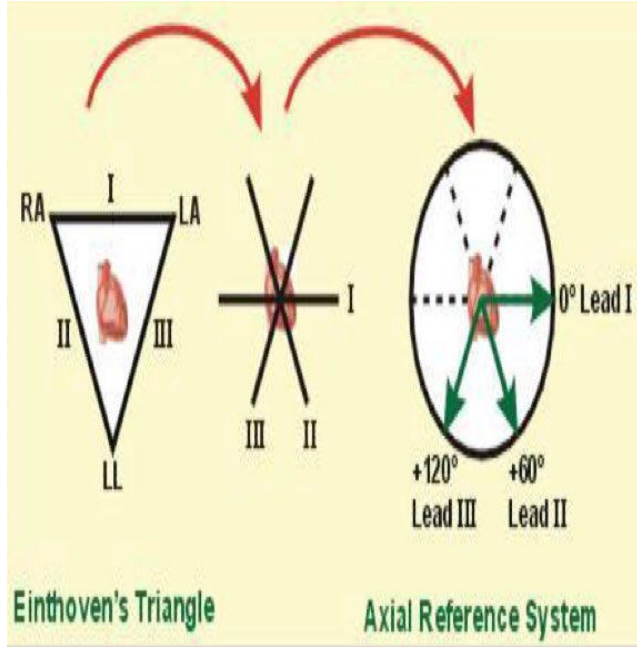
The lower apex is the point at which the left leg connects





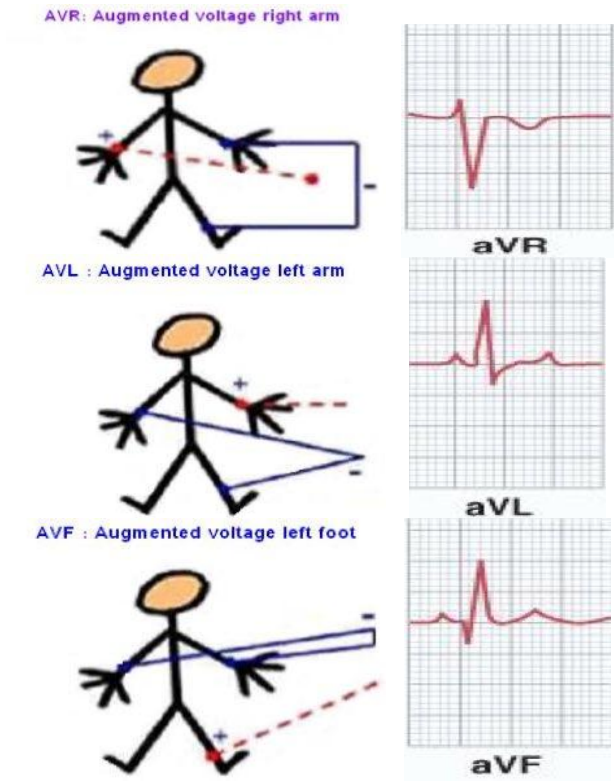
Hexagonal Reference System

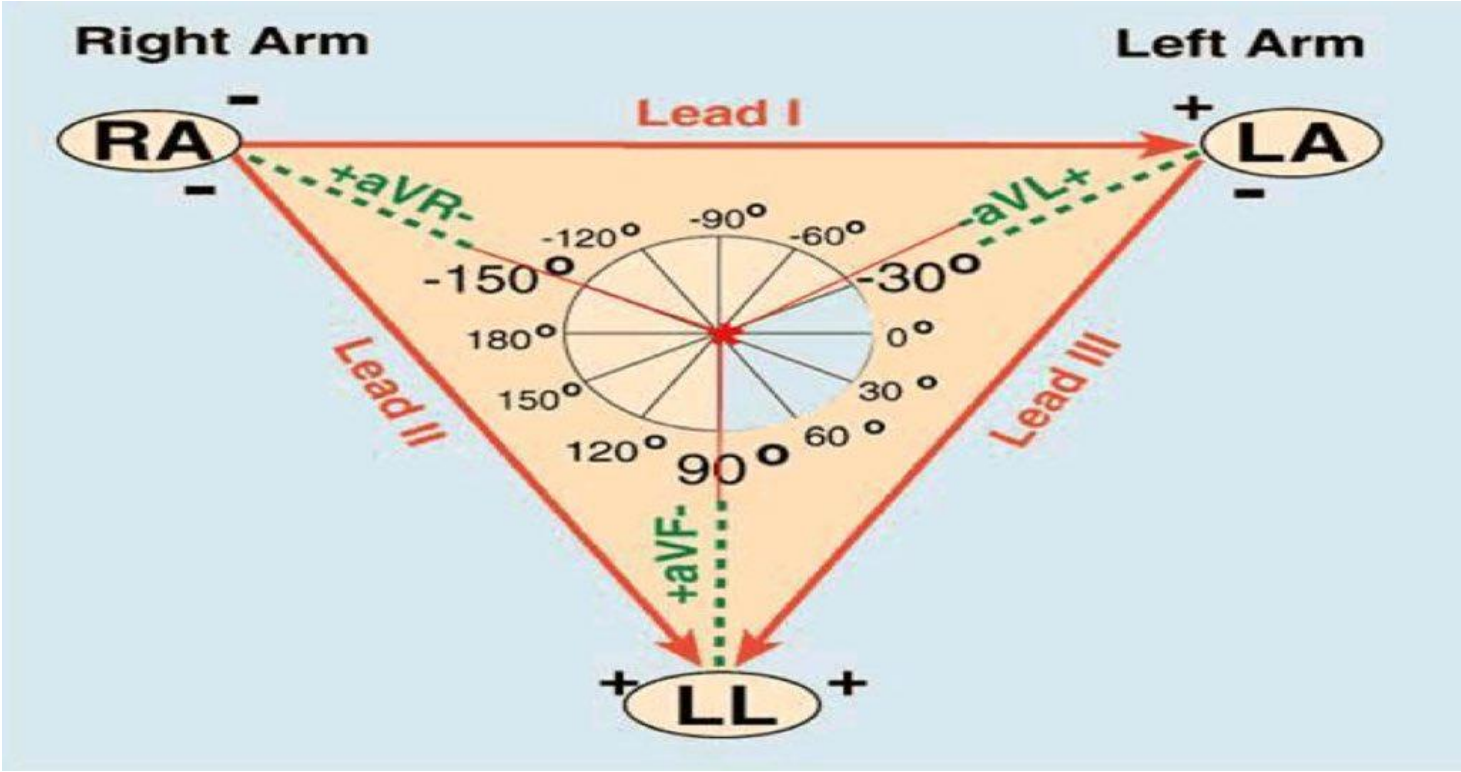
- The direction of axis of 3 standard limb leads can be represented by 3 intersecting lines:
  - The axis of lead I is 0 degree.
  - The axis of lead II is 60 degree.
  - The axis of lead III is 120 degree.



Augmented Unipolar leads

- ECG record is by using an active or exploring electrode connected to an indifferent electrode at zero 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.
- All are similar to the standard limb leads aVR lead is inverted.
- They labeled according to limb to which the exploring (positive) terminal of machine is connected.
- When the positive terminal is connected to right arm and other electrode is connected to other 2 limbs = aVR.
- When the positive terminal is connected to left arm and other electrode is connected to other 2 limbs = aVL.
- When the positive terminal is connected to left foot and other electrode is connected to other 2 limbs = aVF.
- Letter (a) means augmentation i.e. ↑ magnitude of recording 1.5 times.




Right Arm
Left Arm
RA
LA
LL
Lead I
Lead II
Lead III
+aVR-
-aVL+
+aVF-
-150°
-120°
-90°
-60°
-30°
180°
0°
150°
30°
120°
60°
90°

Chest leads

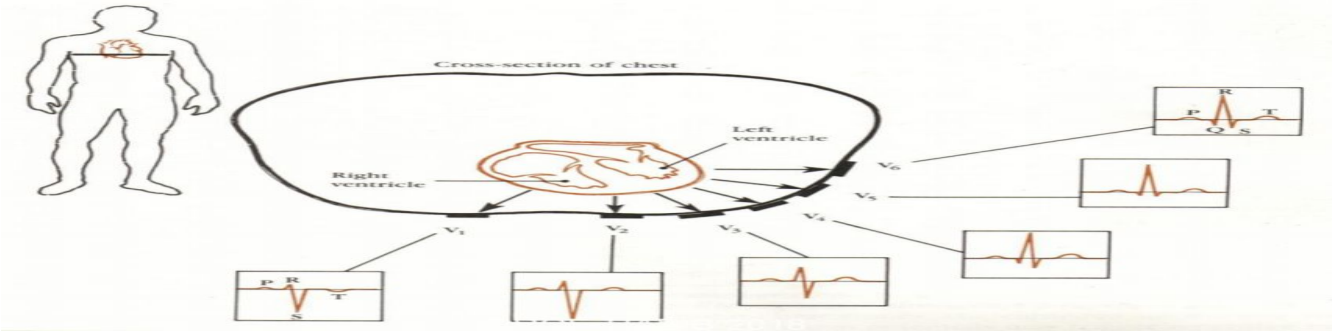
Electrical activity towards a recording electrode = +ve potential

Electrical activity away from a recording electrode = -ve potential

Positive electrode is placed on the chest (V1-6), while the negative is on the limbs (right arm, left arm and leg).

V1 and V2: QRS are mainly negative because the chest leads are nearer to the base of the heart (electronegative).

V3, V4 and V6 are mainly positive because the chest electrode are nearer to the apex (electropositive).



Normal ECG Recording

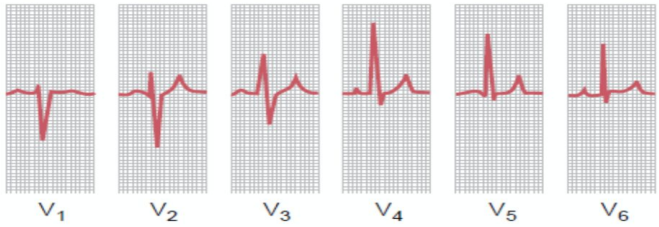


Figure 11–9

Normal electrocardiograms recorded from the six standard chest leads.

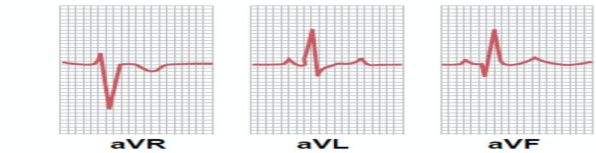


Figure 11–10

Normal electrocardiograms recorded from the three *augmented unipolar limb leads.*

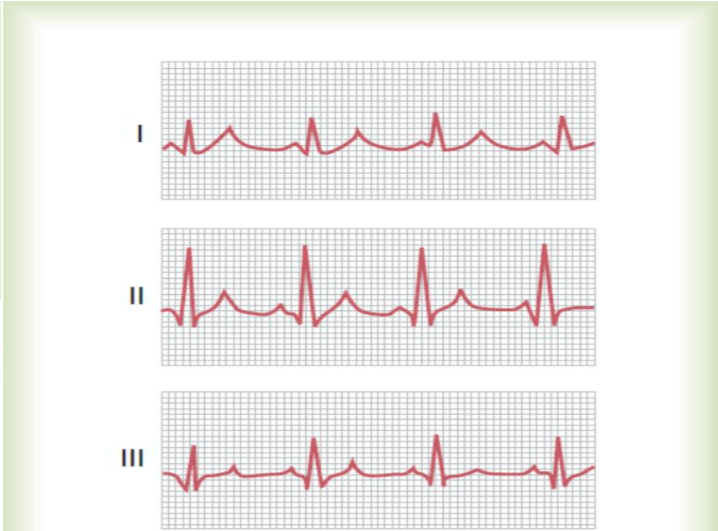
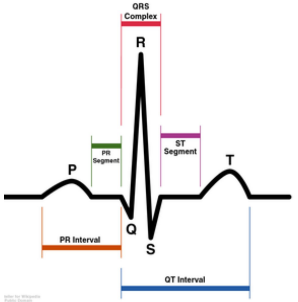


Figure 11–7

Normal electrocardiograms recorded from the three *standard* electrocardiographic leads.

Summary

- ECG definition : ECG is a graphical representation of the sum of all the electrical activities of the Heart usually recorded from the body surface.
- ECG has five different waveforms P,Q,R,S,T and they shape the structure of an ECG depending on how much time each one takes .



- There are two types of leads in ECG unipolar and bipolar
- In total there 12 leads each put in specific area and get signal from different areas of the heart respectively .
- Leads V1 to V6 are unipolar chest leads.
- lead aVR is put on the right arm, lead aVL is put on the left arm, lead aVF is put on the left foot and they are all unipolar.
- 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.

Septal	Anterior	Lateral	Inferior	Special
		aVL	aVF	aVR
V1	V3	I	II	
V2	V4	V5 V6	III	

Quiz

1\ PR interval represent :

A- Ventricular repolarization.

B- Ventricular depolarization.

C- Atrial depolarization.

D- Impulse from atria to ventricles.

2\ The normal P wave duration is :

A- 0.8 sec

B- 0.01 sec

C- 0.09 sec

D- 0.02 sec

3\ atrial repolarization occur at the same time with ventricular depolarization

A- true

B- false

4\ V4 lead is placed in :

A- 4th ICS midclavicular.

B- 5th ICS midclavicular.

C- between V3 and V5

D- None of the above

5\ the first part of the ventricles to become depolarized is the right endocardial surface of the septum.

A- true

B- false

5\ A
4\ B
3\ B
2\ C
1\ D

Thank you for checking our work

Team Leader:

العنود سلمان

Male Team:

أنس السويداء
أنس السيف
خالد شويل
ريان الموسى
سعد الهداب
سعود العطوي
سيف المشاري
عبدالجبار اليماني
عبدالرحمن آل دحيم
عمر الفوزان
فهد الحسين
نايف المطيري
نواف اللويمي
محمد الحسن
هشام الشايع
خالد العقيلي
سعد الفوزان
عبدالله الزيد
نواف اللويمي

Female Team:

الآء الصويّغ
رناد المقرن
رهف الشنيبر
روان التميمي
روان مشعل
ريم القرني
ليلى الصباغ
فلوة السعوي
نورة بن حسن
نورة الحربي
نورة العثيم
مجد البراك
لينا العوهلي
عهد القرين
مها النهدي
مها بركة
سارة الفليج
هند العريعر
ريناد الغريبي
عائشة الصباغ

Any questions?

Contact us at

- twitter:@physio437
- physiologyteam437@gmail.com