Cardiovascular System Block

The Electrocardiogram

(ECG)

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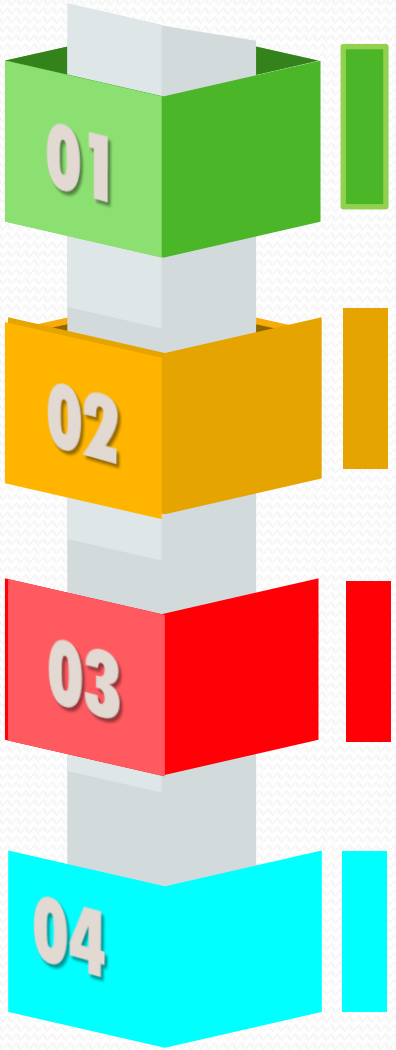
Lecture Objectives



01 **Identify waves, intervals & segments of the normal ECG trace and the physiological cause of each wave**

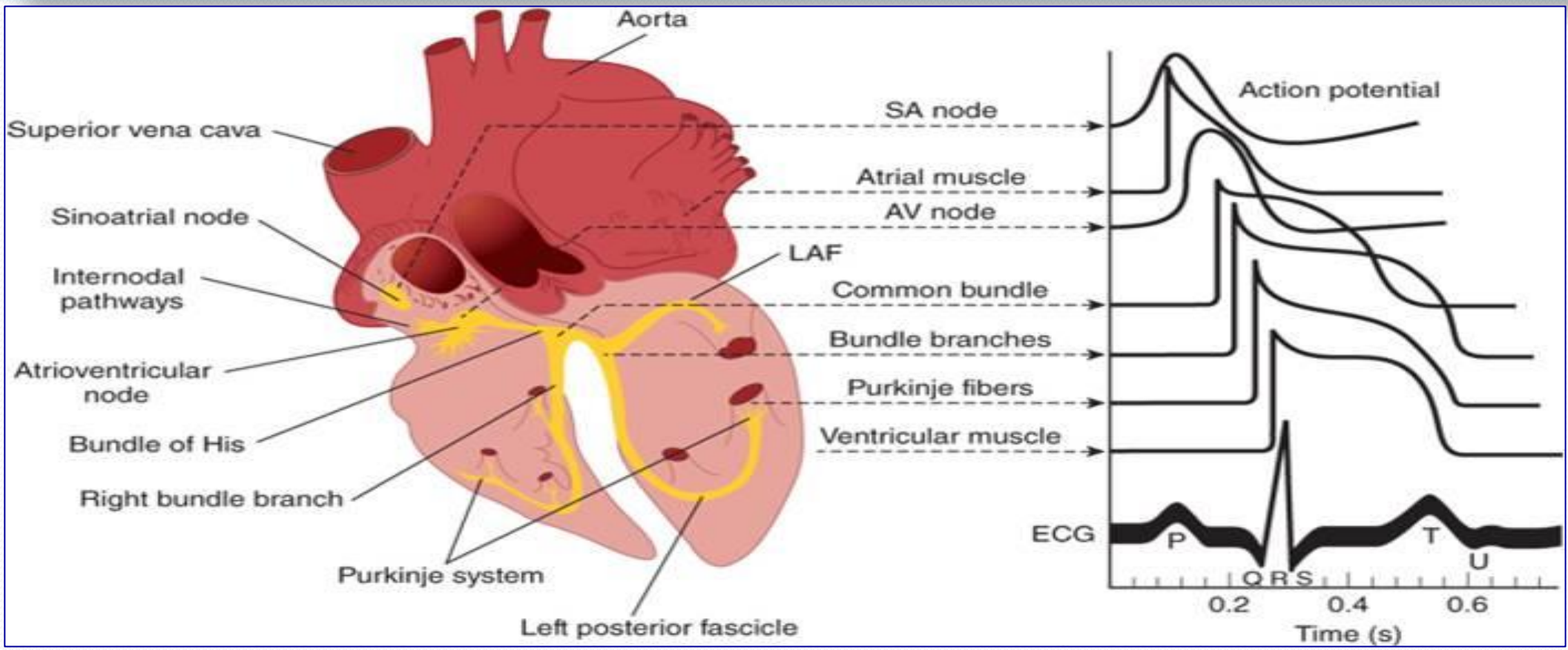
02 **Determine the bipolar, unipolar and chest leads**

03 **Know what is Einthoven's triangle and Einthoven's law**

04 **Describe the practical use of the ECG**

The Electrocardiogram (ECG)

It is the record of the algebraic sum of electrical activity i.e. action potentials generated by the heart during cardiac cycle

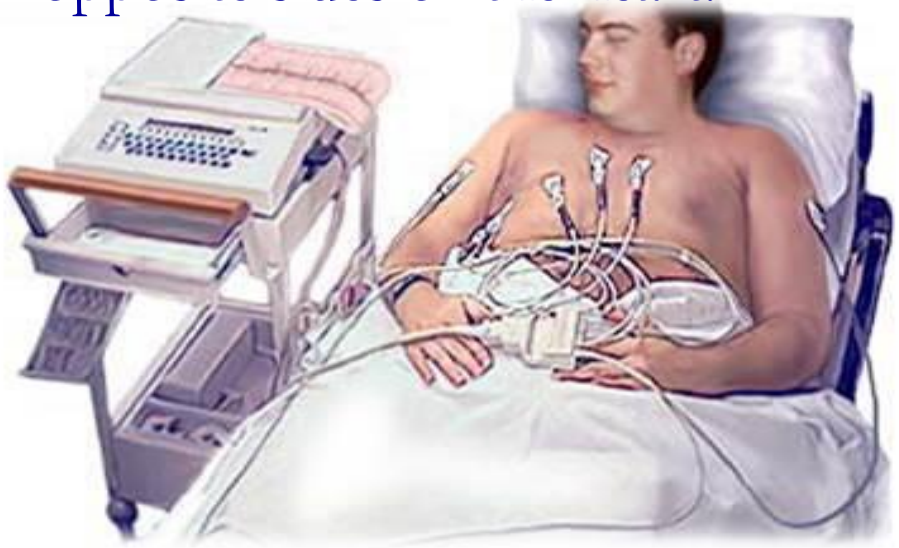


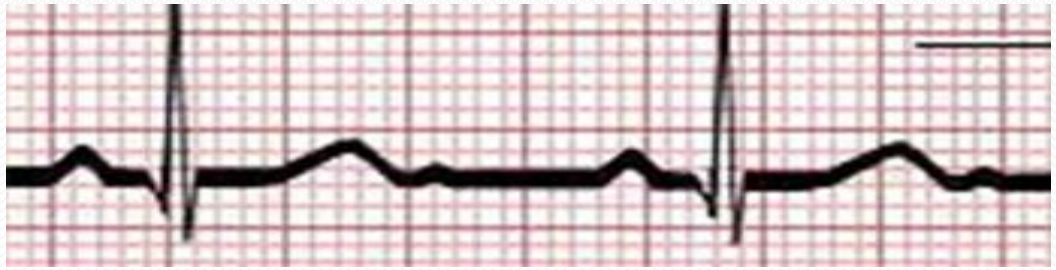
The Principle of ECG

- 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 surface electrodes.
- The record is the ECG.

How ECG can be recorded?

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





ECG tracing

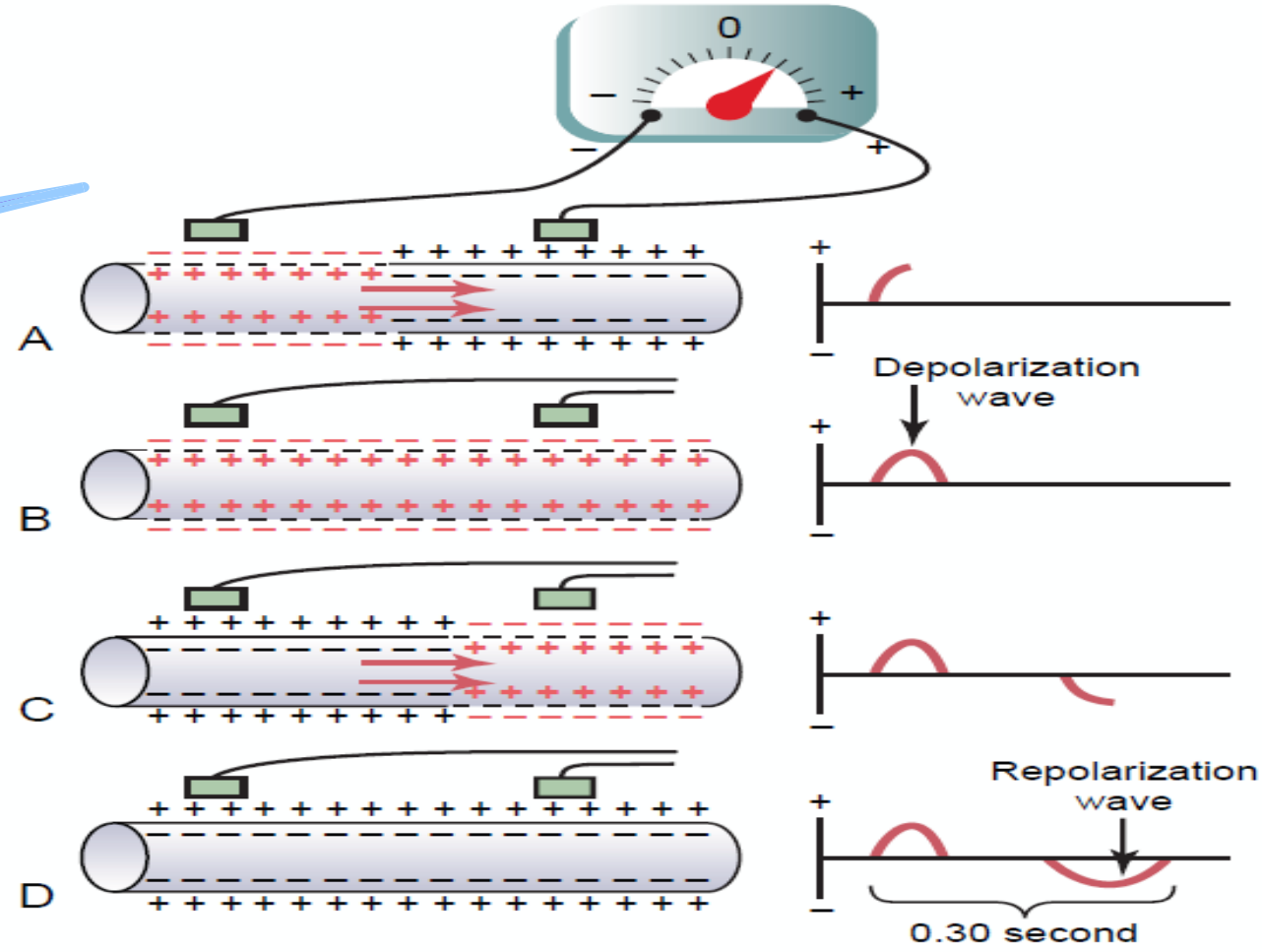
The Principle of ECG…Cont.

Depolarization, is traveling from left to right

Depolarization completed

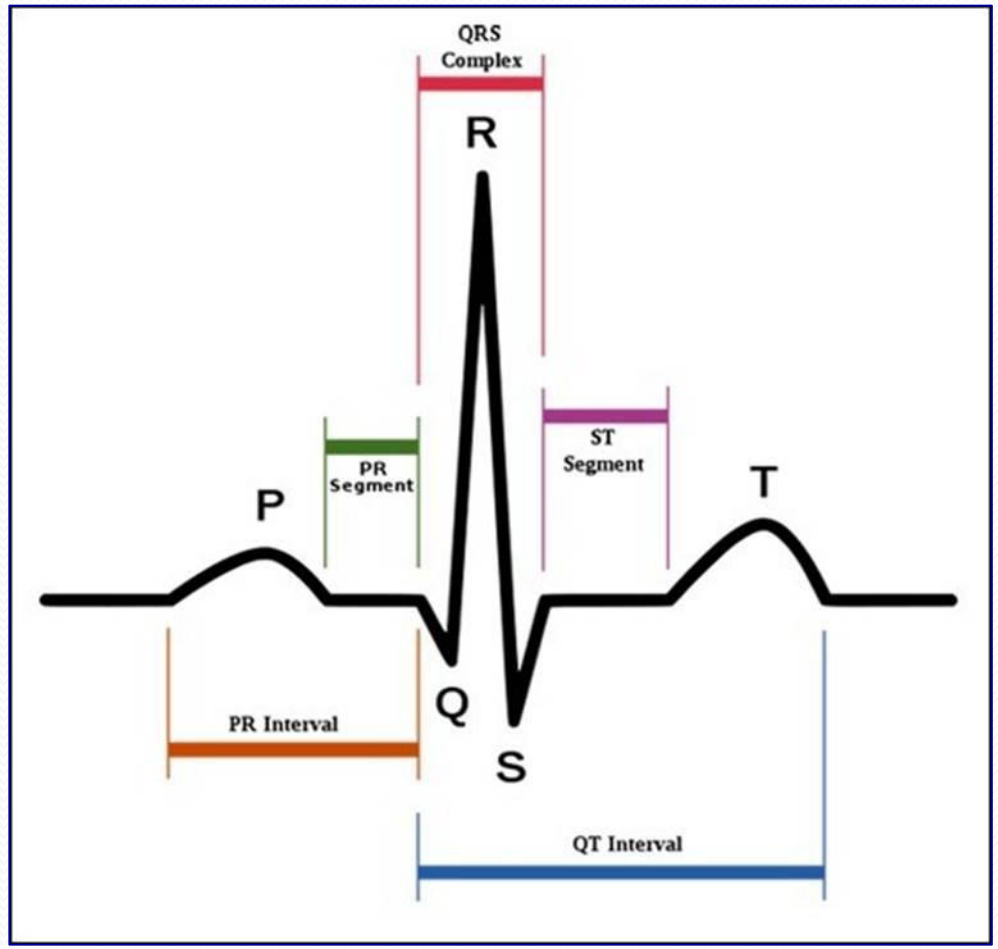
Repolarization, is traveling from left to right

Repolarization completed

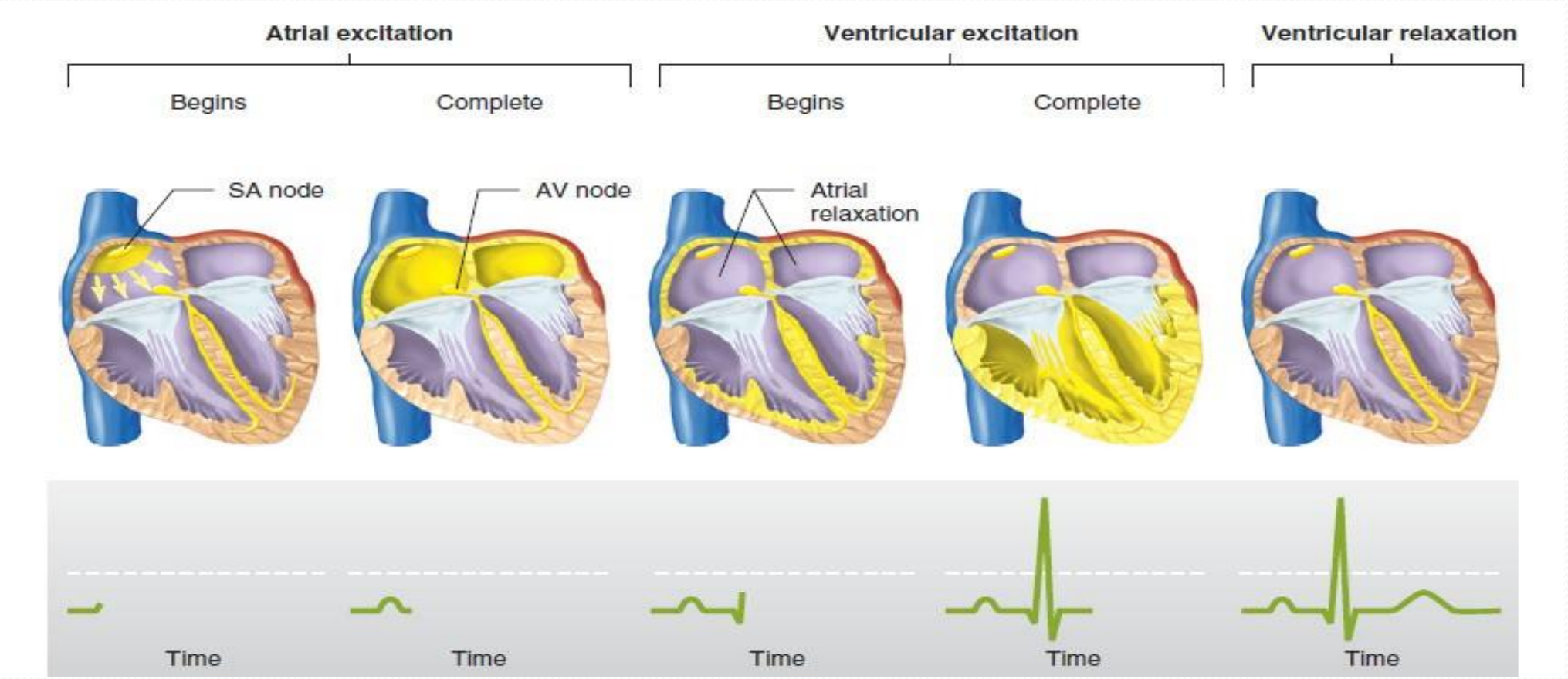


ECG Waveforms, Intervals & Segments

- **3 waves: (deflections)**
  - P- wave
  - QRS complex
  - T- wave
    - P, R & T- waves are positive
    - Q & S- waves are negative
- **3 time intervals: (include waves)**
  - PR interval
  - QT interval
  - RR interval
- **3 segments: (isoelectric, & doesn't include waves)**
  - ST segment
  - TP segment
  - PR segment



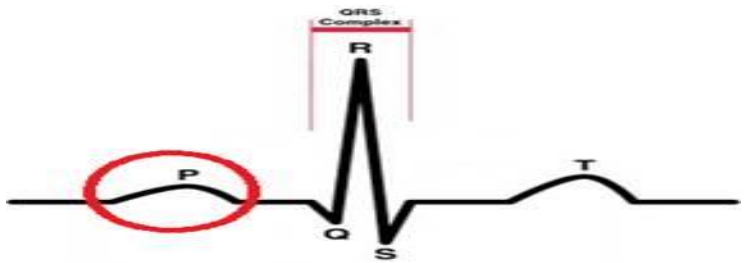
Sequence Of Cardiac Excitation



Anatomical Position of Electrical Activity with Corresponding ECG

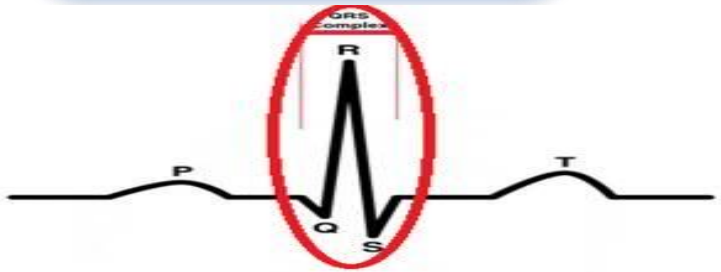
Analysis of Normal ECG

P-wave



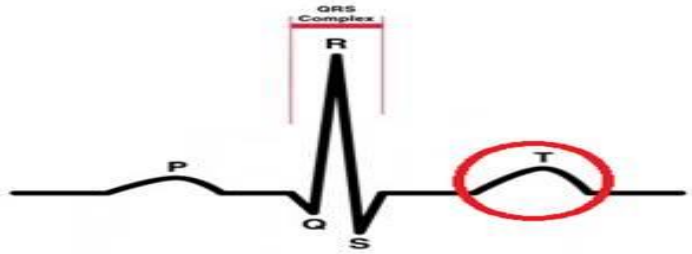
- Due to ***atrial depolarization***
- **P-wave** is recorded before the onset of atrial systole
- Atrial repolarization occurs at the same time with ventricular depolarization. But, since ventricular depolarization wave is giant, it masks the atrial repolarization wave

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

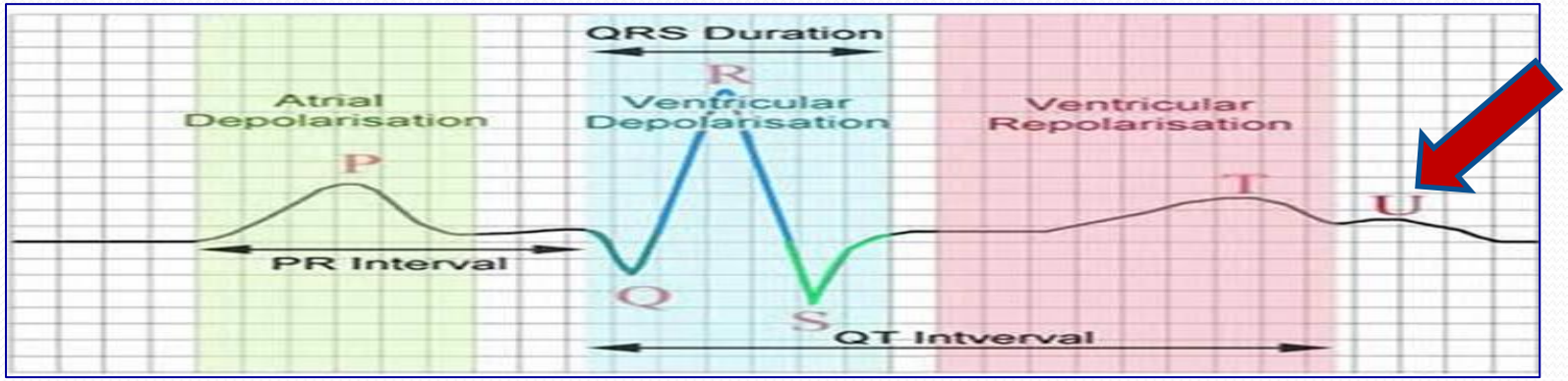
T-wave



- Due to ***ventricular repolarization***
- **T-wave** is recorded before the onset of ventricular diastole

U-WAVE

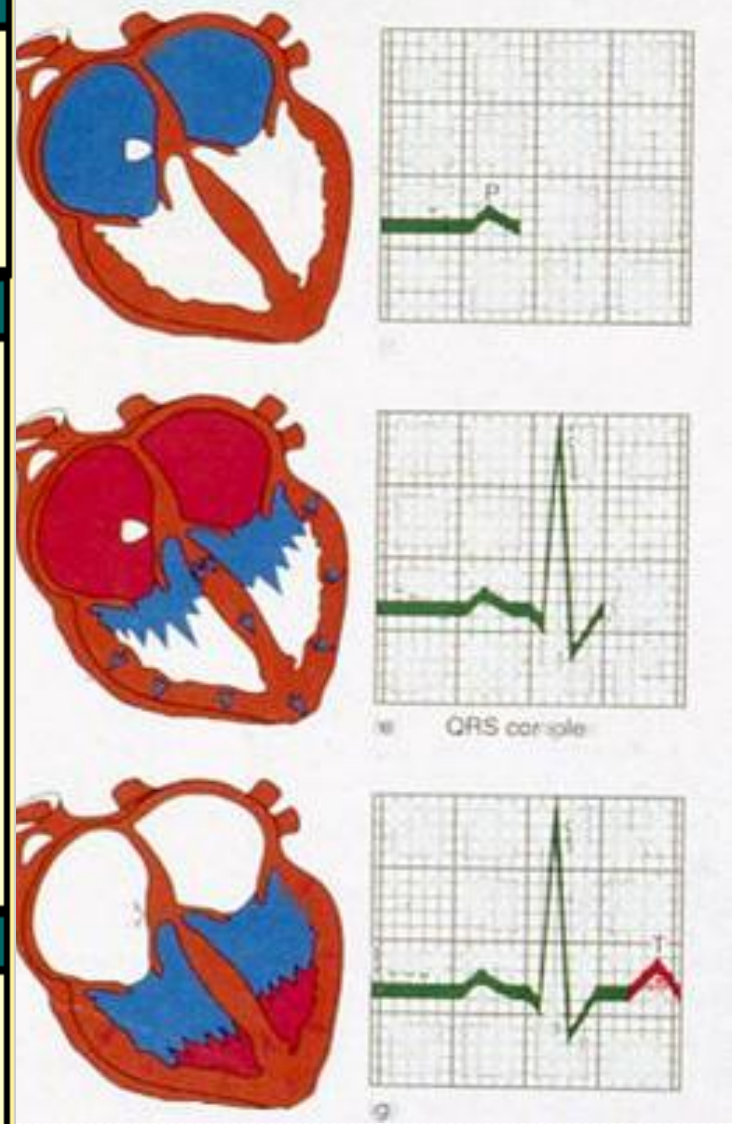
- The U wave is a wave on an ECG that is not always seen.
- It is typically small, round, symmetrical and positive in lead II.
- It follows and is the same direction as T wave.
- U waves are thought to represent repolarization of the papillary muscles or Purkinje fibers



- 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

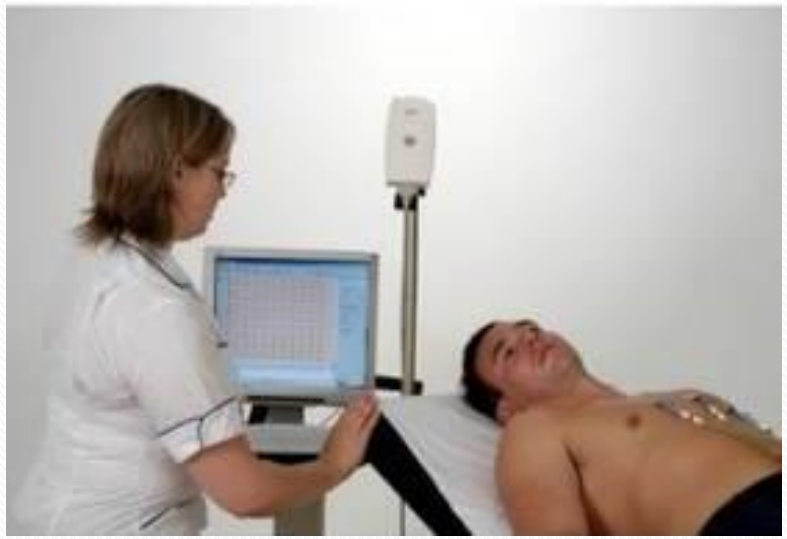
Summary: ECG Waves & Causes

ECG Wave	Cause	Represent
P- wave	Atrial depolarization	◆ Time of electrical impulse from SA node to spread through atrial muscle ◆ Precedes atrial contraction by ≈ 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 ◆ 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



Modern ECG Machines for Recording ECG

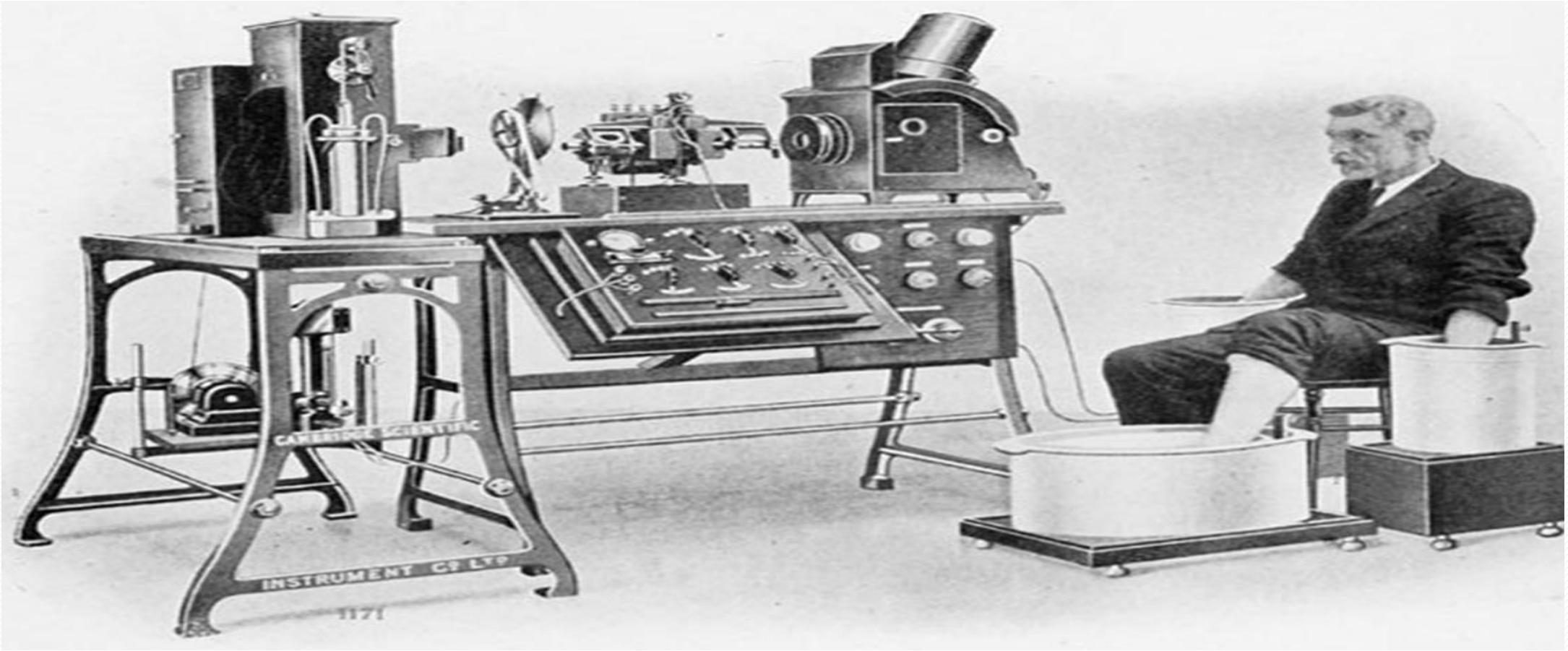
Computer-based and electronic display



Pen recorder and a moving sheet

Einthoven's Original Machine

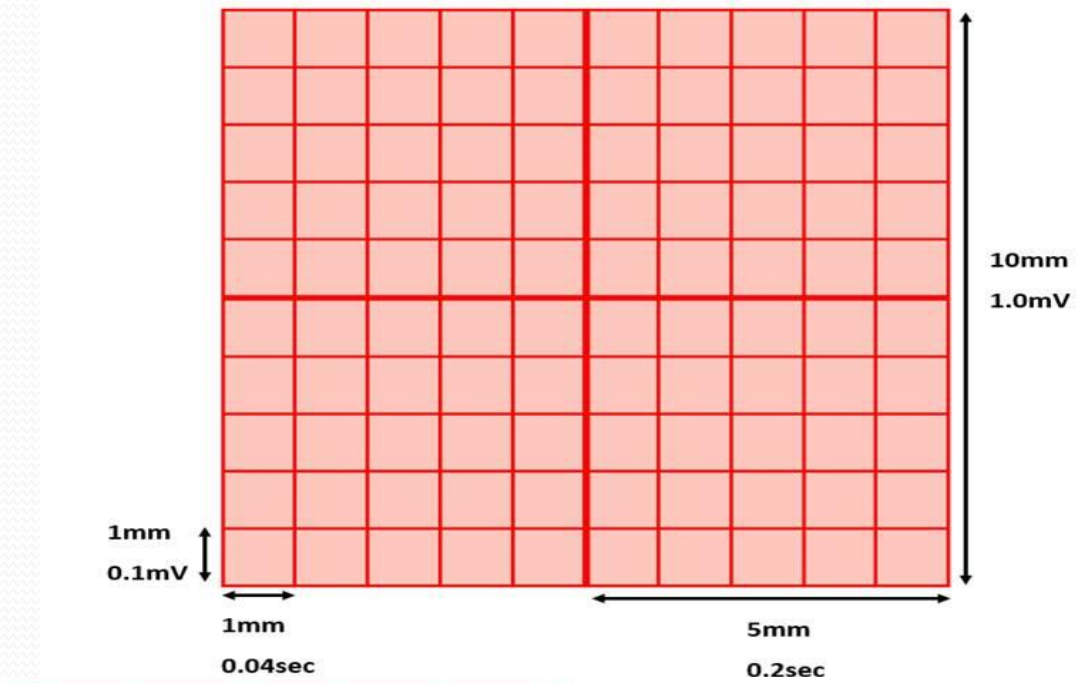
It weighed 500 pounds and needed five operators

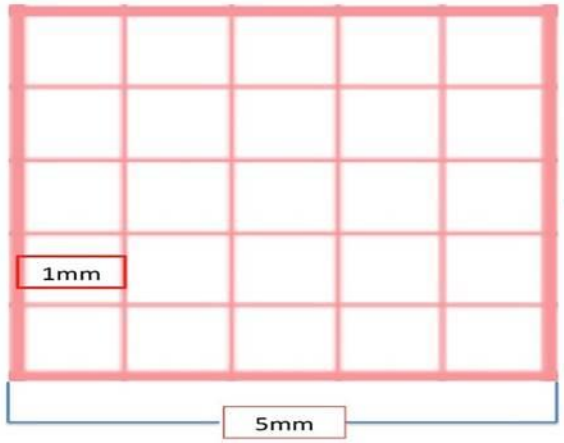


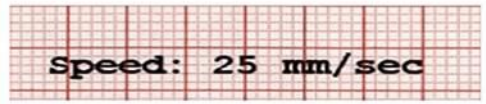
Photograph of a complete electrocardiograph, showing the manner in which the electrodes are attached to the patients, in this case the hands and one foot being immersed in jars or salt solution

ECG Paper Calibration: Voltage and Time

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

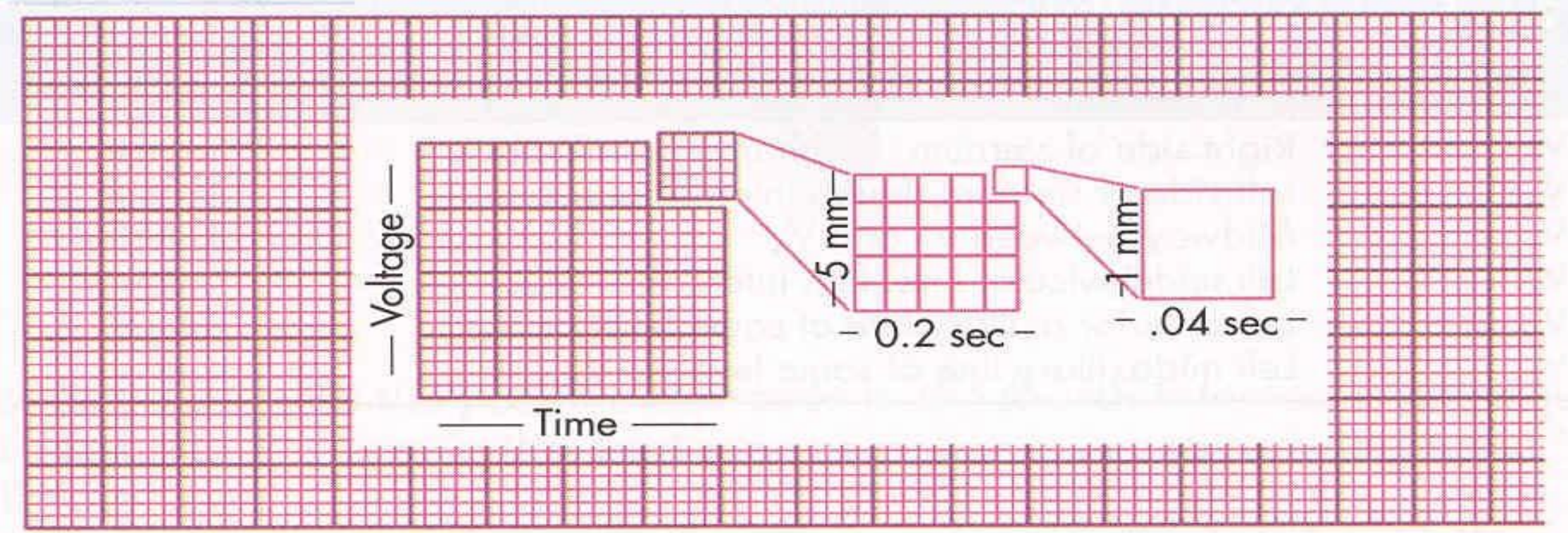






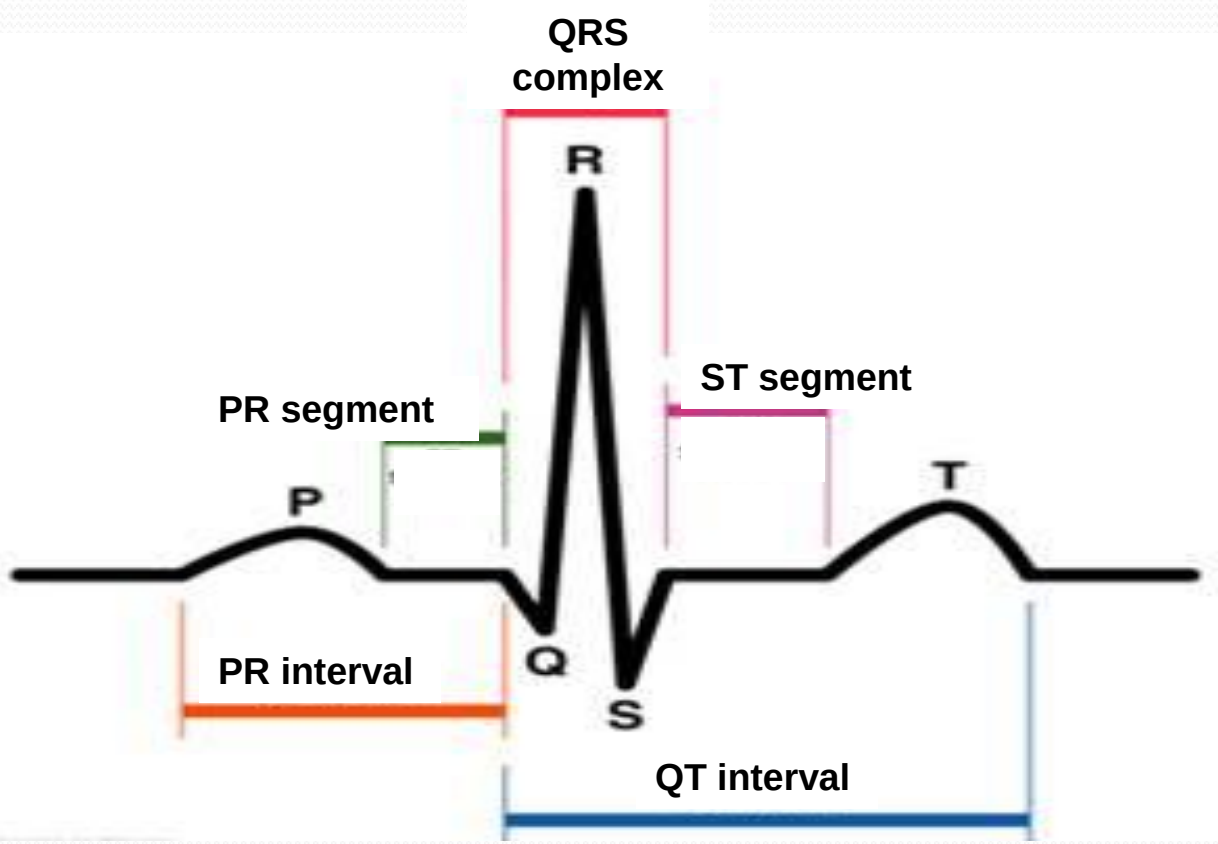
- 25mm = 1 second
- 5mm = 0.2 sec or 200msec
- 1mm = 0.04sec or 40msec

ECG Paper Calibration: Voltage and Time



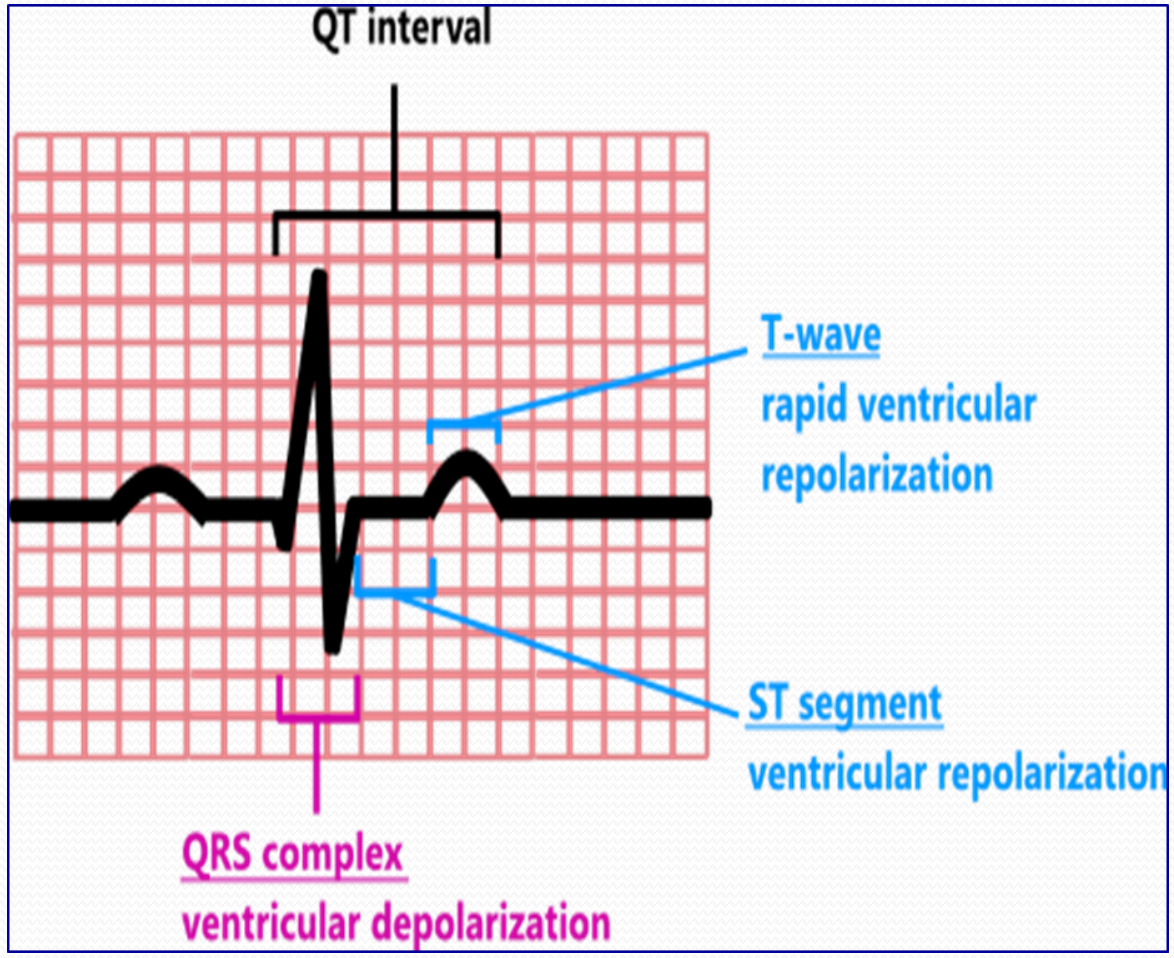
PR interval

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



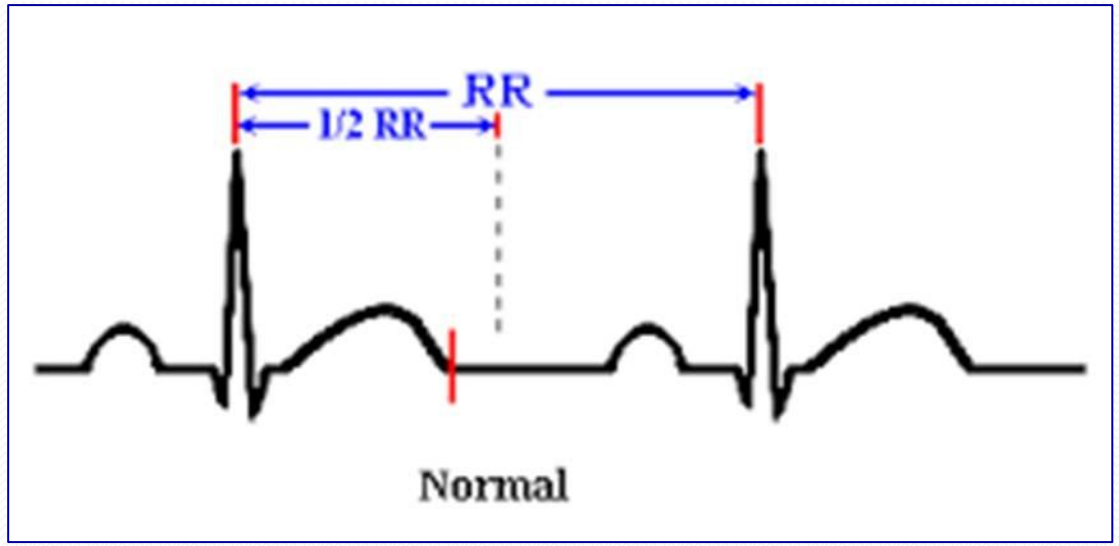
QT interval

- QT 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 QT interval includes the QRS complex, ST segment & T- wave.
- QT interval range = 0.35 – 0.45 sec.
- Approximate refractory period of ventricle.



RR 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.

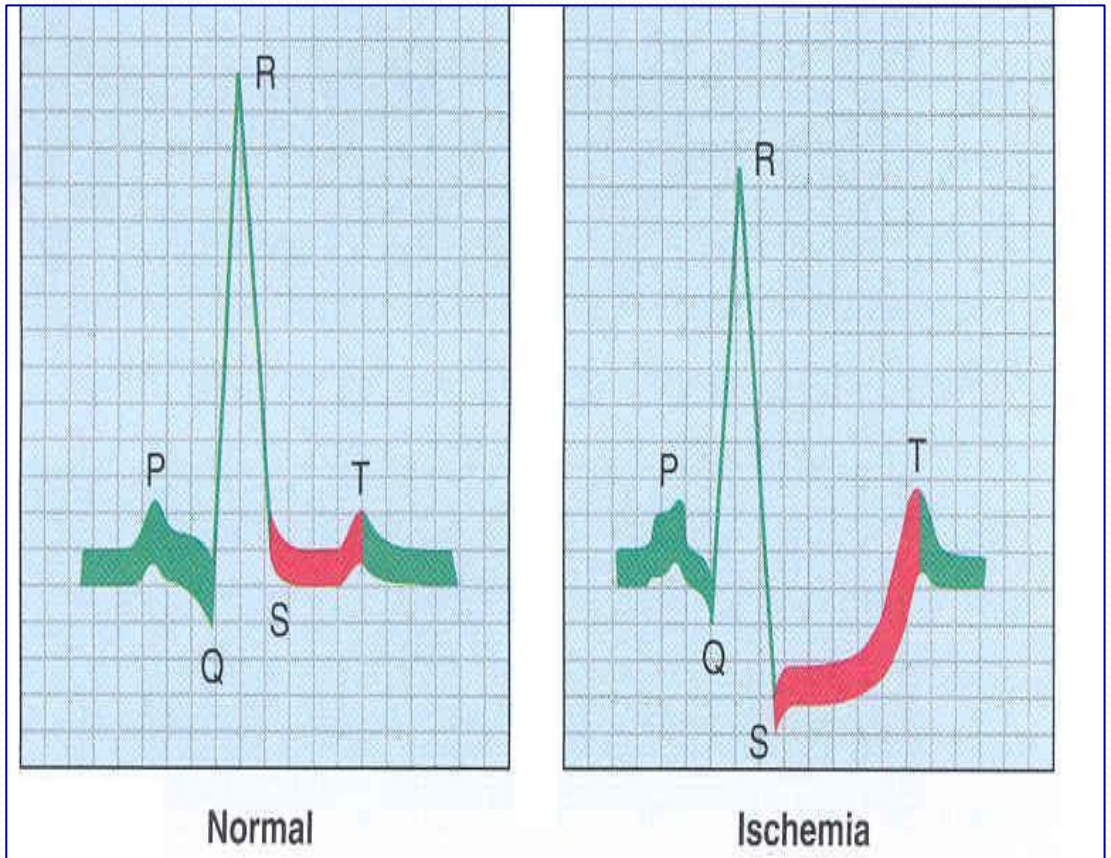


How to calculate HR from ECG

$$\text{Heart Rate} = \frac{300}{\text{No. large squares between two QRS complexes}}$$

ST segment

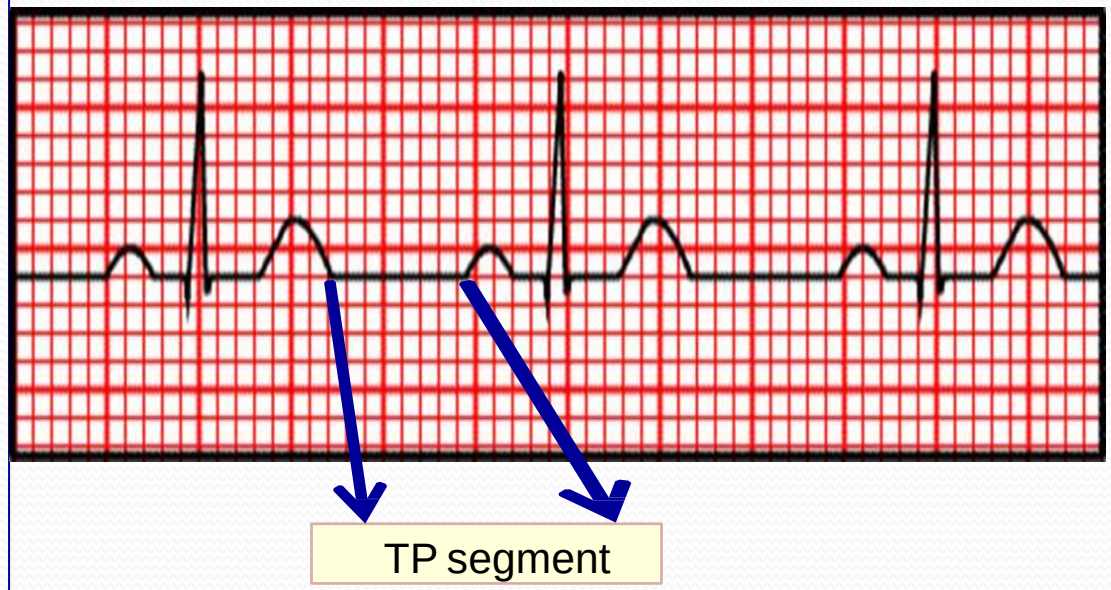
- It is segment of ECG from end of S wave to beginning of T wave.
- During this segment all ventricular muscles are completely depolarized, i.e. no potential difference between areas of myocardium at this stage.
- It roughly corresponds to the plateau phase of the ventricular action potential
- A normal ST segment is on isoelectric line.
- If it is deviated up or down, it indicates diseased fibers.
- The criteria for a ST elevation myocardial infarction (STEMI) is ST segment elevation and inverted T wave in two or more contiguous leads



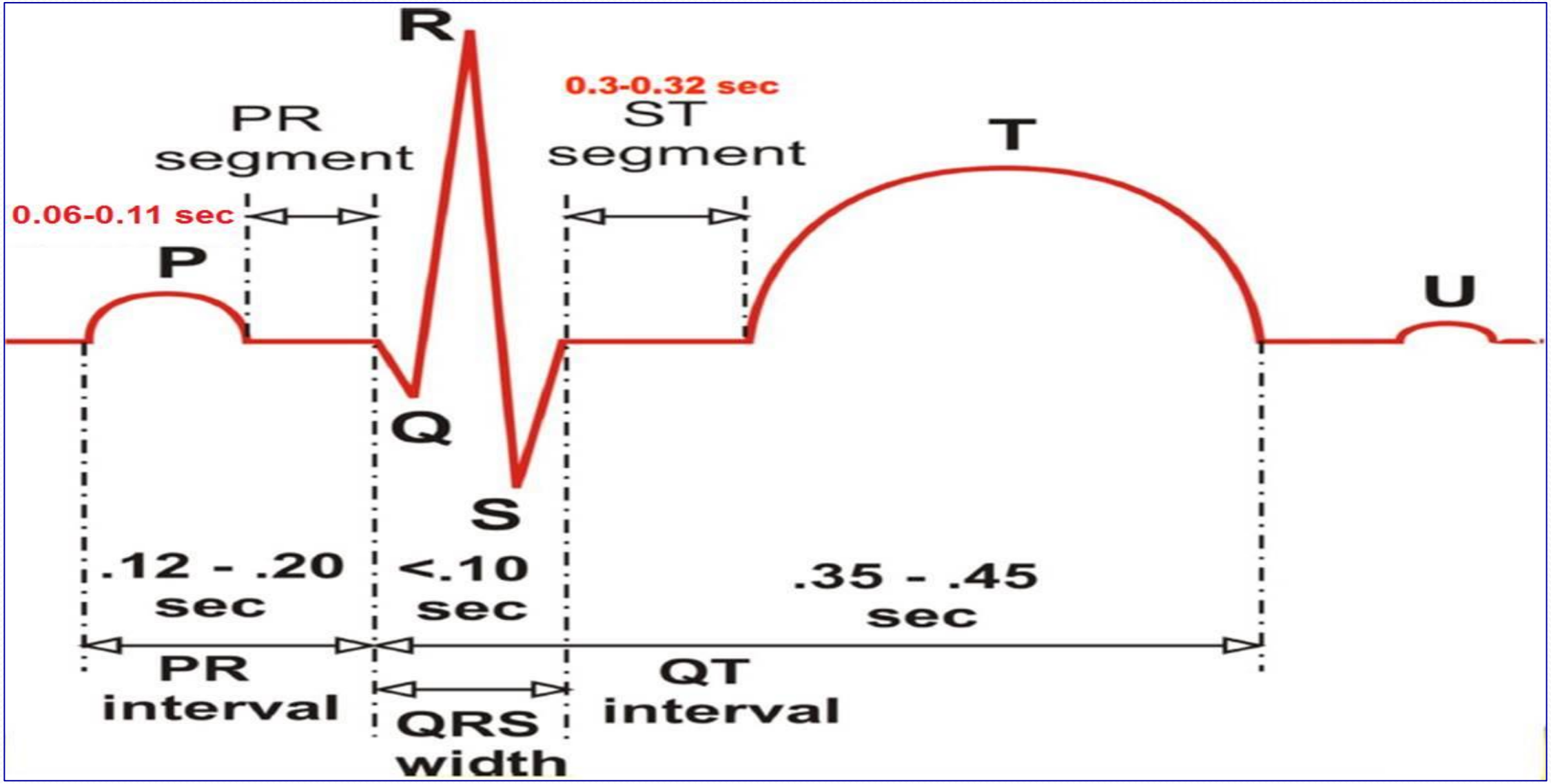
Depression of the S-T segment as a result of myocardial ischemia

TP 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



Summary: Duration of ECG Waves & Intervals



Summary: Duration of ECG Waves & Intervals

Intervals	Normal Durations		Events in the Heart during Interval
	Average	Range	
PR interval★	0.18★	0.12–0.20	Atrioventricular conduction
QRS duration	0.08	to 0.10	Ventricular depolarization
QT interval	0.40★	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 arte of 130 beats/min.

★ Can be lower (0.35) depending on heart rate.

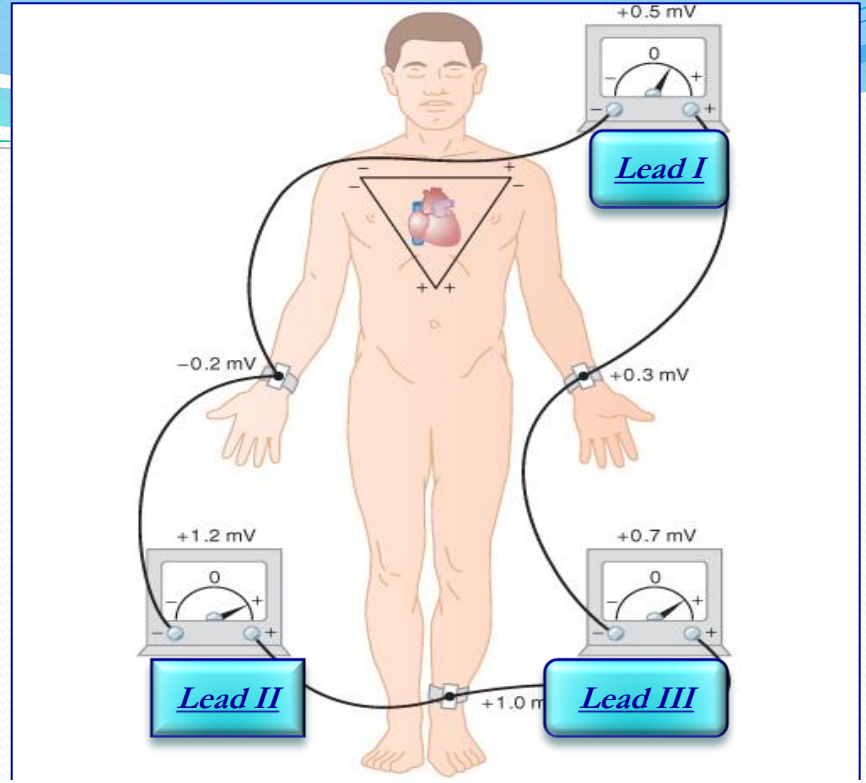
The ECG Leads

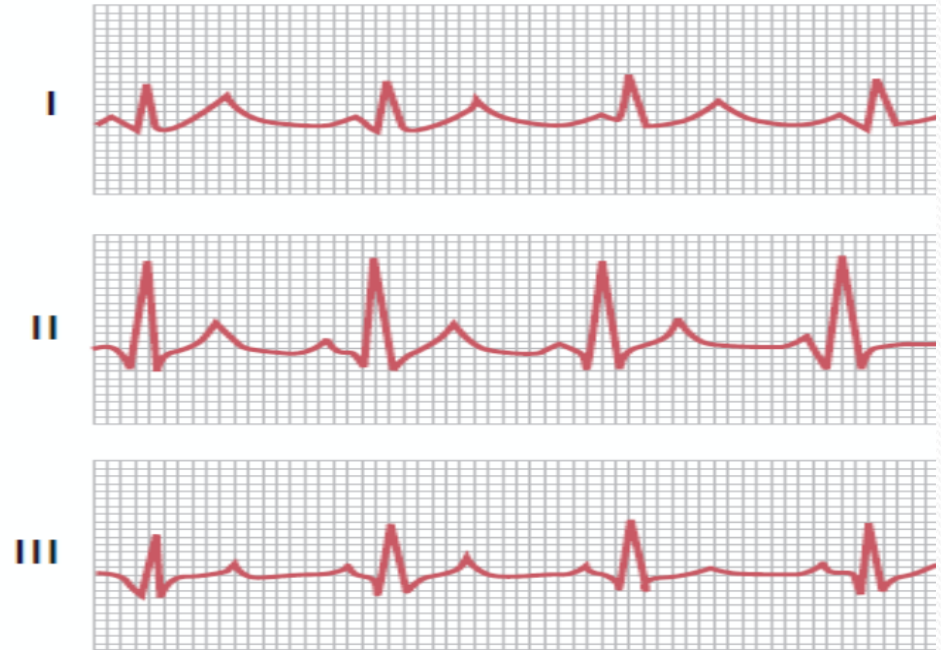
- An ECG lead is a pair of electrodes and their wires to make a complete circuit. They are applied to particular parts of the body.
- ECG leads are 12 leads:-
  - The Bipolar Limb Leads: (I, II, III)
  - Augmented Unipolar Limb Leads (aVR, aVL, aVF)
  - Chest Leads: (V1, V2, V3, V4, V5, V6)

The Bipolar (Standard) Limb Leads

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

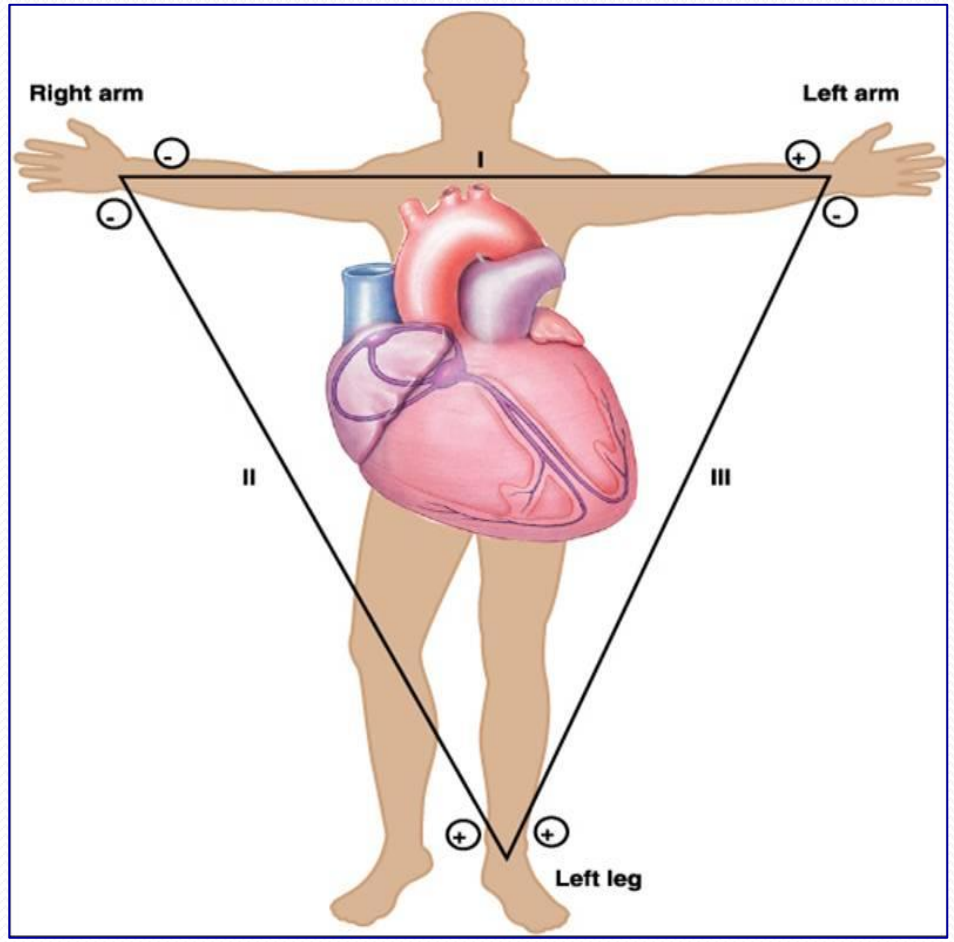
- ***Lead I:***
  - *Connects right arm (-ve) & left arm (+ve)*
- ***Lead II:***
  - *Connects right arm (-ve) & left leg (+ve)*
- ***Lead III:***
  - *Connects left arm (-ve) & left leg (+ve)*





Einthoven's Triangle

- The standard limb leads can be represented by Einthoven triangle. The heart is considered to lie in center.
- The two apices at the upper part of the triangle represent the points at which the two arms connect electrically
- The lower apex is the point at which the left leg connects

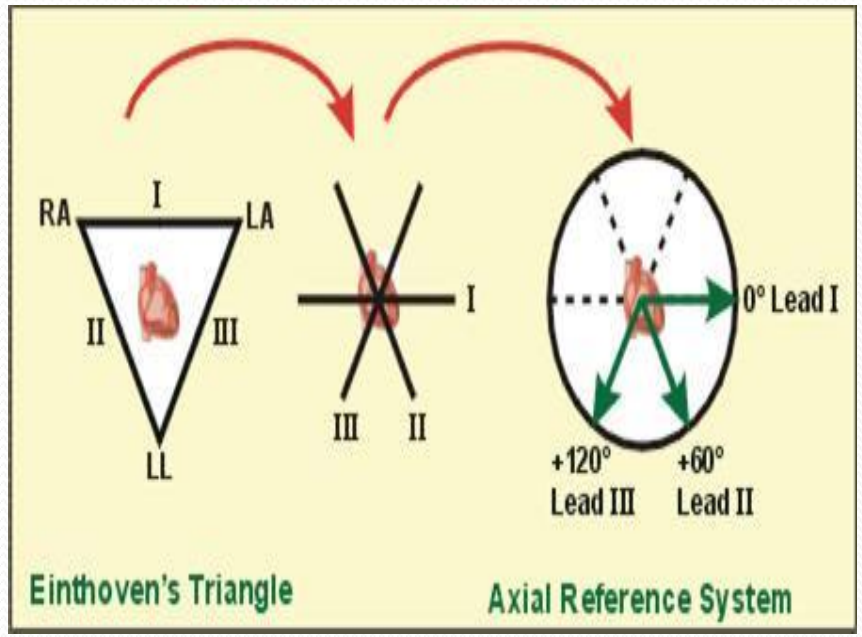


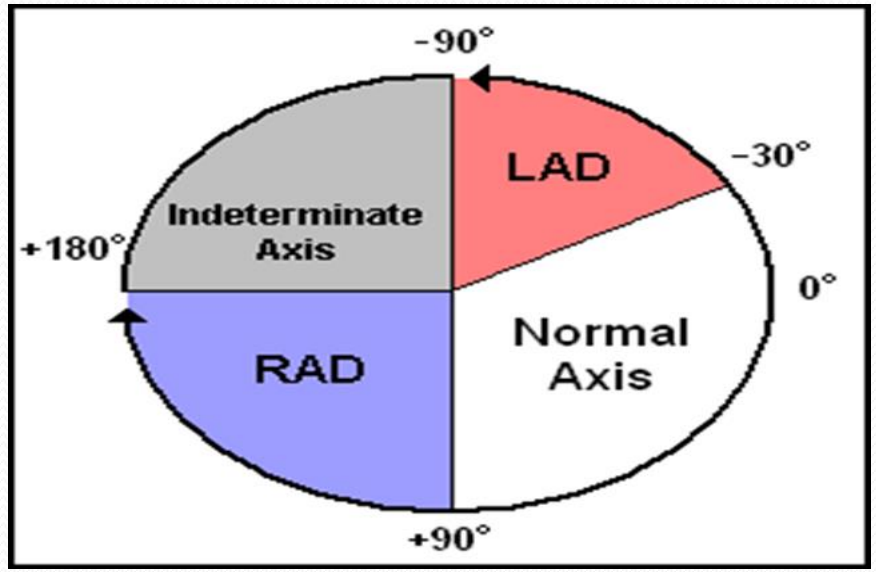
Einthoven's Law

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.

Hexagonal reference system

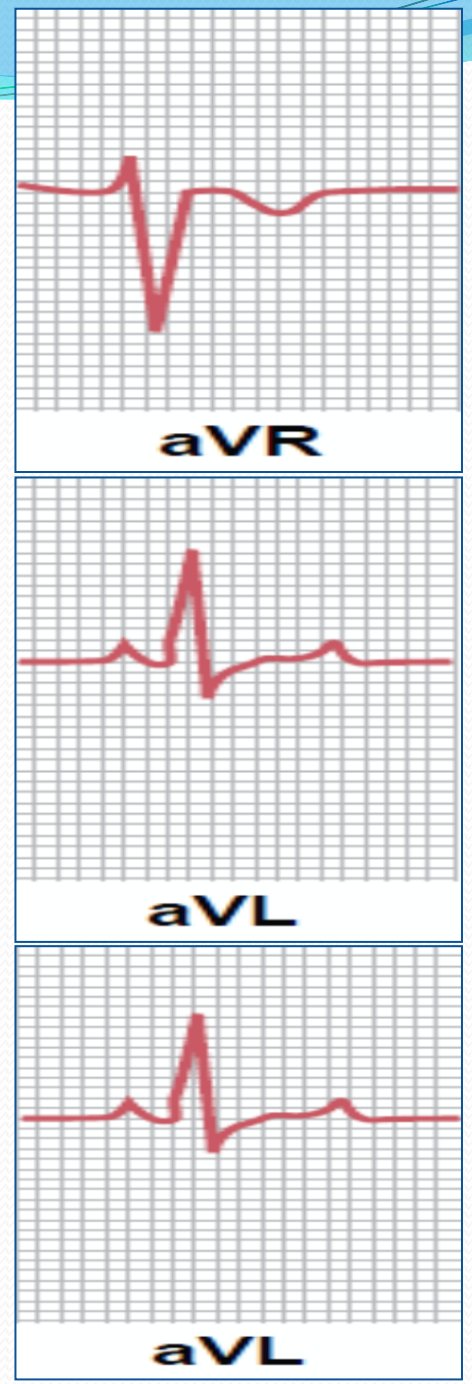
- The direction of axis of 3 standard limb leads can be represented by 3 intersecting lines:-
  - The axis of lead I is 0 degree
  - The axis of lead II is 60 degree
  - The axis of lead III is 120 degree.





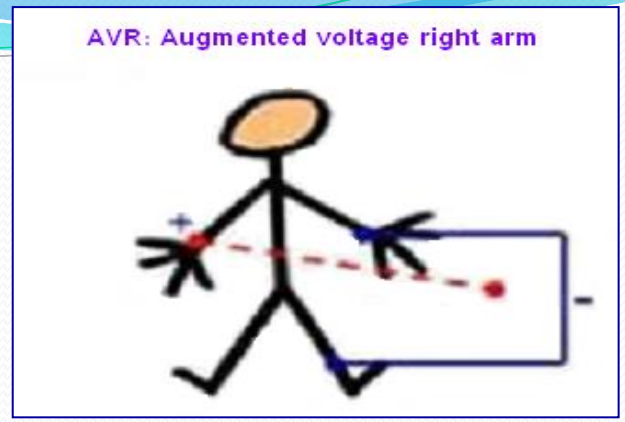
Augmented Unipolar Leads

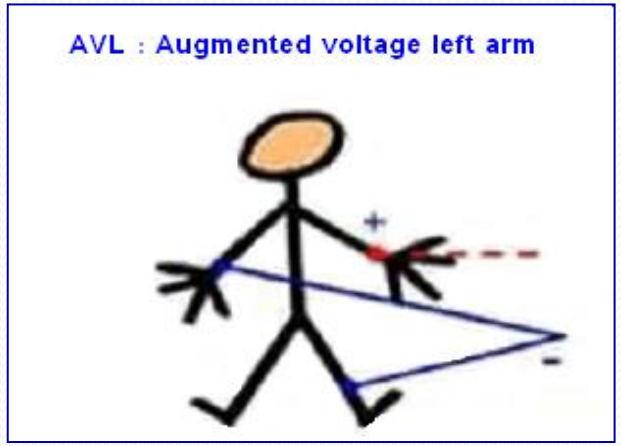
- ECG record is by using an active or exploring electrode a virtual reference point connected to an indifferent electrode at zero electrical potential.
- One limb is connected to the positive terminal of the ECG.
- The other two limbs are connected to the negative terminal of the ECG.
- These are aVR, aVL, aVF
- All are similar to the standard limb leads
- aVR lead is inverted

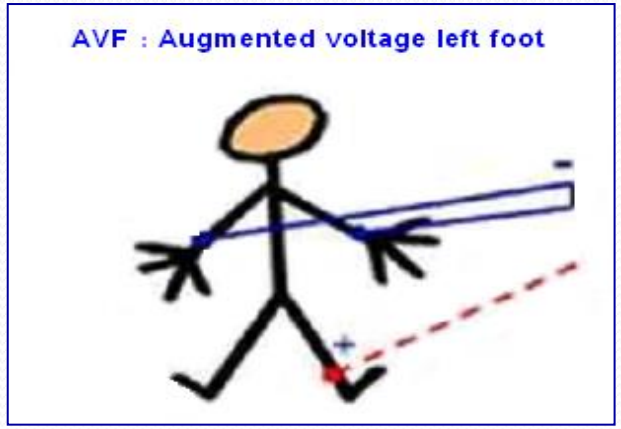


Augmented Unipolar Leads…..Cont.

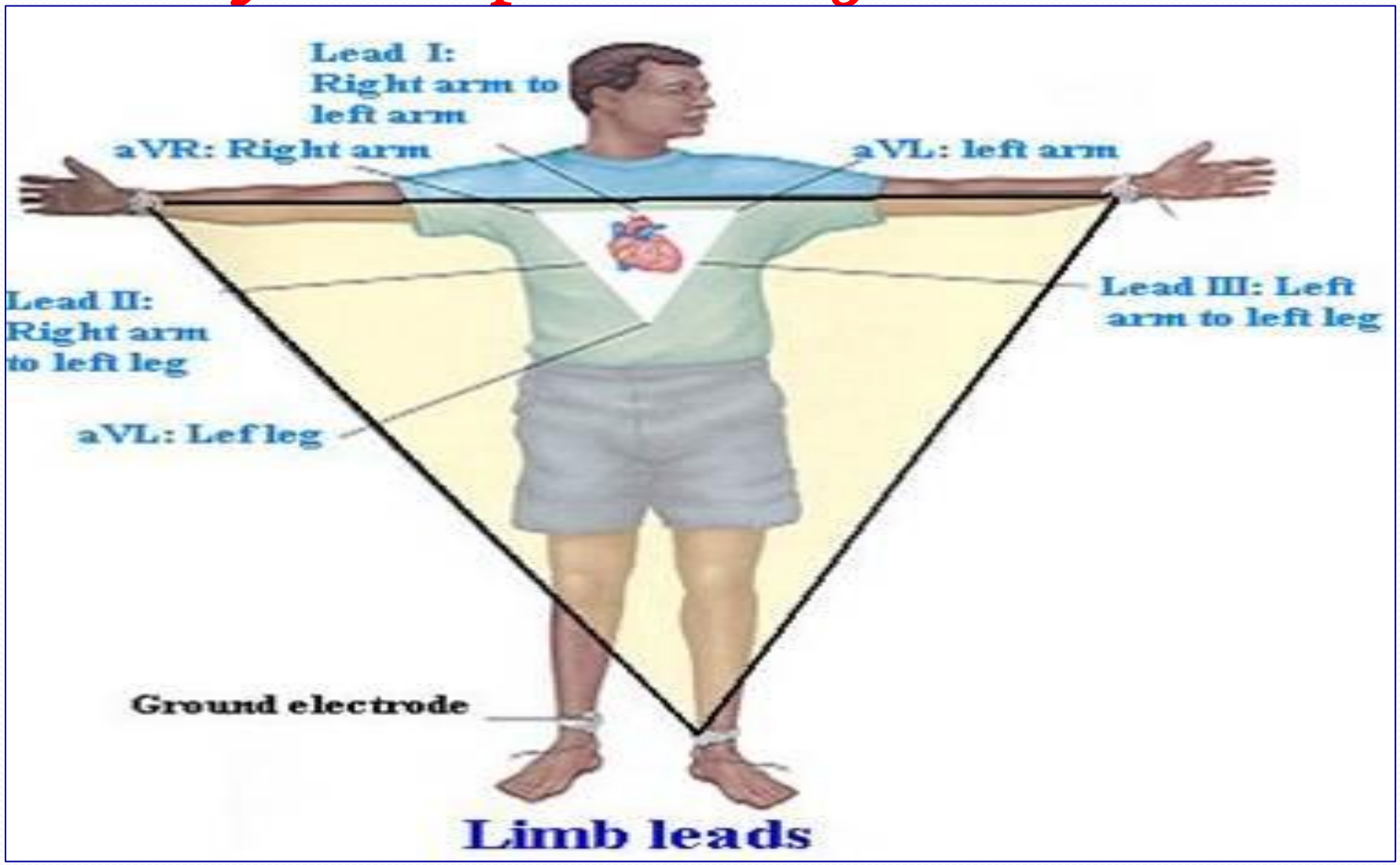
- They labeled according to limb to which the exploring (positive) terminal of machine is connected.
- When the positive terminal is connected to ***right arm*** and other electrode is connected to other 2 limbs = **aVR**.
- When the positive terminal is connected to ***left arm*** and other electrode 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.





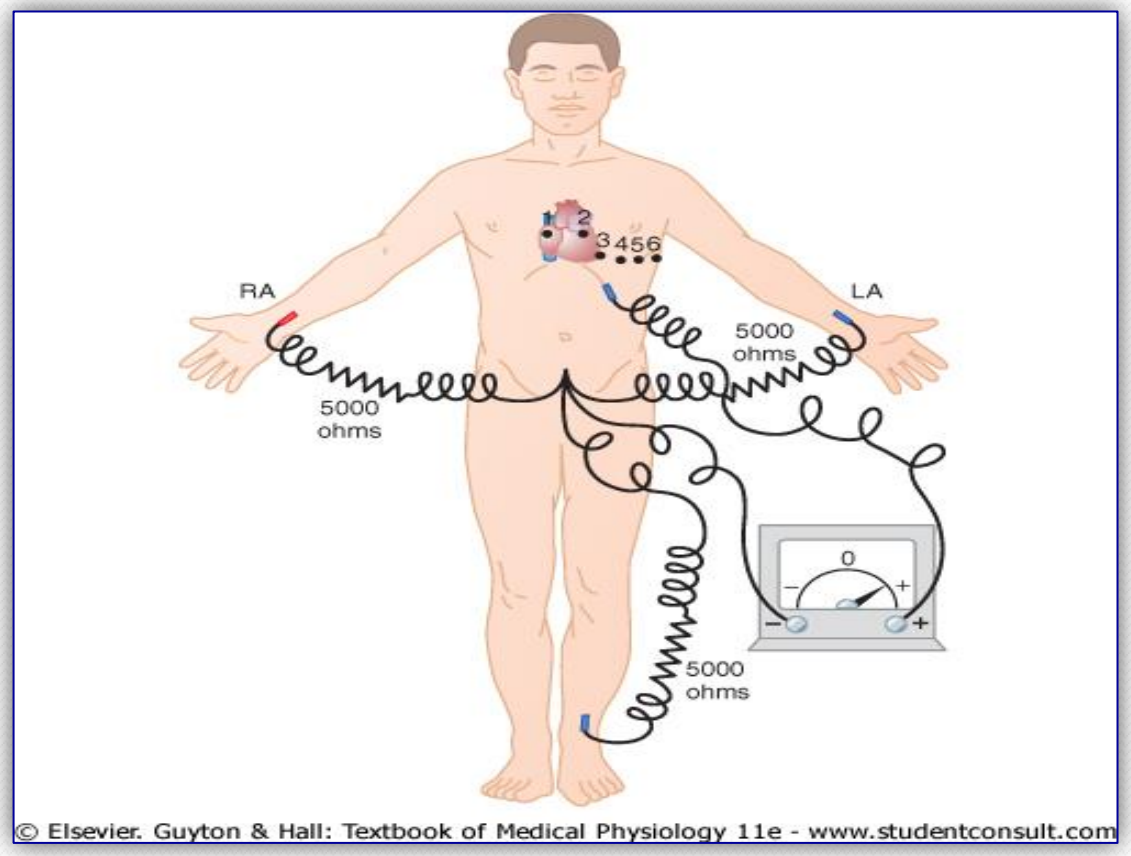


Summary : The Bipolar & Augmented limb Leads



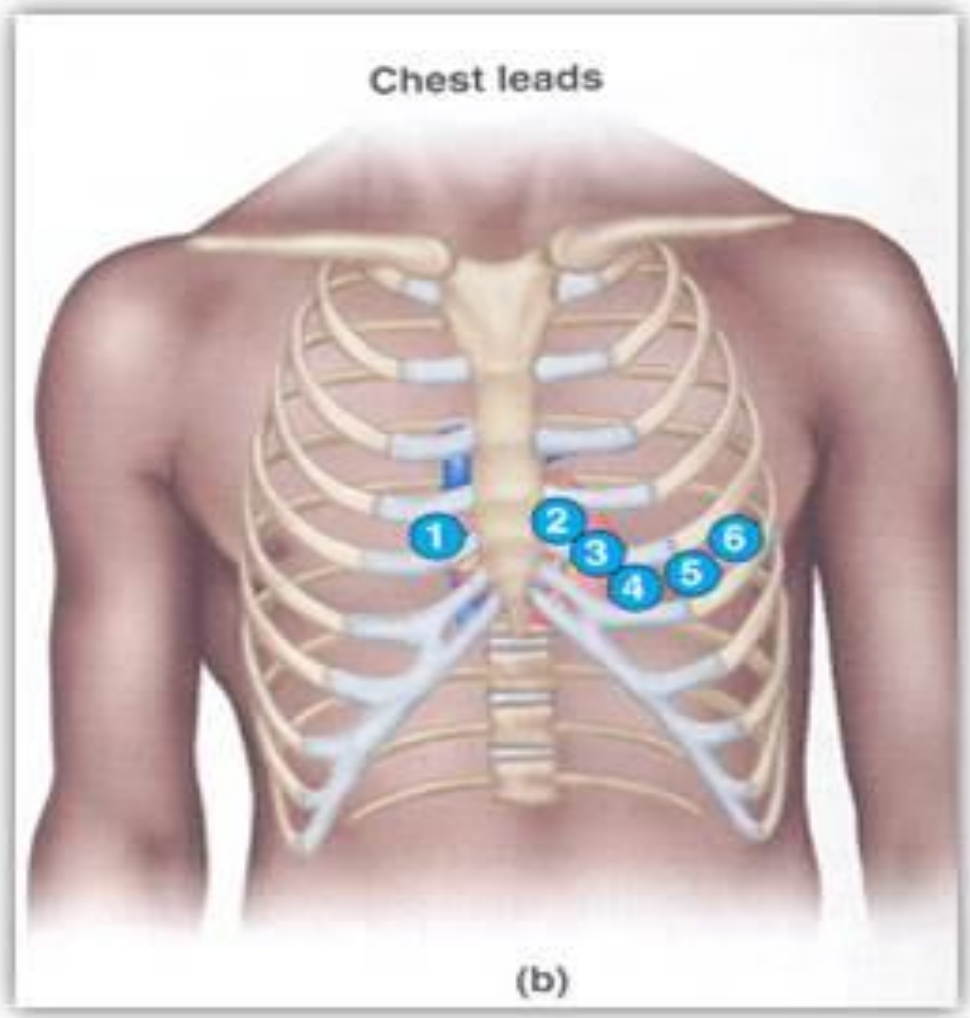
Chest Leads

- 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 I-6.



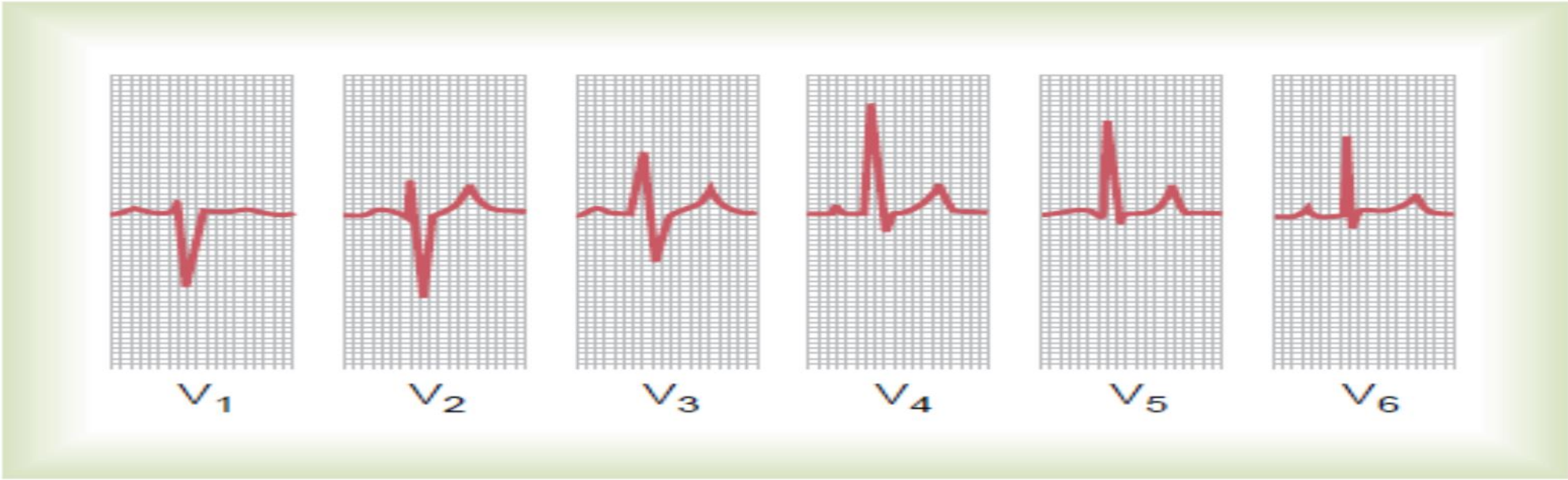
Chest Leads….Cont.

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



Chest Leads…..Cont.

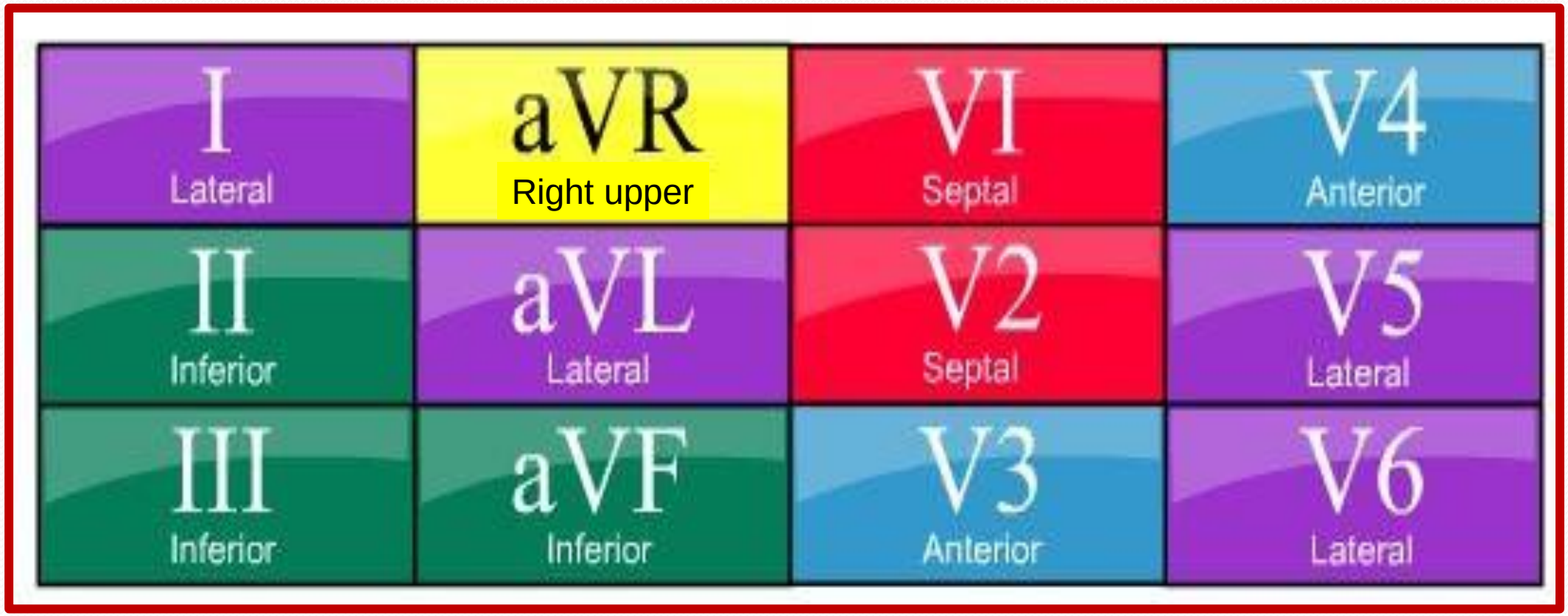
- **V1 & V2:** QRS are mainly negative because the chest leads are nearer to the base of the heart (electronegative).
- **V3, V4, V5 & V6** are mainly positive because the chest electrode are nearer to the apex (electropositive).



Summary of ECG Leads

	Limb Leads	Precordial Leads
Bipolar leads	I, II, III (standard limb leads)	-
Unipolar leads	aVR, aVL, aVF (augmented limb leads)	V_1-V_6

Anatomical relations of leads in a standard 12 lead ECG

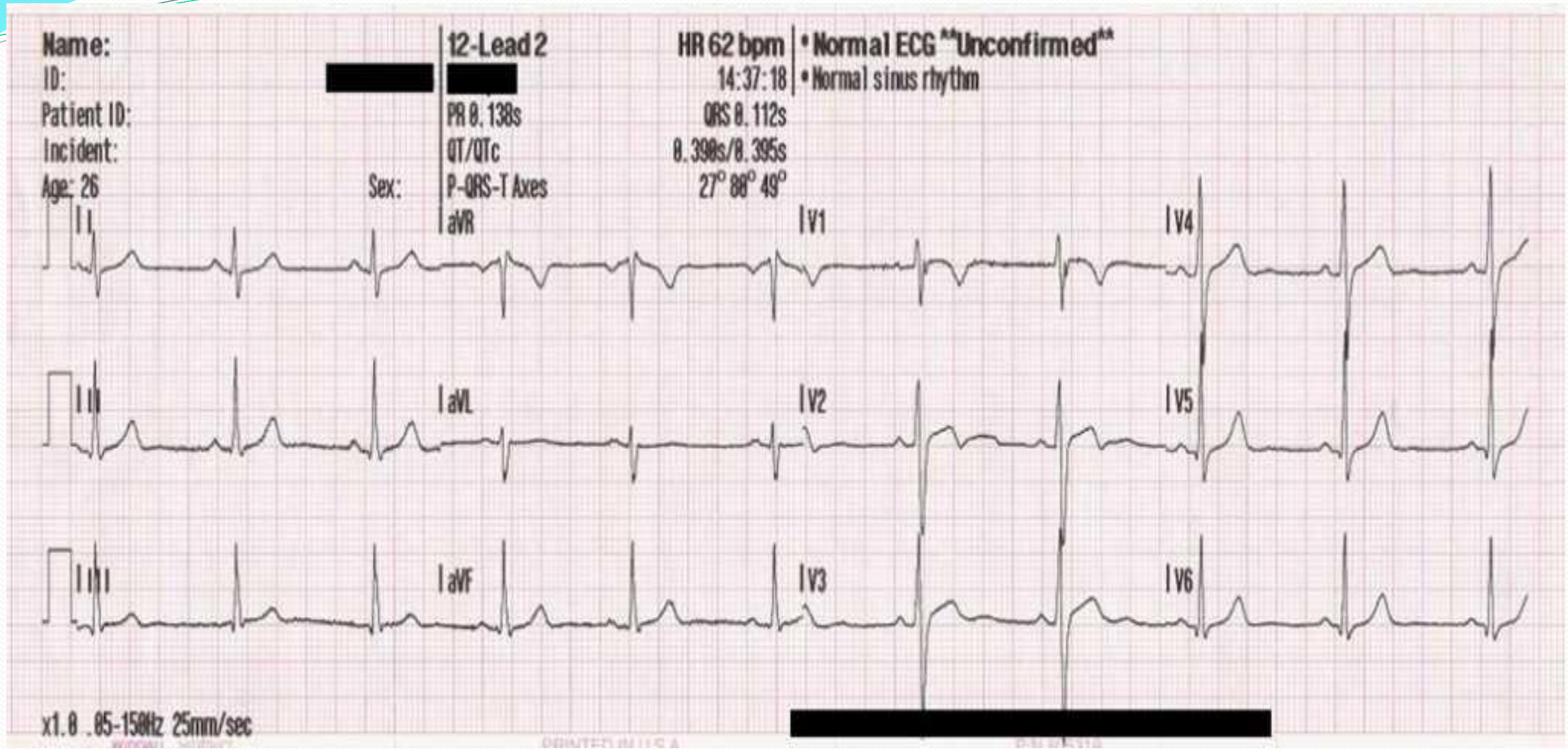


I, aVL, V5, V6: Lateral surface of the heart

II, III, aVF: Inferior surface

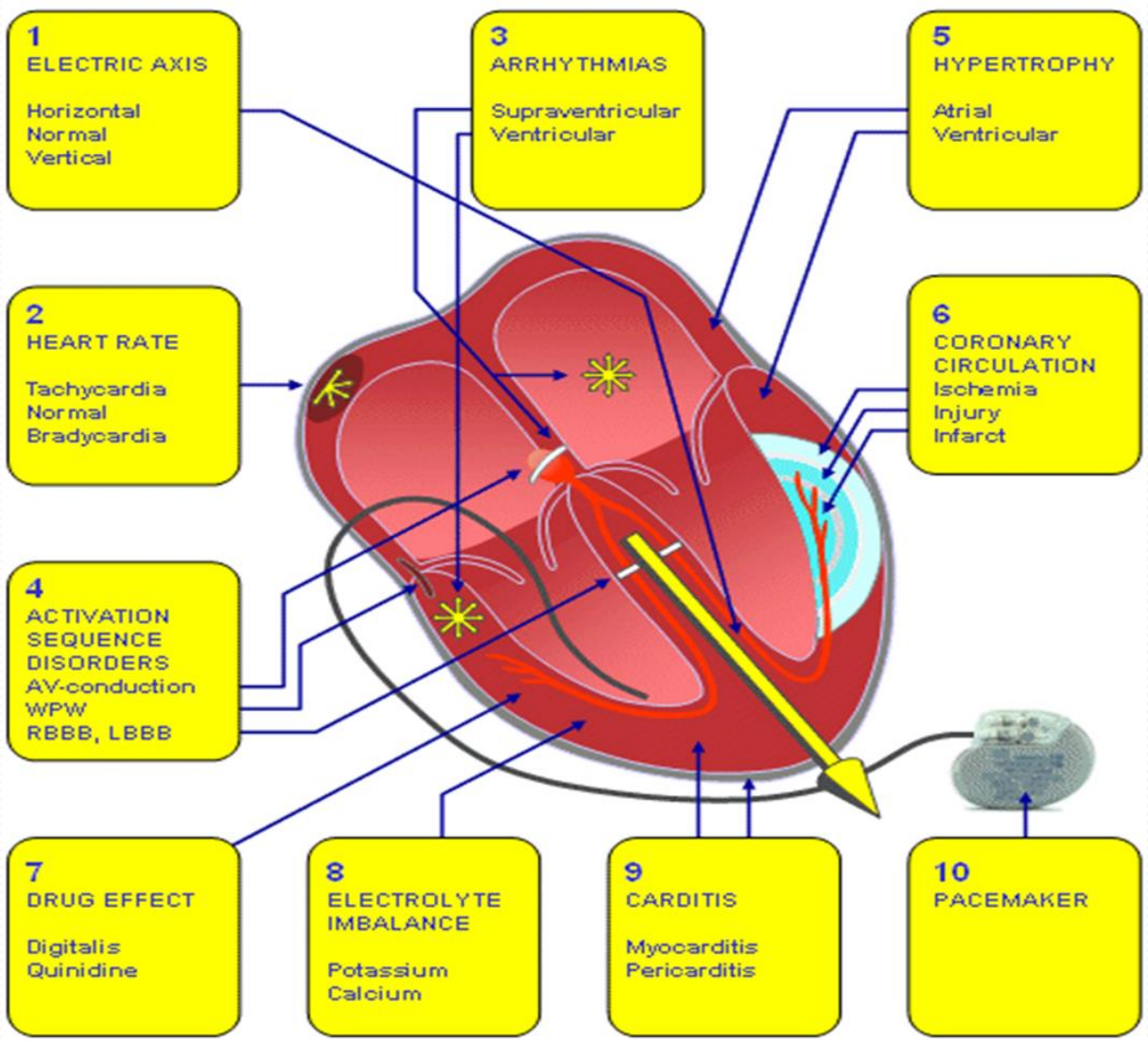
V1 to V4: Anterior surface

aVR: Right upper surface

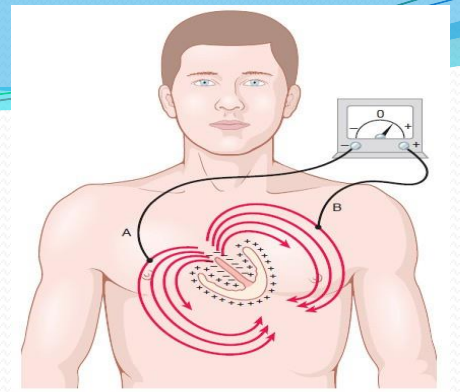

Name:
ID:
Patient ID:
Incident:
Age: 26
Sex:
12-Lead 2
PR 0.138s
QT/QTc
P-QRS-T Axes
aVR
HR 62 bpm
14:37:18
QRS 0.112s
0.398s/0.395s
27° 88° 49°
• Normal ECG **Unconfirmed**
• Normal sinus rhythm
I
II
III
aVL
aVF
V1
V2
V3
V4
V5
V6
x1.0 .05-150Hz 25mm/sec

Practical use of the ECG

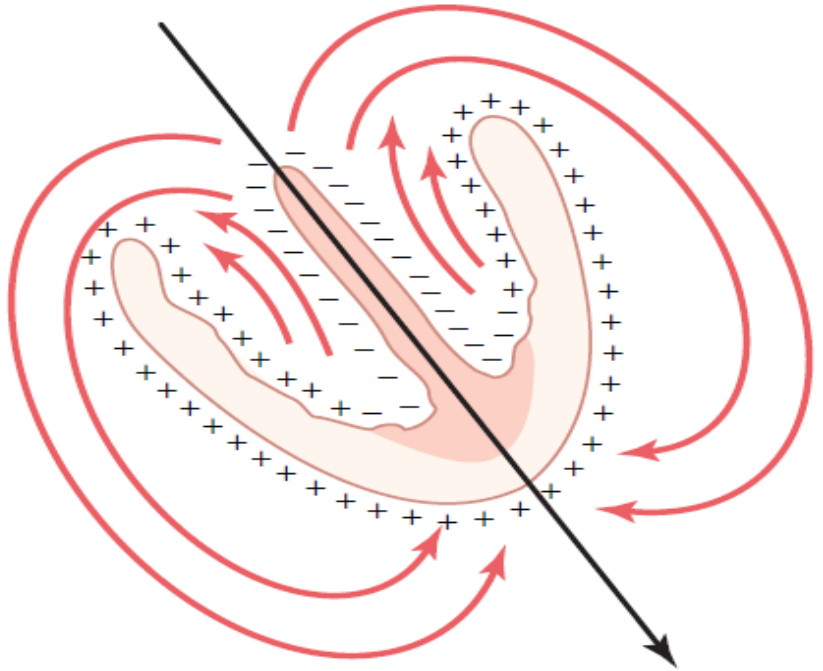
1. Electrical cardiac Axis
2. Heart rate
3. Heart Rhythm
4. Myopathies
5. Chamber Hypertrophy
6. Myocardial Ischemia/MI
7. Drug toxicity (eg; digoxin)
8. Electrolyte disturbances
9. Carditis
10. Conduction defects



Cardiac Vectors



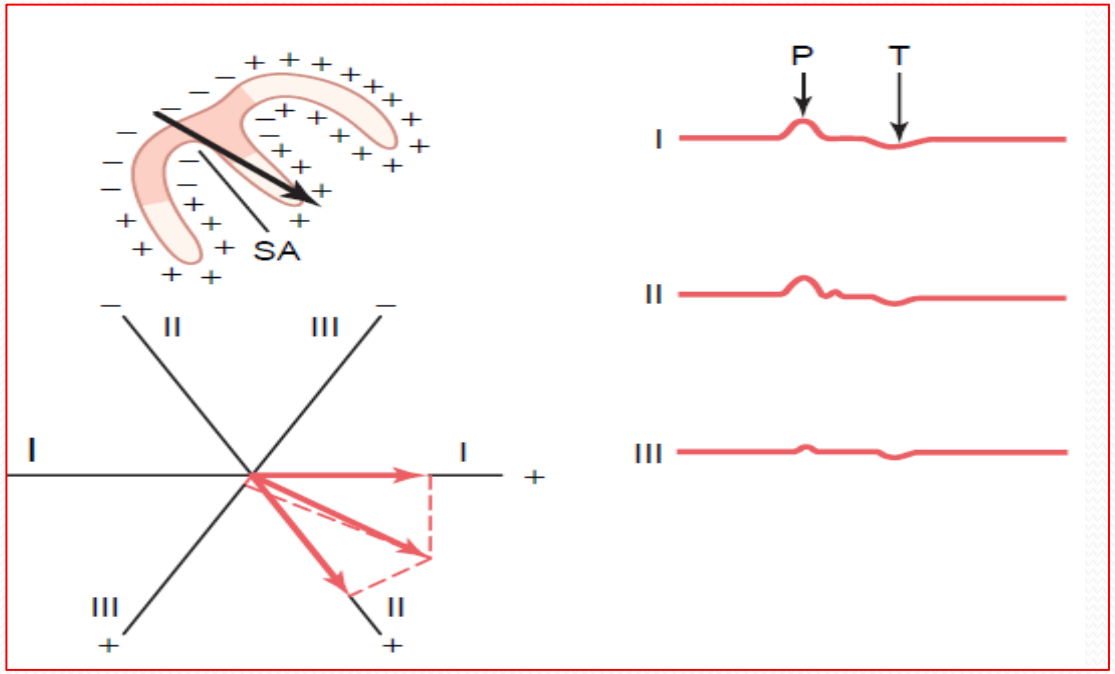
- Electrical forces can be represented in the form of vectors (قوه موجهة)
- A vector is an arrow that points in the direction of the electrical potential generated by the current flow, with the arrowhead in the positive direction.
- The length of the arrow is proportional to the voltage of the potential.



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

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

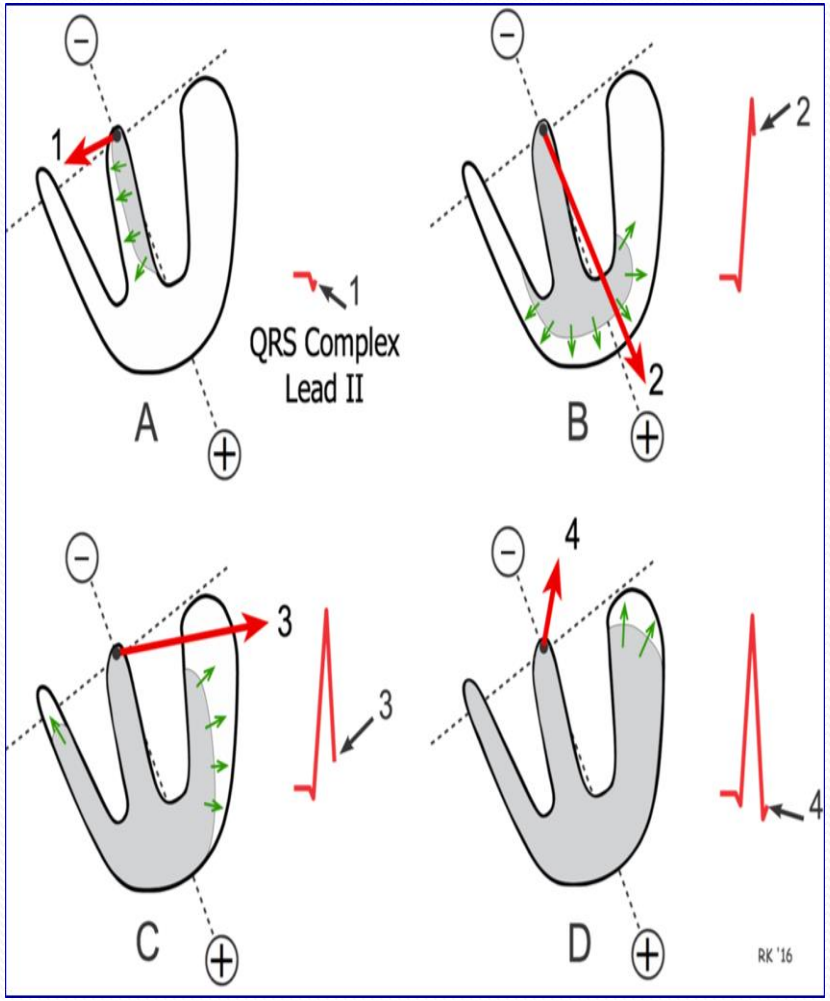
- The area in the atria that becomes depolarized first is the sinus nodal region.
- The area in the atria that becomes repolarized first is the sinus nodal region.
- Therefore, the atrial repolarization vector is backward to the vector of depolarization



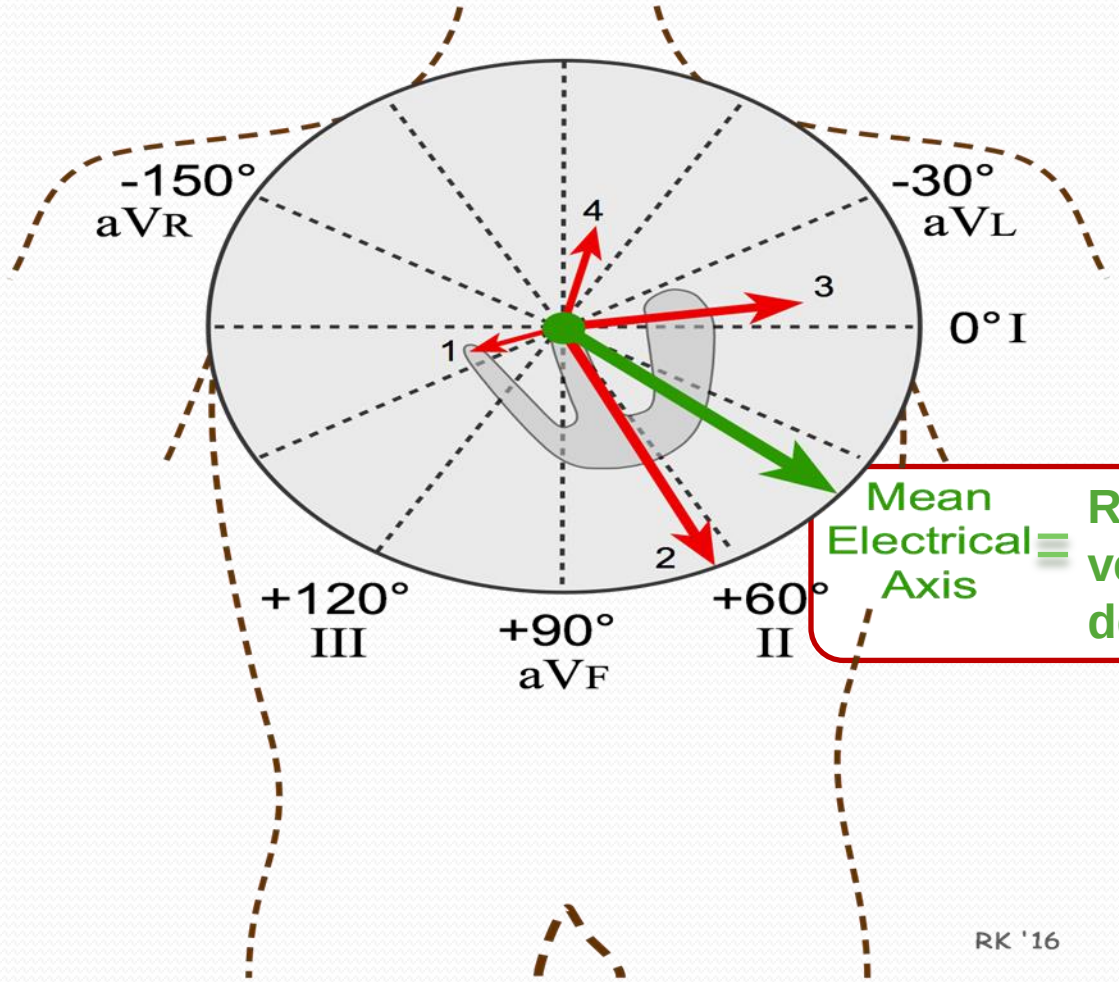
Depolarization of the atria and generation of the P wave, showing the maximum vector through the atria and the resultant vector in the three standard leads.

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.



Vectors That Occur During Ventricular Depolarization

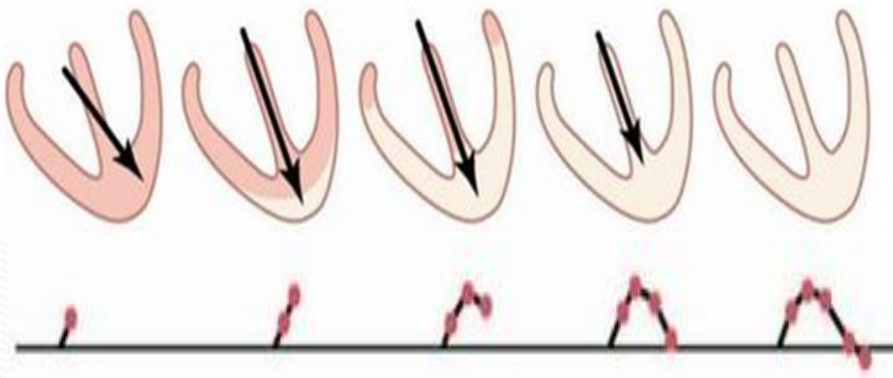


Mean Electrical Axis = Represents the sum of all mean electrical vectors occurring during ventricular depolarization

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 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.



T wave

For further readings and diagrams:

Textbook of Medical Physiology by Guyton & Hall

Chapter 11 (The Normal Electrocardiogram)

Thank You