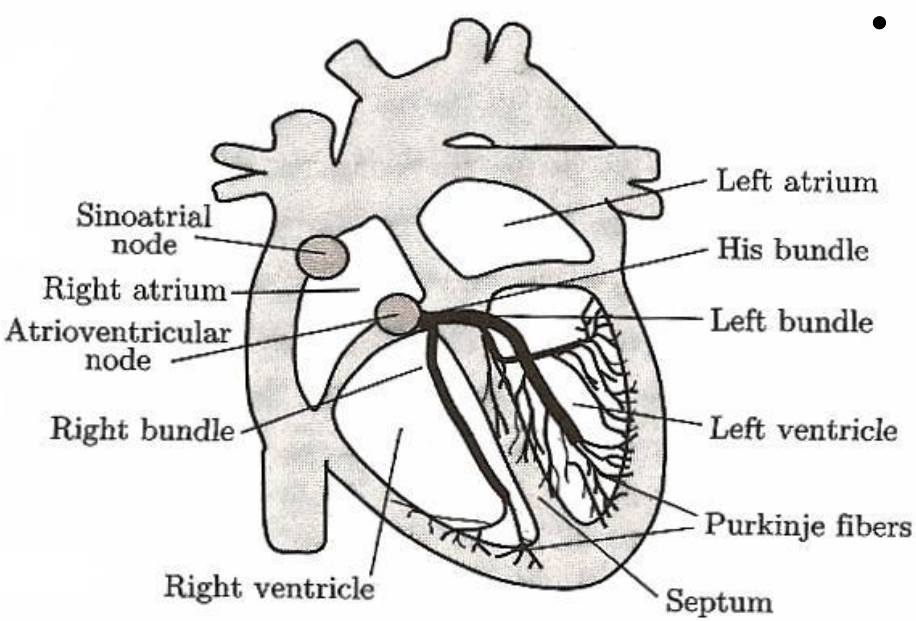
Anatomy of the Hearth
And
Electrocardiogram
&
Electromyogram

Anatomy of the Heart

- The heart is a muscler organ the size of a large fist whose primary function is to pump oxygen-rich blood throughout to body.
- Its anatomy is divided into two “mirrored” sides, left and right, which support different circulatory systems but which pump in a synchronized, rhythmic manner.



- Each side of the heart consists of two chambers:
  - **The *atrium*** → where the blood enters
  - **The *ventricular*** → where the blood is forced into further circulation**.**

Anatomy of the Heart (Cont.)

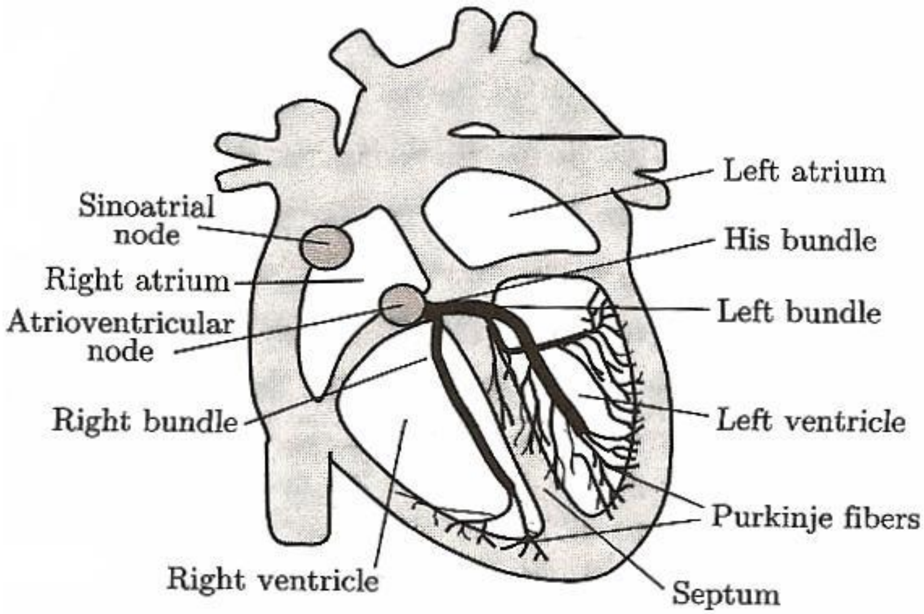
- The two sides are divided by a muscler wall called the ***septum*.**

- The **direction of blood flow** is controlled by four different **valves**.

  - *Atrioventricular valves*
    - which are located between the atria and the ventricles.
  - *Pulmonary and aortic valves*
    - which are located between the ventricles and the arteries.

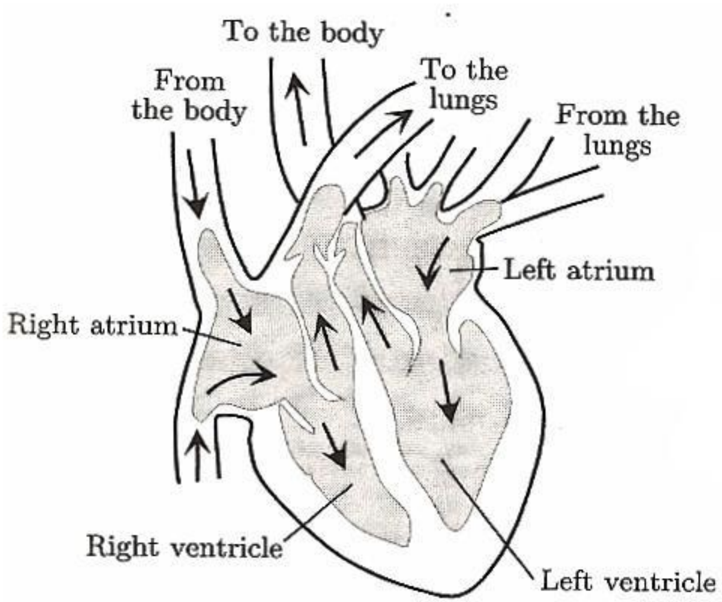
- The wall of the heart is called the ***myocardium.***

- The myocardium is composed of muscle cells which produce the mechanical force during contraction of the heart.



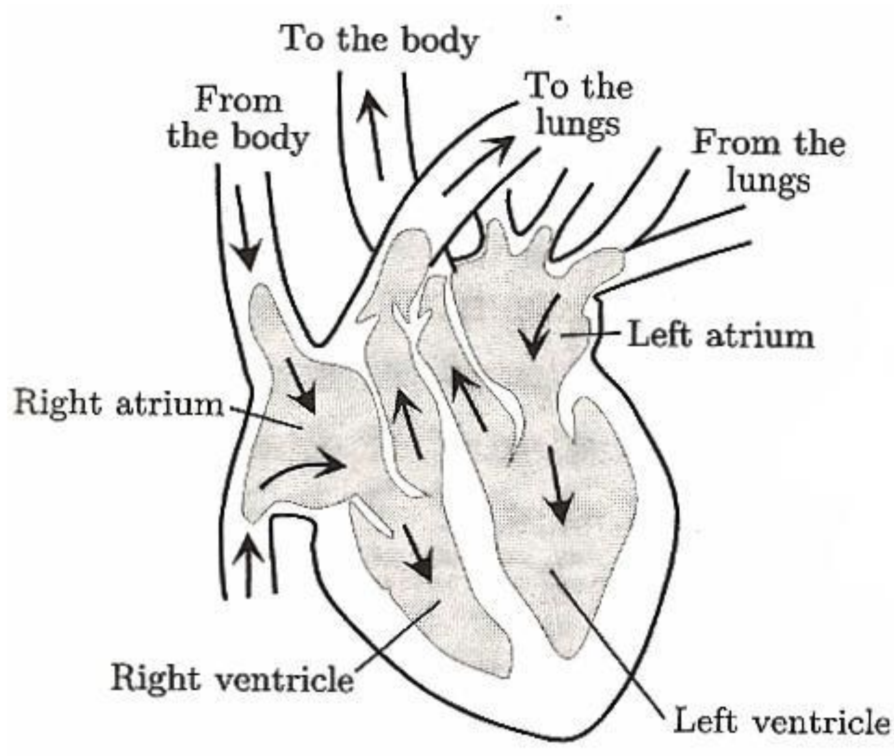
Anatomy of the Heart (Cont.)

- A **cardiac cycle** can be assumed to **start in the right atrium** where the blood is collected from all the veins in the body except those of the lungs.
- When the right atrium is triggered to contract, it forces blood into the right ventricle.
- When the right ventricle has been filled, it contracts and forces blood into the lungs, where excess corbon dioxide is replaced by oxygen.



Anatomy of the Heart (Cont.)

- The **pulmanory veins** return the **oxygenated blood** to the left atrium.
- When the left atrium is triggered to contract, it forces blood into the left ventricle.
- In its capacity as a high pressure pump, the left ventricle forces blood to all of the body organs and tissues except the lungs through the arterial vessels which evolve into capillaries.

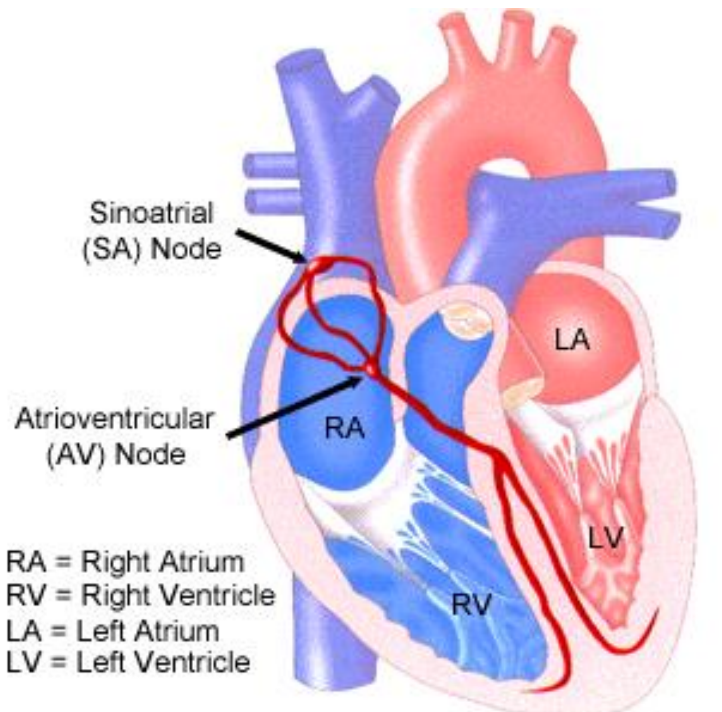


▪ Electrical Activity of the Heart

- **Each cardiac cycle is composed of two phases**
  - Activation
    - Depolarization (electrical term)
    - Contraction (mechanical term)
  - Recovery
    - Repolarization (electrical term)
    - Relaxation (mechanical term)
- Depolarization is manisfested by a rapid change in the membrane potential of the cell.
  - -90mV → 20mV in approximately 1 ms.
- The rapid change in voltage causes neighboring cells to depolarize and, as a result, an electrical impulse spreads from cell to cell throughout the myocardium.
- Depolarization is immediately followed by repolarization during which the membrane potential of the cells gradually returns to its resting state.

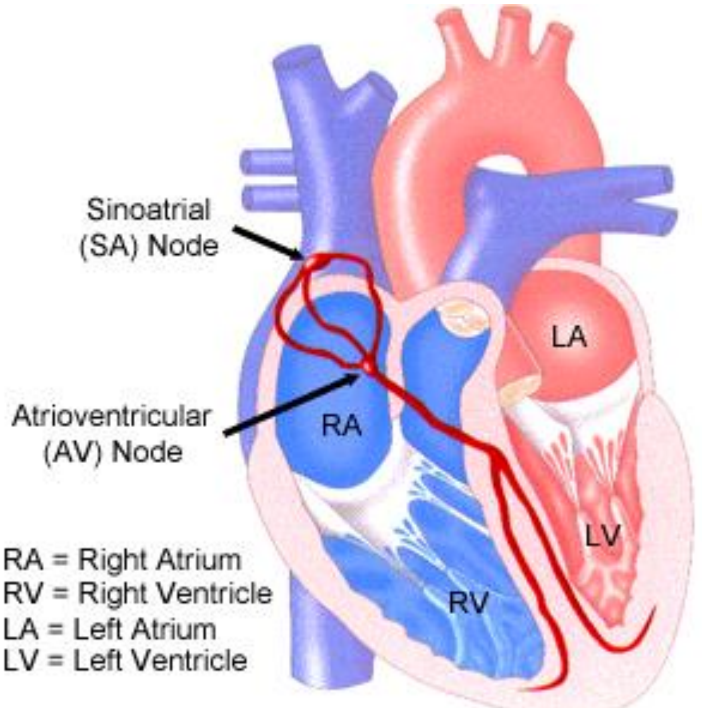
Electrical Activity of the Heart (Cont.)

- The **initialization of a cardiac cycle** occurs in a mass of pacemaker cells with an ability to spontaneously fire an electrical impulse.
- These cells are situated in the upper part of the right atrium, ***sinoatrial (SA) node*** .
- The electrical impulse propagates through the conduction system so that atrial and ventricular contraction and relaxation can take place with the correct time.
- After electrical activation of the right and left atria, the impulse is collected and **delayed at the *atrioventricular (AV) node*** before it enters into ventricles.



Electrical Activity of the Heart (Cont.)

- **The delay allows** the atrial contraction **to further increase the blood volume** in the ventricles before ventricular contraction occurs.
- The delay in the AV node is caused by slower conduction of the impulse by the muscle tissue in this area.
- The impulse enters the wall between the two ventricles at the **bundle of His.**
- This is the only location that electrically connects the atria and the AV node/ventricles.
- The pathway is then divided into rapidly conducting bundles with branches to the left and right ventricles and then into an extensive network of specialized conduction fibers called as **Purkinje fibers**.



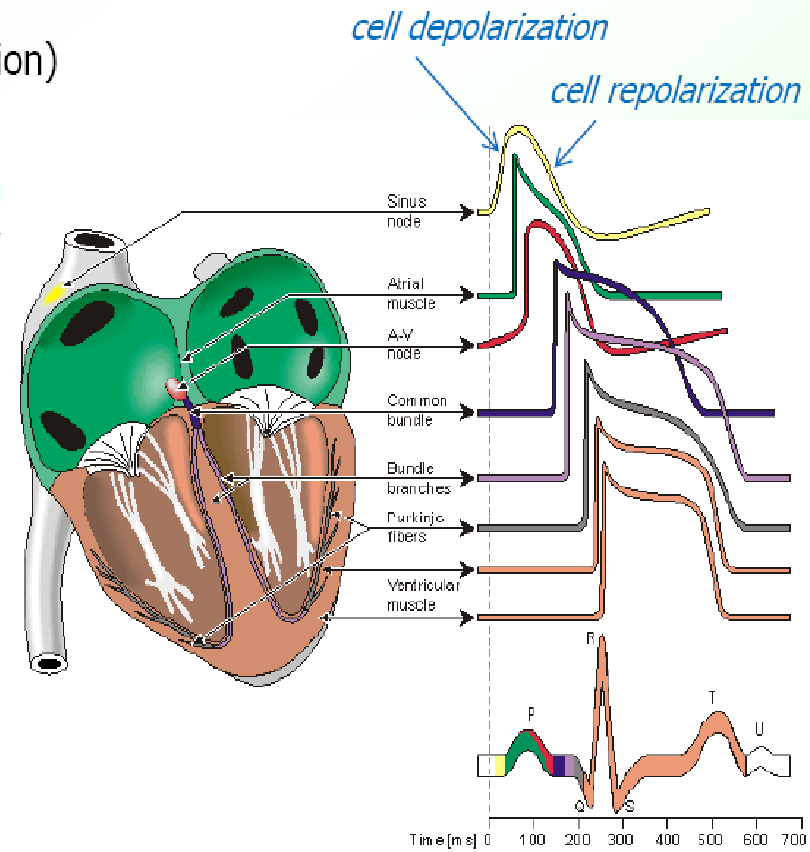
AV node → 0.05m/s

Purkinje fibers → 4m/s

ECG Signal Generation

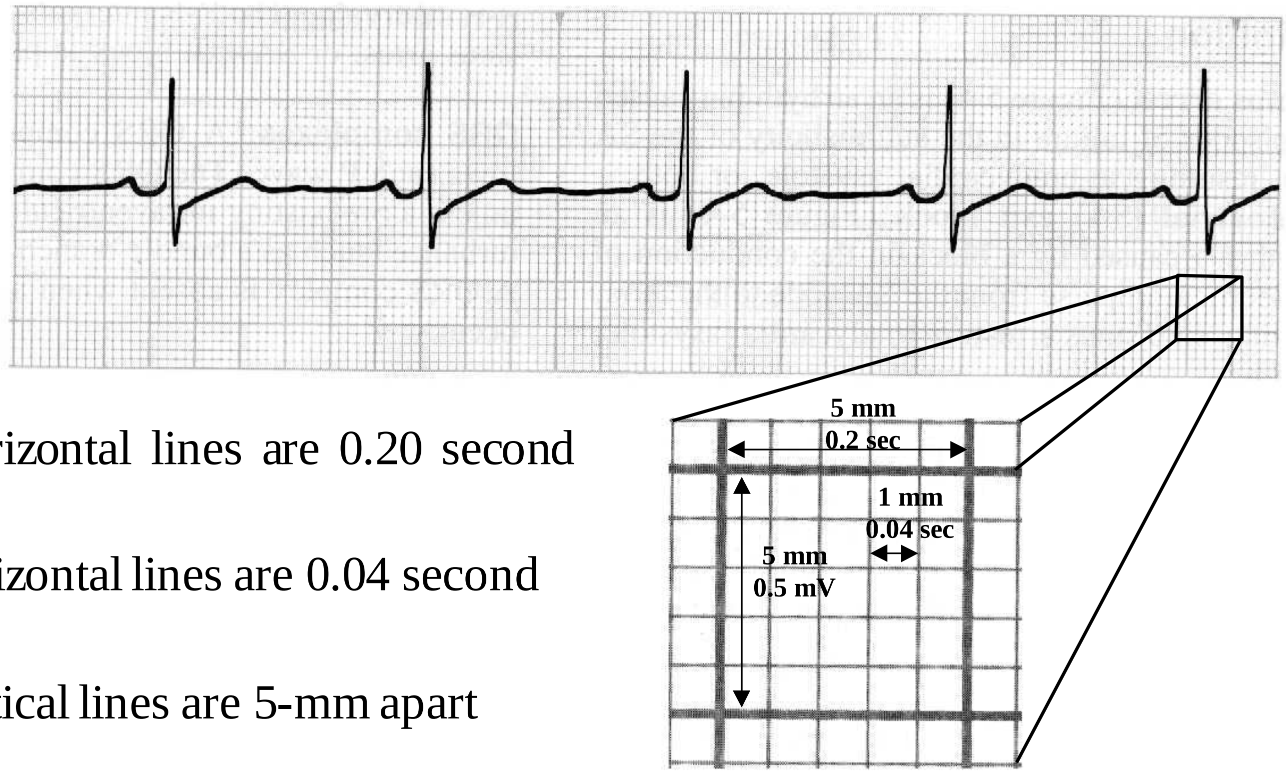
- Action potential to the heart
  - starts at the SN
  - travels through the heart with delay at each point
  - ECG represents superposition of all signals
    - **P wave** (atrial depolarization)
    - **QRS complex** (ventricular depolarization)
    - **T wave** (ventricular repolarization)

Location in the heart	Event	Time [ms]	ECG-terminology	Conduction velocity [m/s]	Intrinsic frequency [1/min]
SA node	impulse generated	0		0.05	70-80
atrium, Right	depolarization *)	5	P	0.8-1.0	
Left	depolarization	85	P	0.8-1.0	
AV node	arrival of impulse	50	P-Q	0.02-0.05	
	departure of impulse	125	interval		
bundle of His	activated	130		1.0-1.5	
bundle branches	activated	145		1.0-1.5	
Purkinje fibers	activated	150		3.0-3.5	
endocardium					
Septum	depolarization	175		0.3 (axial)	20-40
Left ventricle	depolarization	190		-	
				0.8	
epicardium	depolarization	225	QRS	(transverse)	
Left ventricle	depolarization	250			
Right ventricle					
epicardium					
Left ventricle	repolarization	400			
Right ventricle	repolarization				
endocardium			T	0.5	
Left ventricle	repolarization	600			



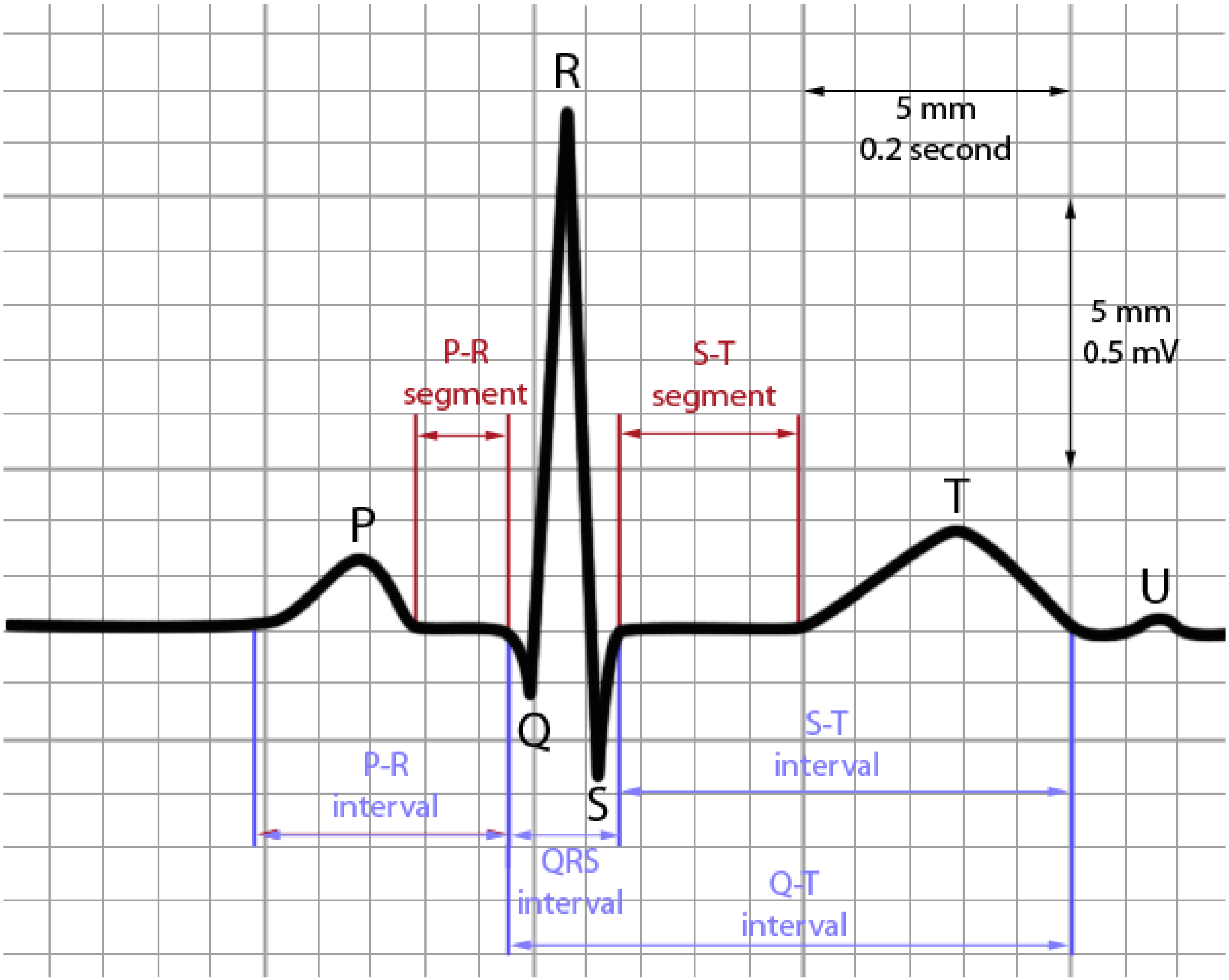
ECG Paper

- The paper used in recording electrocardiograms has a grid to permit the measurement of time in seconds and amplitude in millimeters along the horizontal lines and voltage (amplitude) in millimeters along the vertical lines.

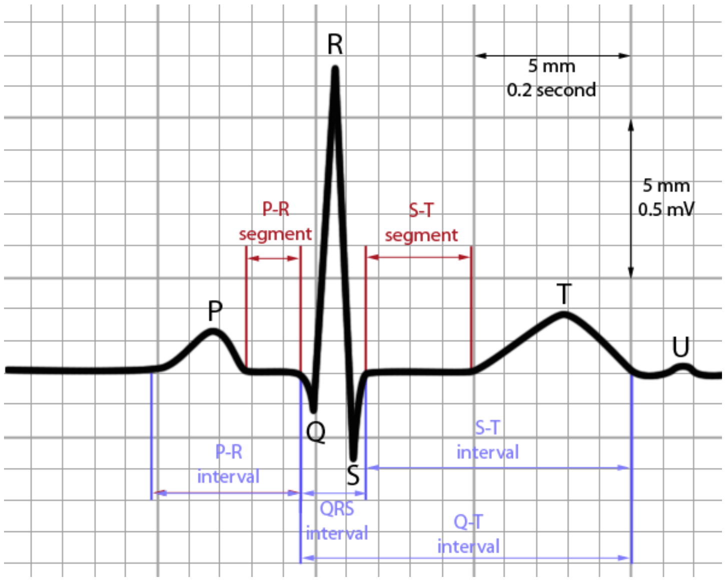


- The dark horizontal lines are 0.20 second (5 mm) apart.
- The light horizontal lines are 0.04 second (1 mm) apart.
- The dark vertical lines are 5-mm apart (0.5 mV)
- The light vertical lines are 1-mm apart (0.1 mV).

▪ ECG Waves and Time Intervals



ECG Waves and Time Intervals (Cont.)



- **RR interval**
  - the length of a ventricular cardiac cycle measured between to succesive R waves.
  - is the fundamental rhythm quantity in any type of ECG interpretation.
  - is used to characterize different arrhythmias as well as to study heart rate variability.

- **QRS complex**
  - depolarization of the right and left ventricles.
  - its duration is about 70-110ms.
  - it has the largest amplitude of the ECG waveforms, sometimes reaching 2-3mV.
  - the frequency content of the QRS complex is concentrated in the interval 10-50 Hz.

- **T wave**
  - reflects ventricular repolarization and extends about 300ms after the QRS complex.
  - The position of this wave is strongly dependent on the heart rate, becoming narrower and closer to QRS complex at rapid rates.
  - This contraction property does not apply to the P wave or the QRS complex.
  - The normal T wave has a smooth, rounded morphology which is associated with a single positive peak.

ECG Waves and Time Intervals (Cont.)

- **RR interval**
  - the length of a ventricular cardiac cycle measured between to succesive R waves.
  - is the fundamental rhythm quantity in any type of ECG interpretation.
  - is used to characterize different arrhythmias as well as to study heart rate variability.
- **PQ interval**
  - time interval from the onset of atrial depolarization to the onset of ventricular depolarization.
  - This interval reflects the time required for the electrical impulse to propagate from the SA node to the ventricles.
- **QT interval**
  - represents the time from the onset of ventricular depolarization to the completion of ventricular repolarization.
  - Prolongation of this interval has been observed in various cardiac disorders associated with increased risk of sudden death.

ECG Rhythms

Sinus rhythm

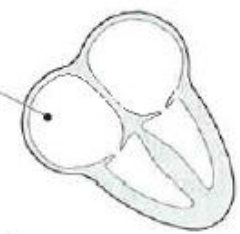


FIG. 3.2
Sinus rhythm

Key points:
- heart rate is 80 per minute
- P waves are upright (lead II)
- QRS complex after every P wave

Sinus bradycardia

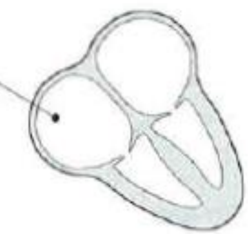
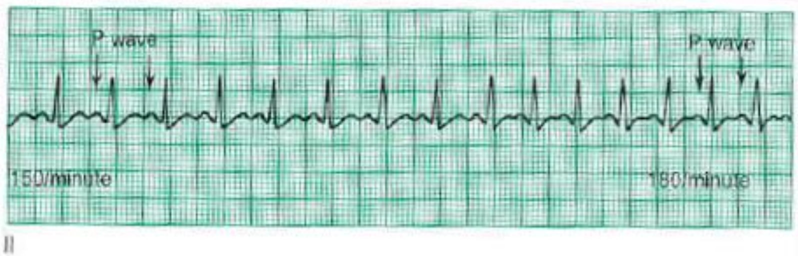


FIG. 3.3
Sinus bradycardia

Key points:
- heart rate is 43 per minute
- P waves are upright (lead II)
- QRS complex after every P wave

ECG Rhythms (Cont.)

Sinus tachycardia



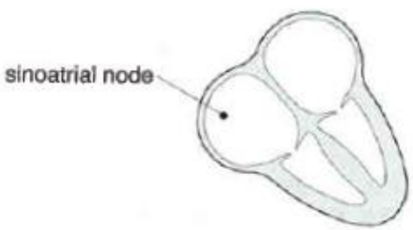


FIG. 3.4

Sinus tachycardia

Key points:
- heart rate is 150–180 per minute
- P waves are upright (lead II)
- QRS complex after every P wave

Sinus arrhythmia

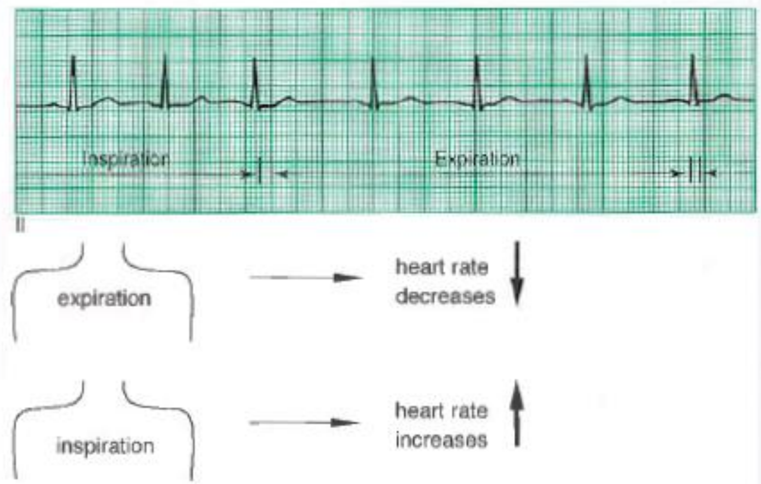


FIG. 3.5

Sinus arrhythmia

Key points:
- heart rate is 75 per minute during expiration
- heart rate is 90 per minute during inspiration

ECG Rhythms (Cont.)

Atrial fibrillation

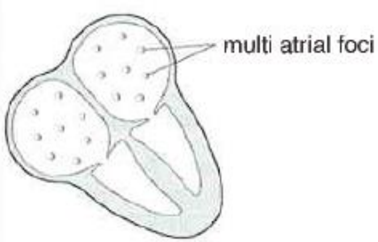


FIG. 3.13

Atrial fibrillation

Key points:
- irregularly irregular rhythm
- no P waves visible
- QRS rate is 170 per minute

Ventricular arrhythmia

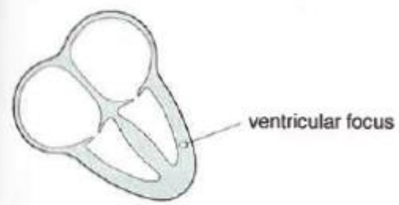


FIG. 3.19

Ventricular tachycardia (VT) and ventricular fibrillation (VF)

Key points:
- broad-complex tachycardia at a rate of 190 per minute (VT)
- degenerates into chaotic rhythm (VF)

ECG Rhythms (Cont.)

AV block

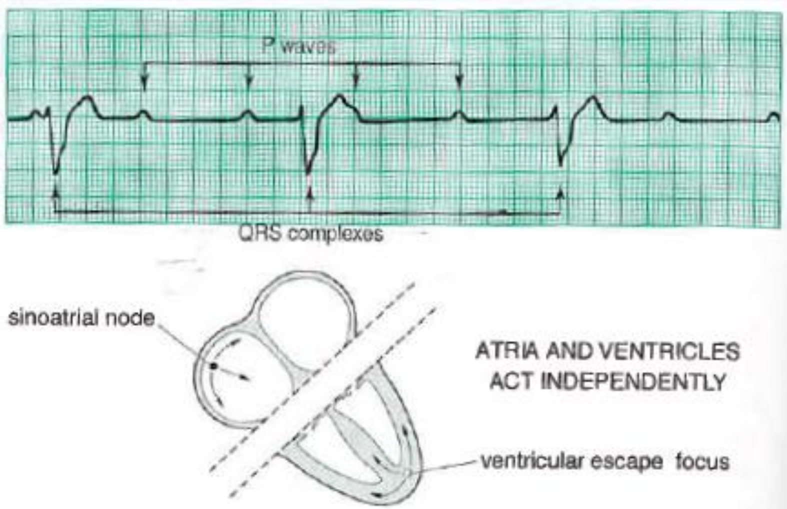


FIG. 3.31

Complete ('third-degree') AV block

Key points:
- P wave rate is 75 per minute
- QRS rate is 33 per minute

AV dissociation

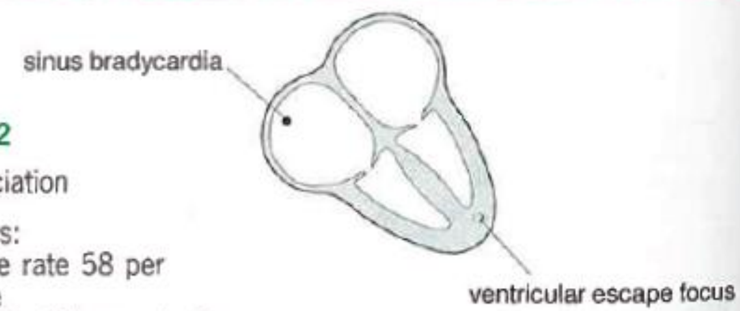
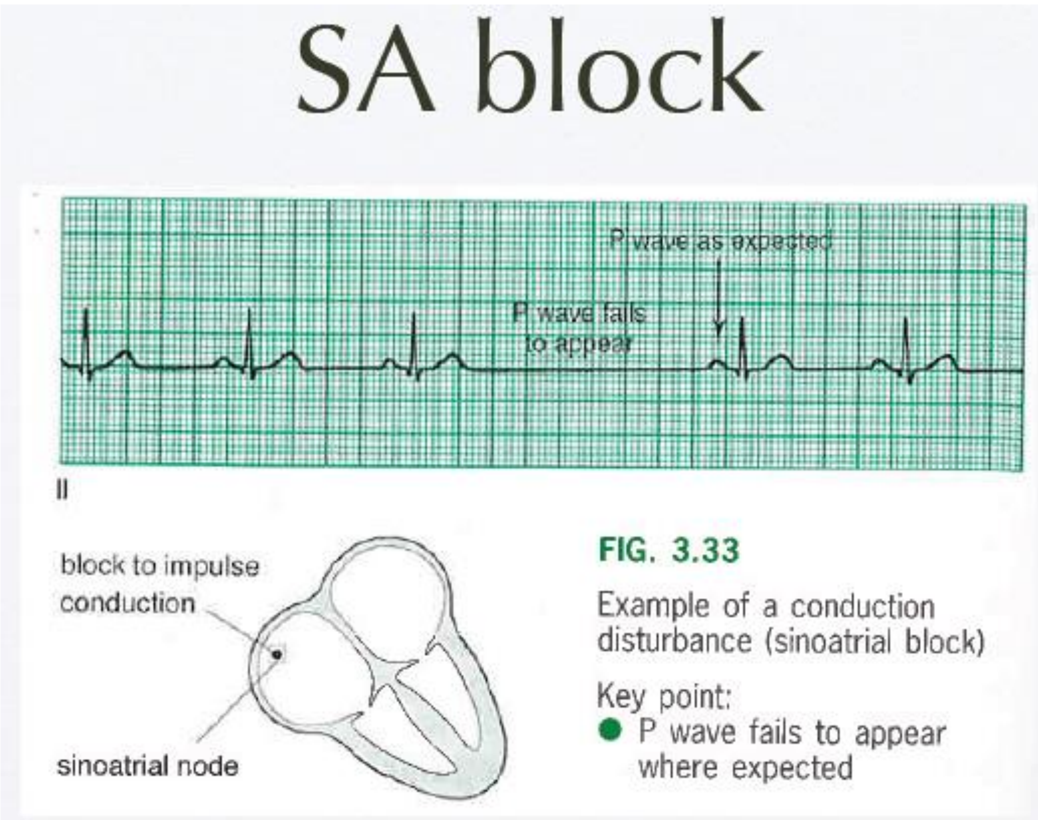


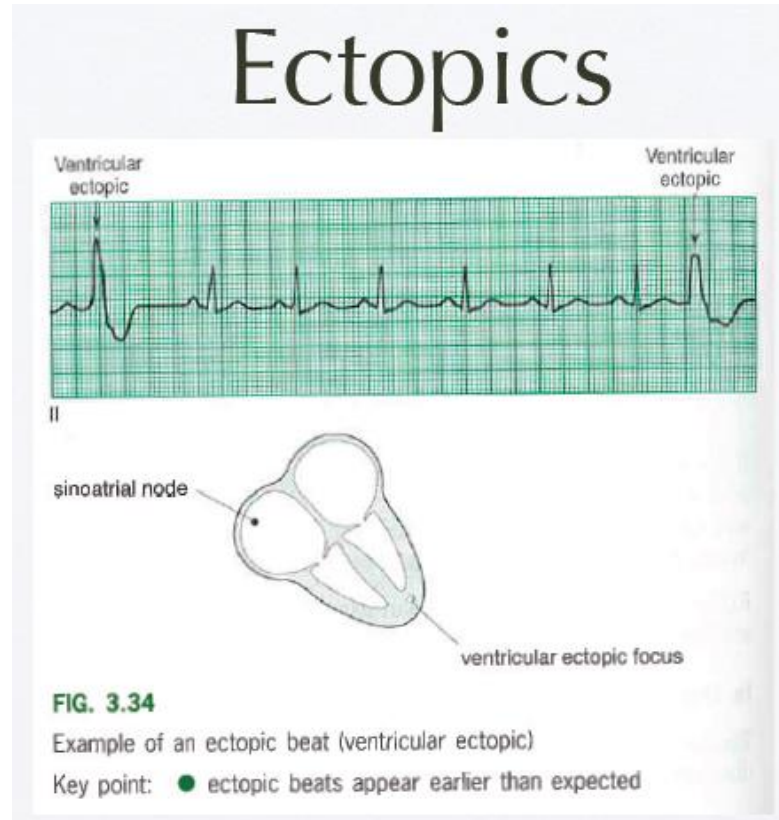
FIG. 3.32

AV dissociation

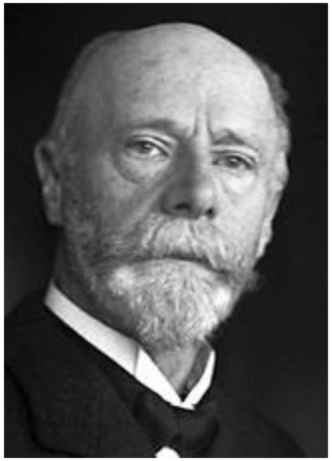
Key points:
- P wave rate 58 per minute
- QRS rate 65 per minute

ECG Rhythms (Cont.)





▪ 12-Lead ECG - Einthoven's Triangle



William Einthoven
1860-1927

In 1924, Einthoven was awarded the Nobel Prize in Medicine for inventing the first practical system of electrocardiography used in medical diagnosis.

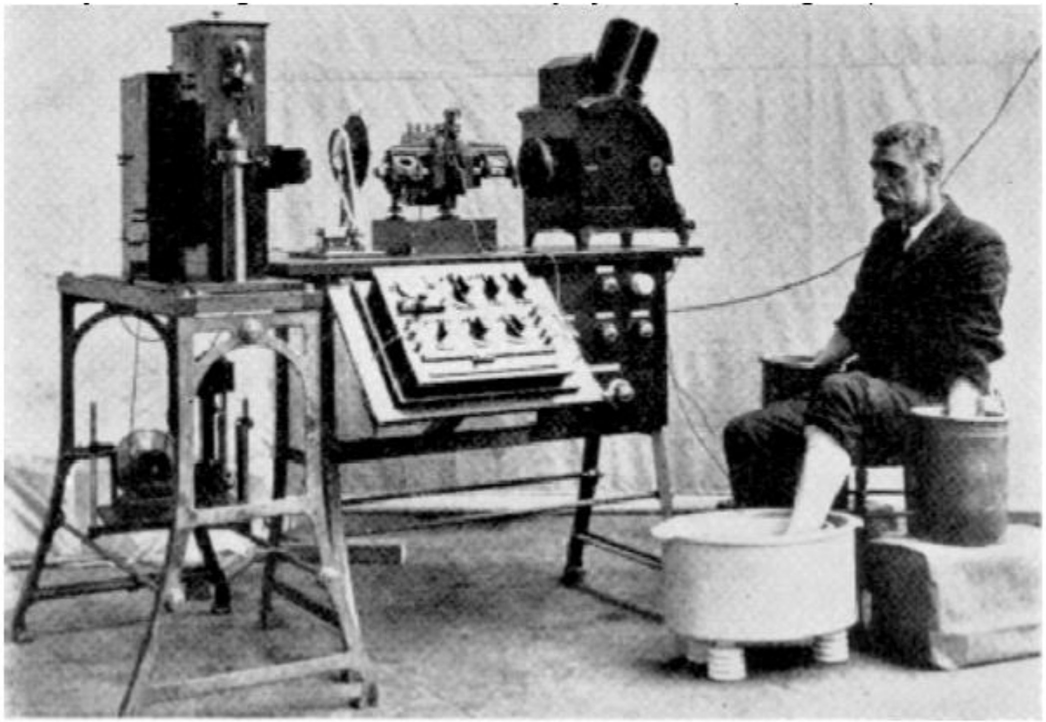


Fig. 6. The first table-model Einthoven electrocardiograph manufactured by the Cambridge Scientific Instrument Company of London in 1911. On the right hand side the arch lamp, in the centre on the table the string galvanometer, and below the switching board for the leads, next left to the camera the timer (rotating wheel with spokes), and on the left hand side the falling-plate camera (from Burch, De Pasquale, A History of Electrocardiography p 33 [14]).

▪ ECG leads

- Electrical signals generated by the heart that is sensed by either one of two ways:

  - two discrete electrodes of opposite polarity
  - one discrete positive electrode and an "indifferent," zero reference point.

- A lead composed of two discrete electrodes of opposite polarity is called *a **bipolar lead**.*
- A lead composed of a single discrete positive electrode and a zero reference point is *a **unipolar lead**.*

- Depending on the ECG lead being recorded, the positive electrode may be attached to
  - the right arm
  - the left arm
  - the left foot
  - around chest (in total 6 electrodes)

- The negative electrode is usually attached to an opposite arm or foot or to a reference point made by connecting the limb electrodes together.

▪ 12-Lead ECG

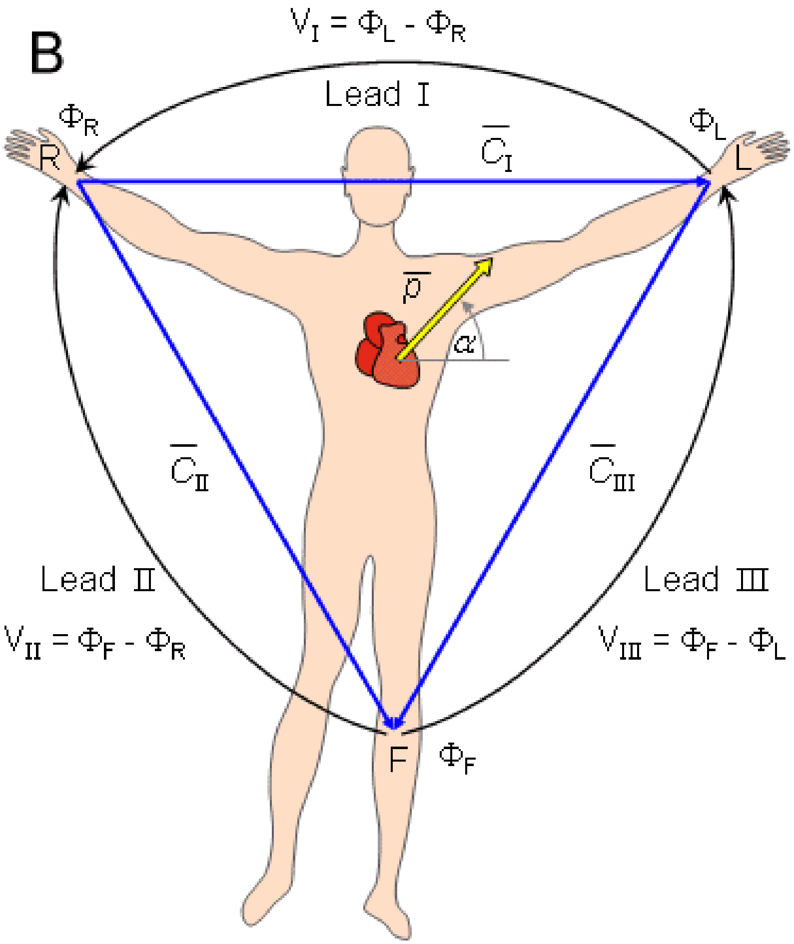
- For a detailed analysis of the heart's electrical activity, usually in the hospital setting, an ECG recorded from 12 separate leads (the 12-lead ECG) is used.
- The 12-lead ECG is also used in the prehospital phase of emergency care in certain advanced life support services to diagnose acute myocardial infraction and to help in the identification of certain arrhythmias.
- **A 12-lead ECG consists of**
  - <u>Three standard (bipolar) limb leads</u>
    - lead I
    - lead II
    - lead III
  - <u>Three augmented (unipolar) leads</u>
    - lead aVR
    - lead aVL
    - lead aVF
  - <u>Six precordial (unipolar) leads (V1, V2, V3, V4, V5, and V6)</u>
- When monitoring the heart solely for arrhythmias, a single ECG lead, such as the standard limb lead II, is commonly used, especially prehospital phase of emergency care.

12-Lead ECG - Limb Leads

- **The Einthoven limb leads (standard leads)** are defined in the following way:
  - Lead I: VI $= \Phi_L - \Phi_R$
  - Lead II: VII $= \Phi_F - \Phi_R$
  - Lead III: VIII $= \Phi_F - \Phi_L$

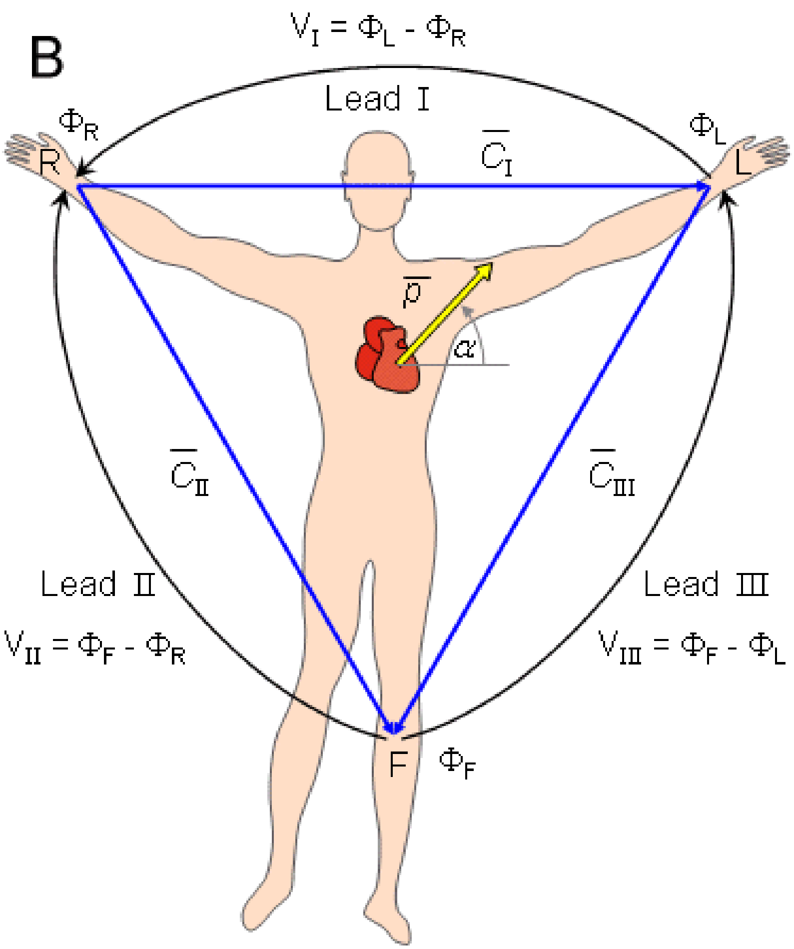
where

- V_I = the voltage of Lead I
- V_{II} = the voltage of Lead II
- V_{III} = the voltage of Lead III
- Φ_L = potential at the left arm
- Φ_R = potential at the right arm
- Φ_F = potential at the left foot

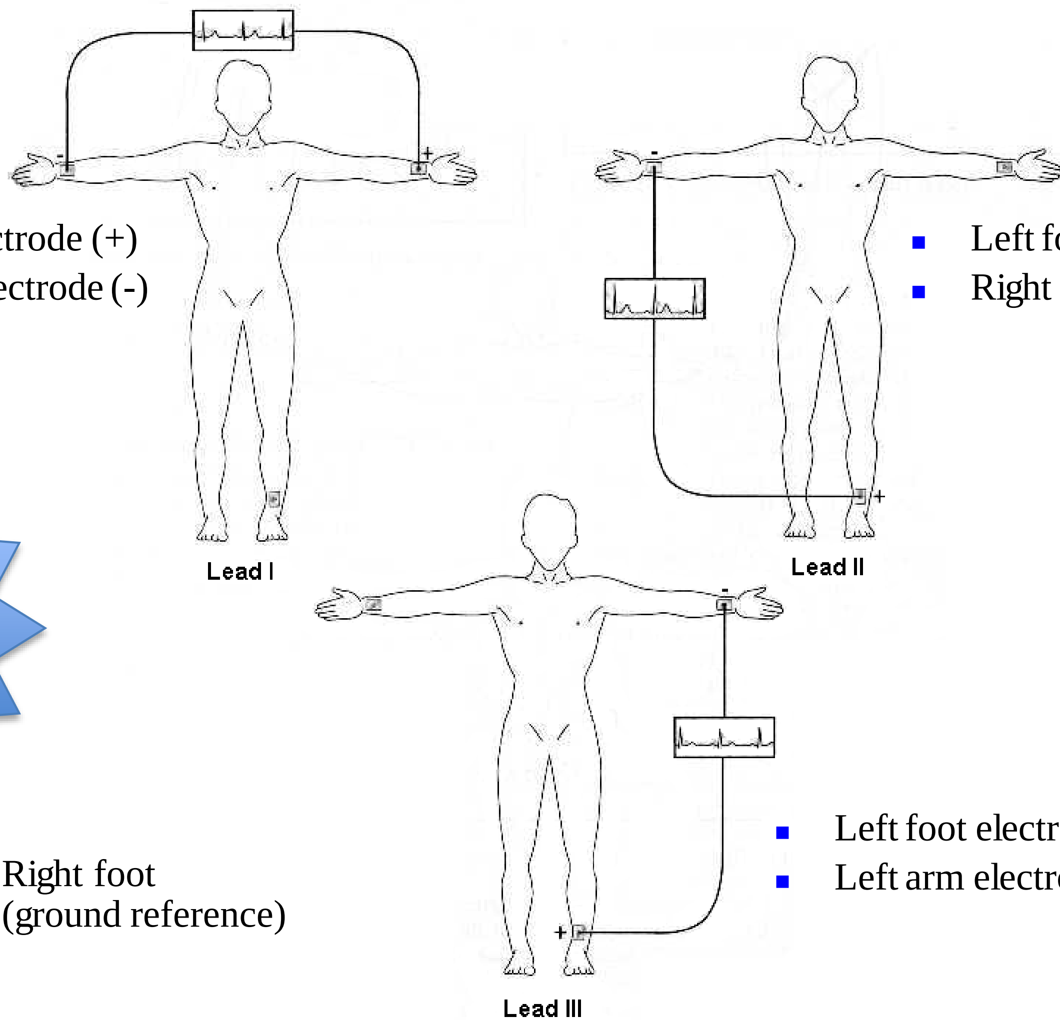


12-Lead ECG - Limb Leads (Cont.)

- (The left arm, right arm, and left leg (foot) are also represented with symbols LA, RA, and LL, respectively.)
- According to Kirchhoff's law these lead voltages have the following relationship:
  - $V_I + V_{III} = V_{II}$
- hence only two of these three leads are independent.



12-Lead ECG - Limb Leads (Cont.)



- Left arm electrode (+)
- Right arm electrode (-)

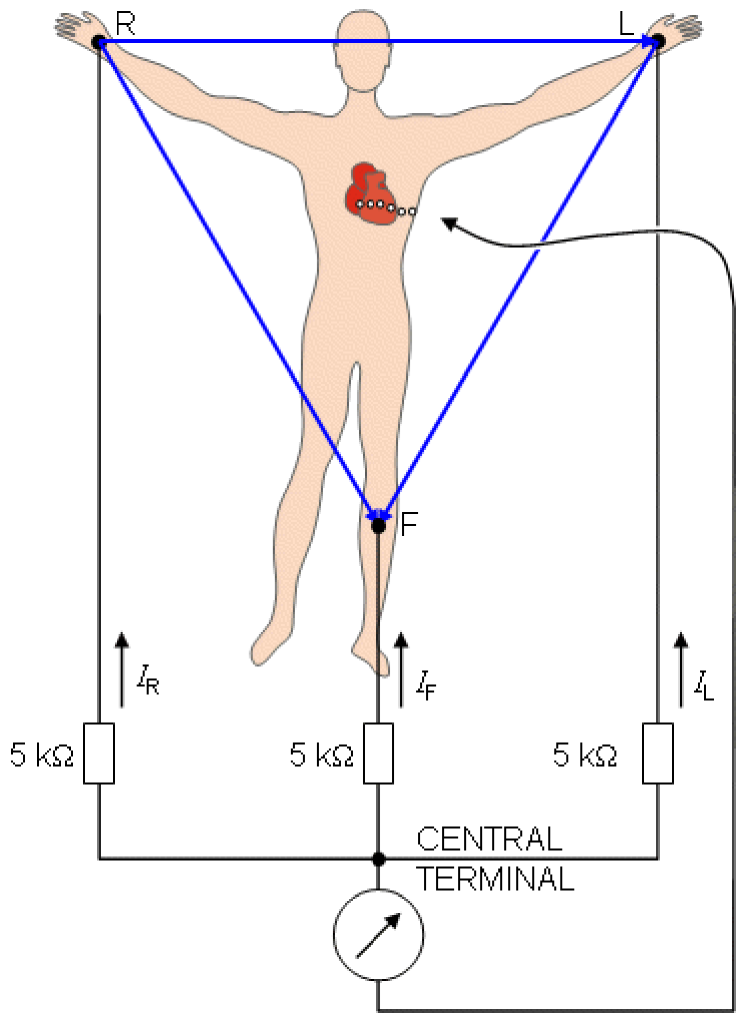
- Left foot electrode (+)
- Right arm electrode (-)

- Left foot electrode (+)
- Left arm electrode (-)

- Right foot
  (ground reference)

Watch video#2

12-Lead ECG-Wilson Central Terminal

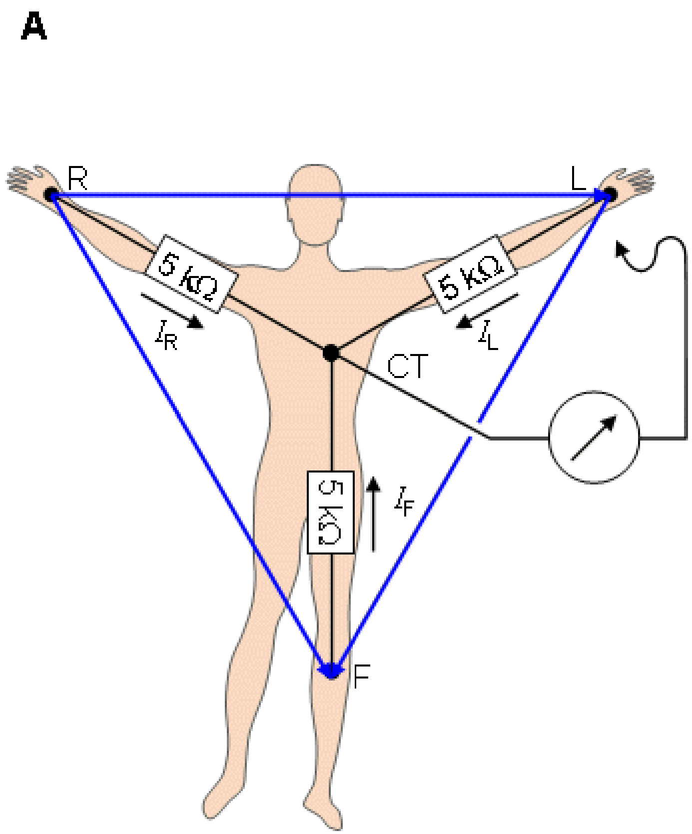


- The Wilson central terminal (CT) is formed by connecting a 5k resistance to each limb electrode and interconnecting the free wires; the CT is the common point.
- The Wilson central terminal represents the average of the limb potentials.
- Because no current flows through a high-impedance voltmeter, Kirchhoff's law requires that $I_R + I_L + I_F = 0$.

$$I_R + I_L + I_F = \frac{\Phi_{CT} - \Phi_R}{5000} + \frac{\Phi_{CT} - \Phi_L}{5000} + \frac{\Phi_{CT} - \Phi_F}{5000}$$

$$\text{Wilson central terminal} \rightarrow \Phi_{CT} = \frac{\Phi_R + \Phi_L + \Phi_F}{3}$$

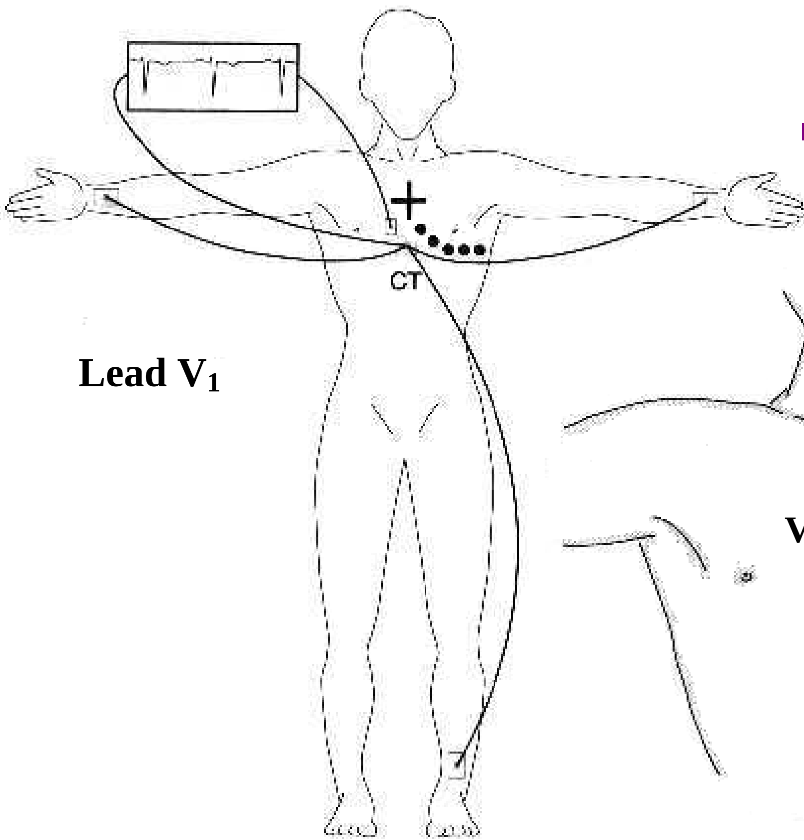
12-Lead ECG-Wilson Central Terminal (Cont.)



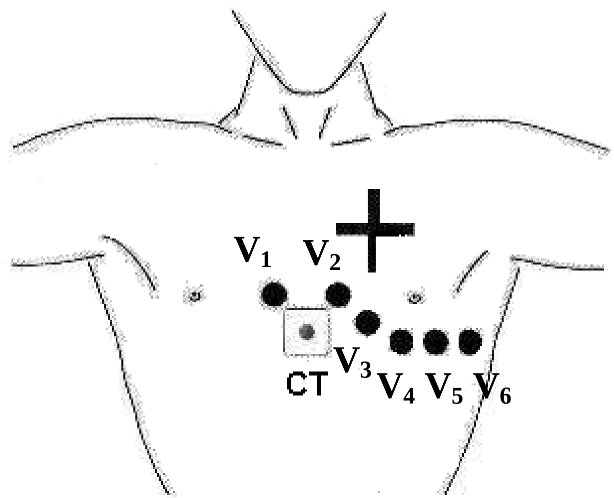
- Wilson advocated 5 kΩ resistances; these are still widely used, though at present the high-input impedance of the ECG amplifiers would allow much higher resistances.
- A higher resistance increases the CMRR and diminishes the size of the artifact introduced by the electrode/skin resistance.
- It is easy to show that in the image space the Wilson central terminal is found at the center of the Einthoven triangle.

▪ 12-Lead ECG – Precordial Leads

- The electrodes for the precordial leads (V1, V2, V3, V4, V5 and V6) are placed directly on the chest.
- Wilson's central terminal is used for the negative electrode, and these leads are considered to be unipolar .



Lead V_1



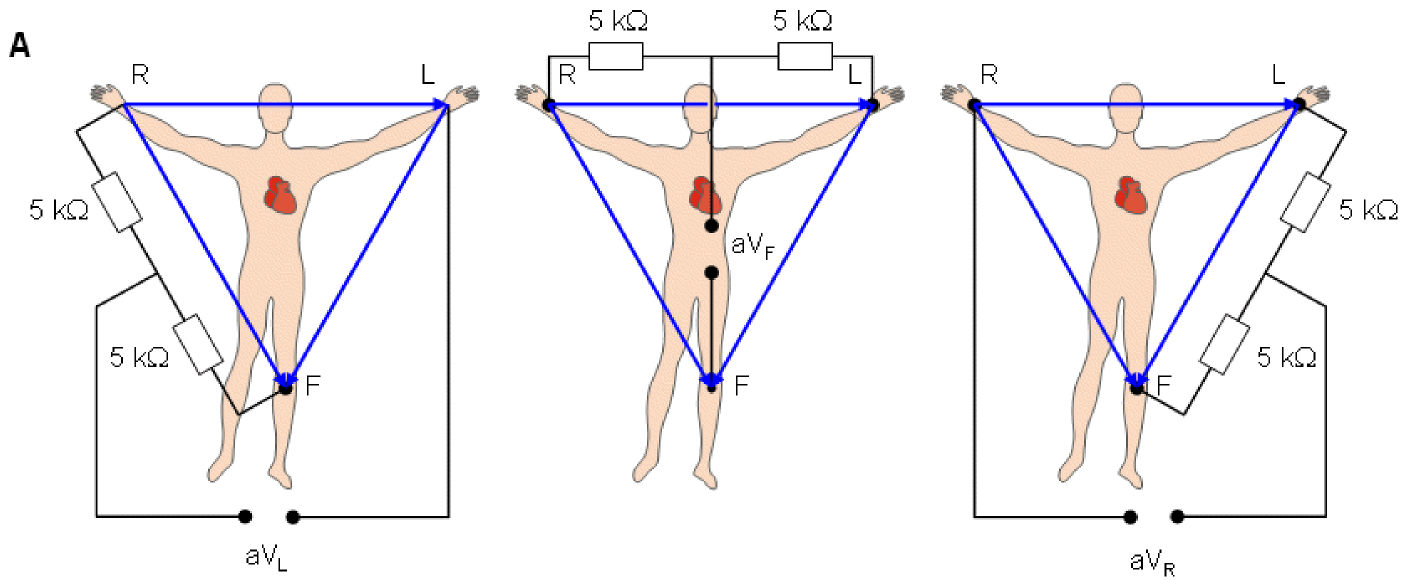
- Right foot (ground reference)

12-Lead ECG - Augmented Leads

- Three additional limb leads, V_R, V_L, and V_F are obtained by measuring the potential between each limb electrode and the Wilson central terminal.

$$V_F = \Phi_F - \Phi_{CT} = \frac{2\Phi_F - \Phi_R - \Phi_L}{3} \qquad (1)$$

- In 1942 E. Goldberger observed that these signals can be augmented by omitting that resistance from the Wilson central terminal, which is connected to the measurement electrode.

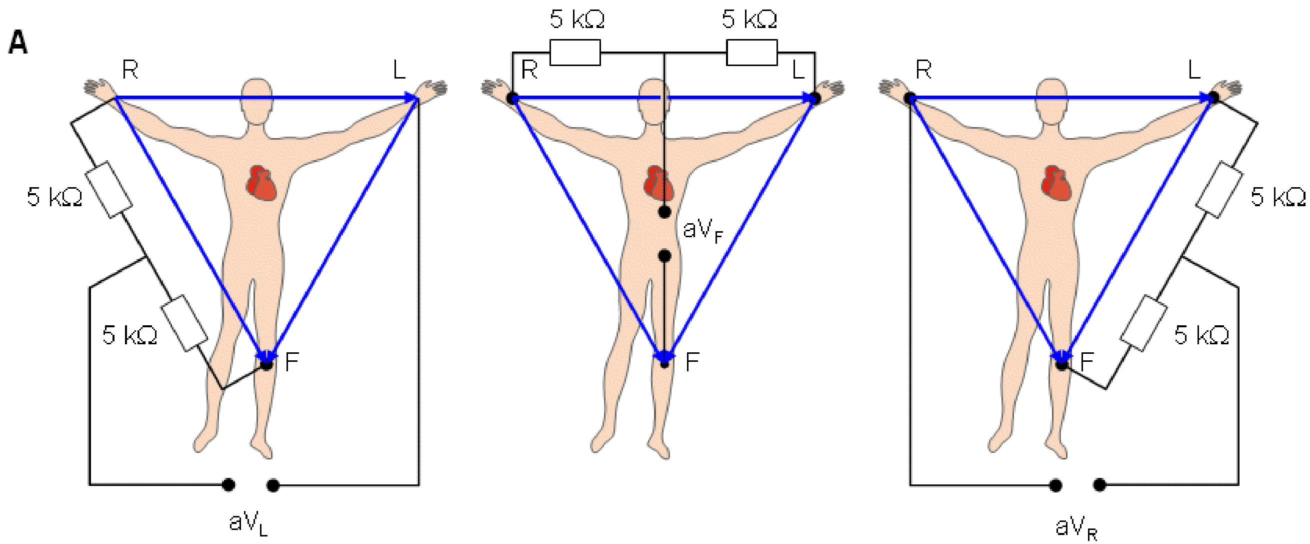


12-Lead ECG - Augmented Leads (Cont.)

- In this way, the aforementioned three leads may be replaced with a new set of leads that are called augmented leads because of the augmentation of the signal

$$V_{aV_F} = \Phi_F - \Phi_{CT/aV_F} = \Phi_F - \frac{\Phi_L + \Phi_R}{2} \qquad (2)$$

- A comparison of Eq 1 with Eq 2 shows the augmented signal to be 50% larger than the signal with the Wilson central terminal chosen as reference.
- It is important to note that the three augmented leads, aVR, aVL, and aVF, are fully redundant with respect to the limb leads I, II, and III.



12-Lead ECG - Augmented Leads (Cont.)

- The augmented unipolar limb leads are denoted aVF,aVL, and aVR and are defined as voltage differences between one corner of the triangle and the average of the remaining two corners:

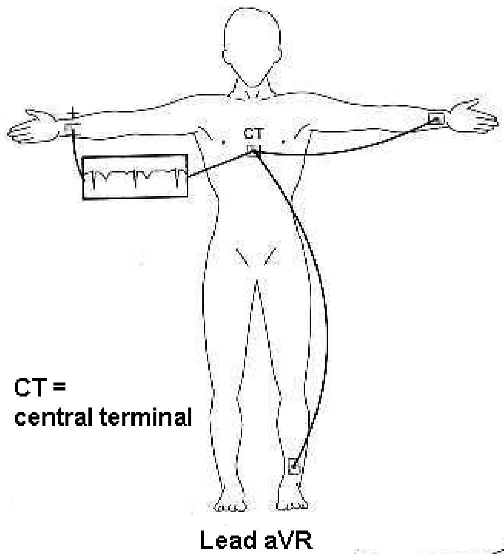
$$V_{aV_R} = \Phi_R - \Phi_{CT/aV_R} = \Phi_R - \frac{\Phi_F + \Phi_L}{2} \Longrightarrow -aVR = \frac{I + II}{2}$$

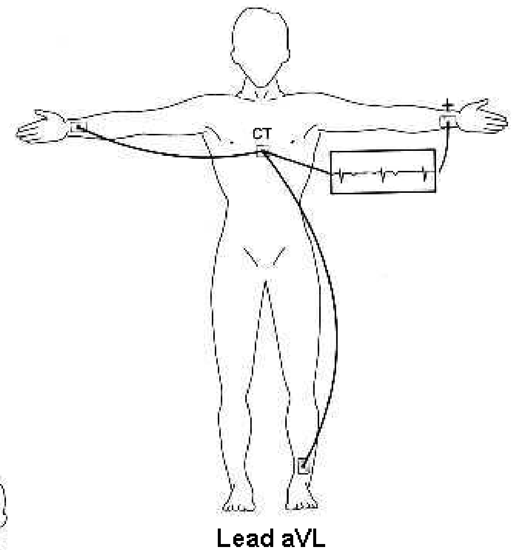
$$V_{aV_L} = \Phi_L - \Phi_{CT/aV_L} = \Phi_L - \frac{\Phi_F + \Phi_R}{2} \Longrightarrow aVL = \frac{2I - II}{2}$$

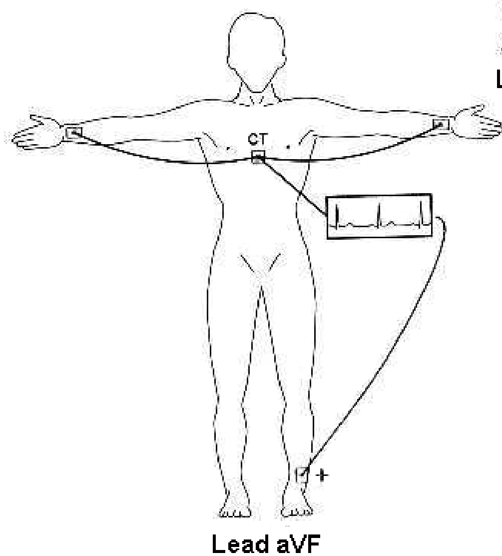
$$V_{aV_F} = \Phi_F - \Phi_{CT/aV_F} = \Phi_F - \frac{\Phi_L + \Phi_R}{2} \Longrightarrow aVF = \frac{2II - I}{2}$$

- Similar to lead *III*, the augmented limb leads do not have to be recorded but can be easily computed from leads *I* and *II*.

12-Lead ECG - Augmented Leads (Cont.)

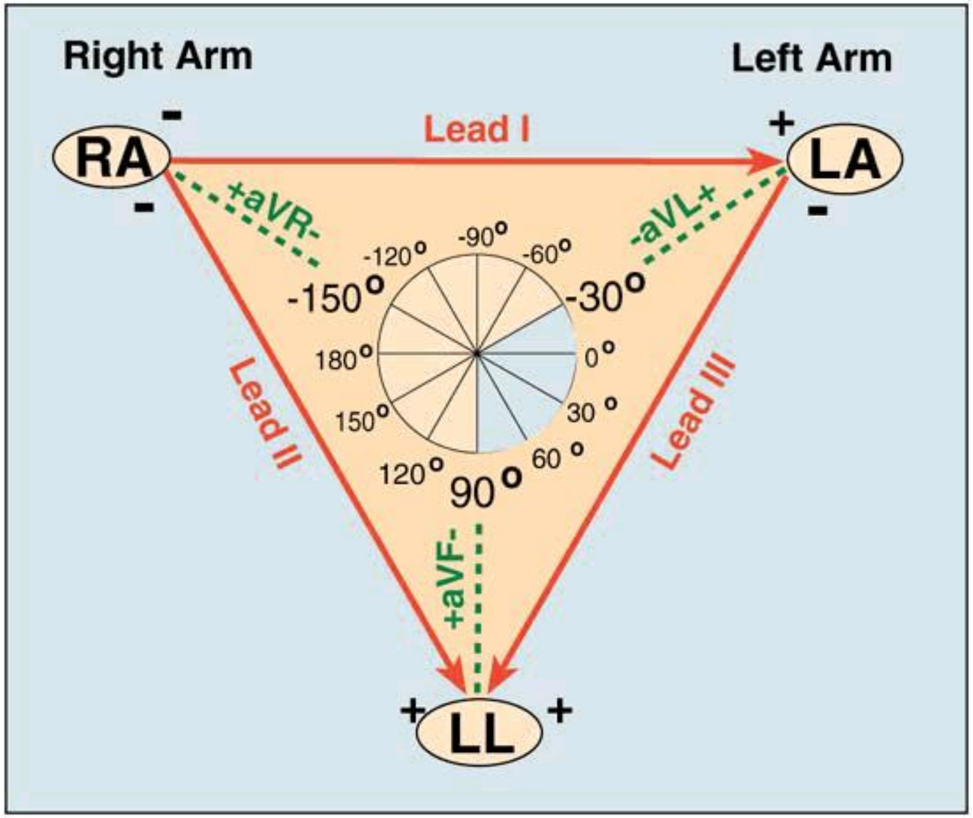


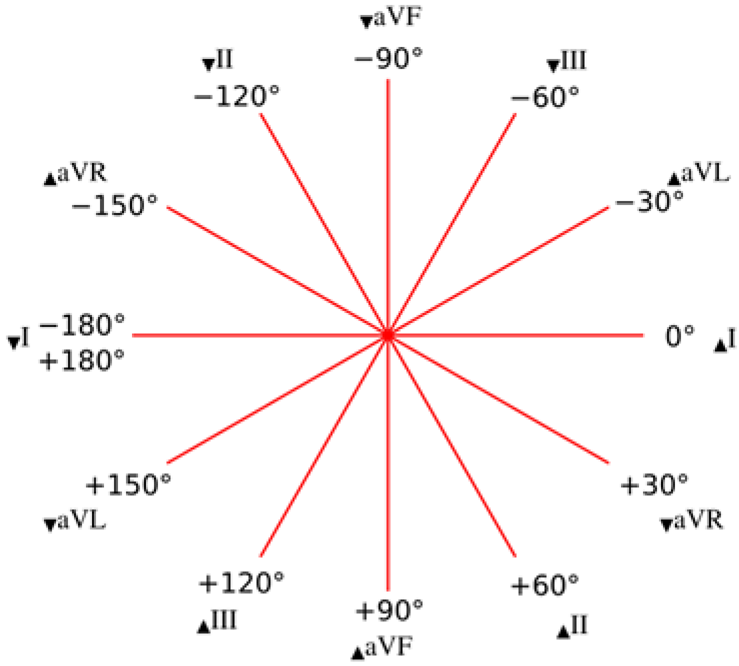




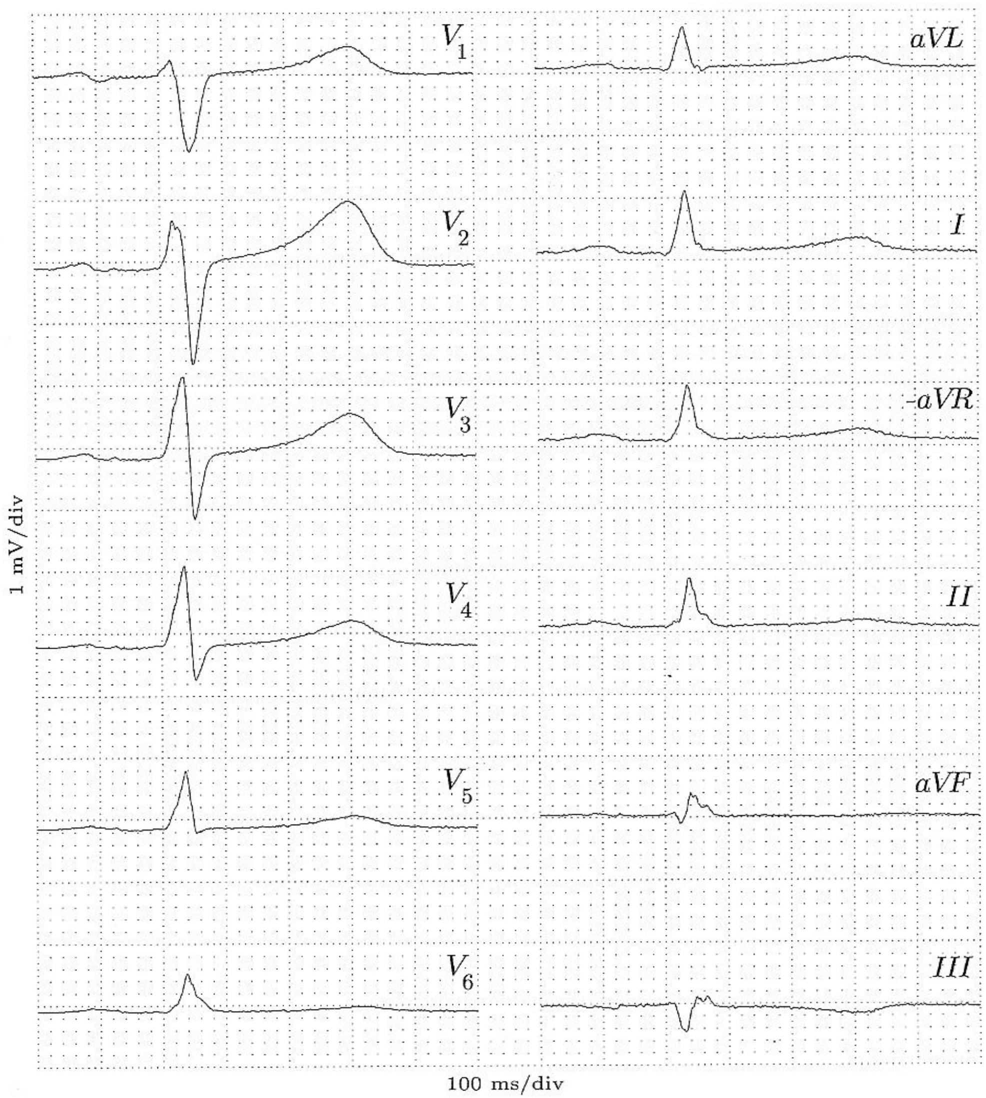
- Right leg
  (ground reference)

12-Lead ECG - Angles Between The Leads in Einthoven's Triangle

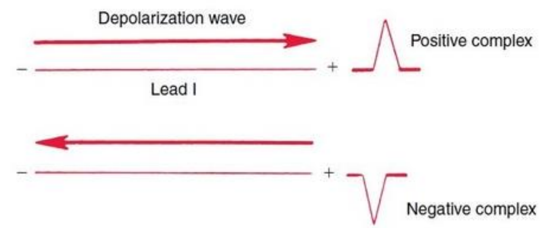


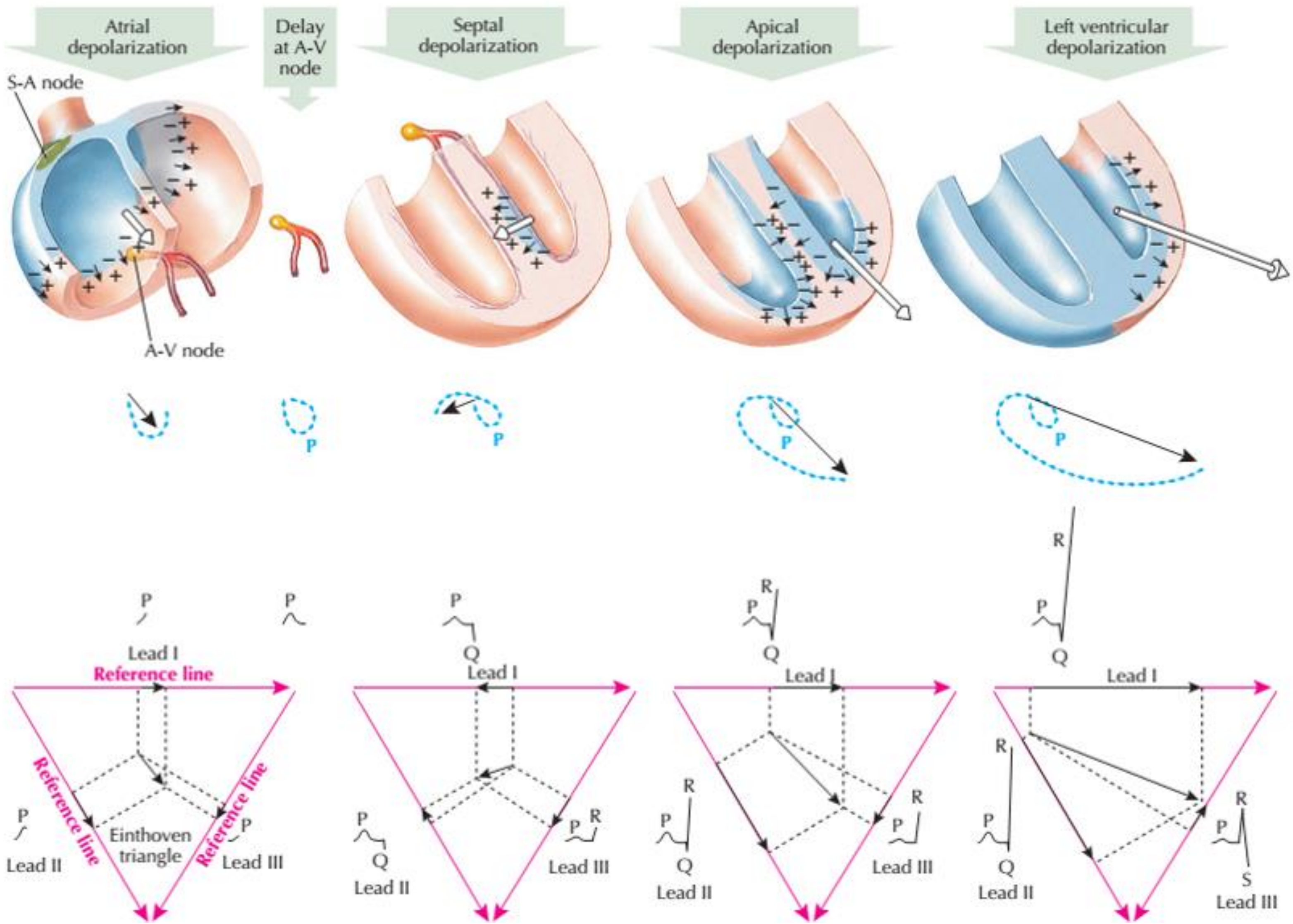


→ A record from 12-Lead ECG

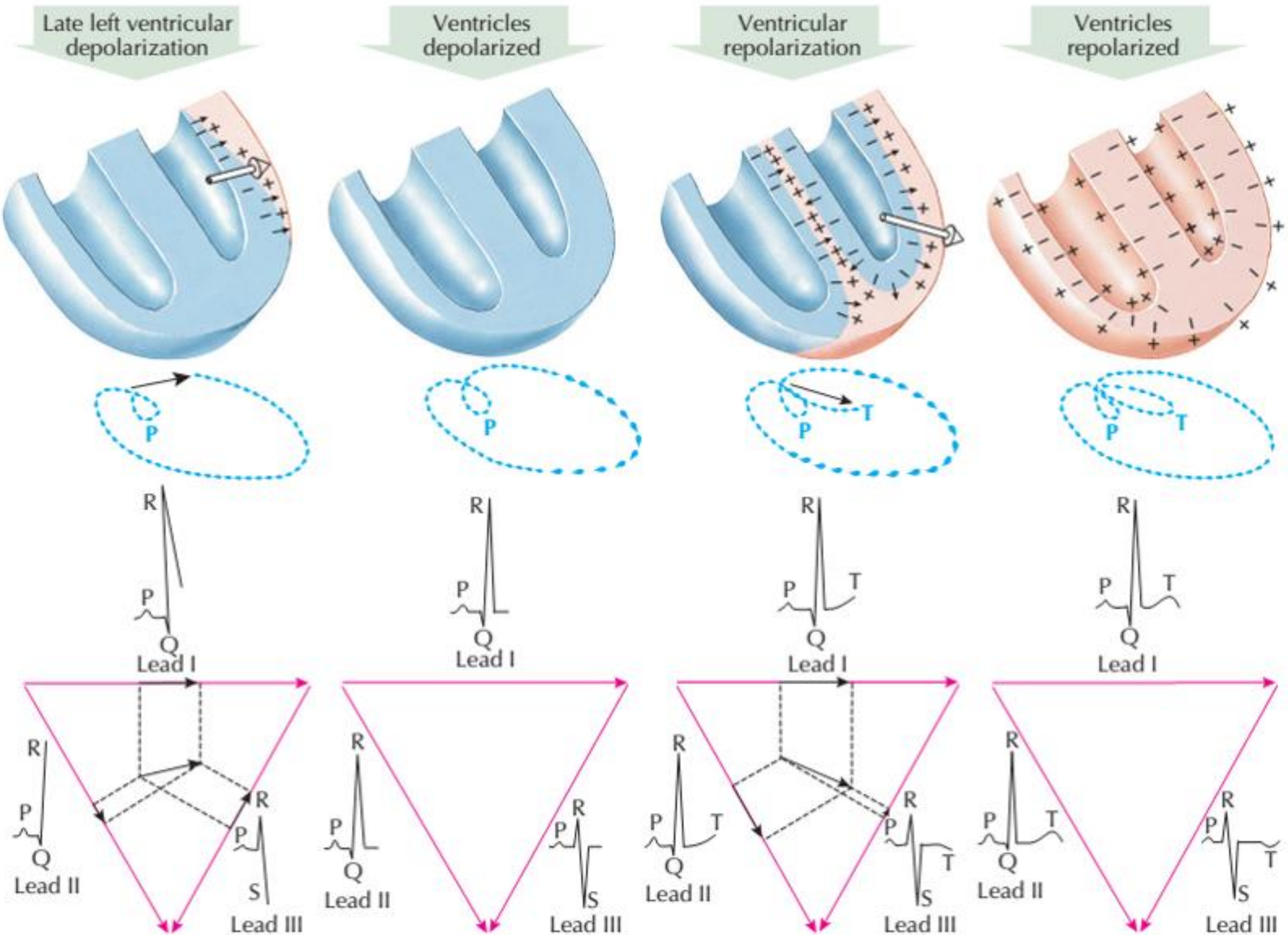


- MEAN INSTANTANEOUS VECTORS- Limb Leads

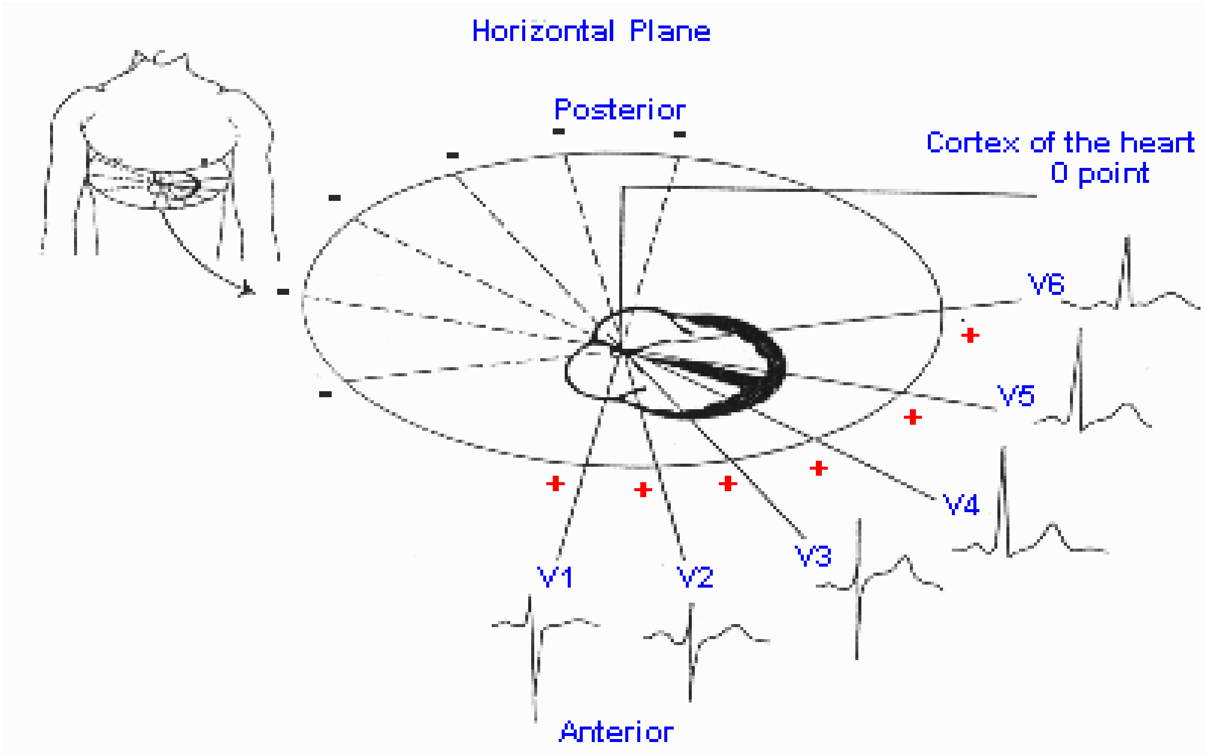


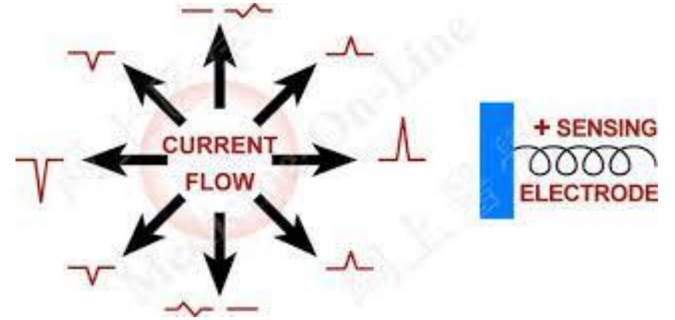


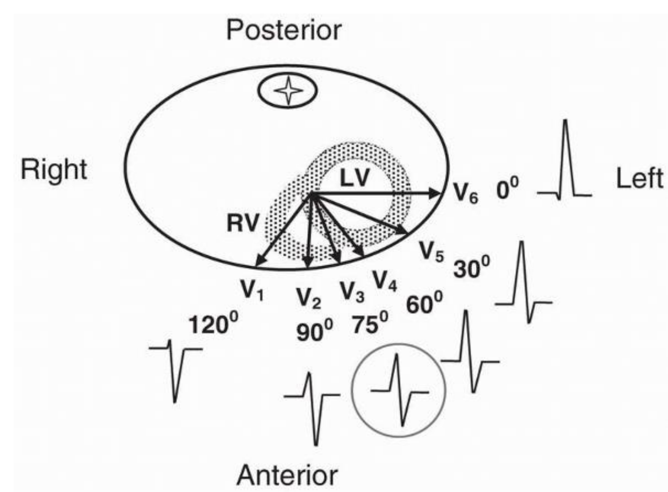
- MEAN INSTANTANEOUS VECTORS- Limb Leads



- MEAN INSTANTANEOUS VECTORS- Precordial Leads



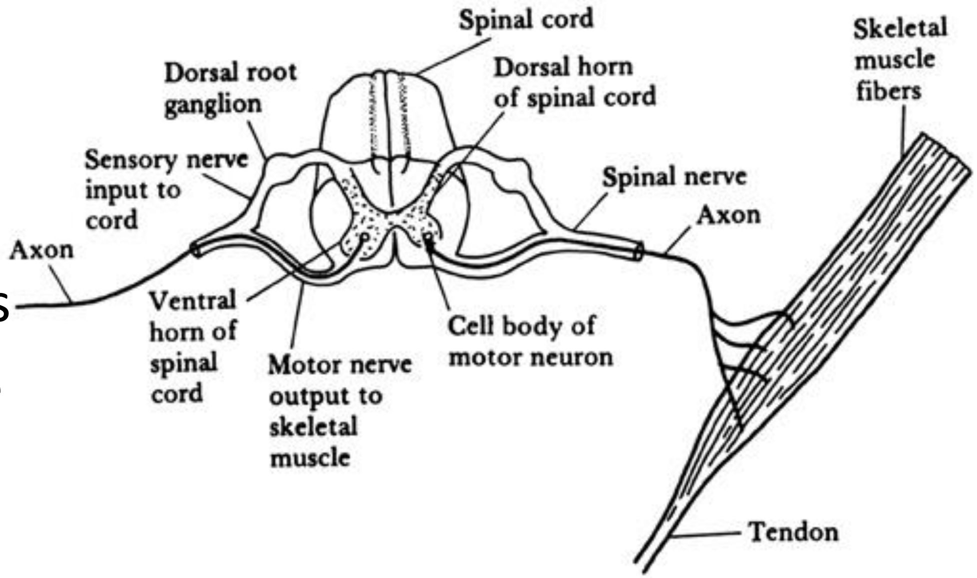




Electromyogram (EMG)

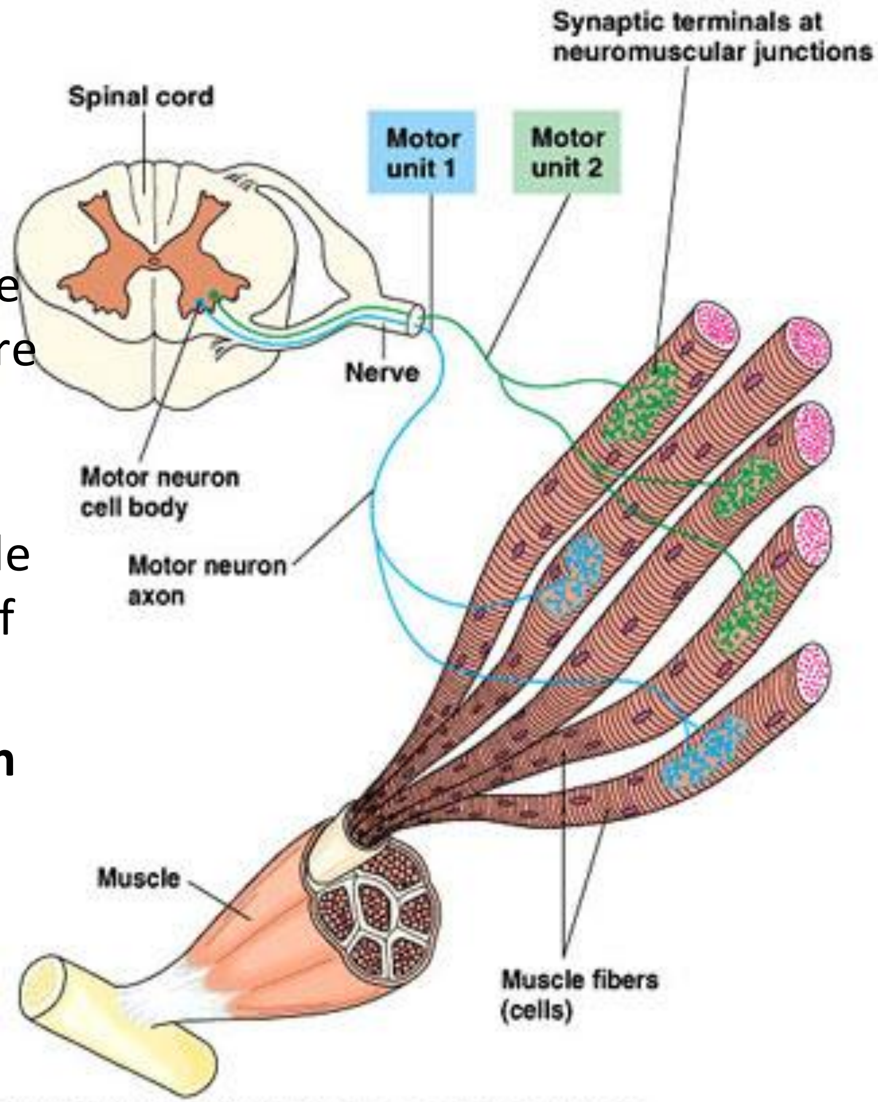
- EMG detects the electrical potential generated by muscle cells activated electrically or neurologically
  - composed of superimposed motor unit action
  - potentials (MUAPs) from several motor units

- Motor unit
  - a single motor nerve fiber
    and the bundle of muscle fibers
  - smallest unit of skeletal muscle
    that can be activated



Electromyogram (EMG)- (Cont.)

- Skeletal muscle is organized functionally on the basis of the single motor unit (SMU).
- SMU is the smallest unit that can be activated by a volitional effort where all muscle fibers are activated synchronously.
- SMU may contain 10 to 2000 muscle fibers, depending on the location of the muscle.
- **Factors for muscle varying strength**
  - Number of muscle fibers contracting within a muscle
  - Tension developed by each contracting fiber



Electromyogram (EMG)- (Cont.)

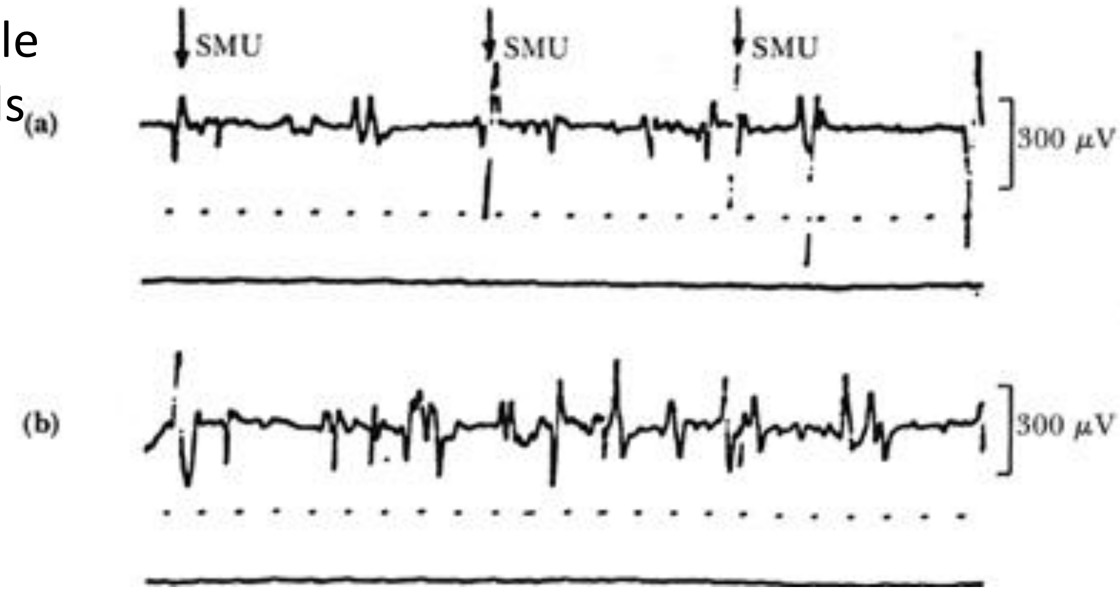
- The properties of the field potentials of the active fibers of an SMU are:
  - Triphasic waveform,
  - Duration of 3-15 ms,
  - Amplitude range from 20 to 2000 μV,
  - Discharge rate varies from 6 to 30 per second.

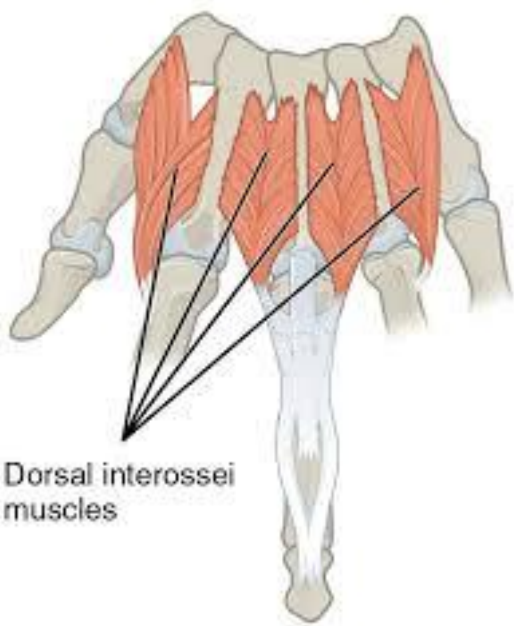
- Surface electrode record field potential of surface muscles and over a wide area.
- Monopolar and bipolar insertion-type needle electrode can be used to record SMU field potentials at different locations.

- Disadvantage of using surface electrode:
  - Only used with superficial muscle
  - Sensitive to electrical activity over too wide an area.
- Types of electrode for deep tissue recording:
  - Monopolar needle
  - Bipolar needle
  - Multipolar insertion-type needle

Electromyogram (EMG)- (Cont.)

- (a) and (b) shows observable motor unit action potentials from normal dorsal interosseus muscle during powerful contraction

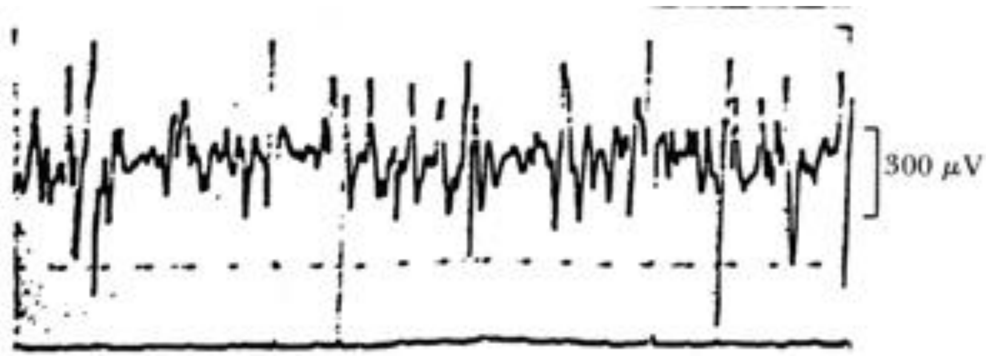




Electromyogram (EMG)- (Cont.)

- (c) shows the interference pattern where individual units are not distinguishable.

(c)



- (d) shows the interference pattern during very strong muscular contraction

(d)