Cardiovascular system

Introduction to the CVS (Physiologic anatomy, Heart valves and sounds).

Objectives:

1. Explain the functions of the heart.
2. Describe the flow of blood through the heart.
3. Explain the functions of the heart valves.
4. Explain the mechanism of the heart sounds.

The heart

The heart is a muscular organ enclosed in a fibrous sac (the pericardium).The pericardial sac contains watery fluid that acts as a lubricant as the heart moves within the sac. The wall of the heart is composed of cardiac muscle cells, termed the myocardium. The inner surface of the wall is lined by a thin layer of endothelial cell; the endothelium. The heart is actually two separate pumps; a right heart which pumps blood through the pulmonary artery into the lung, and a left heart which pumps blood through the aorta into the peripheral organ. Each of these two pumps is consists of two chambers, an atrium and a ventricle, separated by atrioventricular valve (left; mitral valve and right; tricuspid valve). Blood exists from the right ventricle through the pulmonary valve to the pulmonary trunk, and from the left ventricle through the aortic valve into the aorta.

Pulmonary and Systemic Circulations

Blood whose oxygen content has become partially depleted and carbon dioxide content has increased as a result of tissue metabolism returns to the right atrium. This blood then enters the ventricle, which pumps it into the pulmonary trunk and pulmonary arteries. The pulmonary arteries branch to transport blood to the lungs, where gas exchange occurs between the lung capillaries and the alveoli of the

lungs. Oxygen diffuses from the air to the capillary blood; while carbon dioxide diffuses in the opposite direction. The blood that returns to the left atrium by way of the pulmonary veins is therefore enriched in oxygen and partially depleted of carbon dioxide. The blood that is ejected from the right ventricle to the lungs and back to the left atrium completes one circuit: called **the pulmonary circulation.**
Oxygen-rich blood in the left atrium enters the left ventricle and is pumped into a very large, elastic artery; the aorta. The aorta ascends for a short distance, makes a U-turn, and then descends through the thoracic and abdominal cavities. Arterial branches from the aorta supply oxygen-rich blood to all of the organ systems and are thus part of the systemic circulation. As a result of cellular respiration, the oxygen concentration is lower and the carbon dioxide concentration is higher in the tissues than in the capillary blood. Blood that drains into the systemic veins is thus partially depleted of oxygen and increased in carbon dioxide content. These veins empty into two large veins; the superior and inferior venae cavae that return the oxygen-poor blood to the right atrium. This completes **the systemic circulation**; from the heart (left ventricle), through the organ systems, and back to the heart (right atrium).

Physiology of cardiac muscle

The heart is composed of three major types of cardiac muscle.

1- The atrial muscle.

2- The ventricular muscle.

3- Specialized excitatory and conductive muscle fibers; an excitatory system of the heart that helps spread of the impulse (action potential) rapidly throughout the heart.

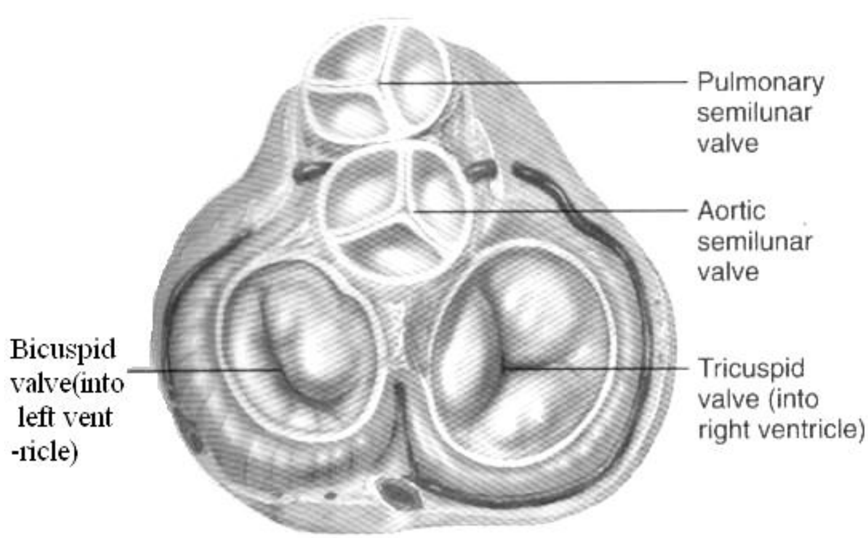
The function of the heart valves

The atrioventricular valves (AV valves) are composed of thin membranous cusps (fibrous flaps of tissue covered with endothelium), which hangdown in the ventricular cavities during diastole. After atrial contraction and just before ventricular contraction, the AV valves begin to close and the leaflets (cusps) come together by mean of backflow of the blood in the ventricles towards the atria.

The AV valves include:

- The mitral valve; the left AV valve; bicuspid valve, which consists of two cusps (anterior and posterior), located between left atrium and left ventricle.
- The tricuspid valve; the right AV valve, which consists of three cusps, located between right atrium and right ventricle.

The function of AV valves is to prevent backflow (prevent regurgitation; leakage) of blood into the atria during ventricular contraction. Normally they allow blood to flow from the atrium to the ventricle but prevent backward flow from the ventricle to the atria. The atrioventricular valves contain and supported by papillary muscles.



Function of papillary muscles

The AV valves (mitral and tricuspid) are supported by papillary muscles that attach to the flaps of these valves by the chordae tendineae. The papillary muscles originated from the ventricular walls and contract at the same time when the ventricular walls contract, but these muscles do not help the valves to close or open. Instead, they pull the flaps of the valves inward, toward the ventricles to prevent too much further bulging of the flaps (cusps) backward toward the atria during ventricular contraction, to prevent leakage of blood into the atria (keep the valve flaps tightly closed). In other words, contractions of papillary muscles prevent evertion of the flaps of the AV valves into the atria which could be induced by high pressure produced by contraction of the ventricles.

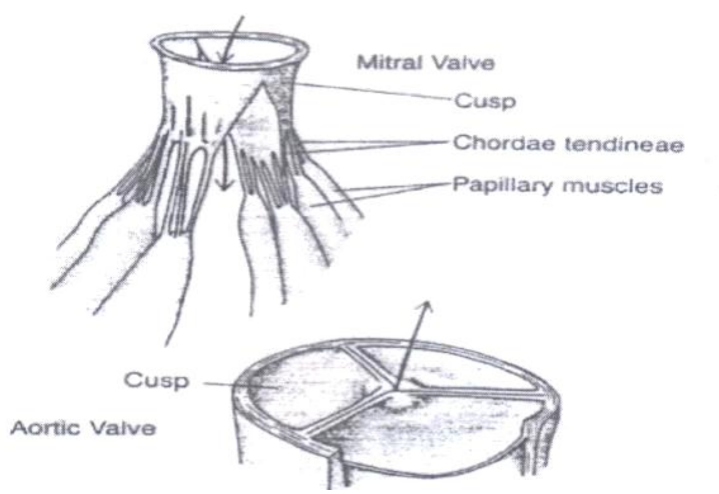


Figure: Mitral (two cusps) and Aortic (three cusps) valves.

Heart Sounds

When the stethoscope is placed on the chest wall over the heart, two sounds are normally heard during each cardiac cycle (1st & 2nd heart sounds). Heart sounds are associated with closure of the valves with their associated vibration of the flaps of the valves and the surrounding blood under the influence of the sudden pressure changes that develop across the valve. That is, heart sound does not produced by the opening of the valve because this opening is a slow developing process that makes no noise.

1-The first heart sound (S_1): is caused by closure of the AV valves when ventricles contract at systole. The vibration is soft, low-pitched lub.

2-The second heart sound (S_2): is caused by closure of the aortic and pulmonary valves when the ventricles relax at the beginning of diastole. The vibration is loud, high-pitched dup. It is rapid sound because these valves close rapidly and continue for only a short period i.e., rapid, short and of higher pitch dup.

3-The third heart sound (S_3): is caused by rapid filling of the ventricles, by blood that flow with a rumbling motion into the almost filled ventricles; at the middle one third (1/3) of diastole i.e., it is caused by the vibrations of the ventricular walls during the period of rapid ventricular filling that follows the opening of AV valves. It is a low-pitched sound and can be heard after the S_2. It is heard in normal heart; in children and in adult during exercise. It is also heard in anemia, and AV valve regurgitation.

4-The fourth heart sound (S_4): it is an atrial sound when the atria contract (at late diastole). It is a vibration sound (similar to that of S_3) associated with the flow of blood into the ventricle. It is not heard in normal hearts but occurs during ventricular overload as in severe anemia, Thyroitoxicosis (hyperthyroidism) or in reduced ventricular compliance and in hypertension. If present, it is heard before S_1. (S_4, S_1, S_2, S_3).

Heart murmurs

They are abnormal sounds, can be produced by blood flowing rapidly in the usual direction but through an abnormally narrowed valve (stenosis), by blood flowing backward through a damaged, leaky valve (incompetent, regurgitant valve) or by blood flowing between the two atria or two ventricles through a small hole: ASD (atrial septal defect), VSD (ventricular septal defect).

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*Pitch = the audible range of frequencies (cycles/sec).

Properties of the cardiac muscle

In addition, to the syncytium property, the cardiac muscle has the property of:

- Automaticity and rhythmicity (Autorhythmicity).
- Excitability and conductivity.
- Contractility

Autorhythmicity, Excitability and conductivity:

Electrical activity of the heart (action potential):

Objectives:

1. Describe action potentials in cardiac muscle cells.
2. Explain how the SA node functions as the pacemaker.

Specialized excitatory and conductive system of the heart: consists of:

1. Sinus node "SA" node: also called sinoatrial node, located in the right atrium. It is concerned with the generation of rhythmical impulse; it is the pacemaker of the heart that initiates each heart beat. This automatic nature of the heart beat is referred to as automaticity.

2. Internodal pathways conduct the impulse generated in SA node to the AV node.

3. The AV node (atrioventricular node), located near the right AV valve at the lower end of the interatrial septum, in the posterior septal wall of the right atrium. At which impulse from the atria is delayed before passing into the ventricles.

4. The AV bundle (bundle of His) conducts the impulse from the atria into ventricles.

5. The left and right bundles of purkinje fibers, which conduct the cardiac impulse to all parts of the ventricles. The purkinje fibers distribute the electrical excitation to the myocytes of the ventricles.

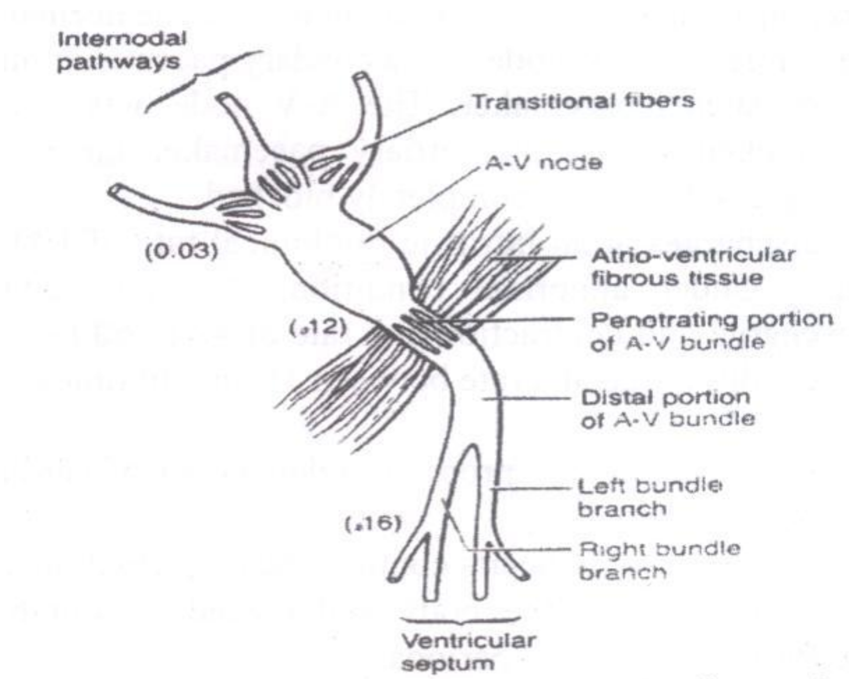


Figure: organization of the AV node.

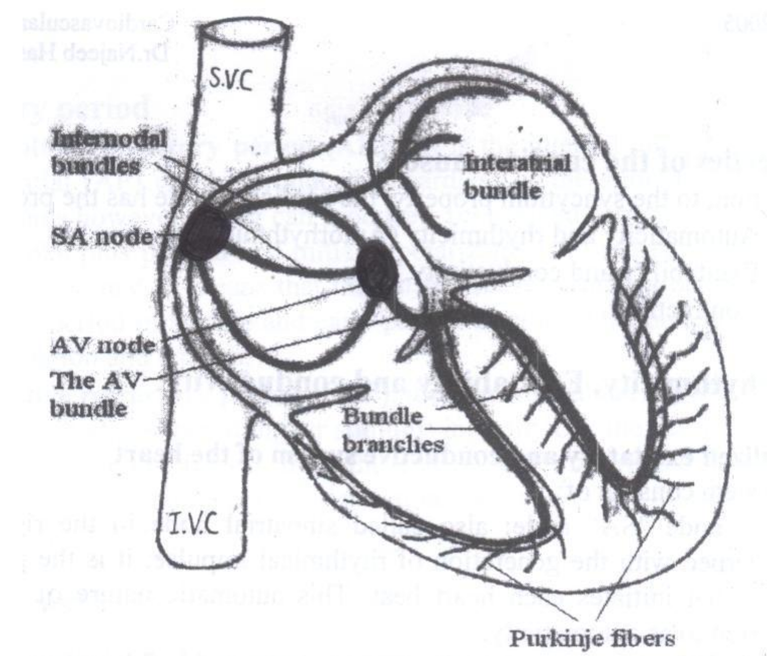


Figure: The cardiac conduction system.

The SA node as the pacemaker of the heart: (Automaticity & rhythmicity)

Automaticity is the property of self-excitation (i.e. the ability of spontaneously generating action potentials independent of any extrinsic stimuli) while rhythmicity is the regular generation of these action potentials. In other words, the cardiac impulse normally arises in the SA node, which has the capability of originating action potentials and functioning as pacemaker. This action potential then spreads from the SA node throughout the atria and then into and throughout the ventricles.

The contractile cardiac muscle cells don't normally generate action potentials but they can do in certain pathological conditions. This mean that all parts of the conduction system are able to generate a cardiac impulse; (autorhythmicity), but the normal primary pacemaker is the SA node, while the AV node is a secondary pacemaker and the Purkinje system is a tertiary (or latent) pacemaker. The AV node acts only if the SA node is damaged or blocked, while the tertiary pacemaker takes over only if impulse conduction via the AV node is completely blocked.

The SA node discharges at an intrinsic rhythmical rate of 100-110 times per minute (sinus rhythm). Under abnormal condition; the AV nodal fibers can exhibit rhythmical discharge and contraction at a rate of 40 to 60 times/minute. While those of purkinje fibers discharge at a rate between 15 and 40 times/minute.

Autorhythmicity is a myogenic property independent of cardiac innervation. This is evidenced by the following:

- Completely denervated heart continues beating rhythmically.
- Hearts removed from the body and placed in suitable solutions continue beating for relatively long periods.
- The transplanted heart (denervated heart) has no nerve supply but they beat regularly.

Atrioventricular node (AV node):

The conductive system is organized, so that cardiac impulse will not travel from the atria into ventricles too rapidly. There is a delay of transmission of the cardiac impulse in the AV node to allow time for the atria to empty their blood into the ventricles before ventricular contraction begins.

Ionic basis of the action potential of the cardiac ventricular muscle fiber cell:

The action potential of cardiac ventricular muscle fiber cell includes the following phases (a):

- **Phase 0** (upstroke): initial rapid depolarization with an overshoot to about +20 mV are due to opening of the voltage-gated Na^+ channels with rapid Na^+ influx.
- **Phase 1** (partial repolarization): initial rapid repolarization is due to K^+ efflux (K^+ outflow) followed the closure of Na^+ channels when the voltage reaches at nearly +20 mV.
- **Phase 2** (plateau): subsequent prolonged **plateau** is due to slower and prolonged opening of the voltage-gated Ca^{+2} channels with Ca^{+2} influx, Ca^{+2} enter through these channels prolong depolarization of the membrane.
- **Phase 3** (rapid repolarization): final repolarization is due to opening of the voltage-gated K^+ channels at zero voltage with rapid K^+ outflow (K^+ efflux) followed the closure of Ca^{+2} channels and, this restores the membrane to its resting potential.
- **Phase 4** (complete repolarization): The membrane potential goes back to the resting level (-90 mV) i.e., restoration of the resting potential. This is achieved by the Na^+-K^+ pump that works to move the excess K^+ in and the excess Na^+ out.

Relationship of the ECG to the cardiac cycle (Timing):

The ECG (electrocardiogram) shows the P, QRS and T waves. They are electrical voltages generated by the heart and recorded by the ECG:

- P-wave is caused by atrial depolarization; this is followed by atrial contraction, which causes a slight rise in the atrial pressure curve after the P wave.
- About 0.16 second after the onset of the P wave, the *QRS waves* appear as a result of electrical depolarization of the ventricles, which initiates contraction of the ventricles and causes the ventricular pressure to begin rising, as shown in the figure. Therefore, the QRS complex begins slightly before the onset of ventricular systole.
- T-wave represents ventricular repolarization at which the ventricles begin to relax. Therefore, the T wave occurs slightly before the end of ventricular contraction.

Relationship of the Heart Sounds to Heart Pumping

When listening to the heart with a stethoscope, one does not hear the opening of the valves because this is a relatively slow process that normally makes no noise. However, when the valves close, the cusps of the valves and the surrounding blood vibrate under the influence of sudden pressure changes, giving off sound that travels in all directions through the chest. When the ventricles contract, one first hears a sound caused by closure of the A-V valves. The vibration is low in pitch and relatively long-lasting and is known as the *first heart sound.* When the aortic and pulmonary valves close at the end of systole, one hears a rapid snap because these valves close rapidly, and the surroundings vibrate for a short period. This sound is called the *second heart sound.*

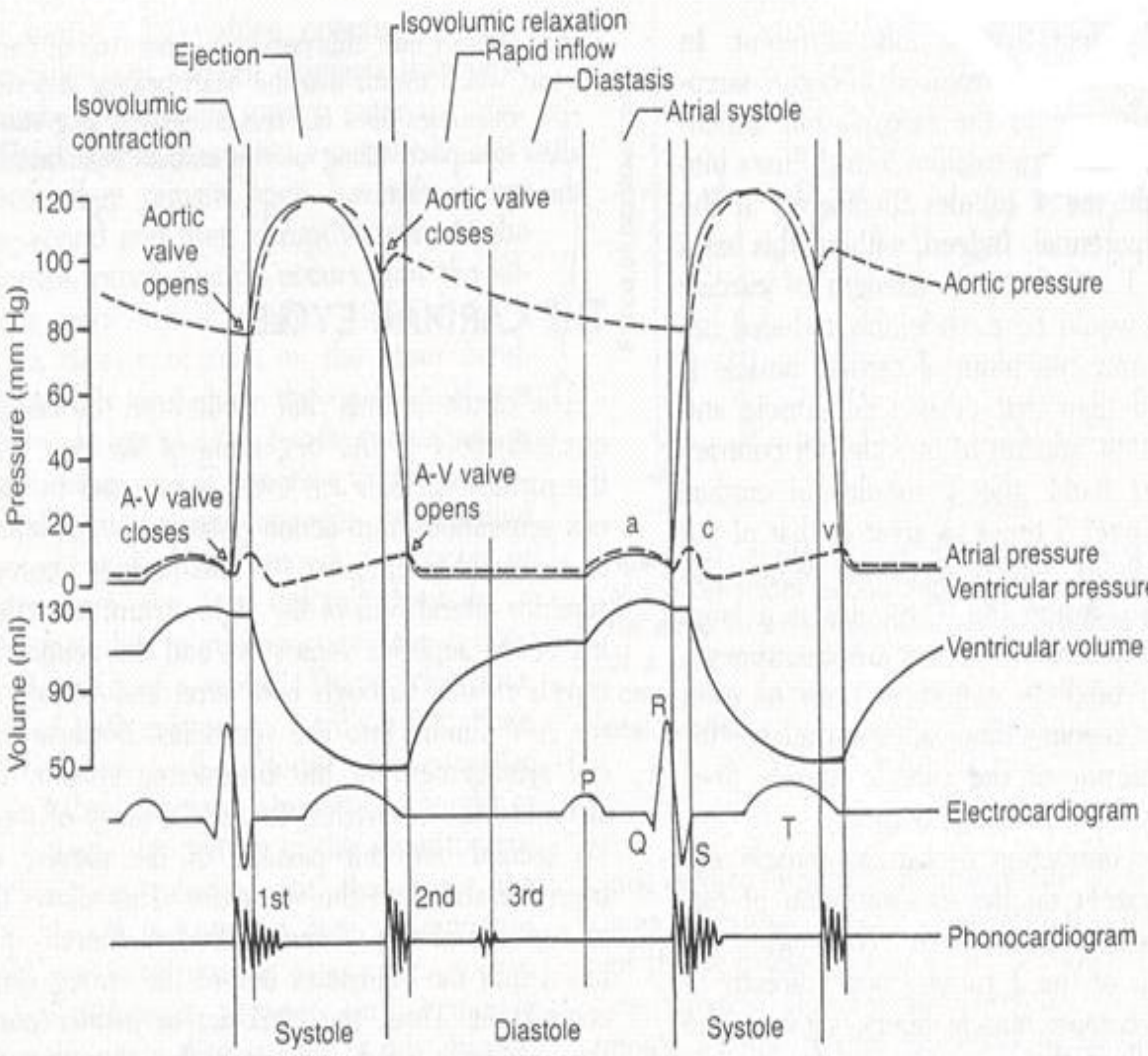


Figure 9–5. Events of the cardiac cycle for left ventricular function showing changes in left atrial pressure, left ventricular pressure, aortic pressure, ventricular volume, the electrocardiogram, and the phonocardiogram.

Electrical potential of the heart

The electrocardiogram (ECG):

Objectives:

1. Draw an ECG classical waveform and label each component (P, QRS, T).
2. Draw diagrams indicating the 6 standarad limb leads (I,II,III,aVR,aVL,aVF).

The ECG is the recording of the electrical potential of the heart that extend to the body surface. By placing the electrodes of an ECG instrument on the skin surface, you can record the waves of depolarization and repolarization that are generated by the cardiac muscle. The apparatus used is called the electrocardiograph; it is formed basically of a sensitive galvanometer and an amplifier.

A standard ECG consists of 12 leads:

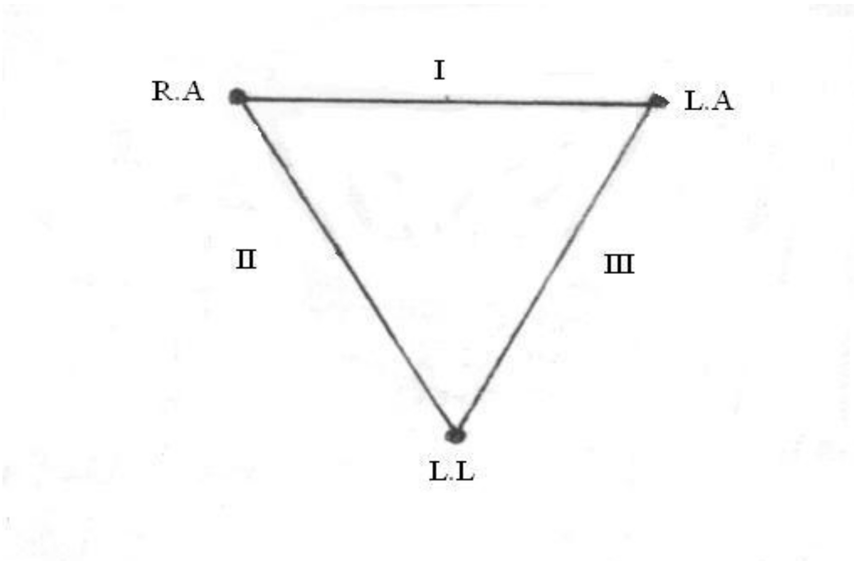
- 3 Bipolar standard limb leads (I, II, III).
- 3 unipolar limb leads (aVR, aVL, aVF).
- 6 unipolar chest leads.

Bipolar standard limb leads (I, II, III):

These leads record the differences between the potentials in 2 limbs, by applying electrodes usually at the wrist and ankle. The 3 standard bipolar limb leads include:

- Lead I: This records the difference between the potential in the left arm (LA) and that in the right arm (RA).
- Lead 11: This records the difference between the potential in the right arm (RA) and that in the left leg (LL).
- Lead III: This records the difference between the potential in the left leg (LL) and that in the left arm (LA).

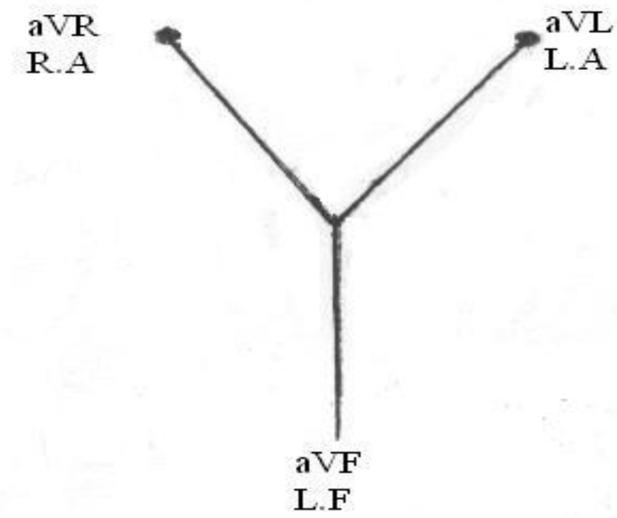
Einthoven's triangle: This is an equilateral triangle, the sides of which represent the 3 bipolar standard limb leads while the heart lies at its centre.



Unipolar limb leads (aVR, aVL, aVF):

These measure the absolute (actual) potential at a certain point. This is carried out by applying one electrode from the electrocardiograph to the desired point (it is active, +ve or exploring electrode) while the other electrode represents a common reference point inside the instrument; it is the -ve electrode (0 potential) i.e. the unipolar leads measure the potential differences between active electrodes and zero potential.

They are augmented unipolar limb leads that have magnified amplitudes by about 50 % without any change in their configuration, so they are called aVR, aVL and aVF (a = augmented).



Unipolar chest leads:

Unipolar leads (precordial or chest leads) record the absolute potential at 6 standard points on the anterior chest wall designated as V1 to V6, the locations of which are as follows:

- V1: At the right margin of the sternum in the 4th right intercostal space.
- V2: At the left margin of the sternum in the 4th left intercostal space.
- V3: Midway between V2 and V4.
- V4: At the left midclavicular line in the 5th intercostal space.
- V5: At the left anterior axillary line in the 5th intercostal space.
- V6: At the left midaxillary line in the 5th intercostal space.

The precordial leads look at the heart in a horizontal plane from the front & left sides. Leads V1 & V2 look at the right ventricle and reflect its activity, V3 & V4 look at the interventricular septum and reflect its activity, while leads V5 & V6 look at the left ventricle and reflect its activity.