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Chapter 5

The Cardiovascular System

5.1 INTRODUCTION

Blood is the major channel for communication between the different specialized organs of the body. It carries oxygen from the lungs to all parts of the body. It transports glucose, amino acids, fatty acids and all monomers from the digestive system and liver to all cells of the body. It also carries waste products of cellular metabolism to kidneys and lungs. In addition to above it carries hormones secreted by endocrine glands to target organs. Blood and tissue interchange molecules across the walls of capillaries. Capillaries are made up of endothelium (single layer of epithelial cells). Capillaries are in arterioles which are microscopic vessels with endothelium walls, smooth muscle and connective tissues. Arterioles receive blood from larger arteries. Then the blood is drained into venules. Venules in turn their blood into veins.

The distance between tissue and capillaries must be less than 0.1 mm to diffuse molecules into tissues. So, the vascular system is highly branched like a tree offers resistance to blood flow. This peripheral resistance has to overcome for adequate blood flow (perfusion). This is achieved by keeping the sufficient pressure. The pressure required to overcome peripheral resistance and perfusion is generated by the heart, the muscular pump. The device used to measure arterial pressure is sphygmomanometer.

5.2 THE HEART

The heart is a cone shaped, hollow muscular organ as shown in Figure 5.1. It weighs about 300 grams (220–260 g). Heart is divided by a septum into two sides, right and left. The two sides function independently. Each side of the heart is further divided into two chambers. The upper chamber is called atrium and lower chamber is called ventricle.

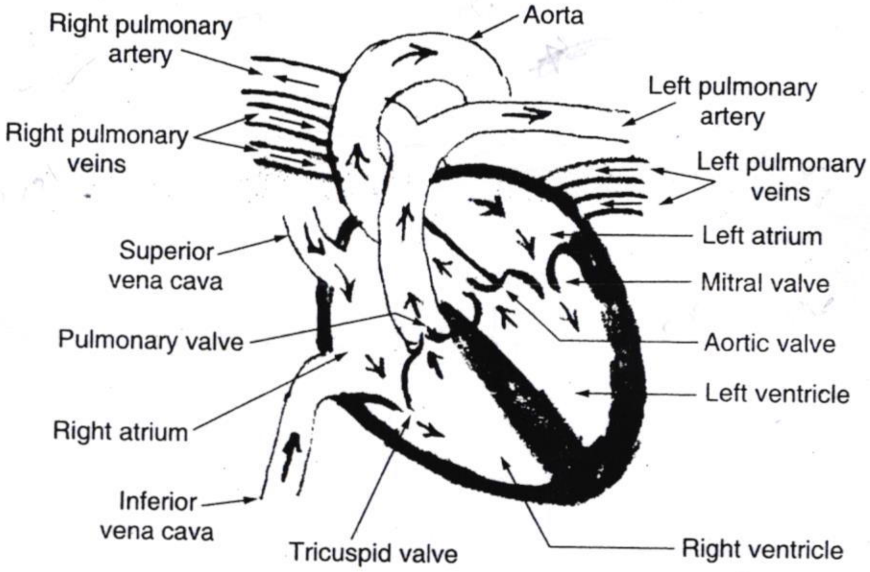


Figure 5.1 Heart.

The atria and ventricles of each side communicate with one another by means of the atrio ventricular openings. These openings are guarded by tricuspid valve in the right side and bicuspid valve (mitral valve) in the left side. These valves are unidirectional valves. It permits flow of blood from atrium to ventricle only. Tricuspid valve consists of three flaps or cusps. Bicuspid valve has two flaps. Heart is composed of special cardiac muscle and is surrounded by a membrane called pericardium. Pericardium consists of two layers; one is visceral pericardium and parietal pericardium. Heart lies in a double sac of pericardium with fluid between the two layers for lubrication and to move freely. The outermost layer is pericardium. The inner line is endocardium and the middle muscular layer is myocardium. Ventricle walls are very thick. Left is thicker than right ventricle wall.

The superior and inferior (one from the upper part of the body and the second from the lower part of the body) vena cava empty their blood into the right atrium. The openings of the aorta and pulmonary artery are guarded by the semi lunar valves. The valve between the left ventricle and the aorta is called aortic valve and this unidirectional valve allows flow from left ventricle to aorta only. The valve between the right ventricle and pulmonary artery is called the pulmonary valve. This unidirectional valve allows blood from right ventricle to pulmonary artery only.

The coronary arteries and pericardium receive blood from aorta. The right and left coronary arteries are the first to leave the aorta and these then divide into smaller arteries which encircle the heart and supply blood to all parts of the organ. Finally the blood is collected by the coronary sinus and returned directly into the right atrium. Even though the action of the heart is rhythmic in character, the rate of contraction of the heart is modified by the signals received from the vagus and sympathetic nerves. There are branches from these nerves into sino-artrial (SA) node. Control signal from sympathetic nerve accelerates the rate of heart beat while control signal from parasympathetic nerve inhibits or slows down the heart beat. Normally heart rate is being inhibited by the vagus. During physical work or emotional excitement the rate of the heart beat increases due to absence of vagal tone or removal of brake. In other words, during physical rest and emotional tranquility the heart rate decreases.

5.3 THE CARDIAC CYCLE

Heart is a pump and it circulates the blood in the entire body. The events occurring in the heart are called cardiac cycle. These sequences of events originate in the sino-atrial (SA) node by generating an EMF. At this instant, the atria contracted and then the electrical impulse moving along the bundle of His and make the ventricle to contract. Contraction is called systole. Similarly, relaxation is called diastole. Atrial contraction and relaxation are called atrial systole and atrial diastole respectively. Similarly, ventricular contraction and relaxation are called ventricular systole and ventricular diastole. Duration of ventricular systole and diastole are 0.3 seconds and 0.5 seconds. Heart beats for the life time and it only rests during ventricular diastole. Systole of atria is shorter than the ventricular systole. Left ventricle has to force the blood to the entire body so it is more forcible and longer. Whereas the right ventricle has to pump to lungs only requires less pressure, through the volume is equal to left ventricle. Figure 5.2 shows the bioelectric potential variation with respect to atrial and ventricular activities.

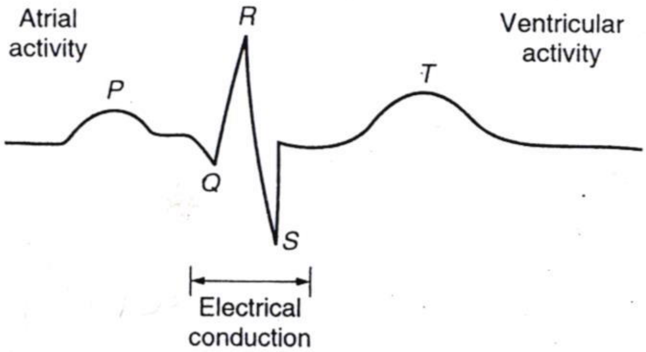


Figure 5.2 Atrial and ventricular activities.

Two sounds may be heard during the action of the heart due to passive closing of valves. Closing of atrio ventricular valves generate the first sound, whereas closing of aortic and pulmonary valves generate the second sound. The first sound is long and dull while the second one is short and sharp. The first one sounds like *lub* and the second sounds like *dub*. There are no other sounds except some extra noises called murmurs. The murmurs may be due to rapid flow of blood or due to deformities of the valves.

Arterial pulse is a wave of increased pressure which is felt at the arteries when blood is pumped out of the heart. A person may feel at any point where an artery crosses a bone and lies superficially. The pumping rate varies as a function of living conditions, working, food intake, age and emotion [see Table 5.1]. Pulse rate is proportional to cardiac cycle. If the pulse count is 80, the cardiac cycle will occur 80 times a minute.

Table 5.1 Normal Pulse Rate Range and Age Group

S. No.	*Age group*	*Heart rate pulse per minute*
1	Newborn infant	140
2	One year old	120
3	Two years old	110
4	Five years old	96–100
5	Ten years old	80–90
6	For an adult	70–80

The amount of blood pumped by heart (ventricle of heart) per minute is called cardiac output. Heart beat of a resting person is about 70 pulses per minute. It means the heart pumps 70 times a minute. The stroke volume is about 70 ml. Therefore, the cardiac output (amount of blood pumped by heart per minute) is 4900 ml (approximately 5 litres). Heart beat of an exercising person is about 150 pulses per minute. The stroke volume is about 150 ml. Therefore, the amount of blood pumped by heart per minute is 22500 ml (approximately 20 to 25 litres). An exactly equal volume of blood is supplied to the heart (returned to the heart) in the veins every minute. If the return blood is not balanced with delivery of blood, then the ventricles fail to deal with the cardiac output. This may lead to heart failure. Large veins near the heart swollen with blood leads to oedema. Oedema occurs due to the back pressure in the veins which increases the filtration of fluid in the capillaries and due to the low cardiac output which reduces the blood flow to the kidney. This may increase the level of sodium which causes retention of water.

5.4 THE CIRCULATION OF THE BLOOD

Heart is the principle organ for the circulation of the blood. It starts from left ventricle through arteries, arterioles and capillaries then returning to the right atrium through veins. This is called greater or systemic circulation. Blood circulation from the right ventricle through the lungs then enters into the left atrium is the lesser or pulmonary circulation. Figure 5.3 shows the flow of blood circulation.

Blood leaves the left ventricle of the heart through aorta, the largest artery in the body. This branches into smaller arteries and carries blood to various parts of the body. These smaller arteries branch further into still smaller arteria till they reach the arterioles. Arterioles have muscular walls which narrow their path and resist the flow of blood.

Arterioles have two functions. One is that it maintains the blood pressure by varying the thickness of the path and it regulates the flow of blood to the capillaries. Thin walls in the capillaries allow the exchange between plasma and the interstitial fluid. Capillaries unite and form larger vessels called venules and become veins. Veins unite to form venous trunks. Inferior vena cava collects blood from the venous trunks of lower extremities and superior vena

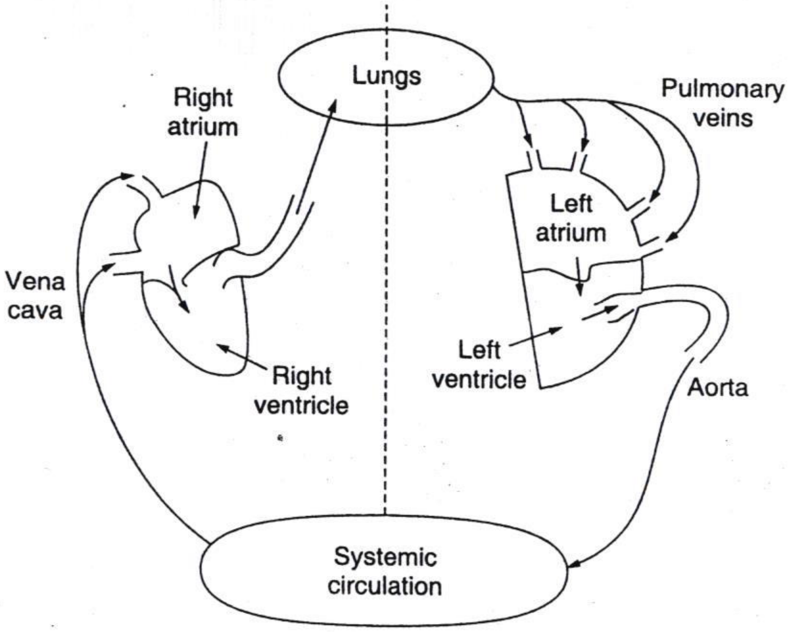


Figure 5.3 Flow of blood circulation.

cava collects blood from the venous trunks of upper extremities. Both inferior and superior vena cavas drain their blood into the right atrium of the heart. This part of circulation is called greater or systemic circulation.

Right ventricle receives blood from the right atrium and pumps into pulmonary artery. Pulmonary artery divides the blood into right and left lungs. The lungs give very small resistance to the blood in the branches of artery. Each branch of artery divides into many arterioles and further into pulmonary capillaries which cover the alveoli in the lung tissue. Release of carbon dioxide and absorption of oxygen takes place across the alveolar–capillary membrane. Then the pulmonary capillaries rejoin until veins are formed and the blood is returned to left atrium of the heart by four pulmonary veins. Blood then flows into the left ventricle and from there pumps into the aorta. This circulation is called lesser or pulmonary circulation.

Pulmonary oedema leads to failure of the left side of the heart. Lungs function may be impaired due to tissue fluid collected in the lungs. Pulmonary oedema may occur if a patient is over hydrated and his lungs may become water logged. In the lever, the blood from the stomach, intestines, pancreas and spleen are collected through portal vein. Another blood supply to the lever is from aorta through hepotic artery. Both these blood supply are getting into the capillary system to traverses the substances of this organ. Then the blood is collected by a system of veins which combine to form the hepatic vein. Hepatic vein sends the collected blood to the inferior vena cava and then to the heart. Portal blood circulation is shown in Figure 5.4. Portal obstruction may happen if a branch or some of the branches of portal vein are obstructed due to heavy injury to the liver or due to some instances in hepatitis.

The heart rate is controlled depending upon the SA node impulse frequency. But sympathetic nerve and vagus nerve cause the heart rate to fasten or slow down respectively depending upon the functional requirement and oxygen demand of the body. Function of presso receptors or baro receptors are to alter the vagal tone whenever the blood pressure within

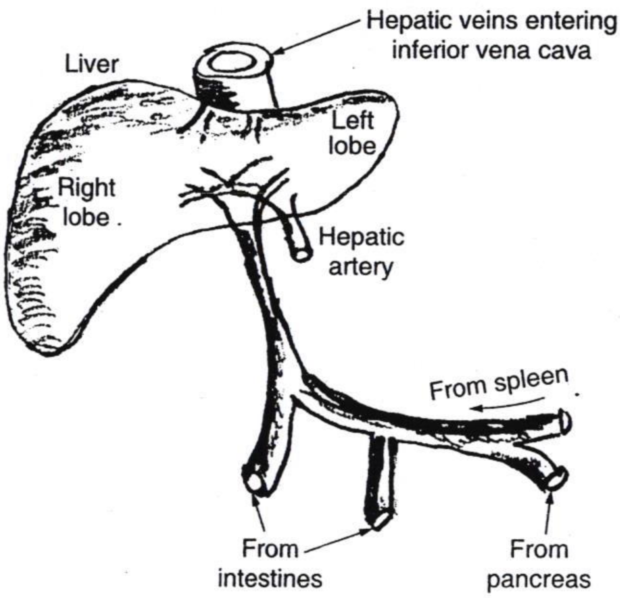


Figure 5.4 Portal circulation.

the aorta or carotid sinus changes. If the blood pressure rises, then vagal tone is increased and hence the heart rate slows down. Similarly, if the blood pressure falls, then the vagal tone is decreased and hence the heart rate increases.

5.5 BLOOD PRESSURE

Blood exerts some pressure against the wall of the blood vessels and this force of pressure is known as arterial blood pressure. This arterial blood pressure varies during cardiac cycle. When the left ventricle forces the blood into the aorta, then the pressure rises to a peak. This is called systolic pressure. Similarly, the pressure falls to the lowest value during diastole. This is called diastolic pressure. Systolic blood pressure is produced by the heart muscle which drives the contents of the ventricle into the already stretched arteries. During diastole the arteries are kept partly distended because the peripheral resistance of the arterioles prevents all the blood running off into the tissues. Thus, the blood pressure depends partly on the force and volume of the blood pumped by the heart and partly on the contraction of the muscles in the walls of the arterioles. This contraction is maintained by vaso constrictor nerves which are controlled by the vaso motor centre in the medulla oblongata of the brain. The vasomotor centre adjusts the peripheral resistance to maintain the blood pressure relatively constant. It changes slightly whenever physiological variations of exertion as in exercise, or with mental changes of anxiety and emotion, or as in sleep and when eating. For this reason the blood pressure is always taken when a person is relaxed, resting and preferably recumbent.

The events in the heart that relate to the blood pressure with respect to time should be understood for measurement of blood pressure. Figure 5.5 shows the blood pressure variations with respect to time. In Figure 5.5, both systole and diastole phases of operation are plotted. Along with this, blood pressure variation in aorta, left atrium, left ventricle are also plotted to show the phase and magnitude relationships. Note that Figure 5.5 also shows the correlation between ECG, heart sounds and blood pressure by plotting ECG and heart sounds in the same time scale.

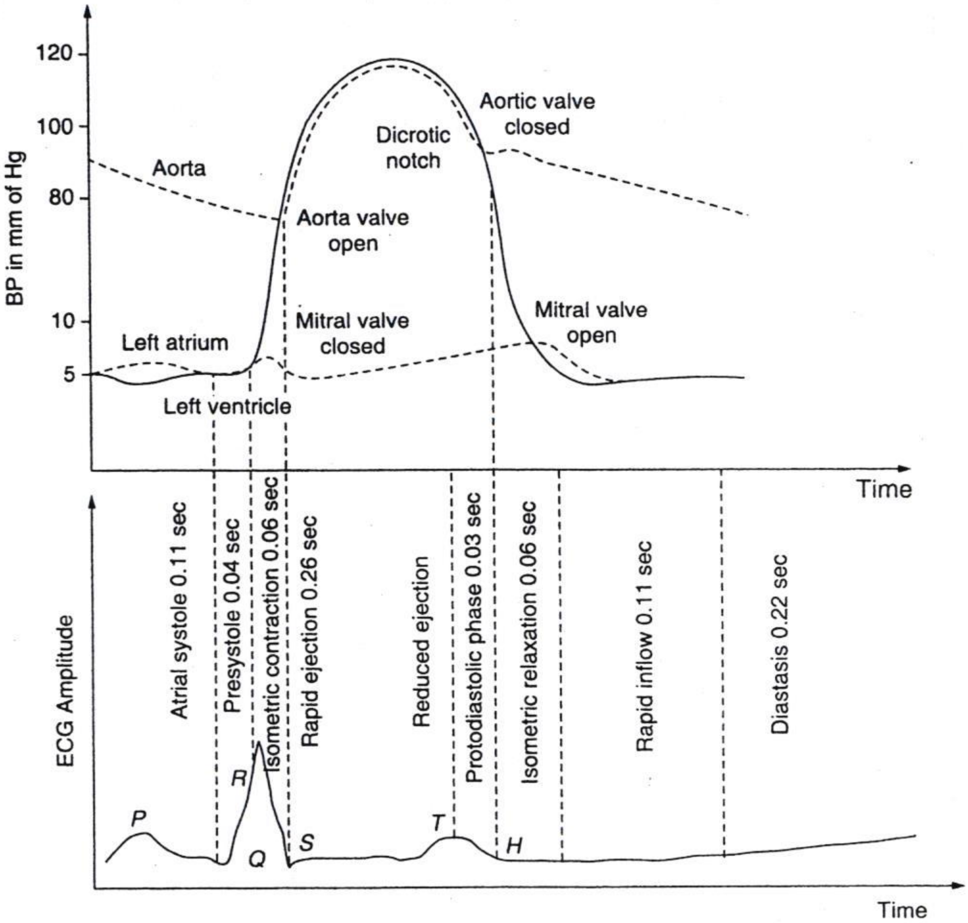


Figure 5.5 Blood pressure variation, ECG and heart sounds.

As shown in Figure 5.5, aortic wave shows that the ejection of blood from the left ventricle is fast at first. So, there is a sudden increase in pressure in the aorta. Then the pressure falls slowly resulting in a rounded maximum. Pressure falls slowly because it is the function of stroke volume of left ventricle, rate of ejection, and elongation of walls of aorta. A diseased heart may produce unwanted blood pressure (BP) due to ventricular contractibility and rigid arteries.

On completion of systolic period, aortic valve is closed by the back pressure of blood. This effect can be seen on the pressure pulse waveform as the dicrotic notch. Arterial pressure gradually decreases as the blood flows into the countless peripheral vascular system. The speed at which pressure decreases is function of maximum pressure reached during systolic, outflow rate to peripheral nerves and diastolic duration. Blood pressures at various points of system are shown in Table 5.2.

Table 5.2 Blood Pressure at Various Points of the System

S. No.	*Part*	*Blood pressure in mm of Hg*
1	Arterioles	30–60
2	Venous system (capillaries)	12–25
3	Venules	8–12
4	Vena cava	2–3

Note that the lowest pressure in the vein is about 2 mm of Hg. So, it requires a high accuracy instruments to measure venous pressure. Arteries and veins have large pressure difference. Veins carry low pressure blood only, therefore, it has thin walls whereas arteries have thick walls. Veins have larger inner diameter and carries 75–80% of total blood.

5.6 BLOOD FLOW CHARACTERISTICS

Blood flow is the volume of blood that crosses a point per unit time. It is measured in millilitres/min or litres/min. Blood flow is highest at pulmonary artery and in aorta. The flow rate at these two points is about 3.5 litres/min to 5 litres/min for an adult. In the capillaries the flow of blood cells can be observed by a microscope. Stroke volume of the blood can be calculated by dividing the cardiac output by number of heart beats per minute. Similarly, if the total volume of blood in the circulation is known, then the mean time for circulation can be calculated. This can be achieved by dividing the total volume by cardiac output.

In the arteries blood flow rate is pulsating during specific part of heart cycle. The elasticity of the walls damps out the pulsation in the arteries. Blood pressure and flow resistance of the blood vessels are analogous to electrical voltage and resistance in a circuit. Therefore, the flow rate of blood is proportional to blood pressure. The flow resistance of the capillary is function of temperature and drugs consumed. As temperature decreases, the capillaries are narrowed and resistance to blood flow is increased. This effect is called vaso-constriction of the capillaries. Similarly, increase in temperature, excitement and local inflammation widen the capillaries and increase the blood flow rate. This effect is called vaso-dilation of the capillaries. Hence the blood pressure alone cannot predict the status of the circulatory system. Velocity of the blood through the blood vessels is not uniform in the cross-section of the vessel. This is due to sticky effect of the blood on the walls. A typical velocity profile is shown in Figure 5.6.

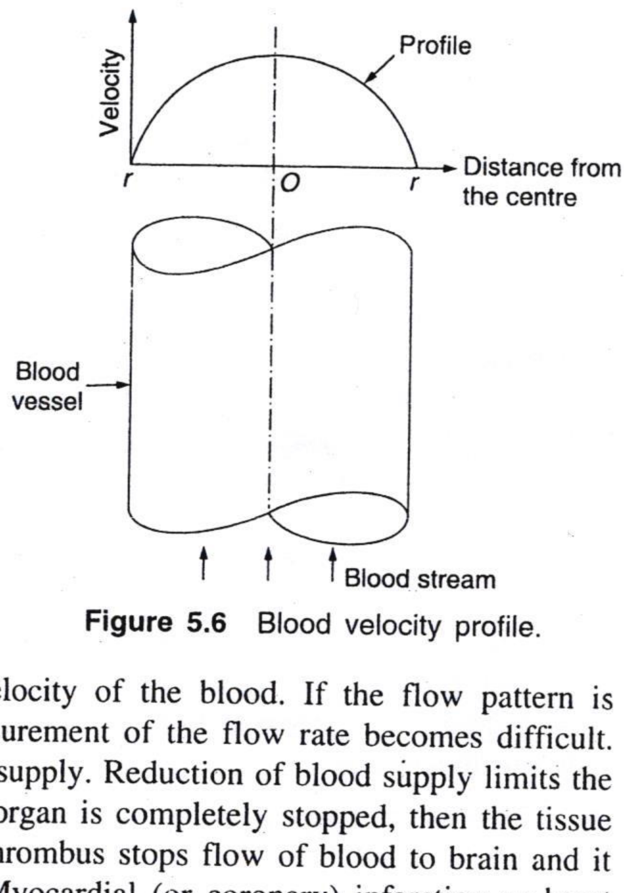


Figure 5.6 Blood velocity profile.

Blood flow meters measure the average velocity of the blood. If the flow pattern is changed from laminar to turbulent, then the measurement of the flow rate becomes difficult. Functioning of any organ depends upon the blood supply. Reduction of blood supply limits the function of that organ. If the blood supply to an organ is completely stopped, then the tissue in and around the organ may die. Blood clot or thrombus stops flow of blood to brain and it may lead to stroke or cerebrovascular accident. Myocardial (or coronary) infarction or heart attack may occur if any obstruction of blood flow occurs to coronary arteries of heart. If any reduced flow occurs in coronary arteries, then angina pectoris or severe chest pain may occur. Similarly, severe injury at one point may prevent the blood from returning to the heart and hence a shock may occur. Another reason cardiac failure may be due to leaking or torn heart valve. These problems are may lead to fatal results. Therefore, it is important to find the blood flow for early diagnosis and treatment.

5.7 HEART SOUNDS

Sounds and vibrations associated with heart will be useful to diagnoses some heart disorders. The method of observation of organ's sound and vessel's sound is called auscultation. It requires skill, experience and hearing ability to interpret leading to correct diagnosis. The heart sounds heard by physician through stethoscope appears that it is due to snapping of the heart valves. It is not so because of cushioning effect of the blood. It is the sound due to vibrations setup in the blood because of closure of valves and eddy currents induced in the blood as it is flowing through the closing valves. The *lub-dub* heard in the stethoscope caused by closure of atrioventricular valves and closing of semilunar valves respectively. *Lub* is the first heart sound and *dub* is the second heart sound. Apart from these two, a third and fourth sounds may be heard in young adults due to rush of blood frum the atria into ventricles and ventricular distension respectively. This third and fourth atrial heart sounds are not audible, but may be seen in the plot. The amplitude and frequency of all sounds are shown in Figure 5.7.

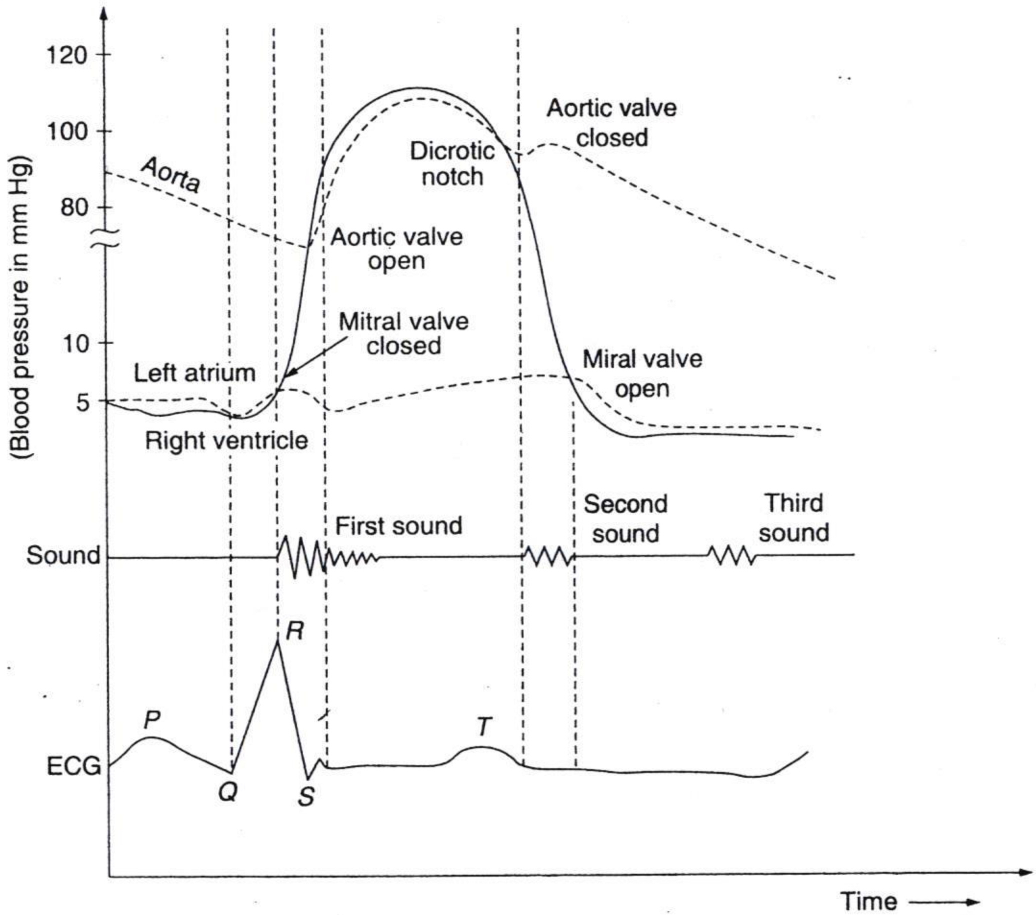


Figure 5.7 Relation between the blood pressure, ECG and heart sounds.

In addition to the four sounds, additional sounds may be heard. These additional in between sounds are called murmurs. These murmurs are all due to improper opening of the valves or due to backward flow of blood through incomplete closing of valves. Another murmur may be due to small opening in the septum, a separator of left and right side of the heart. This will by pass the blood from systemic circulation (goes from left heart to right heart).

Normal heart sounds are of quite short duration (about 0.1 second), while murmurs are long and between normal sounds. Figure 5.8 shows normal heart sounds and murmurs due to various problems in the system. The frequency of the heart sounds are tabulated in Table 5.3.

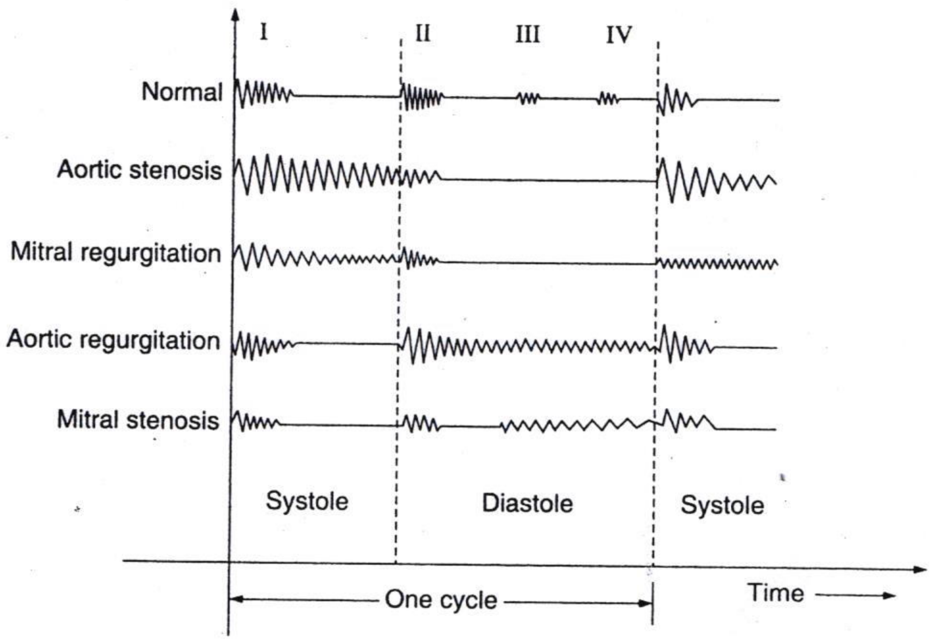


Figure 5.8 Normal and abnormal heart sounds and its causes.

Table 5.3 Heart Sounds and their Frequencies

S. No.	*Sound*	*Frequency range*
1	First sound	30–45 Hz
2	Second sound	50–70 Hz
3	Third sound	<30 Hz (weak)
4	Murmurs	even up to 600 Hz

The recording of heart sound is called phonocardiogram. Vibro cardiogram is the recording of vibrations of the side of the heart thumps against the chest walls. Apex cardiogram is the recording of vibrations due to tip or apex of the heart hitting the rib cage. Ballistocardiogram is recording of dynamic forces of heart as it beats and pumps into major arteries. The heart exerts certain forces on the body during its course of action, but because of greater mass of the body it cannot be noticed. By using special platform that is free to move because of heart dynamics, can be used to record the forces exerted by heart. This recording is called ballistocardiogram.

5.8 CARDIOVASCULAR MEASUREMENTS

The electrocardiogram (ECG) is the plotting of time varying potentials produced by myocardium during cardiac cycle. Figure 5.9 shows the fundamental waveform of the normal electrocardiogram. *P*, *Q*, *R*, *S* and *T* waves reflect the rythemic electrical depolarization and re-polarization of the myocardium in synchronization with the function of atria and ventricles. ECG is clinically used to find heart diseases and heart conditions. It can also be used as timing reference for other measurements. We have discussed how ECG waveform is generated in Chapter 1. The shape and duration of the each part of ECG waveform is important for physician. The waveform mainly depends upon the lead configuration used. The time duration of each significant part of ECG and its magnitudes are important for a cardiologist. Normal values of significant parts of ECG are given in Table 5.4.

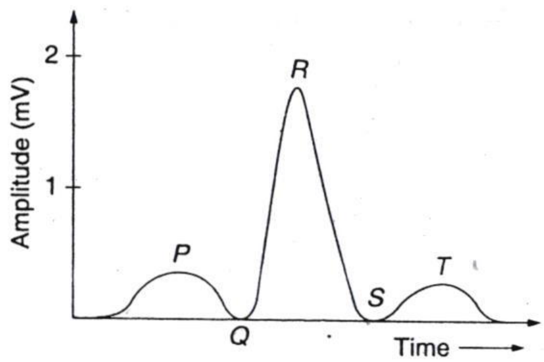


Figure 5.9 A typical ECG waveform.

Table 5.4 Significant Parts of ECG Signal

S. No.	*Wave*	*Amplitude*	*Interval/segment*	*Duration in seconds*
1	*P*	0.25 millivolts	*P–R*	0.12–0.20
2	*R*	1.60 millivolts	*R*	0.11
3	*Q*	25% of R Wave	*QT*	0.35–0.44
4	*T*	0.1 to 0.5 millivolts	*ST* and *QRS*	0.05–0.15 and 0.09

As a first thing, a cardiologist would like to see patient's heart rate. The normal value lies in the range of 60–100 beats/min. If the heart rate is less than this range, then it is called bradycardia, and if it is greater than this range, then it is called tachycardia. If the cycles are not evenly spaced, then it is called arrhythmia. Note that the *PR* interval is 0.12 second to 0.2 second. If this interval is greater than 0.2 second, then there may be a chance of blockage of the AV node. ECG of healthy heart is reasonably constant shape irrespective of heart rate. Electrical axis is defined as the line at which the maximum emf is generated during cardiac cycle. It is function of position of heart in the thoracic region and position of the body. Electrical axis shifts continuously but it has some repeatable pattern during every cardiac cycle. Depends upon the pathological conditions, several changes may reflect in the ECG. There may be modified paths of excitation in the heart, change in the origin of waves, change in the time sequence and change in the magnitude and durations.

Electrocardiograph is an instrument used to obtain and record the ECG waveforms. It is the first and widely used electrical instrument to diagnose the cardiac disorders. Even though it gives valuable information regarding myocardial infarction and arrhythmias, it is not possible to diagnose some disorders related with heart valves. It requires additional information that can be obtained by using angiography and echocardiograph.

5.9 ECG AMPLIFIERS

The main problem in the use of amplifiers in biomedical application is electrical interferences. This problem can be eliminated by using differential amplifiers as discussed in Chapter 3. The operation amplifier is a versatile device because it amplifies both ac and dc input signals. Generally the differential amplifier, as discussed in Chapter 3 are used in biomedical applications to amplify differences between two input signals such as the output of the Wheatstone bridge circuits. Differential amplifiers are preferred in these applications because they can reject common mode (noise) voltages better than the single input circuits. Therefore, instrumentation amplifier (differential amplifier with high input impedance) is used for the ECG measurement applications.

5.10 ELECTRODES AND LEADS

To record an ECG, usually five electrodes are affixed to the body of the patient. These electrodes are connected to the ECG machine by wires. These wires are called leads. Voltage generated by the pumping action of the heart is vector quantity and time varying. ECG is recorded by using electrodes placed at various points on the body. The quality and appearance and disappearance of some segments depend upon the placement of the electrodes. Because of this, ECG is recorded from number of leads, (usually 5 but it may vary up to 12), to ensure the ECG with important details. Placement of electrodes, names of electrodes and configuration of the leads are standardized and are used the same way throughout the world.

5.11 ELECTRODES

The point at which the electrode to be attached, colour code used to identify each electrode are shown in Figure 5.10. Einthovan found (1912) that it is advantageous to record ECG by placing the electrodes horizontally as well as vertically. He used only three electrodes. Two electrodes will be placed each in one hand and the one in the left leg. He selected the left leg probably because it terminates vertically below heart. Nowadays electronic amplifiers are used; it requires an additional connection as a reference. This reference may be selected anywhere in the body, but using the right leg is convention. As a fifth electrode, chest or pericardial electrode was introduced later. This electrode is normally suction type while other electrodes are plate electrodes.

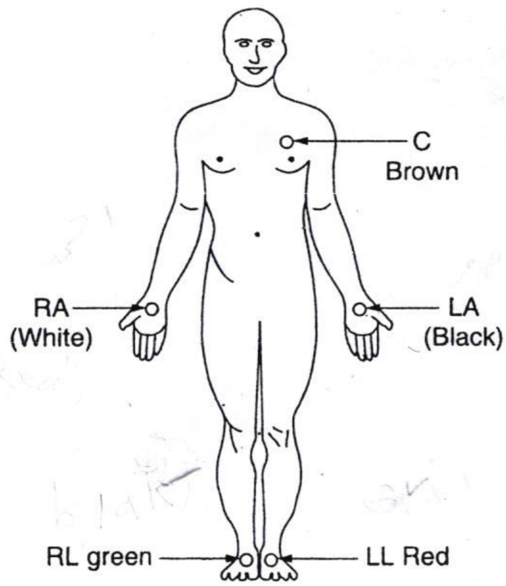


Figure 5.10 Abbreviations and colour codes for ECG electrodes.

5.12 LEADS

Four electrodes are normally used to record ECG and the fifth in the right leg is used as reference. To record the ECG, it requires only two leads at a time. Therefore, a selection must be made among the available electrodes. The 12 standard leads used most frequently are shown in Figure 5.11. The first three are introduced by Einthoven. Lead I configuration is between left arm (LA) and right arm (RA), Lead II configuration is between left leg (LL) and right arm (RA)

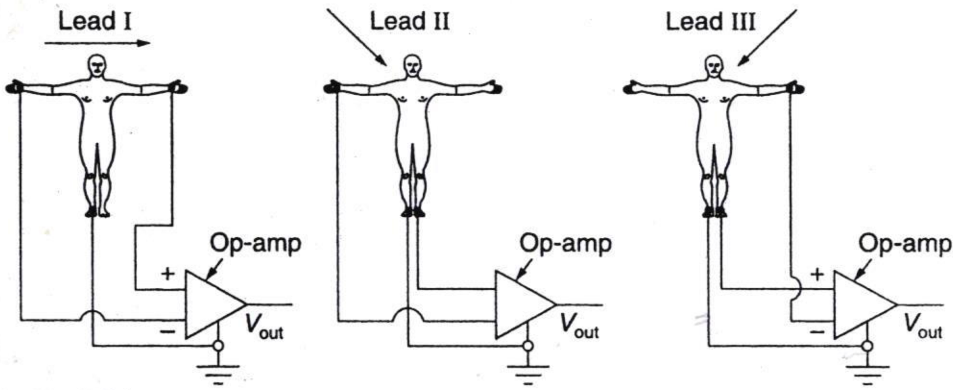
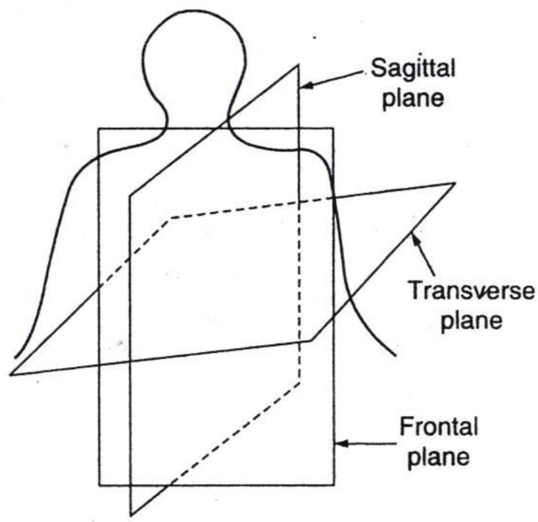
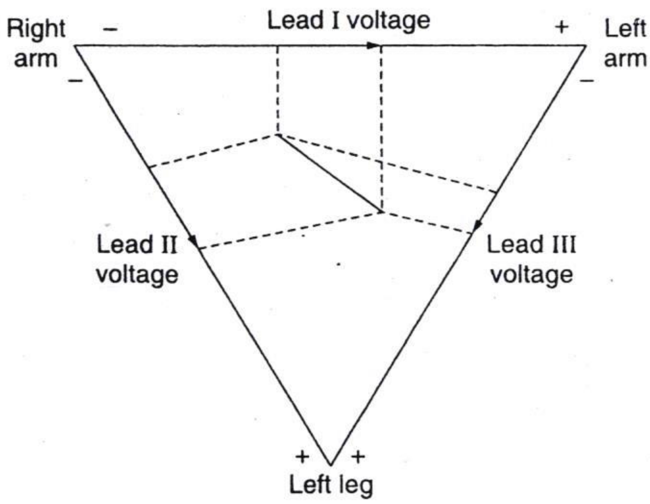


Figure 5.11 Einthovan lead configurations.

and Lead III configuration is between left leg (LL) and left arm (LA). This type is called bipolar limb leads. In this type only two leads are used at a time and the third one is left free. In this Einthovan method, the frontal plane representation of electrical axis of the heart is a two-dimensional vector as shown in Figure 5.12(a). Einthovan also assumed that the origin of the vector is near the centre of an equilateral triangle whose apexes are the right and left shoulder and the crotch. He further assumed that ECG potentials at the shoulders are equal to the potentials at the wrists. Similarly, he assumed that the potential at the crotch differ little from ankle and the apexes are electrode positions. This triangle is called Einthovan triangle as shown in Figure 5.12(b). Potentials of the three leads are represented by three vectors parallel to the



(a) Cardiography plane



(b) Einthovan triangle

Figure 5.12 Einthovan triangle.

sides of the triangle. Einthovan proved that sum of the three vectors is zero. In other words, sum of any two vectors is equal to the third vector. This becomes practically true when lead II is reversed. The amplitude of the R wave of lead II is equal to the sum of the R wave amplitudes of lead I and lead III. ECG waveform obtained in this method is shown in Figure 5.13. The human torso is neither homogeneous nor triangular, therefore, the electric field of heart is distorted. The measurements obtained in this method do not give accurate values, but the clinical interpretation of this data is purely empirical from the extensive analysis of normal and abnormal ECG's.

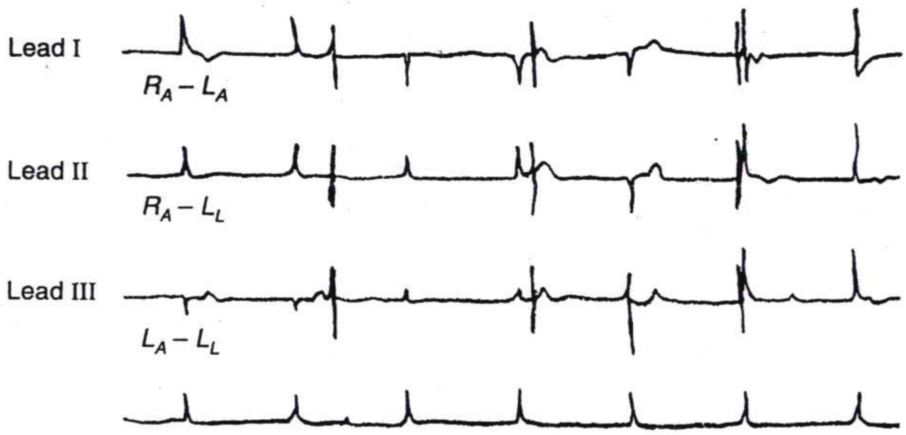


Figure 5.13 ECG waveform in Einthovan configuration.

The next type is unipolar type introduced by Wilson in 1944. In this method the ECG is recorded between a central electrode and exploratory electrode. Potential of the central electrode is corresponding to the centre of the body. The central electrode is obtained by connecting LA, LL and RA through equal resistors. But this method gives very small amplitude, therefore, a modified version of this is used as shown in Figure 5.14.

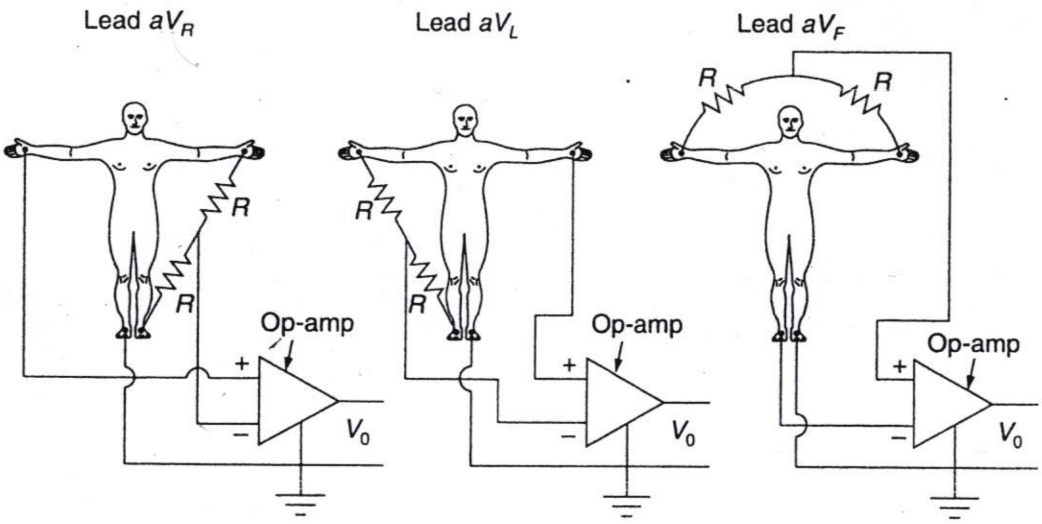


Figure 5.14 Augmented unipolar lead configurations.

This method is called augmented unipolar limb leads. In this method, central electrode is not the combination of all three. Instead of this, except exploratory electrode, other two electrodes are connected to form the central electrode. There is no appreciable change between the unipolar and augmented unipolar method except the amplitude. The leads in the augmented method are designated as aV_R, aV_L and aV_F. The third variation is unipolar chest leads. In this case, a single exploring electrode as a chest electrode is sequentially placed on each six pre-designated points on the chest as shown in Figure 5.15(a).

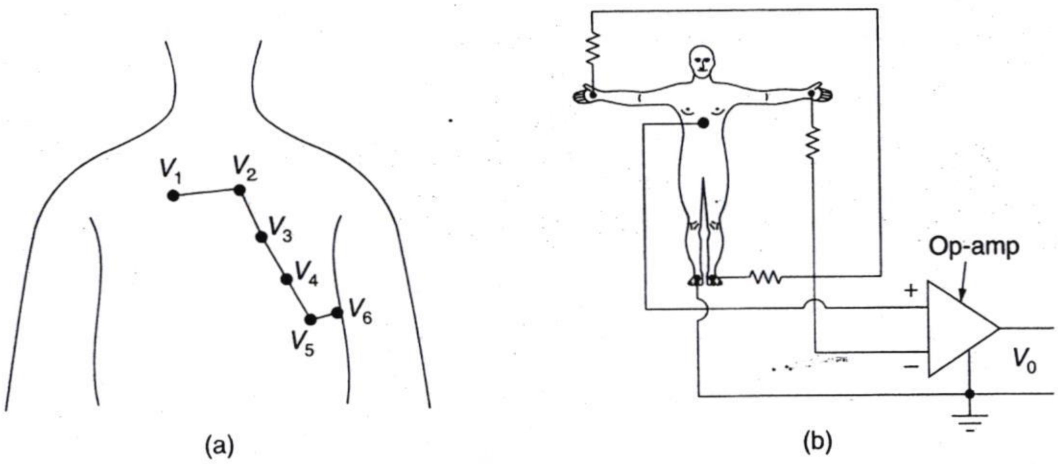


Figure 5.15 Unipolar chest leads configuration.

These six leads are called chest unipolar leads (V_1 through V_6). Here also we have a central electrode obtained by connecting LA, LL and RA through equal resistors as shown in Figure 5.15(b). ECG obtained by using these 12 leads is shown in Figure 5.16. Note that the ECG obtained by lead I configuration and lead II configuration are close to the ideal ECG waveform and all other waveforms are different in shape and magnitude. Another variation apart from 12 leads is Marrio lead or modified chest lead I configuration. It is useful in coronary care unit.

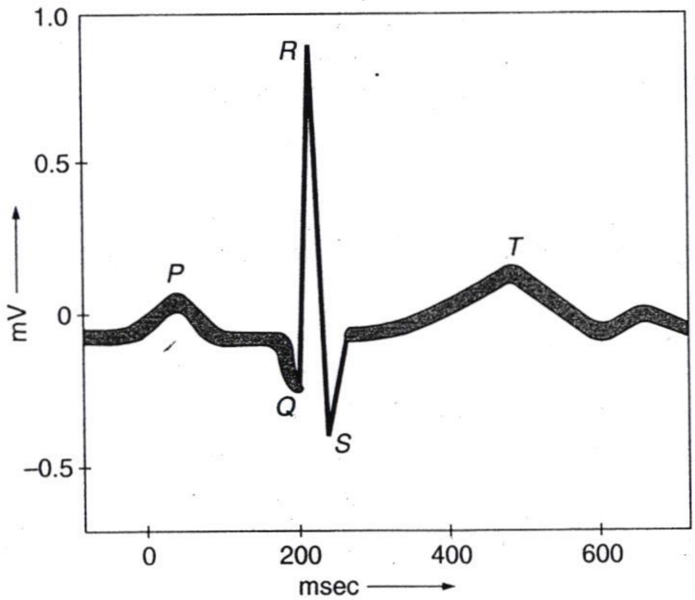


Figure 5.16 Typical ECG obtained using chest leads configuration.

5.13 FUNCTIONAL BLOCKS OF THE ELECTROCARDIOGRAPH

Figure 5.17 shows the block diagram of a typical clinical ECG unit. The function of each block and overall operation are as follows:

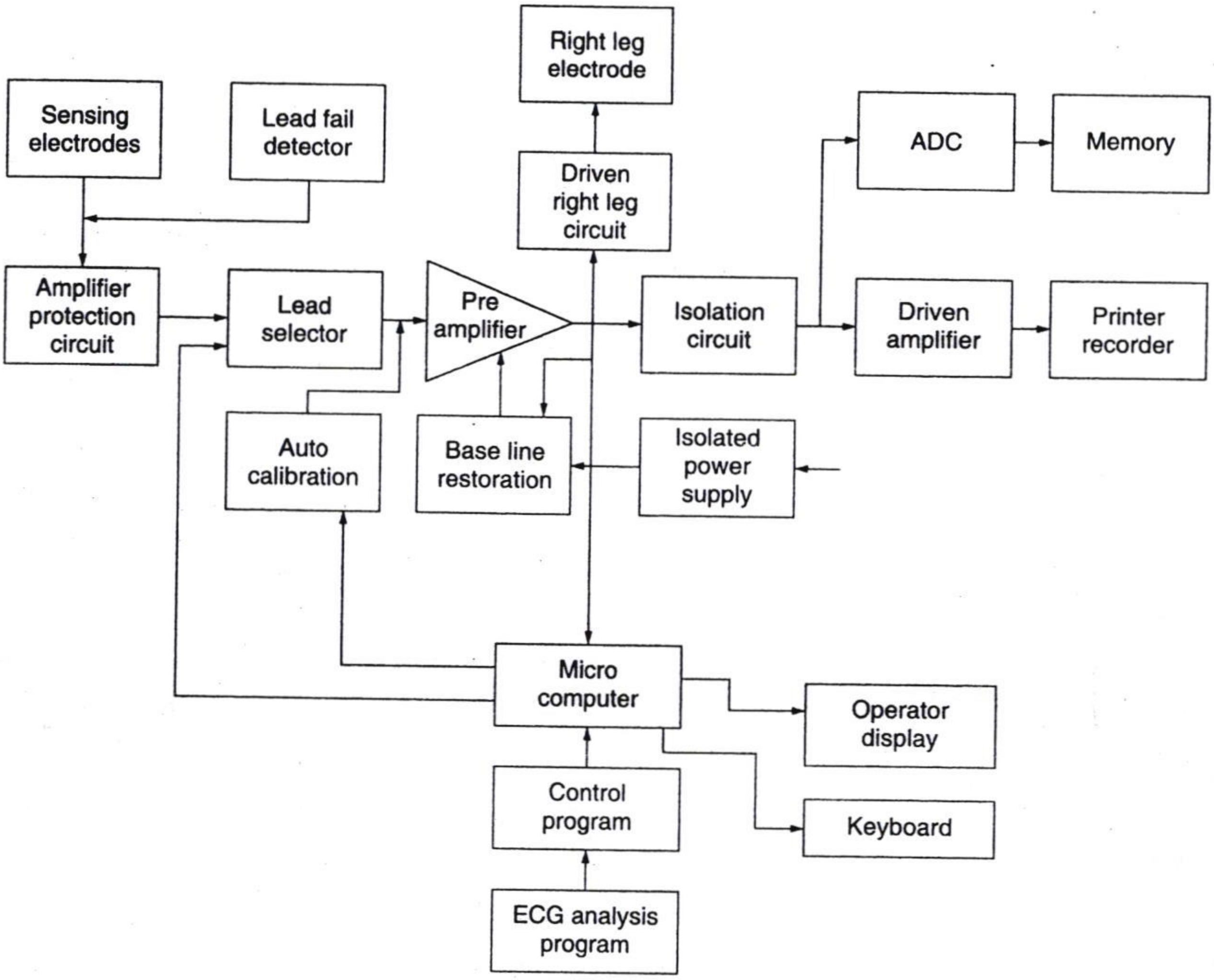


Figure 5.17 Block diagram of an electrocardiograph.

Protection circuit

It is to protect the ECG unit from accidental high voltage appearing across the input terminals.

Lead selector

All electrodes are connected to the circuit of ECG unit through this block. It decides which two leads to be connected to the circuit of the ECG unit at a time. In this block central electrode is configured. It can be controlled either manually or through microcomputer. It selects the particular leads to be plotted. In auto mode these selections are done sequentially one after another for selected fixed short duration.