Module 2

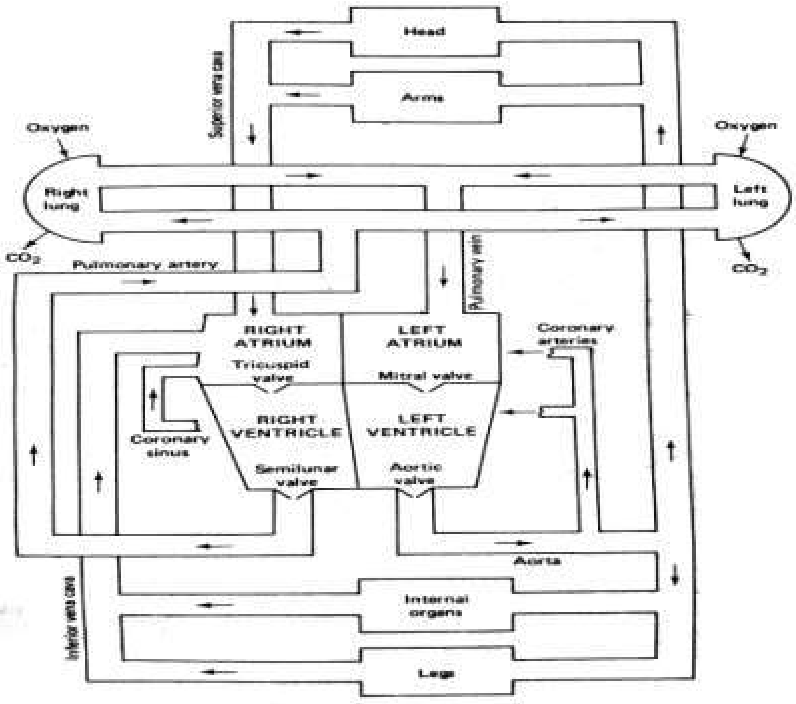
Heart and cardiovascular system (brief discussion), electro conduction system of the heart. Electrocardiography, ECG machine block diagram, ECG lead configurations, ECG recording system, Einthoven triangle, analysis of ECG signals. (3 Hrs)

Measurement of blood pressure: Direct, indirect and relative methods of blood pressure measurement, auscultatory method, oscillometric and ultrasonic non-invasive pressure measurements. (2Hrs)

Measurement of blood flow: Electromagnetic blood flow meters and ultrasonic blood flow meters(2 Hrs)

The Heart & Cardiovascular system :

Heart considered as 2 stage pump.The right half of the heart known as the right heart is the pump that supplies blood to the rest of the system .The circulatory path for blood flow thro lungs is pulmonary circulation and the circulatory system that supplies oxygen and nutrients to the cells of the body is called systemic circulation. Pumping action is by contraction of heart muscles and these muscles receive blood supply from coronary arteries. Blood enters the heart on the right side through 2 main veins.(i) superior (ii) inferior vena cava which leads from the bodys upper and lower extremities.Incoming blood fills the right atrium, and when it is full contracts and force blood through triscupid valve into right ventricle which the contracts to pump the blood into pulmonary circulation system.When ventricular pressure exceeds the atrial pressure , triscupid valve closes and pressure inside the ventricle forces the semilunar valve to open and therefore blood flows to the pulmonary artery which divides into the 2 lungs. In the meantime blood from the coronary sinus also flows to the right ventricle. In the alveoli of lungs exchange of gases takes place. Blood enters the left atrium from pulmonary vein and from there pumped through biscupid valve to the left ventricle. Again pressure force the aortic valve to open and blood is pumped to the aorta.



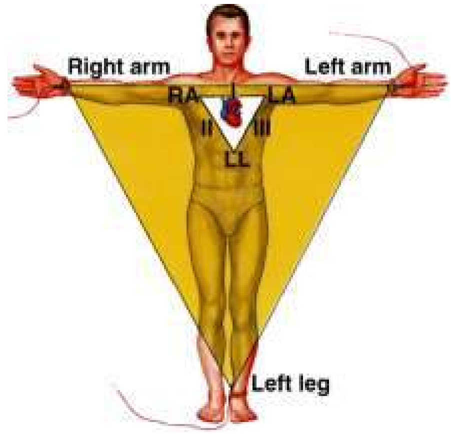
Lead Placement

Electrocardiographic electrodes, or leads, are used to record electrical potential at the surfaces of the body. Different arrangements of the leads produce corresponding patterns with the ECG. Three electrodes are used: right arm (usually white), left arm (usually black), and left leg (usually red).The left leg was used as it terminates vertically below the heart.

With the introduction of ECG amplifier , an additional connection was needed as a ground reference .For this right leg was used. Because the input of the ECG recorder has only 2 terminals, a selection must be made among the available active electrodes.

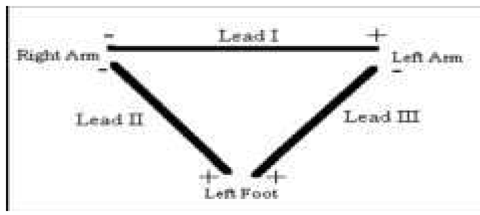
Orientation of the 12 Lead ECG

It is important to remember that the 12-lead ECG provides spatial information about the heart's electrical activity in 3 approximately orthogonal directions:Right Left ,Superior Inferior ,Anterior Posterior. Each of the 12 leads represents a particular orientation in space, as indicated below (RA = right arm; LA = left arm, LF = left foot): The 3 bipolar limb lead selections was first introduced by Einthoven. Each of the leads are bipolar; i.e., it requires two sensors on the skin to make a lead. If one connects a line between two sensors, one has a vector. There will be a positive end at one electrode and negative at the other. The positioning for leads I, II, and III were first given by Einthoven. Einthovens assumption is that heart is near the center of the equilateral triangle. This triangle is known as the Einthoven triangle. The instantaneous voltage measured from any one of the three limb lead position is approx. equal to the algebraic sum of the other two(for this polarity of lead II must be reversed).

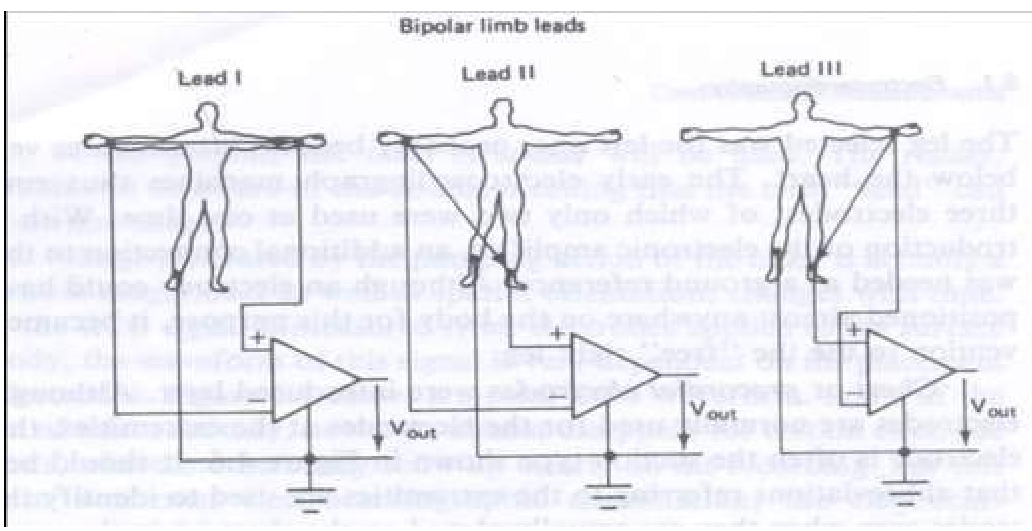


(1) **<u>Bipolar limb leads</u>** (called so because for each lead the electrocardiogram is recorded from 2 electrodes and the third is not connected):

Lead I: RA (-) to LA (+) (Right Left, or lateral)
Lead II: RA (-) to LF (+) (Superior Inferior)
Lead III: LA (-) to LF (+) (Superior Inferior)



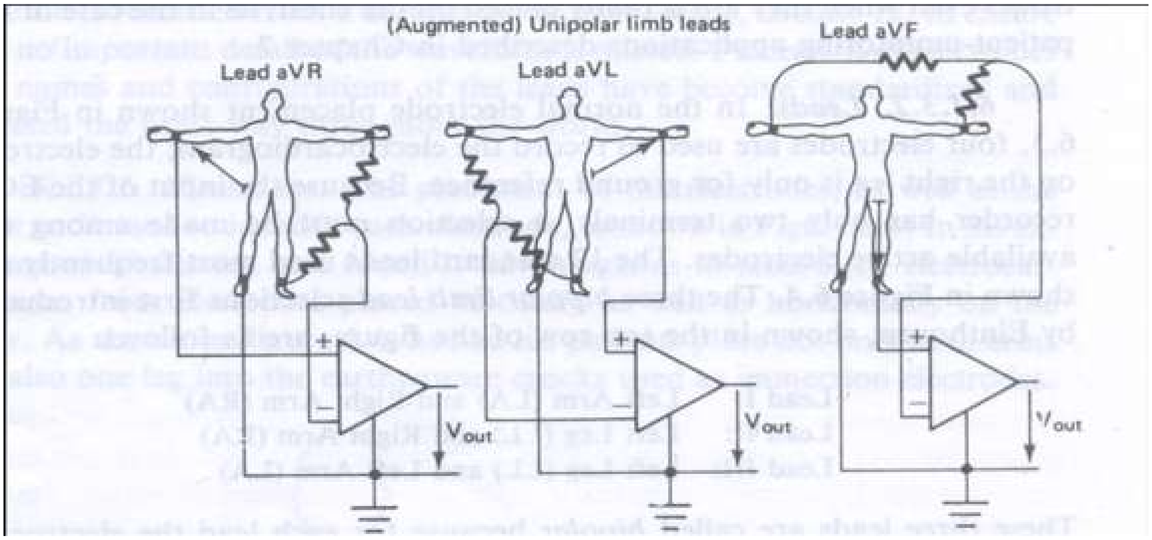
<u>Bipolar leads</u> record voltage between electrodes placed on wrists & legs (right leg is ground).<u>Lead I</u> records between right arm & left arm .<u>Lead II</u>: right arm & left leg(greatest R wave,R wave of lead II = sum of R wave amplitude of lead I and III) <u>Lead III</u>: left arm & left leg.



(2)**<u>Augmented unipolar limb leads</u>** (frontal plane):

Lead aVR: RA (+) to [LA & LF] (-) (Rightward)
Lead aVL: LA (+) to [RA & LF] (-) (Leftward)
Lead aVF: LF (+) to [RA & LA] (-) (Inferior)

These are termed unipolar leads because there is a single positive electrode that is referenced against a combination of the other limb electrodes.Reference electrode is got by a combination of several electrodes tied together at one point.

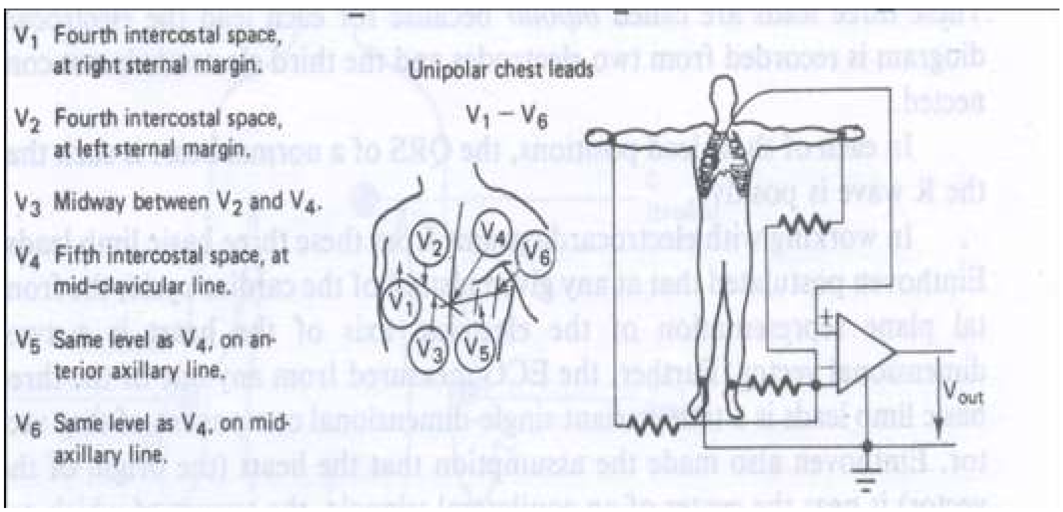


3)**<u>Unipolar (+) chest leads</u>** (horizontal plane):

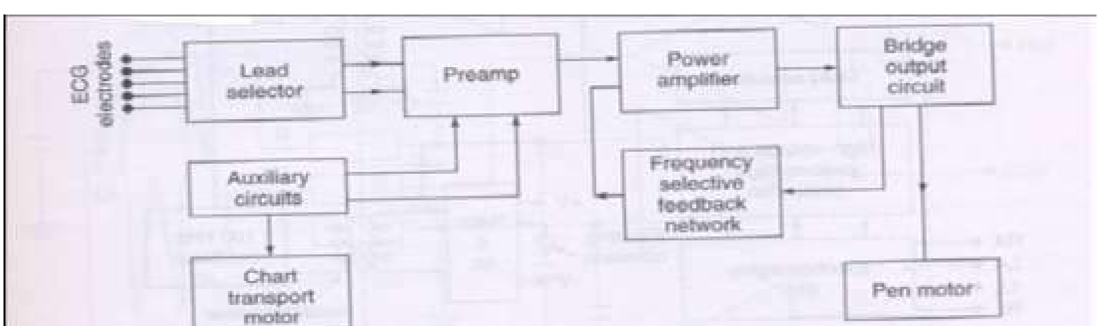
Leads V1, V2, V3: (Posterior Anterior)

Leads V4, V5, V6:(Right Left, or lateral)

- These chest positions are called <u>precordial unipolar leads</u>



<u>Block diagram of ECG recorder</u>



➤ Fig. 5.1 *Block diagram of an ECG machine*

The potentials picked up by the patient electrodes are taken to the lead selector switch. In the lead selector the electrodes are selected two by two by use of lead programs. By means of capacitive coupling the signals is connected symmetrically to the differential preamplifier which has high CMRR. It is ac coupled to avoid problems with small dc voltages that may originate from polarization of the electrodes. The amplified output is given to power amplifier which is of pushpull type. The output of power amplifier is fed to the pen motor, which deflects the writing arm on the paper. The input of the pen amplifier is usually accessible separately, with a special auxillary input jack at the rear or side of the ECG. Frequency selective network is usually a R-C network which provides necessary damping to the pen motor and is preset by the manufacturer.The auxillary circuits provide a 1mv calibration signal and automatic blocking of the amplifier during a change in position of the lead switch. It also includes a speed control circuit for the chart drive motor.

Types of ECG recorders:

1. Single channel recorders:
2. Three channel recorders
3. Vector Electrocardiographs
4. ECG systems for stress testing
5. ECG fro computer processing
6. Continuous ECG recording

Measurement of blood pressure:

Accurate Blood Pressure Measurement is the first step in treating hypertension or high blood pressure.Primary factor in 68% of heart attacks and 75% of strokes. Hypertension is one of the major modifiable risk factors for many cardiovascular diseases. Blood Pressure- measurement of the force exerted by blood against the walls of the arteries.Maximum blood pressure is exerted on the walls of arteries when the left ventricle of the heart pushes blood through the aortic valve into the aorta at the beginning of systole. Pressure rises as the ventricle contracts and falls as the heart relaxes. This continuous contraction and relaxation of the left ventricle creates a pressure wave that is transmitted through the arterial system.Blood pressure is recorded as two numbers—the systolic pressure (as the heart beats) over the diastolic pressure (as the heart relaxes between beats). The measurement is written one above or before the other, with the systolic number on top and the diastolic number on the bottom.

- **Systolic pressure** (numerator) – the highest pressure reached during cardiac ejection
- **Diastolic pressure** (denominator) – the lowest pressure occurring at the end of a ventricular relaxation.
- **Pulse pressure** – the difference between Systolic and Diastolic pressure.
- **Mean blood pressure**: diastolic + 1/3 of pulse pressure

Measured in millimeters of mercury (mm Hg) and recorded as a fraction. (Example 120/80 – systolic 120, diastolic 80, pulse pressure 40). Most frequently measured pressures are arterial and venous pressure

- Pressure Value of arterial system - 30 to 300 mmHg

- Pressure Value of the venous system – 5-15 mmHg

Methods For Obtaining a BP :

All blood pressure measurements are made with reference to the atmospheric pressure.

1. DIRECT – Direct intra-arterial measurement with a catheter
   (i)arterial(ICU,surgery) (ii)venous (ICU)

2. INDIRECT – Compression of the brachial artery using a sphygmomanometer (blood pressure cuff) or using automatic equipment

- Differential Auscultatory technique

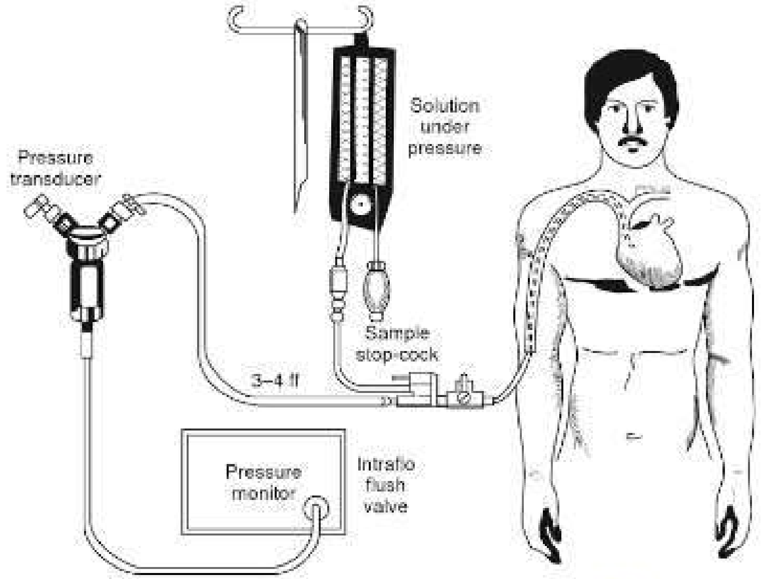
- Oscillometric measurement method

- Ultrasonic doppler shift method

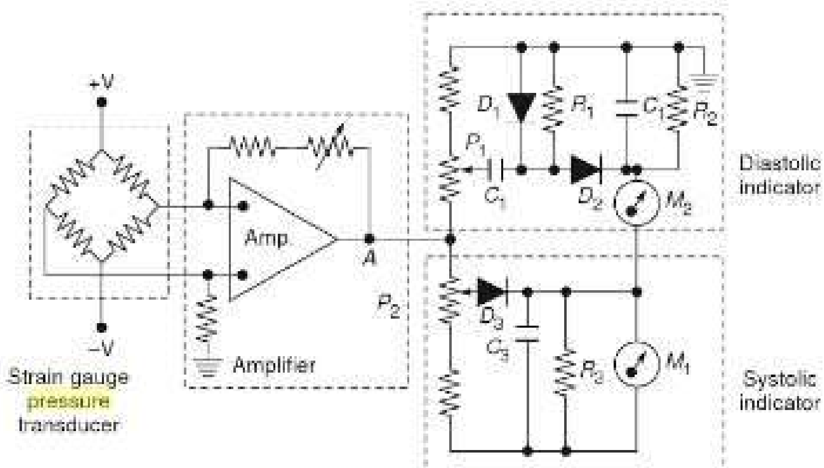
1.Direct Method : This method is used when high degree of accuracy, dynamic response and continuous monitoring is required. Also used to measure pressure in deep regions not accessible by indirect method. In this method a catheter or a needle type probe is inserted through the vein or artery to area of interest.

2 types of probes : 1. Extravascular pressure sensor in which catheter tip probe which has sensor at the tip and pressure exerted on it are converted to proportional electrical signals. 2. Intravascular pressure sensor in which Fluid filled catheter type which transmits the pressure exerted on the fluid to an external transducer and the transducer converts pressure to electrical signals.

This method gives details of systolic pressure, diastolic pressure and means pressures. This also gives visualization of pulse contour, stroke volume, duration of systole, ejection time and other variables. A typical set-up of a fluid filled system for measuring BP is shown below. Before insertion of the catheter , the fluid filled system should be thoroughly flushed. A steady flow of sterile saline is passed through the catheter to avoid clotting of blood. The system should be free from air bubbles as the frequency response of the system may be dampened.



Typical set up of a pressure measuring system by direct method



Circuit diagram for measurement of systolic and diastolic blood pressure

The block diagram represents the measurement of arterial pressure.The transducer is excited with a 5v dc excitation. The excitation for the transducer comes from an amplitude controlled bridge oscillator through an isolating transformer. The electrical signals corresponding to the arterial pressure are amplified in a carrier amplifier.For measurement of systolic pressure , a conventional peak reading type voltmeter is used.When a positive going pressure pulse appears at A, D3 conducts and charges C3 to peak value of input signal which corresponds to systolic value. Time constant R3C3 is chosen such that it gives steady output to the indicating meter. The value of the diastolic is derived in the following way. A clamping circuit consisting of C1 and D1 is used to develop a voltage equal to the peak to peak value of the pulse pressure. This voltage appears across R1. 2 will conduct and charge C2 to the peak value of the pulse signal. The diastolic pressure is indicated by the second meter M2 which shows the peak systolic minus the peak to peak pressure signal.Central venous pressure (CVP) measurements made with needle cannulation technique prove extremely useful in management of acute circulatory failure and in the maintenance of blood volume in difficult fluid balance problems. Simple water manometers are still the most common measuring device in use.

The transducers cannot be conveniently mounted at the catheter tip and small positional changes cause lager errors in venous pressure. CVP is usually measured from a catheter located in the superior vena cava. CVP reflects the pressure of the right atrium and is also referred to as the right atrial pressure. Catheters used for CVP monitoring are usually 25 to 30 cm long. Regardless of the electrical or physical principles involved , direct measurement of BP is got by one of three methods.

1. Percutaneous insertion
2. Catheterization (vessel cut down)
3. Implantation of a transducer in a vessel or in the heart

- For percutaneous insertion ,a local anesthetic is injected near the site of invasion. The vessel is occluded and a hollow needle is inserted at a slight angle toward the vessel. When needle is in place, a catheter is fed through the hollow needle and when catheter is in place in the vessel the needle and the guide are withdrawn.
- Catheterization helps in getting BP as well as to get blood samples from the heart for oxygen content analysis and also for location of abnormal blood flow pathways.
- Implantation techniques involve major surgery .This method helps in keeping the transducers in the appropriate vessel for long periods of time. The transducers used may be capacitive , inductive and resistive .The most commonly used type is the resistive type.

Intra vascular sensors

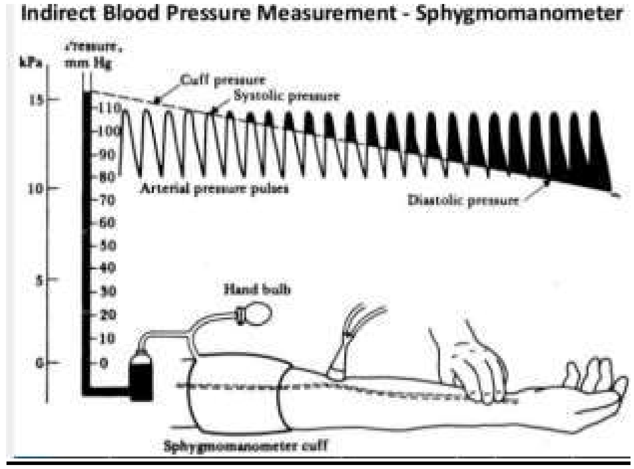
- **Advantages:**

1. Enable the physician to obtain a high frequency response
2. No time delay encountered when the pressure pulse is transmitted in a catheter–sensor system

- **Disadvantages:**

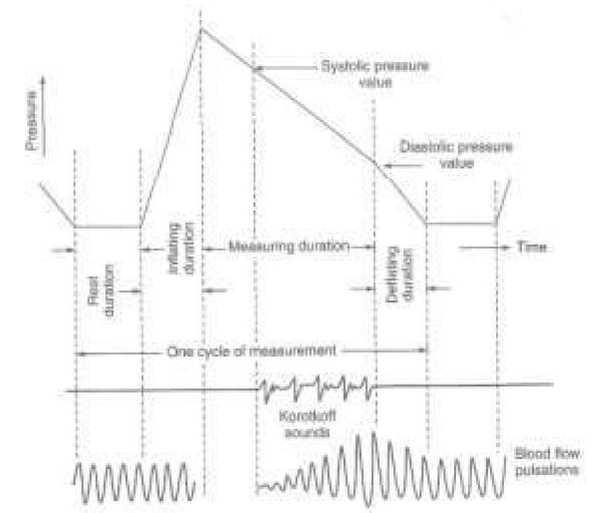
1. more expensive
2. may break after only a few uses

2. Indirect BP measurement:



1. KOROTOKOFF SOUNDS METHOD
2. AUSCULTATORY METHOD
3. OSICILLOMETRIC METHOD
4. RHEOGRAPHIC METHOD

1. KOROTOKOFF SOUNDS METHOD : **Korotkoff** are the sounds that medical personnel listen for when they are taking blood pressure using a non-invasive procedure. If the pressure is dropped to a level equal to that of the patient's systolic blood pressure, the first Korotkoff sound will be heard. As the pressure in the cuff is the same as the pressure produced by the heart, some blood will be able to pass through the upper arm when the pressure in the artery rises during systole.



➤ Fig. 6.26 *Principle of blood pressure measurement based on Korotkoff sounds*

The sounds heard during measurement of blood pressure are not the same as the heart sounds 'lub' and 'dub' that are due to the closing of the hearts valves. If a stethoscope is placed over the brachial artery in the antecubital fossa in a normal person (without arterial disease), no sound should be audible. As the heart beats, these pulses are transmitted smoothly via laminar (non-turbulent) blood flow throughout the arteries and no sound is produced. Also, if the cuff of a sphygmomanometer is placed around a patient's upper arm and inflated to a pressure above the patient's systolic blood pressure, there will be no sound audible. This is because the pressure in the cuff is high enough such that it completely occludes the blood flow. It is similar to a flexible tube or pipe with fluid in it that is being pinched shut.

The Five Korotokoff Sounds : Korotkoff actually described five types of Korotkoff sounds:

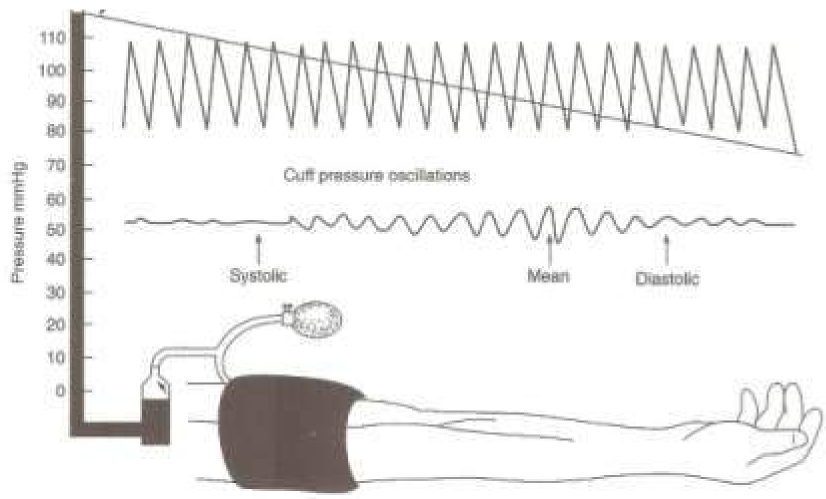
1. The first Korotkoff sound is the snapping sound first heard at the systolic pressure.
2. The second sounds are the murmurs heard for most of the area between the systolic and diastolic pressures.
3. The third = A loud, crisp tapping sound.
4. The fourth sound, at pressures within 10 mmHg above the diastolic blood pressure, were described as "thumping" and "muting".
5. The fifth Korotkoff sound is silence as the cuff pressure drops below the diastolic blood pressure.
6. The second and third Korotkoff sounds haven't had clinical significance.

2. AUSCULTATORY METHOD: The *auscultatory* method (from the Latin word for *listening*) uses a stethoscope and a sphygmomanometer. This comprises an inflatable cuff placed around the upper arm at roughly the same vertical height as the heart, attached to mercury or aneroid manometer.The mercury manometer measures the height of a column of mercury, giving an absolute result without need for calibration, and consequently not subject to the errors and drift of calibration which affect other methods.The use of mercury manometers is often required in clinical trials and for the clinical measurement of hypertension in high risk patients, such as pregnant women. A cuff of appropriate size is fitted smoothly, then inflated manually by repeatedly squeezing a rubber bulb until the artery is completely occluded. Listening with the stethoscope to the brachial artery at the elbow, the examiner slowly releases the pressure in the cuff.When blood just starts to flow in the artery, the turbulent flow creates a "whooshing" or pounding (first Korotkoff sound). The pressure at which this sound is first heard is the systolic BP.The cuff pressure is further released until no sound can be heard (fifth Korotkoff sound), at the diastolic arterial pressure. The auscultatory method has been predominant since the beginning of BP measurements but in other cases it's being replaced by other noninvasive techniques.

Fig : Auscultatory method aneroid sphygmomanometer with stethoscope

 Fig: Mercury Manometer

3.OSCILLOMETRIC METHOD: Automated method of non invasive BP measurement . It has some distinct advantages over the auscultatory method. Automated method of non invasive BP measurement .It has some distinct advantages over the auscultatory method. Sound is not used during measurement.This technique does not require a microphone or transducer in the cuff. This is based on oscillometric pulses generated in the cuff during inflation or deflation.

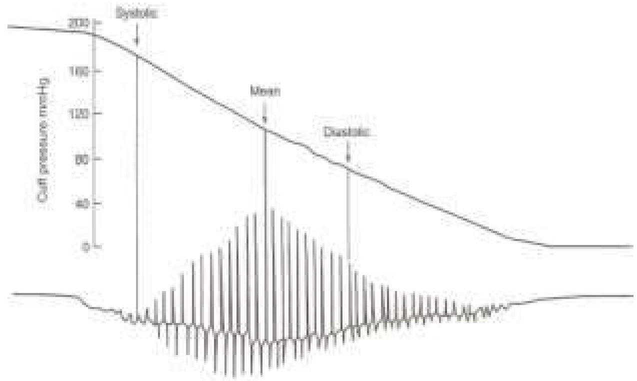


(a) Oscillometric method

Disadvantage of oscillometric method as well as auscultatory method is that the excessive movement or vibration can cause inaccurate readings.

PRINCIPLE:

“occluding cuff deflates from a level above the systolic pressure,the artery walls begin to vibrate as the blood flows through the partially occluded artery and these vibrations will be sensed in the transducer system monitoring cuff pressure”. As pressure decreases in the cuff , the oscillations increase to a maximum amplitude and then decrease untill the cuff fully deflates and blood flow returns.



(b) Oscillations in cuff pressure

➤ Fig. 5.31 *Illusration of oscillometric method of blood pressure measurement*

The cuff pressure at the point of maximum oscillations usually corresponds to the mean arterial pressure. The point above the mean pressure at which the oscillations begin to rapidly decease in amplitude correlates with the diastolic pressure.

Advantages:

In this method of measuring BP, the cuff need not be precisely positioned as in the case with the korotkoff microphone which is to be fixed exactly above an artery. Also, the readings are not affected by ambient sound.

Disadvantages:

Many devices use fixed algorithms leading large variance in blood pressures.

Ultrasonic Doppler shift method:

Automatic BP monitors have been designed based on the ultrasonic detection of arterial wall motion.The control logic incorporated in the instrument analyzes the wall motion signals to detect the systolic and diastolic pressures and displays the corresponding values. The observed doppler frequency can be expressed as

$$\Delta f = \frac{2V_t}{\lambda_c}$$

Δf = Doppler frequency (Hz)

V_t = velocity of the object(m/s)

= carrier wavelength (m)

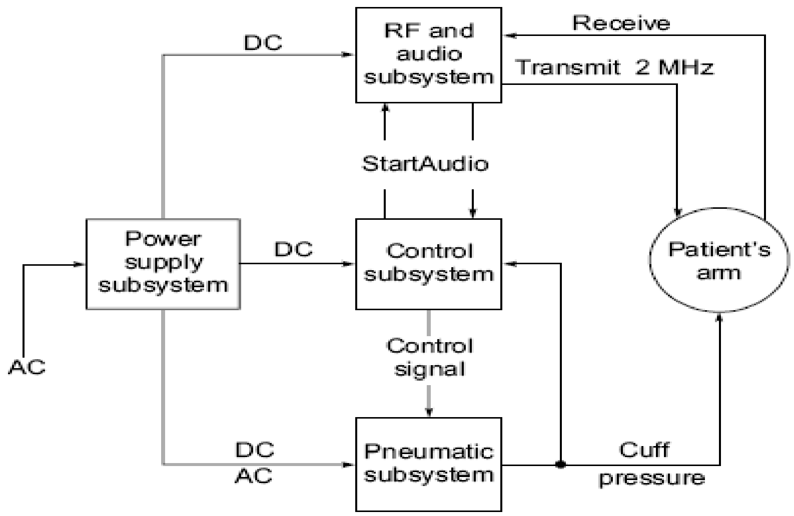
➢ For blood pressure measurement, the brachial artery is the object from where the ultrasound gets reflected. Arterial movement produces the Doppler frequency shift.

$$\lambda c = \frac{V_c}{f_c}$$

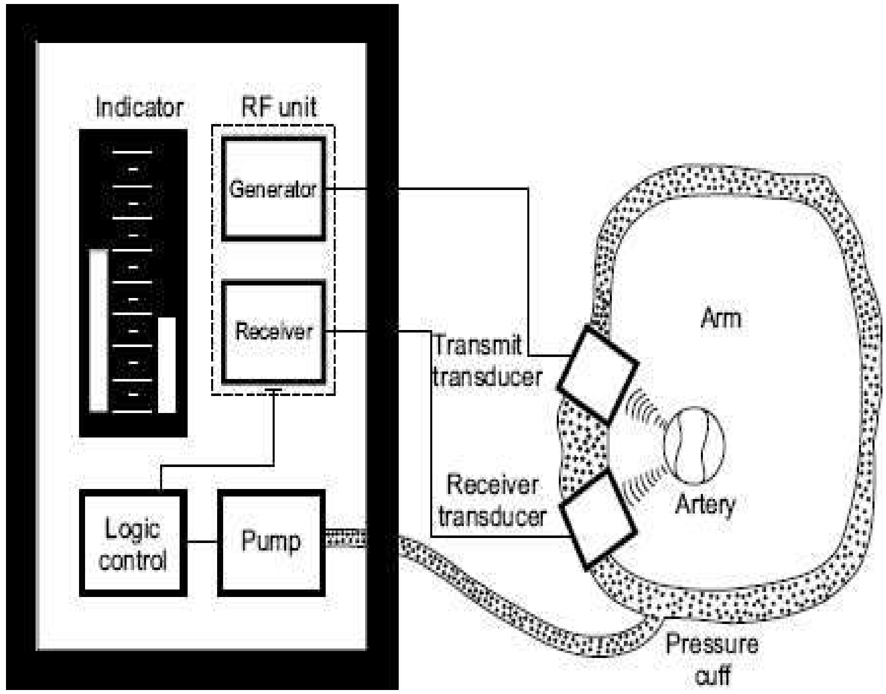
fc is carrier frequency in the medium

Vc is velocity of the carrier frequency in the medium

Instruments making use of ultrasonic doppler shift principle is based on the detection of the frequency shift that may be due to back scattering from moving blood particles. The blood pressure instrument filters out these higher frequency reflections and senses the lower frequency refractions from the movement of the relatively slow moving arterial wall.

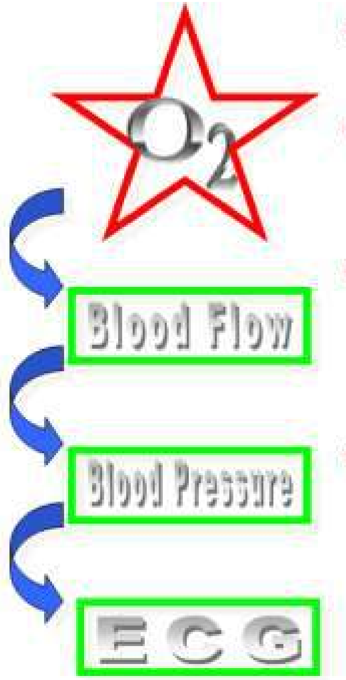


- In principle, the instrument consists of four major subsystems as shown in figure .The power supply block converts incoming ac line voltage to several filtered and regulated dc voltages required for the pneumatic subsystem in order to inflate the occlusive cuff around the patient's arm.At the same time, control subsystem signals gate-on the transmitter in the RF and audio subsystem, thereby generating a 2 MHz carrier, which is given to the transducer located in the cuff. The transducer converts the RF energy into ultrasonic vibrations, which pass into the patient's arm. The cuff pressure is monitored by the control subsystem and when the pressure reaches the preset level, further cuff inflation stops. At this time, audio circuits in the RF and audio subsystems are enabled by control subsystem signals, and the audio signals representative of any Doppler frequency shift are thus able to enter the control subsystem logic.The control subsystem signals the pneumatic subsystem to bleed off the cuff pressure at a rate determined by the preset bleed rate. As air bleeds from the cuff, the frequency of the returned RF is not appreciably different from the transmitted frequency as long as the brachial artery remains occluded. Till then, there are no audio signals entering the control subsystem.At the systolic pressure, the occluded artery snaps open and the arterial blood flow starts. This artery motion results in a Doppler shift in the returning ultrasonic vibrations. The converted audio frequency signal is recognized as tentative systolic by the control subsystem logic. Four valid artery returns must be recognized in order to register the tentative systole and for it to become fixed as true systole.This reduces the possibility of artefacts from recording a false systole reading. As a further check, the audio returns are examined for width and rate of occurrence to prevent artefacts from being accepted as true artery returns.



An occlusive cuff is placed on the arm shown in figure in the usual manner, with an ultrasonic transducer on the arm over the brachial artery. The cuff is inflated first to above systolic pressure and then deflated at a specified rate. A low energy ultrasonic beam (less than 50 mw/cm2) at a frequency of 2 MHz is transmitted into the arm. The portion of the ultrasound that is reflected by the arterial wall shifts in frequency when the wall of the artery moves. Above systolic, the vessel remains closed due to the pressure of the occluding cuff, and the monitor signals are not received. As the cuff pressure falls to the point where it is just overcome by the brachial artery pressure, the artery wall snaps open.This opening wall movement, corresponding to the occurrence of the first Korotkoff sound, produces a Doppler-shift which is interpreted by logic in the instrument as systolic and displayed accordingly.With each subsequent pulse wave, a similar frequency shift is produced until at the diastolic pressure the artery is no longer occluded. Its rapid motion suddenly disappears and the Doppler-shift becomes relatively small. The instrument notes the sudden diminution in the amplitude of the Doppler shift and cuff pressure at this point is displayed as diastolic pressure.Special electronic circuits used in the instrument help to discriminate against extraneous motion artefacts. A coupling medium is essential between the transducer and the patients' skin for the efficient transmission of ultrasonic energy. Unlike the Korotkoff method, the instruments based on the ultrasonic Doppler-shift principle often provide reliable blood pressure measurements in severe hypotensive states, at unfavourable sites such as the popliteal artery, in neonates where no other indirect method of measurement is feasible, in patients too obese for successful ausculation, under unfavourable conditions such as high ambient noise, and in many species of laboratory research animals.

Measurement Of Blood Flow



O_2 and other nutrition concentration in the cells are one of the primary measurements. Blood flow helps to understand basic physiological processes and e.g. the dissolution of a medicine into the body. It also helps to understand many pathological conditions, since many diseases alter the blood flow. Also the blood clots in the arterial system can be detected. Usually the blood flow measurements are more invasive than blood pressure measurements / ECG.

INDICATOR-DILUTION METHOD THAT USES CONTINUOUS INFUSION

Indicator Dilution Method

In the Fick method, the indicator is O_2.consumption is measured by a spirometer. The arterial- venous concentration difference is measured by drawing samples through catheters placed in an artery and in the pulmonary artery. In the dye-dilution method, dye is injected into the pulmonary artery and samples are taken from the artery. In the thermo dilution method, cold saline is injected into the right atrium and temperature is measured in the pulmonary artery.

Continuous Infusion Method

When a given quantity m0 of an indicator added to volume V, the resulting concentration C of the indicator is given by $C = m0 / V$ .When an additional quantity m of indicator is then added, the incremental increase in concentration is $\Delta C = m/V$. When the fluid volume in the measured space is continuously removed and replaced, as in a flowing stream, then in order to maintain a fixed change in concentration, the clinician must continuously add a fixed quantity of indicator per unit time. $\Delta C = (dm/dt)/(dV/dt)$. From this equation, we can calculate flow $F = dV/dt = (dm/dt) / \Delta C$.

Fick technique

We can use the above equation to measure cardiac output.

$$F = (dm/dt) / C_a - C_v$$

where

F=blood flow, liters/min

dm/dt=consumption of O_2, liters/min

C_a=arterial concentration of O_2, liters/liter

C_v = venous concentration of O_2, liters/liter

- The blood retuning to the heart from the upper half of the body has a different concentration of O2 from the blood returning from the lower half, because the amount of O2 extracted by the brain is different from that extracted by the kidneys, muscles, and so forth. Therefore, we cannot accurately measure Cv in the right atrium.We must measure it in the pulmonary artery after it has been mixed by the pumping action of the right ventricle. The physician may float the catheter into place by temporarily inflating a small balloon surrounding the tip. This is done through a second lumen in the catheter. As the blood flows through the lung capillaries, the subject adds the indicator (the O2) by breathing in pure O2 from a spirometer. The exhaled CO2 is absorbed in a soda-lime canister, so the consumption of O2 is indicated directly by the net gas-flow rate.The clinician can measure the concentration of the oxygenated blood Ca in any artery, because blood from the lung capillaries is well mixed by the left ventricle and there is no consumption of O2 in the arteries. An arm or leg artery is generally used.

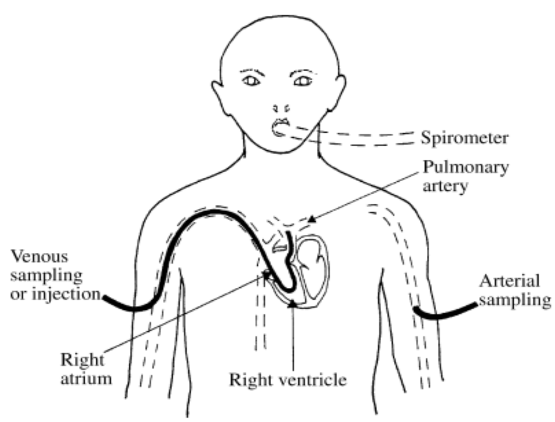


Figure 8.1 Several methods of measuring cardiac output In the Fick method, the indicator is O_2; consumption is measured by a spirometer. The arterial-venous concentration difference is measured by drawing samples through catheters placed in an artery and in the pulmonary artery. In the dye-dilution method, dye is injected into the pulmonary artery and samples are taken from an artery. In the thermodilution method, cold saline is injected into the right atrium and temperature is measured in the pulmonary artery.

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Indicator Dilution – Rapid Injection Method

A bolus of indicator is rapidly injected into the vessel, and the variation in downstream concentration of the indicator versus time is measured until the bolus has passed. An increment of blood of volume dV passes the sampling site in time dt. The quantity of indicator dm contained in dV is the concentration C(t) times the incremental volume.

Hence $dm = C(t)dV$.

$dm/dt = C(t)dV/dt$.

But $dV/dt = Fi$, the instantaneous flow; therefore

$dm = Fi\ C(t)\ dt$.

Integrating time over t1

$$m = \int_0^{t_1} F_i C(t) dt$$

Average flow

$$F = \frac{m}{\int_0^{t_1} C(t) dt}$$

The integrated quantity is obtained from shaded area of below figure. It can obtained by counting the squares using a planimeter.

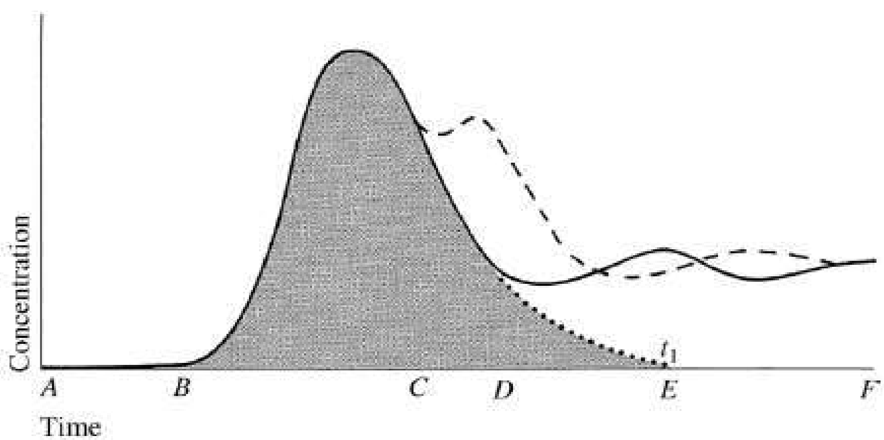

Figure 8.2 Rapid-injection indicator-dilution curve After the bolus is injected at time A, there is a transportation delay before the concentration begins rising at time B. After the peak is passed, the curve enters an exponential decay region between C and D, which would continue decaying along the dotted curve to t_1 if there were no recirculation. However, recirculation causes a second peak at E before the indicator becomes thoroughly mixed in the blood at F. The dashed curve indicates the rapid recirculation that occurs when there is a hole between the left and right sides of the heart.

Dye Dilution

- A common method of clinically measuring cardiac output is to use a colored dye, indocyanine green (cardiogreen). It meets the necessary requirements for an indicator in that it is (1) inert, (2) harmless, (3) measurable, (4) economical, and (5) always intravascular. Its optical absorption peak is 805 nm, the wavelength at which the optical absorption coefficient of blood is independent of oxygenation. The dye is available as a liquid that is diluted in isotonic saline and injected directly through a catheter, usually into the indicator artery. About 50% of the dye is excreted by the kidneys in the first 10 min, so repeat determinations are possible. After the bolus is injected at time A, there is a transportation delay before the concentration begins rising at time B. After the peak is passed, the curve enters an exponential decay region between C and D, which would continue decaying along the dotted curve to t1 if there were no recirculation. The plot of the curve for concentration versus time is obtained from a constant-flow pump.The dashed curve indicates the rapid recirculation that occurs when there is a hole between the left and right sides of the heart.

Thermo Dilution

The most common method of measuring cardiac output is that of injecting a bolus of cold saline as an indicator. A special four-lumen catheter is floated through the brachial vein into place in the pulmonary artery. Catheter 1 : syringe forces a gas through one lumen. The gas inflates a small balloon at end. Catheter 2 : The cooled saline injected through second lumen in to right atrium. The indicator is mixed with blood in right ventricle. The resulting drop in temperature of the blood is detected by a thermistor located near the catheter tip in the pulmonary artery. Catheter3 : The third lumen carries the thermistor wires Catheter4 : The fourth lumen, which is not used for the measurement of thermodilution, can be used for with drawing blood samples.

$$F = \frac{Q}{\rho_b C_b \int_0^{t_1} \Delta T_b(t)\, dt} \text{ (m}^3\text{/s)}$$

vhere

Q = heat content of injectate, J $(= V_i \Delta T_i \rho_i c_i)$
ρ_b = density of blood, kg/m^3
c_b = specific heat of blood, J/(kg·K)

When an investigator uses the thermodilution method, there are a number of problems that cause errors. There may be inadequate mixing between the injection site and the sampling site. There may be an exchange of heat between the blood and the walls of the heart chamber. There is heat exchange through the catheter walls before, during, and after injection. However, the instrument can be calibrated by simultaneously performing dye-dilution determinations and applying a correction factor that corrects for several of the errors.

1. **Electromagnetic flowmeter:** The electromagnetic flowmeter measures instantaneous pulsatile flow of blood and thus has a greater capability than indicator-dilution methods, which measure only average flow. It operates with any conductive liquid, such as saline or blood. It uses a magnetic field applied to the metering tube, which results in a potential difference proportional to the flow velocity perpendicular to the flux lines. The potential difference is sensed by electrodes aligned perpendicular to the flow and the applied magnetic field. The physical principle at work is Faraday's law of electromagnetic induction.

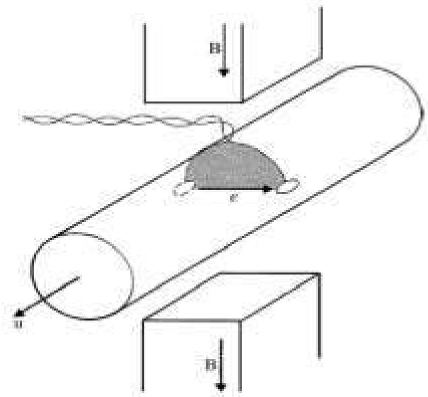

Figure 8.3 **Electromagnetic flowmeter** When blood flows in the vessel with velocity **u** and passes through the magnetic field **B**, the induced emf *e* is measured at the electrodes shown. When an ac magnetic field is used, any flux lines cutting the shaded loop induce an undesired transformer voltage.

2. **Ultrasonic Flow meter** : It measures the velocity of a liquid or gas (fluid) by using the principle of ultrasound. It can measure instantaneous flow of blood. The ultrasound can be beamed through the skin. Using ultrasonic transducers, the flow meter can measure the average velocity along the path of an emitted beam of ultrasound, by averaging the difference in measured transit time between the pulses of ultrasound propagating into and against the direction of the flow. Ultrasonic flow meters are affected by the temperature, density and viscosity of the flowing medium. They are inexpensive to use and maintain because they do not use moving parts. They measure the difference of the transit time of ultrasonic pulses propagating in and against flow direction. This time difference is a measure for the average velocity of the fluid along the path of the ultrasonic beam. Ultrasonic flow meters are also used for the measurement of natural gas flow. One can also calculate the expected speed of sound for a given sample of gas; this can be compared to the speed of sound empirically measured by an ultrasonic flow meter and for the purposes of monitoring the quality of the flow meter's measurements.By passing an ultrasonic beam through the tissues, bouncing it off a reflective plate, then reversing the direction of the beam and repeating the measurement, the volume of blood flow can be estimated. The frequency of the transmitted beam is affected by the movement of blood in the vessel and by comparing the frequency of the upstream beam versus downstream the flow of blood through the vessel can be measured. The difference between the two frequencies is a measure of true volume flow.

Continuous-wave Doppler flowmeter : When a target recedes from a fixed source that transmits sound, the frequency of the received sound is lowered because of the Doppler effect. For small changes, the fractional change in frequency equals the fractional change in velocity. Fd/f0 = u/c where Fd = Doppler frequency shift f0 = source frequency u = target velocity c = velocity of sound.

$$\frac{f_d}{f_0} = \frac{2u}{c+u} \cong \frac{2u}{c}$$

The Doppler flowmeter is capable of recording very rapid pulsatile changes in flow as well as steady flow.

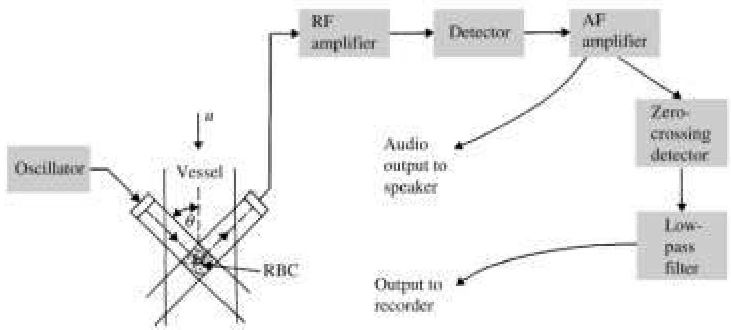

Figure 8.10 Doppler ultrasonic blood flowmeter In the simplest instrument, ultrasound is beamed through the vessel walls, backscattered by the red blood cells, and received by a piezoelectric crystal.

Pulsed Doppler

Continuous-wave flowmeters provide little information about flow profile. Therefore, several instruments have been built that operate in a radar like mode. The transmitter is excited with a brief burst of signal.The transmitted wave travels in a single packet, and the transmitter can also be used as a receiver, because reflections are received at a later time. The delay between transmission and reception is a direct indication of distance, so we can obtain a complete plot of reflections across the blood vessel. By examining the Doppler shift at various delays, we can obtain a velocity profile across the vessel.