# UNIT 1 BASICS OF ECHOCARDIOGRAPHY AND CARDIAC DOPPLER

**Structure**



## 1.0 OBJECTIVES

After going through this unit, you should be able to:

- know the fundamental physics of ultrasound imaging in echo;
- positioning of patient for transthoracic scanning;
- understand the relationship of transducer frequency to imaging goals;
- enlist various views for transthoracic scanning;
- describe basics of cardiac Doppler;
- learn calculations for pressure half time, continuity equation, modified Bernoulli equation for interpretation of Doppler hemodynamics; and
- understand diastology.

## 1.1 INTRODUCTION

Echocardiography is one of the most frequently used imaging modalities for diagnosing cardiovascular diseases. It is versatile and is applicable in the entire spectrum of cardiovascular disease, so much so that now it is considered an extension of the physical examination. It is non-invasive, portable and can be utilized in sick patients, in emergency room or in the walk in symptomatic patients with mitral stenosis or in a young asymptomatic individual with a murmur on routine physical examination. If performed adequately by a skilled operator it can be used as a definitive rather than a screening diagnostic tool. So knowledge about Echocardiography is essential for every physician dealing with cardiovascular diseases.

## 1.2 PRINCIPLES

Echocardiography utilizes principle of ultrasound for visualization of heart and great vessels. It uses sound in the frequency of 1-10 MHz. As the frequency of probe increases resolution improves at the cost of reduction of penetration. Due to thick chest wall in adults, probes with frequency range of 2-5 MHz are used and for paediatric application higher frequency of 7.5-10 MHz probes are used because of thin chest wall.

The underlying principle of cardiac ultrasonography is that speed of sound through tissue is equal to that in water. The transducer which has a Peizoelectric crystal emits a series of burst at a given frequency which is reflected from cardiac and other structures and is returned to the transducer. These received ultrasound waves are then displayed as images of cardiac structures on monitor screen and can be stored in videotape, hard disc or optical disc.

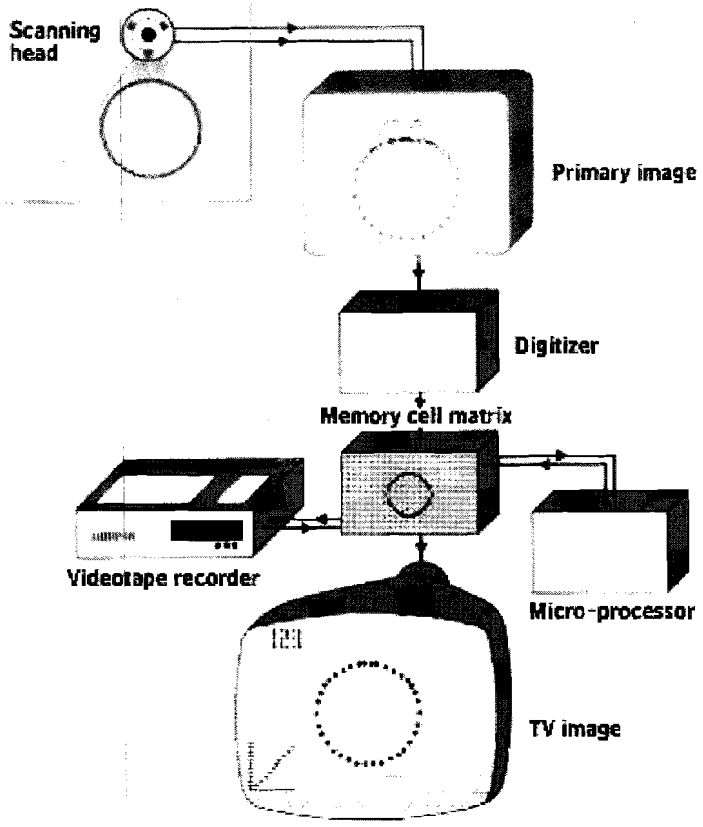


**Fig. 1.1: Showing principle of echocardiography. Probe containing Peizoelectric crystal emits series of burst, which are reflected from cardiac structures and is returned to the transducer. These received ultrasound images are displayed as images on monitor screen and can be stored in videotape or digitalized format.**

The distance of the reflective object from the transducers can be calculated by determining the time required for round trip transit.

$$\text{Distance (meters)} = \frac{\text{Velocity (meters/second)}}{\text{Time (second)}}$$

Velocity = Velocity of sound

The returning strength of ultrasound signal is directly proportional to the reflective intensity of the object and is in integrated into displayed image.

Echocardiography provides valuable information regarding diagnosis, valvular morphology, etiology, identification and quantification of lesions, cardiac size and function, intracardiac hemodynamics and disorders of pericardium and great vessels.

There are various echocardiographic techniques available:

1) Transthoracic echocardiography
2) Transesophageal echocardiography
3) Stress echocardiography:
    a) Exercise
    b) Pharmacological
4) Fetal echocardiography
5) Contrast echocardiography
6) 3-D echocardiography
7) Intravascular ultrasound

Most commonly used technique is transthoracic echocardiography (TTE). Others require further skill and expertise, once the physician has acquired the skills of TTE.

**Niche Areas in Cardiology and Role of Echocardiography**

Echocardiography is a very important tool in diagnosis of cardiovascular diseases and is used virtually in all categories of cardiovascular diseases. There are certain areas where echocardiography provides a definite answer with minimal discomfort and risk and may obviate the need for catheterization in selected patients. Some examples are listed below:

1) LV function
    a) Systolic
    b) Diastolic
2) Cardiac masses
    a) LV-tumors, clot or vegetations
    b) RA/RV masses
3) Diagnosis of hypertrophic cardiomyopathy
4) Pulmonary hypertension
5) To diagnosis complication of myocardial infarction, pseudoaneurysm, aneurysm, thrombus and VSD
6) Pericardial diseases
7) Evaluation of valvular stenosis and regurgitation
8) Prosthetic valve evaluation
9) To diagnose ischemia and viability by stress echocardiography
10) Congenital heart disease e.g. TOF, DORV, ASD, VSD, etc.

**Check Your Progress 1**

1) On what principle does echocardiography work?

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.....

.....

2) What is the crystal used in echocardiographic probe and frequencies which are commonly used?

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.....

3) Which probe has best resolution?

a) 2 MHZ

b) 5 MZ

c) 7.5 MZ

d) 10 MZ

4) Which probe has best penetration?

a) 2

b) 5

c) 7.5

d) 10

## 1.3 MODE OF ECHO AND THEIR APPLICATION

Various modes of examination performed during a transthoracic echocardiography are shown in Table 1.1.

**Table 1.1: Modes of Echocardiographic Examination and their Application**

| | |
|---|---|
| M-Mode | Chamber dimensions, wall thickness, valve motion, endocardial motion |
| 2D | Global and regional left ventricular function, cardiac structural details, detection of mass, thrombus or calcification |
| Pulse wave Doppler | Flow velocity at valve orifices, venous and arterial flows, left and right ventricular diastolic function |
| Continuous wave Doppler | Flow velocity and pressure gradients across stenotic and regurgitant valves |
| Colour Doppler | Valvular regurgitant flow, shunt flow |

***Source***: Oh, J.K., Seward, J.B., Tajik, A.J., *The Echo Manual,* 2nd edn., Little Brown and Company, 1994, p. 20.

Acoustic Quantification

Harmonic Imaging

Tissue Doppler Imaging

### *M-Mode Echocardiography (Motion Mode)*

M-Mode was the earliest form of cardiac ultrasound used clinically. It displays the amplitude signals of various structures along the length of ultrasound beam with distance or depth on vertical axis against the time dimension on the horizontal axis. [Fig.1.2(a) and (b)]

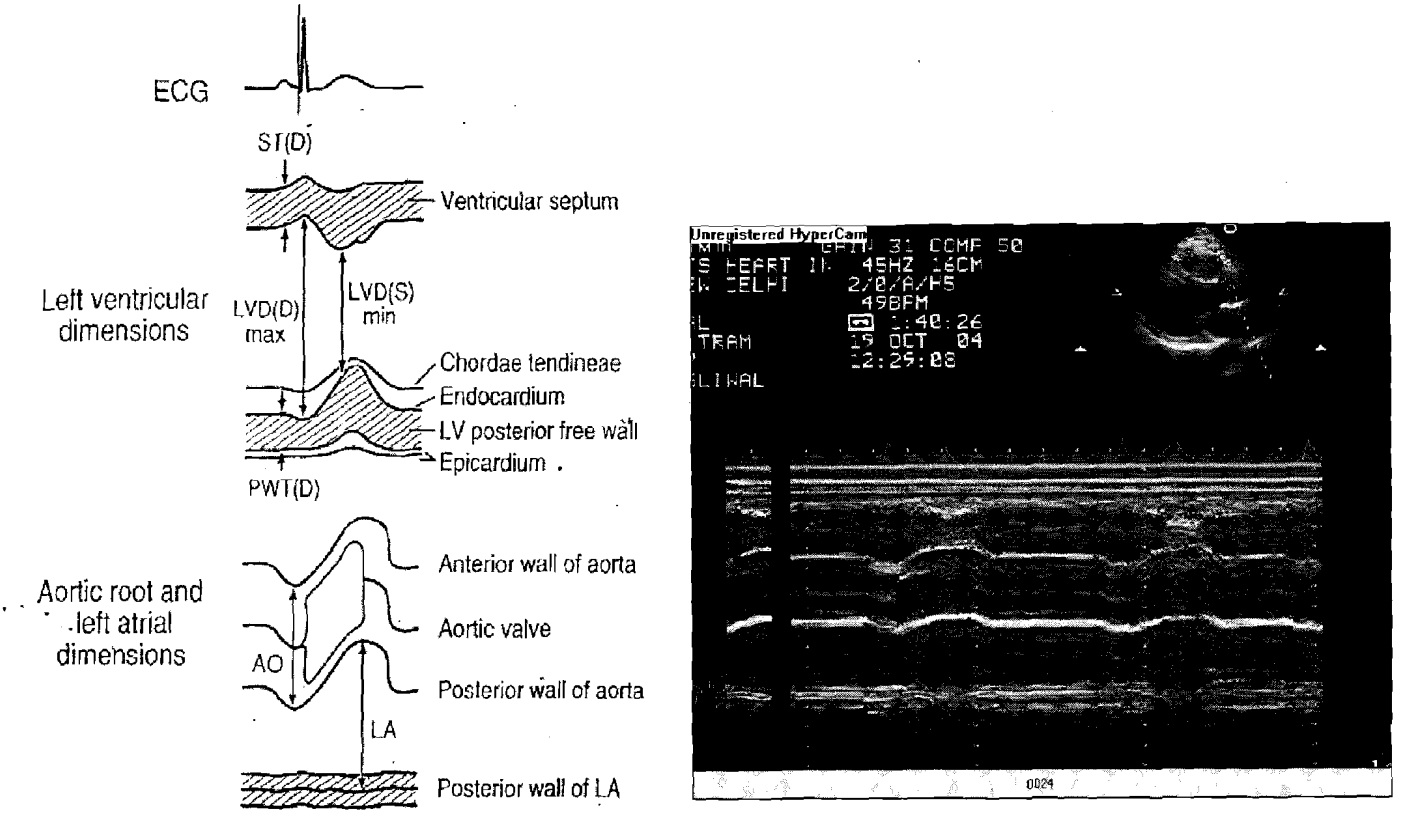



**Fig. 1.2: (a) Showing M-Mode across aorta and (b) left ventricle. This view is taken to take dimensions of aorta, LA, Septum and LV in systole and diastole.**

Main features and advantages are:

1) High sampling rate allows for accurate evaluation of rapidly moving valvular structures and endocardium.

2) High temporal resolution that allows visualization of minute changes in wall or valve motion.

3) Accurate and reproducible measurements of various chamber dimensions and wall thickness.

### *Disadvantages*

Provides one dimensional ("ice pick") view of the heart only provides information with respect to the distance of each object from the transducer and no information in the lateral dimensions 2D echocardiography. 2D

echocardiographic examination involves mechanically or electronically sweeping the ultrasound beam across the tomographic plane to generate a real time image of the heart. 2D images are similar to a thin slice of the heart along the tomographic plane and axis of ultrasound beam.

***Advantages***

1) Allows evaluation of the anatomical details, size and motion of various cardiac structures.

2) Valvular morphology, estimation of valve area by planimetry.

3) Cardiac size, volumes and function.

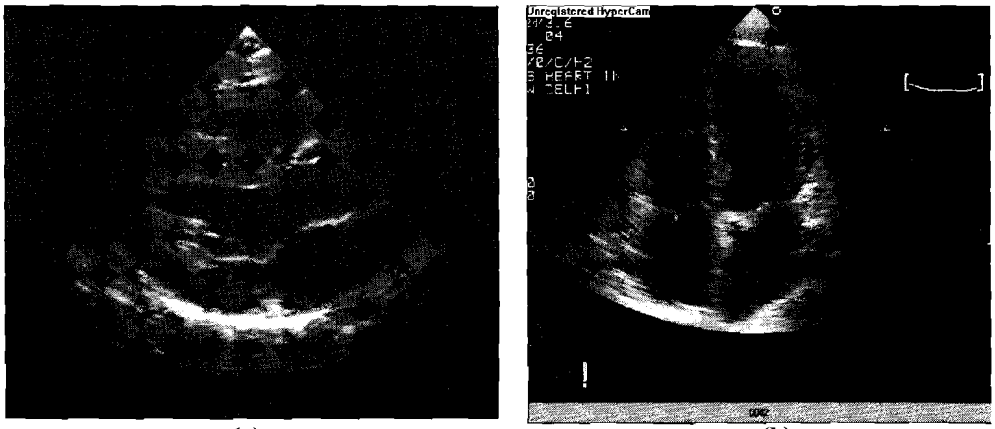
4) Intracardiac hemodynamics.

5) Disorders of pericardium and great vessels.

6) Acts as a guide for the placement of curser and sample volume for accurate M-Mode and Doppler examination.

**Disadvantages**

Various structures are seen in two-dimensional planes; hence mental conceptualization is still required because the heart is three-dimensional. Now, newer technology has evolved and live three-dimensional echocardiography is a reality. [Fig. 1.3 (a) and (b)]




(a) (b)

**Fig.1.3: Two-dimensional echocardiographic images showing (a) PLAX view (b) Four chamber view**

Doppler examination[1] provides hemodynamic information regarding blood flow in the heart and great vessels i.e. comparable to that obtained by cardiac catheterization. It relies on analysis of a shift in the frequency of ultrasound beam due to interaction with moving targets. Doppler studies are usually performed in conjunction with standard echocardiographic imaging. Two types of Doppler examination are:

a) Pulse Wave Doppler (PW) which gives velocity of blood flow at the level of sample volume placed along ultrasound beam

[1] Named after Austrian physicist Johann Christian Doppler (1803-1853). The Doppler effect is caused by the relative motion of the observer and the wave source. It can be observed by listening to the blowing horn or siren of an approaching vehicle, whose pitch rises as the vehicle approaches the observer and falls as it recedes.

b) Continuous Wave Doppler (CW) which records velocities all along the ultrasound beam.

A proper alignment of ultrasound beam or cursor with the flow of blood under consideration is essential for accurate information. (Fig. 1.4)

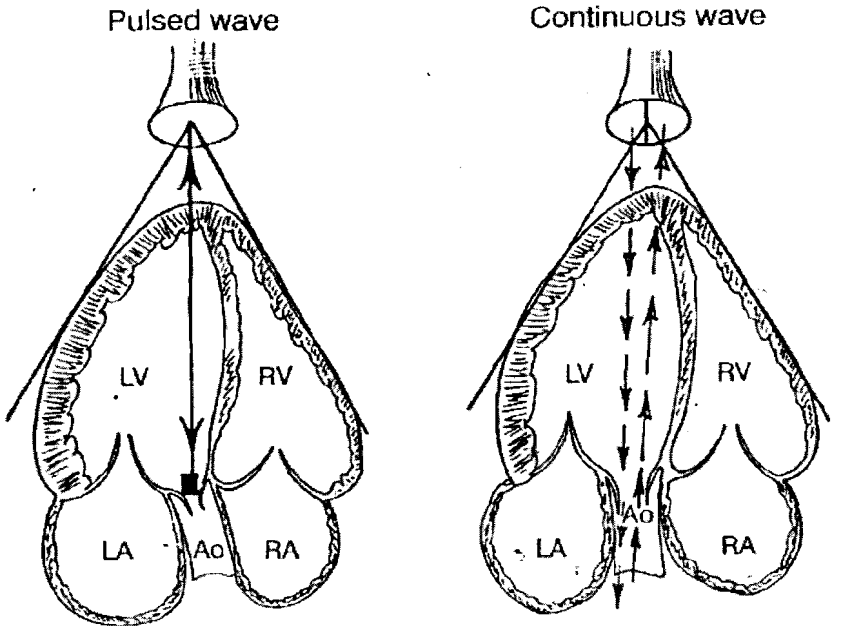
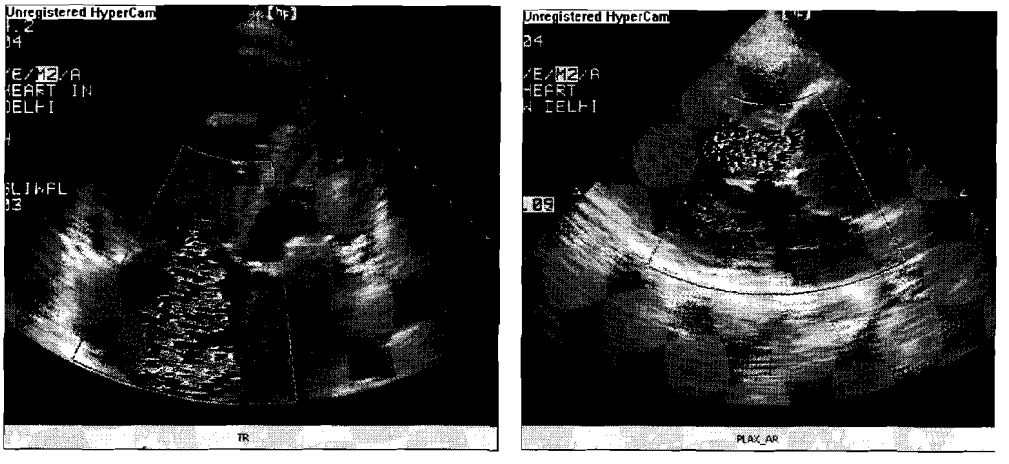



**Fig. 1.4: Schematic representation showing curser position of pulse wave and continuous wave Doppler from apical view.**

A lot of hemodynamic information including maximum and mean velocity, maximum and mean pressure gradients and pressure half time can be obtained from Doppler trace that helps in detection and gradient of valve stenosis and regurgitation, extraction of pulmonary artery pressure and evaluation of aortic, pulmonary venous and hepatic venous flows. Various calculations like stroke volume, cardiac output, valve area, regurgitant fraction and intracardiac shunts can be calculated which can guide the cardiologist and surgeon in taking important decisions regarding timing and type of intervention in individual patients.




(a) (b)

**Fig. 1.5: Colour Doppler across tricuspid valve in apical four chamber view in patient with severe TR (a) and across aortic valve (b) in PLAX view in patients with severe AR**

Colour Doppler is based on principle of pulse wave Doppler and provides a real time display of moving blood in different colours. By convention the blood flowing towards the transducer is encoded in red and blood flowing away form the transducer is encoded in blue colour. Turbulence is indicated by multicoloured or mosaic pattern of flow. Colour Doppler imaging makes the detection and estimation of valve regurgitation and shunts simple and accurate. It also guides in correct placement and angulation of cursor for obtaining pulse or continuous wave Doppler traces. [Fig.1.5(a) and (b)]

## 1.4 TWO-DIMENSIONAL IMAGE ACQUISITION

### Patient Positioning

The patient should be in the left lateral position as this brings the heart into contact with chest wall. The left arm is extended behind the head to permit access to the apical and parasternal windows.

### Probe Positioning

There are four standard transducer positions—parasternal, apical, subcostal and suprasternal which is utilized to visualize heart and great vessels.

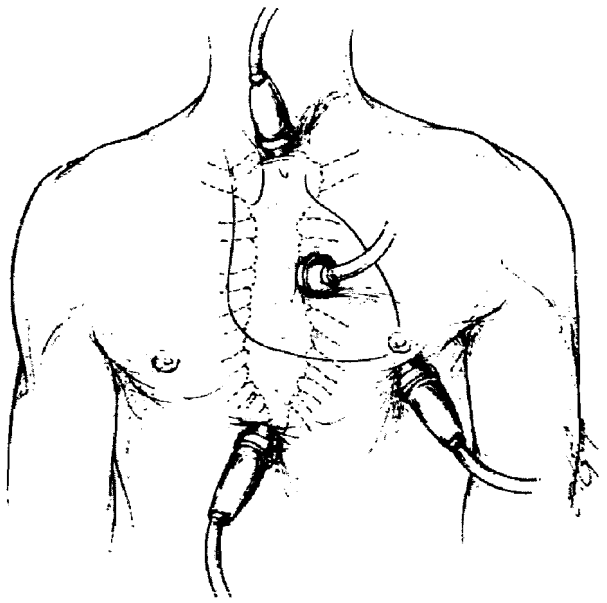


**Fig. 1.6 (a): Four standard transducer position with parasternal, apical, subcostal and suprasternal views**

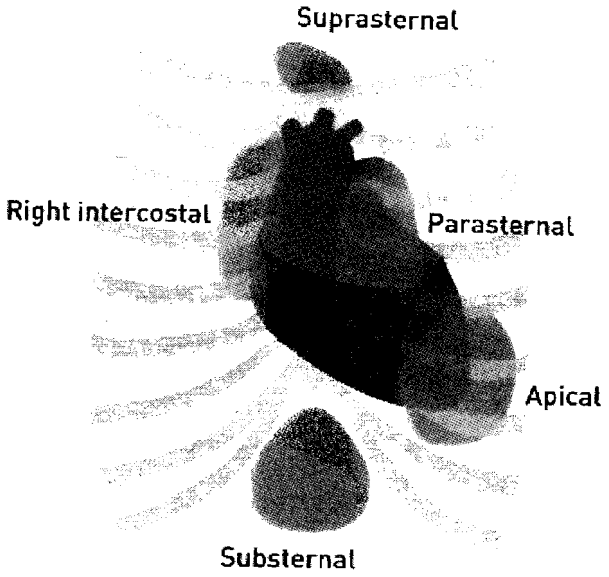



**Fig. 1.6 (b): Also shows right parasternal view used to take aortic gradient in patient of aortic stenosis**

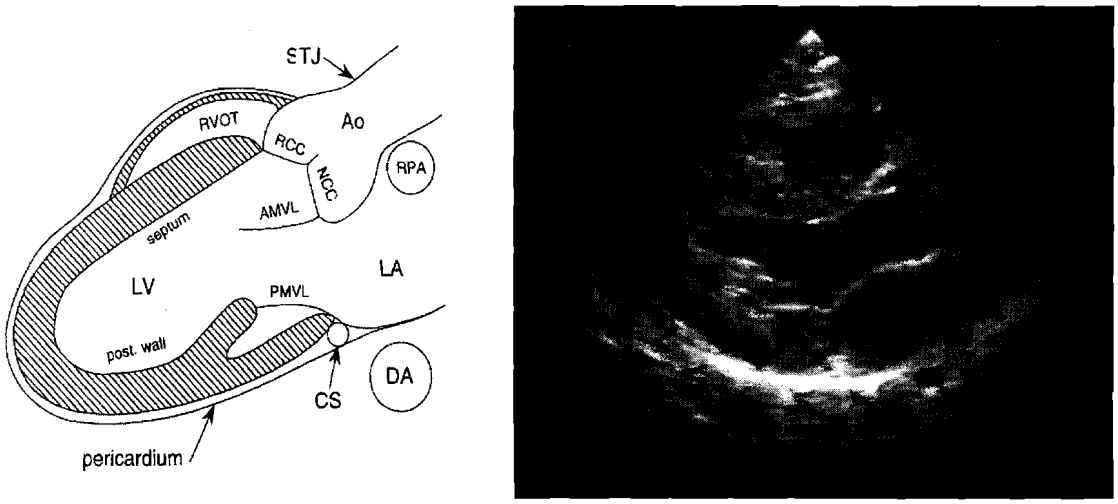
A) ***Parasternal Position***

Examination is begun by placing the transducer in left parasternal region, usually in the third or fourth left intercostal space. From this position, a sector image of the heart along its long and short axis can be obtained.

*Parasternal Long Axis View*

The parasternal long axis view is acquired with the ridge of the transducer pointing towards the patient's right shoulder. Angling the beam toward the right

hip brings the right ventricular inflow into view. Angling the beam towards the right shoulder allows evaluation of right ventricular outflow tract.




(a) (b)

**Fig. 1.7: Plax view-schematic diagram and Two-dimensional echocardiographic image showing various structures visualized**

Various structures visualized are LV, LA, MV, RV, LVOT and AV, ascending aorta.

*Parasteranl Short Axis View*

With the transducer placed in the parasternal position (third or fourth left intercostals space), the probe is then turned 90° clockwise from parasternal long axis view to obtain short axis view. The ridge now points towards left shoulder and observation is made at four levels:

1) At the level of great vessels
2) Mitral valve
3) Papillary muscles
4) Apex

Various structure visualized are apex, MV, Papillary muscles, AV, TV, PV, pulmonary artery and bifurcation, LA, RA and RV. [Fig. 1.8 (a) and (b)]

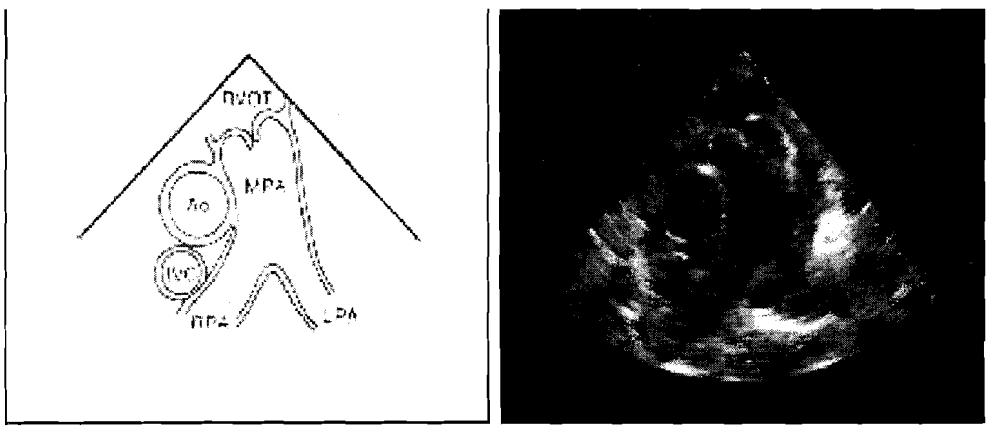



**Fig. 1.8 (a): Schematic diagram and Two-dimensional echocardiographic image of the parasternal short axis view at the aortic level**

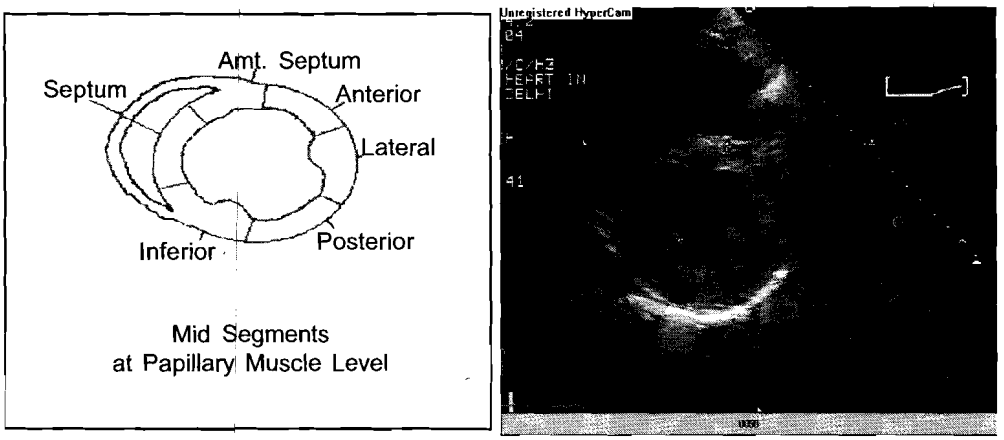



**Fig. 1.8 (b): Schematic diagram and Two-dimensional echocardiographic image of short axis view at level of papillary muscles**

B) ***Apical Window***

The transducer is placed in the mid axillary line with the transducer ridge pointing towards the patients left to obtain the four-chamber view. The left ventricular apex is aligned in the middle of the screen sector by sliding the transducer medially. The ultrasound beam is angled anteriorly to obtain five-chamber view or posteriorly to visualize the coronary sinus. From the four chamber view, the probe is rotated counter clockwise to acquire the two chamber view and further counter clockwise to the apical long axis view.

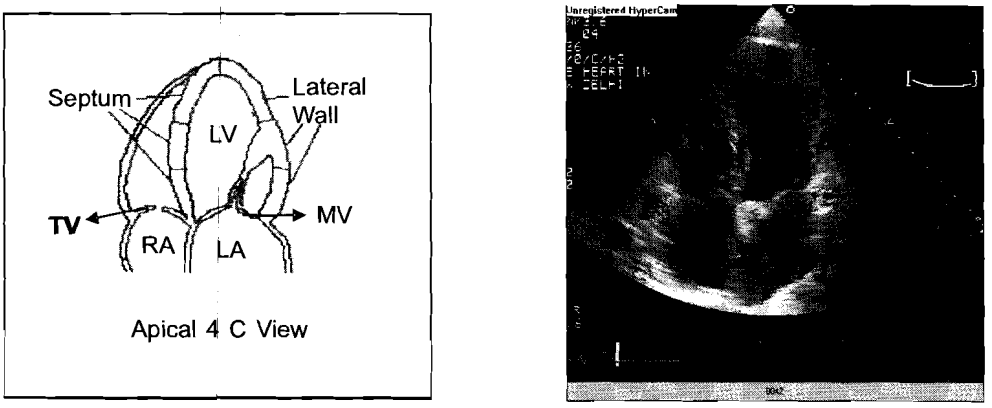



**Fig. 1.9 (a): Schematic diagram and Two-dimensional echocardiographic image of apical four-chamber view**

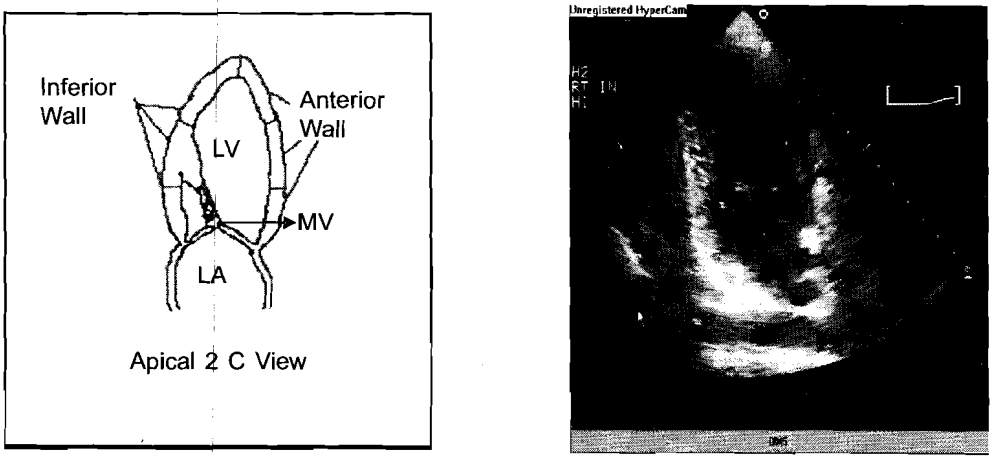
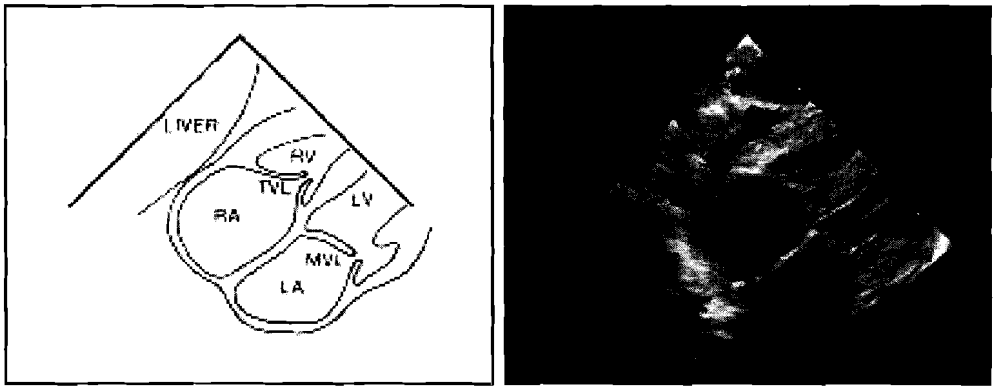



**Fig. 1.9 (b): Schematic diagram and Two-dimensional echocardiographic image of apical two-chamber view**

| Table 1.2: Structures Visualized in Apical View | | |
|---|---|---|
| Apical | 4 Chamber | LA, RA, LV, RV, MV, TV, IVS |
| | 2 C | LA, LV, MV |
| | 5 C | LA, LV, RA, RV, AV, ascending aorta |

C) ***Subcostal Views***

In addition to parasternal and apical transducer position. Subcostal view also provides imaging window in adult patients. The patient is supine with knees flexed to relax the abdominal muscles. The transducer is moved to the subxiphoid position with the ridge pointing towards the patients left. The subcostal transducer position can be very effective in-patient with chronic lung diseases in whom parasternal and apical view are obscured by intervening lung tissue. The subcostal views also provide excellent visualization of the atria septum and the connections between IVC and right atrium.




(a) (b)

**Fig. 1.10: Schematic diagram and Two-dimensional echocardiographic image of subcostal four-chamber view**

D) ***Suprasternal Views***

These views are obtained by placing the transducer in the suprasternal notch with the ridge pointing cephalad. The neck is extended during the suprasternal notch examination. This position may be uncomfortable for many patients.

It provides a view of the arch of the aorta and includes the great vessels in the majority of patients and positions of the main pulmonary artery. (Fig. 1.11)

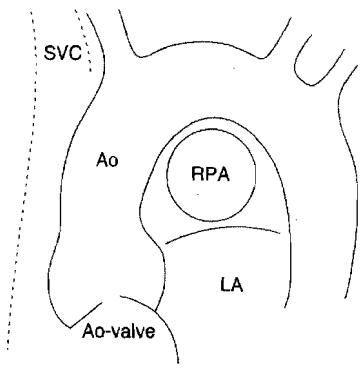



**Fig. 1.11: Schematic diagram of the aorta and right pulmonary artery from the suprasternal notch window**

E) ***Right Parasternal Windows***

It is a view obtained in right lateral decubitus position with the transducer in the right parasternal area and can be helpful in evaluating the ascending aorta and the interatrial septum.

## 1.5 CARDIAC DOPPLER

Doppler echocardiography measures blood flow velocities and direction of blood flow in the heart and great vessels. The characteristics of blood flow are evaluated using both audio information and a graphic display of the Doppler spectral analysis.

Qualitative and quantitative Doppler information may aid in the non-invasive assessment of:

A) **Valvular Abnormalities**

- Stenosis—as indicated by increased blood flow velocity and turbulence beyond an obstruction.
- Regurgitation—detection of high velocity turbulent retrograde flow in cardiac chamber proximal to be regurgitant valve.

B) **Congenital Cardiac Defects**

- Shunt Lesions—detection of flow across a septal defect or from a patent ductus arteriousus and quantification of the degree of shunting.

C) **Cardiac Function**

- Velocity time intervals
- Estimates of cardiac output
- Other potential estimation of cardiac function

### 1.5.1 Principles of Doppler Echocardiography

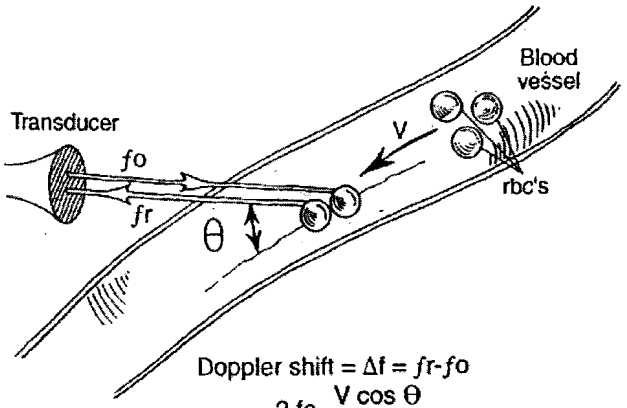
Doppler echocardiography is based on the Doppler effect, which was described by the Austrian physicist Christian Doppler in 1842.

The Doppler effect states that sound frequency increases as the sound source moves towards the observer and decreased as the source moves away. In the circulatory system, the moving target is the red blood cells (rbc). When an ultrasound beam with known frequency (Fo) is transmitted to the heart or great vessels, it is reflected by rbc's. The frequency of reflected ultrasound waves (Fr) increases when rbc's are moving towards the source of ultrasound and vice versa. The change in frequency between transmitted and reflected sound is seemed the frequency shift ($\Delta F$) or Doppler shift (Fr-Fo).

If cos $\theta$ is 0 degree (i.e., the ultrasound beam is parallel with the direction of blood flow), the maximal frequency shift is measured because the cosine of 0 degree is 1. This explains the proper alignment of ultrasound beam or cursor with the flow of blood to achieve accurate information.

Peak Flow Velocity is derived from Doppler shift by rearranging Doppler equation:

$$V = \frac{C}{2} \times \frac{\Delta F}{Fo}$$




$$\text{Doppler shift} = \Delta f = fr - fo$$
$$= 2\,fo\,\frac{V\cos\theta}{C}$$

fo = transmitted frequency
fr = reflected frequency
V = velocity of red blood cells
C = speed of ultrasound in blood

**Fig. 1.12: Schematic diagram showing Doppler effect**

Various information can be obtained from spectral display of Blood flow-
Velocity the speed of sampled blood cells (calculated from spectral analysis information).

Direction of flow—either towards or away from the transducer (positive or negative Doppler shifts). (Fig.1.13)

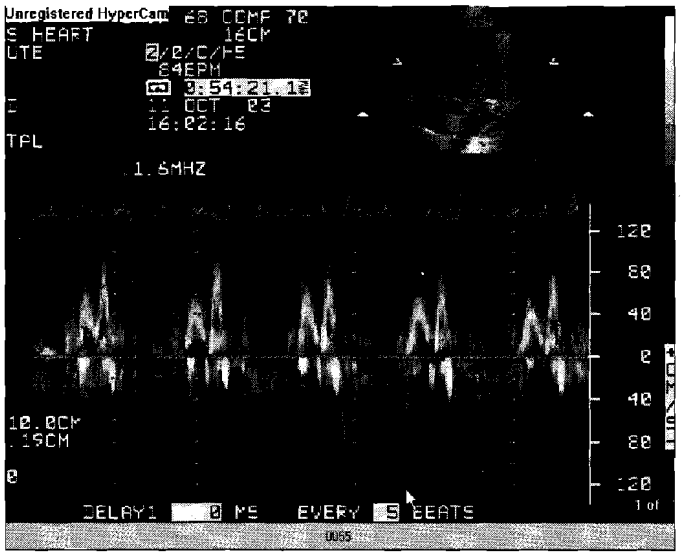



**Fig. 1.13 (a): Apical four chamber view showing pulse wave Doppler trace across mitral valve, since blood flow is from LA to LV i.e. towards transducer therefore shows positive trace.**

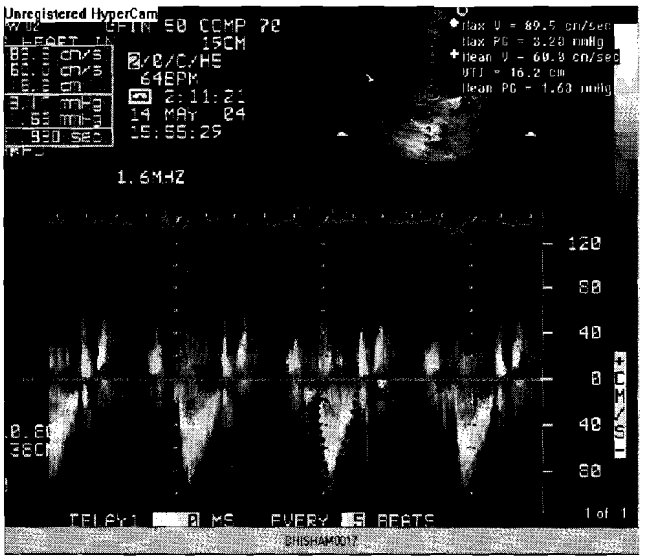



**Fig. 1.13 (b): Apical four chamber view showing pulse wave across aortic valve, since blood flow is from LV to aorta i.e. away from transducer therefore shows negative trace.**

Timing—instantaneous velocity and direction of flow throughout the various positions of cardiac cycle.

Intensity—the amplitude of individual velocities within the Doppler signal at any point of time—the more intense the signal, the greater number of blood cells moving at that velocity.

## 1.5.2 Types of Cardiac Dopler

There are two types of Doppler examination:

1) Pulse wave Doppler

2) Continuous wave Doppler

Both these modalities are necessary part of Doppler echocardiography and provide complimentary information.

### 1) Pulse Wave Doppler

Pulse wave transducer has one Doppler crystal. This crystal emits a short burst of ultrasound at a certain frequency [PULSE REPETITION FREQUENCY (PRF)]. The ultrasound is reflected from moving rbc's and is received by the same crystal (Fig.1.14).

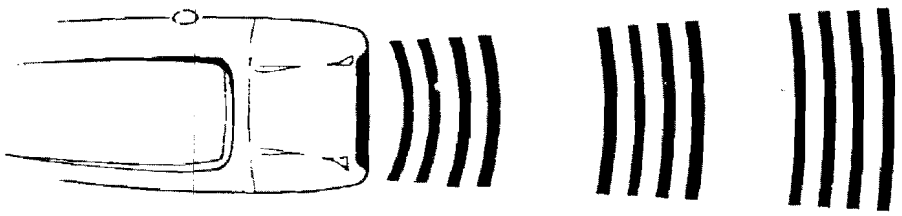


**Fig. 1.14: Schematic diagram showing pulse wave transducer emitting bursts of waves. There is one Doppler crystal to emit and receive ultrasound waves**

The pulse wave transducer will not send out a new burst of waves until it has received returning echoes from previous pulse, which must travel to and fro from the location indicated by the sample volume. The pulse wave Doppler gives velocity of blood flow at the level of sample volume placed along ultrasound beam.

Pulse repetition frequency, as well as transducer frequency, plays a role in determining the maximum velocity that can be measured using a pulsed Doppler method. These relationships come into play especially when attempting to record or to measure increased velocities that might occur in the case of obstructive lesions such as valvular stenosis. This maximal measured velocity is called NYQUIST LIMIT.

The NYQUIST LIMIT—It is a sampling phenomenon, which limits the maximum frequency shift measurement to one half of the sampling frequency (PRF).

By its nature, pulse wave Doppler is a sampling system while continuous wave Doppler is not. The nyquist limit is a theoretical maximum frequency that a sampling system can accurately measure.

Sample frequency — Unambiguous maximum velocity measurement

$$\frac{\text{NUMBER OF PULSES/SEC}}{2} = \text{NYQUIST LIMIT}$$

If the frequency shift is higher than the Nyquist frequency, aliasing occurs; i.e., the Doppler spectrum is cut off the Nyquist frequency and the remaining frequency shift is recorded on the opposite side of baseline.(Fig.1.15)

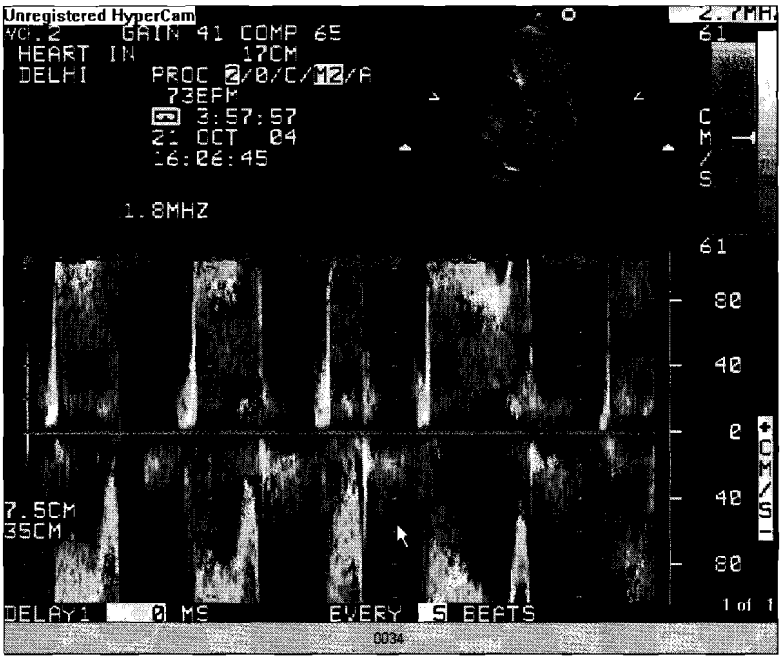



**Fig. 1.15: Pulse wave across mitral valve in-patient of mitral stenosis showing phenomenon of aliasing**

The PRF varies inversely with the depth of the sample volume the shallower the location of the sample volume, the higher the PRF and Nyquist frequency. In other words, higher velocities can be recorded without aliasing by pulse wave Doppler if the sample volume is closer to transducer.

2) **Continuous Wave Doppler**

In continuous wave Doppler, the transducer has two Doppler crystals, one to constantly transmit and one to continuously receive. (Fig.1.16)

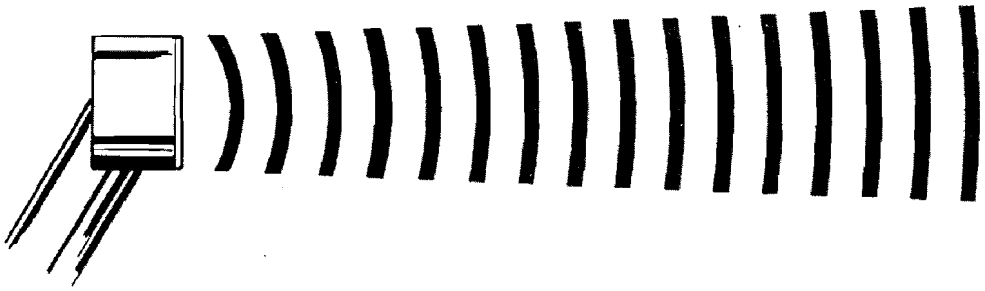


**Fig. 1.16: Schematic diagram showing continuous wave transducer. It was two crystals one to constantly transmit and one to continuously receive**

As a result of this continuous mode of transmitting and receiving, motion of blood and tissue occurring all along the ultrasound beam will be received, analysed and displayed without an indication of the depth from which each velocity arose. Also, the maximal frequency shift that can be recorded by continuous wave Doppler is not limited by the PRF or the Nyquist phenomenon hence, it is used to detect and record the highest velocity available.

The comparison of Pulse Wave and Continuous Wave Doppler is given below in Table 1.3.

**Table 1.3: Comparison of Pulse Wave and Continuous Wave Doppler**

| Pulse Wave | Continuous Wave |
|---|---|
| • Measures specific blood flow velocity by placing the "sample volume" at the region of interest | • Measures blood flow velocities along the axis of the entire ultrasound beam (range ambiguity) |
| • Maximal measurable velocity without aliasing is usually < 2 m/s | • Able to measure high velocities ≤ 9 m/s |
| • Performed by duplex transducer (two-dimensional and Doppler) | • Performed by duplex as well as by non-imaging transducer |
| • Suited for measuring low velocity at a particular intracardiac location | • Suited for measuring peak velocities (i.e. gradients) across intracardiac orifices |
| • Clinical applications: Used for determining | • Clinical applications: used for determining |
| • LVOT velocity and TVI | • Peak flow velocity and TVI |
| • Diastolic function/filling | • Valvular pressure gradient |
| • Mitral inflow velocity | • Pressure half time |
| • Pulmonary and hepatic vein velocities | • Dynamic LVOT gradient |
| • Location of flow disturbance | • Pulmonary pressure |
| • Mitral annulus velocity (DTI) | • Dp/dt |

**Check Your Progress 2**

1) What is the colour of Doppler when blood is flowing towards the transducer?

   a) Red

   b) Yellow

   c) Blue

   d) Mosaic

2) How many crystals are there is the transducer used for pulse wave doppler?

   a) One

   b) Two

   c) None

3) ..... Doppler is better for low velocity flow.

## 1.5.3 Doppler Calculations

Like M-Mode and 2-D ultrasound displays, the Doppler flow pattern is seen by many researchers as offering non-invasive alternative to measurements, which, in the past, could be made using invasive techniques.

In this section, you will find discussion of some of the most commonly used formulas and methods which are being developed to quantitate Doppler flow information. Also included is a table showing normal ranges (Table 1.4) and

| Table 1.4: Maximal Velocities Recorded Non-invasively with Doppler Ultrasound in Normal Individuals (m/sec)* | | |
|---|---|---|
| | Children | Adults |
| Mitral Flow | 1.0 (0.8–1.3) | 0.90 (0.6–1.3) |
| Tricuspid Flow | 0.60 (0.5–0.8) | 0.50 (0.3–0.7) |
| Pulmonary Artery | 0.90 (0.7–1.1) | 0.75 (0.6–0.9) |
| Left Ventricle | 1.00 (0.7–1.2) | 0.90 (0.7–1.1) |
| Aorta | 1.50 (1.2–1.8) | 1.35 (1.0–1.7) |

***Source:*** L. Hatle and B. Angelsen, *Doppler Ultrasound in Cardiology*, Philadelphia, Lea and Febiger, 1982, p.72.

step-by-step procedures for performing those Doppler calculations which are in most frequent use.

— Normal velocity ranges

— The simplified Bernoulli equation

— Mitral pressure half time

— Cardiac output

— Pulmonary artery flow time intervals

— Right ventricular and pulmonary artery systolic/diastolic pressure estimation

### The Simplified Bernoulli Equation[2]

The simplified Bernoulli equation may be applied to peak velocity measurements to make non-invasive estimates of pressure gradients.

$$\Delta P = 4 (V_2^2 - V_1^2)$$

Where $V_1$ = peak velocity proximal to an obstruction

$V_2$ = peak velocity distal to the obstruction.

This equation takes into consideration the velocity of flow on both sides of an obstruction.

*Example*: Peak velocity measured in the ascending aorta is 3 m/sec, peak velocity measured in the left ventricular outflow is 2 m/sec.

Gradient across the aortic valve $= 4 (3^2–2^2)$

$= 4 (9–4)$

$= 20$ mmHg.

If V is close to 1 m/sec, it can be neglected and then even simpler version of the Bernoulli equation may be used:

$$P = 4 V^2$$

2 Bernoulli's Principle: relates pressure, velocity and height for a non-viscous fluid with steady flow. A consequence is that for horizontal, as the speed of a fluid increases, the pressure it exerts decreases. Derived by Danial Bernoulli (1700–1782), a distinguished Swiss mathematician.

*Example*: Peak velocity measured on the ascending aorta is 3 m/sec, velocity measured in the left ventricular outflow tract is 1 m/sec.

Gradient across the aortic valve $= 4 (V)^2$

$= 4 (3)^2$

$= 36$ mmHg

When V is both significant and discernible (a $V_1$ value of 1.2 m/sec would be considered significant), the long form of the Simplified Bernoulli equation should be used.

Because gradient obtained using Doppler velocity measurements represent a maximal instantaneous gradient rather than a peak-to-peak gradient, there may be minor discrepancies between gradient values calculated by Doppler and those obtained in cardiac catheterization lab.

**Estimating The Severity of A-V Valve (mitral valve) Stenosis Using The Pressure Half-Time[3]**

Calculation

Step 1 – Measure peak velocity (V) in m/sec

Step 2 – Calculate velocity at pressure half-time

Step 3 – Determine the length of time it takes for the flow velocity to drop to pressure half-time velocity

Step 4 – A-V valve area ($cm^2$) = $\frac{220}{T\frac{1}{2}(ms)}$

*Example*:

1) Peak velocity measurement in 2 m/sec

$$P\frac{1}{2} = \frac{V}{\sqrt{2}} = \frac{2\,m/sec}{\sqrt{2}} = 1.4\ m/sec$$

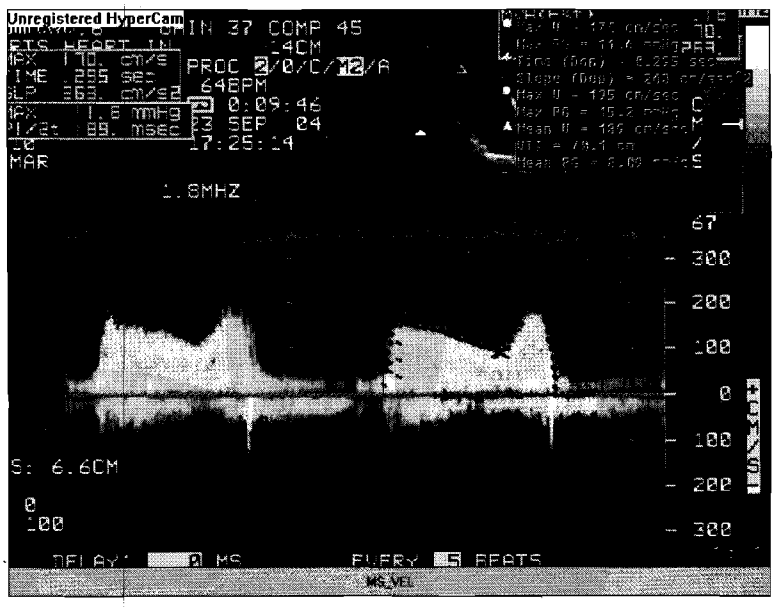



**Fig. 1.17: Continuous wave Doppler across mitral valve in-patient of mitral stenosis. The Doppler signal to traced to give peak velocity maximum and mean gradient and pressure half time.**

2) The length of time required for this pressure to drop is:

$T½ = 280$ ms

3) A-V valve area

$$= \frac{220}{T½ms}$$

$$= \frac{220}{280\,ms}$$

$= 0.79\ cm^2$

**Calculation of Cardiac Output Using Doppler Flow Velocities Measured in LVOT**

Step 1 = Determine the cross-sectional area (CSA) of the aortic annulus (LVOT).

Step 2 = Determine the flow velocity integral (FVI) by planimetry of the area under aortic velocity curves and calculating an average

Step 3 = Calculate stroke volume (SV) +
SV = FVI × CSA

Step 4 = Determine heart rate (HR)

Step 5 = Calculate Cardiac Output,
CO = SV × HR

*Example:*

1) Aortic annulus diameter measurement from M-Mode or 2–D is 3 cm

$$CSA = \frac{\pi D^2}{4}$$

$$= \frac{\pi(3cm2)}{4}$$

$$= \frac{3.14(9cm)2}{4}$$

$$= 7.07cm2$$

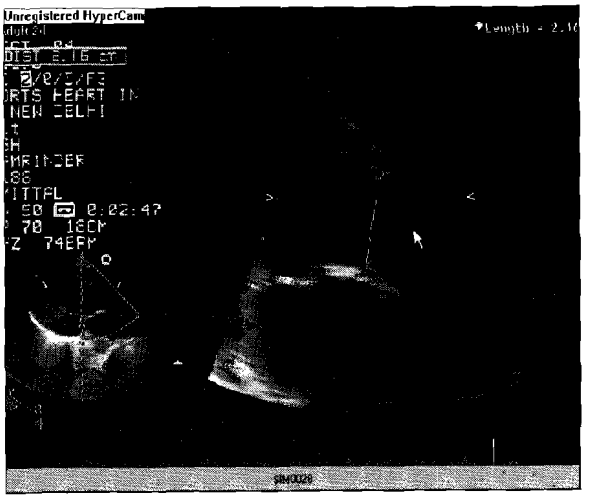



**Fig. 1.18 (a): LVOT annulus**

2) Integrate the area under the LVOT velocity curve and average 3-6 beats

Average planimetered flow velocity integral (FVI) = 13 cm

3) Stroke volume (SV) = FVI × CSA

= 13 cm × 7.07 $cm^2$

= 92 $cm^3$

= 0.092 liters

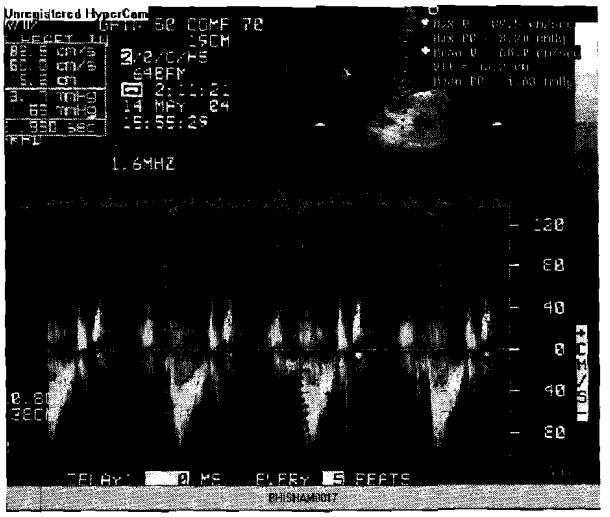



**Fig. 1.18 (b): LVOT velocity trace**

4) Heart rate (HR) is determined to be 60 beats/minutes

5) Cardiac output = SV × HR

= 0.092 liters/beat × 60 beats/min

= 5.52 liters/minute

**Sources of Error in Doppler Cardiac Output Determinations**

***Limitations of the Technique***

Though it has been suggested that Doppler echocardiography may be useful for non-invasive determinations of stroke volume and cardiac output, it should be recognized that there are limitations and sources of error in the technique. Because of these limitations, Doppler cardiac output calculations have been accepted especially for detecting relative changes in flow volume.

Doppler cardiac output calculations are based on a series of assumptions about the geometry of the aorta (or other site of velocity measurement with in the heart) and about the flow velocity profile in that vessel. Two primary assumptions about the hemodynamics of flow are:

1) Flow is occurring in a rigid, circular tube

2) There is a uniform velocity profile across that tube

The greatest source of error in this technique is the measurement of the LVOT area.

Difficulties associated with accurate aortic flow are measurements and calculations

- The aorta is elastic and changes size over the course of a cardiac cycle
- LVOT area increases with increased flow volume
- The diameter and cross sectional area may vary at different measurement sites
- Any error in a diameter measurement will be magnified when it is squared for an area calculation. As the diameter of the aorta decreased a measurement error will increase the degree of error in the area calculation
- If the vessel area is planimetered from a two-dimensional view, error may occur due to obliquity of the ultrasound beam

The blood flow velocity measurement is the second component of the cardiac output calculation. Since flow velocities are not uniform across the vessel, which spectral velocities should be used to represent aortic velocity: peak velocity, mean velocity, mode velocity?

The most important aspect of the velocity measurement is thorough sampling technique, taking care to orient the ultrasound beam as parallel to flow as possible (as indicated by the strength of the flow signal and the peak velocity measurement).

**Check Your Progress 3**

Continuous wave Doppler across aortic valve yields Vel of $4m^2$. Velocity at LVOT by pulse wave Doppler is $1m^2$. LVOT diameter is $2.2cm^2$. Calculate the aortic valve area.

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**Detection of Pulmonary Hypertension Using Doppler Techniques**

***Right Ventricular (RV) and Pulmonary Artery Systolic Pressure Estimation***

Pressure calculation made using the Bernoulli equation may be used in conjunction with pressure measurements made by other modalities to determine various intracardiac pressure.

A) Right ventricular pressure may be determined by measuring the peak velocity of a regurgitant jet through an incompetent tricuspid valve and applying the following formula:

RV systolic Pressure = $4V^2 + 10$ mmHg

*Note:* 10 mmHg is an assumed value for mean right atrial pressure. An alternate approach to the quantitation of right atrial pressure is assessment of the jugular venous pulse. (Fig.1.19)

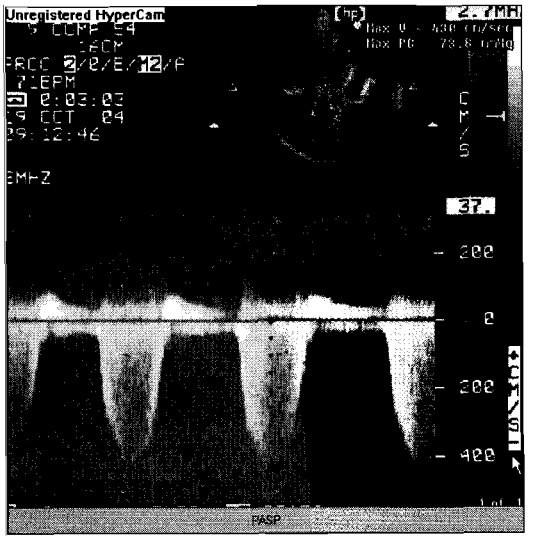



**Fig. 1.19: Continuous wave Doppler across TR jet giving peak velocity of TR jet. This gives PASP estimation (see text)**

B) When a ventricular septal defect (VSD) is present, with no aortic stenosis, the peak velocity across the defect reflects the difference in pressure between the right ventricle and left ventricle. The higher the VSD velocity, the lower the RV pressure.

RV pressure = arm BP—VSD gradient

*Example*:

Arm BP = 120 VAD velocity = 3 m/sec

$\Delta P = 4\ (3)^2$

$= 36$ mmHg

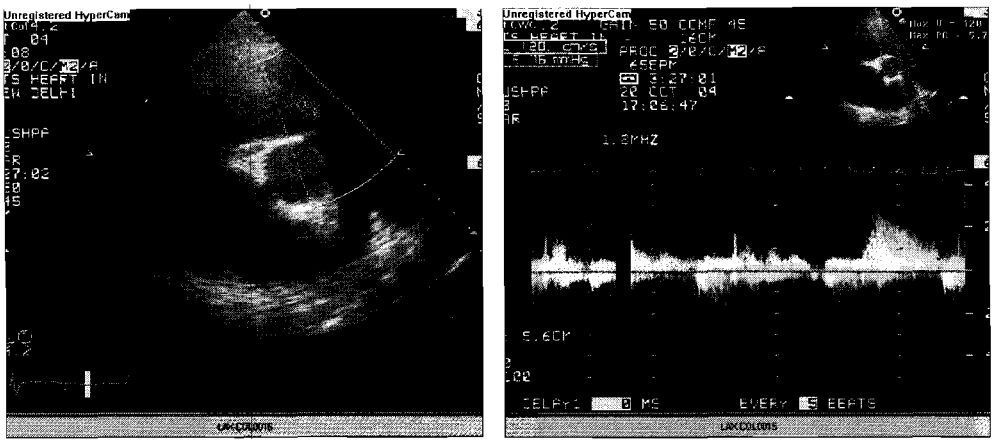
RV pressure $= 120$ mmHg—36 mmHg

$= 84$ mmHg

In the absence of pulmonic stenosis, right ventricular systolic pressure should be equivalent to pulmonary artery systolic pressure.

C) Pulmonary Artery Diastolic Pressure (PADP).

PADP may be determined by measuring the end diastolic velocity of




(a) (b)

**Fig. 1.20: Continuous wave Doppler across pulmonary valve in patient with PR showing peak velocity. It is useful in PADP estimation (see text)**

Pulmonary regurgitant signal and applying the following formula

$PADP = 4\ V^2 + 10$ mmHg

V is the end diastolic velocity of pulmonary regurgitant signal

10 mmHg is an assumed value for mean right atrial pressure [Fig. 1.20 (a) and (b)].

D) Right Atrial Pressure (RAP)

RAP can be determined semiquantitatively by assessing collapse of the inferior vena cava during inspiration. The inferior vena cava is imaged subcostally and its diameter is examined 1 cm before it joins the right atrium. Correlation of RA pressure with IVC size is tabulated below. (Fig. 1.21, Table 1.5).


**Fig. 1.21: M-Mode across IVC (See text for correlation of RA pressure with IVC size)**

**Table 1.5: Semi Subjective Estimation of Right Atrial Pressure from IVC**

| Diameter on Expiration (cm) | Collapse on Inspiration (per cent) | Pressure Estimate (mmHg) |
|---|---|---|
| <2 | complete | 0-5 |
| <2 | >50% | 5-10 |
| >2 | 25-50% | 10-15 |
| >2 | <25 | 15-20 |

**Check Your Progress 4**

Jet velocity of TR jet is $5m^2$. Estimate the pulmonary artery systolic pressure.

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## 1.6 ASSESSMENT OF DIASTOLIC FUNCTION

Diastolic dysfunction is responsible for one third of cases of heart failure alone and rest two third of cases in combination with systolic dysfunction. Diastolic dysfunction can be assessed by Doppler echocardiography (basics of diastolic dysfunction would be covered in this section)

Doppler Echocardiographic Indices of Diastolic Function:

1) Mitral inflow velocity (E = wave, A = wave E/A ratio)
2) Mitral E = wave deceleration time
3) Isovolumetric relaxation time (IVRT)
4) Pulmonary vein systolic and diastolic velocity (S,D,S/D ratio)
5) Pulmonary vein atrial systolic reversal (PVa)
6) Difference between PVa and mitral a wave duration
7) Tissue Doppler at mitral annulus

Transducer position: Place the pulsed sample at the level of tips of the mitral leaflets in their fully open diastolic position. The ultrasound beam need to be parallel with the direction of blood flow. (Fig. 1.22).

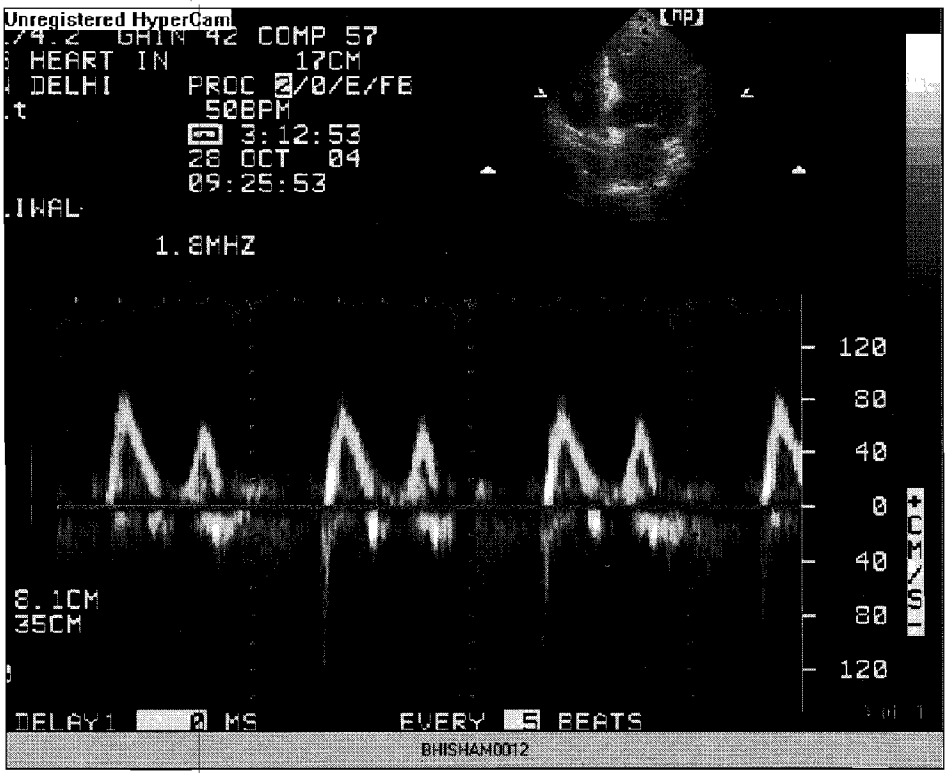


**Fig. 1.22: Position of pulse sample for taking mitral flow velocity to evaluate diastolic function. The pulse sample is placed at tip of mitral leaflets in fully open diastolic position**

### Where to record Doppler of mitral and pulmonary venous flow velocity

***Mitral Flow Velocity***

The normal flow pattern cross-mitral valve is a tall E wave where is due to early rapid filling and small A-wave which is due to atrial contraction. E/A ratio >1.

*Transducer Position*

The pulse sample is placed 1-2 cm into the right upper pulmonary vein in 4 chamber vein. (Fig. 1.23).

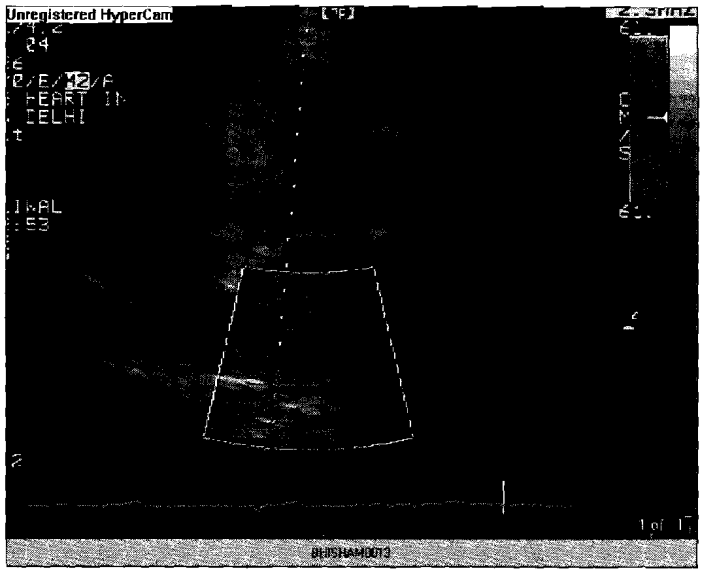


**Fig. 1.23: Position of pulse sample in pulmonary view. The pulse sample is place 1-2 cm in right upper pulmonary vein in four chamber view**

Pulmonary vein Doppler recordings show 4 distinct velocity components. Two systolic velocities ($PVs^1$ AND $PVs^2$),diastolic velocity (PVd) and atrial flow reversal (Pva.).

In normal filling $PVs^2 \geq PVd$. [Fig. 1.24 (a) and (b)]

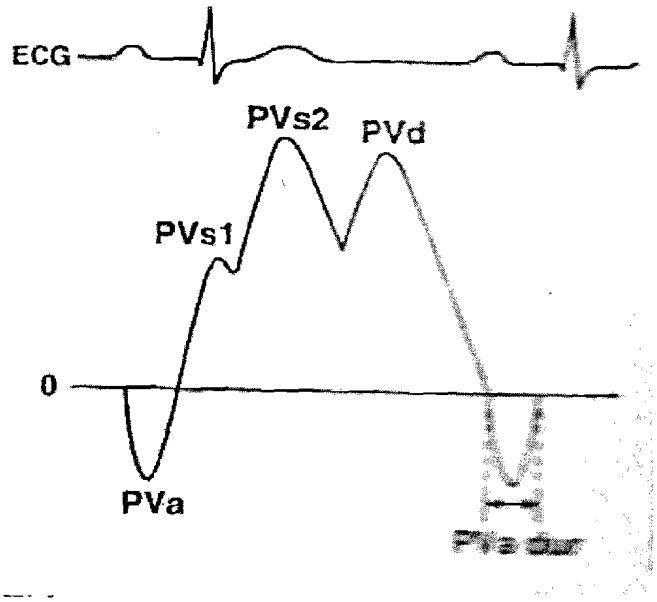


**Fig. 1.24 (a): Schematic representation of pulmonary vein Doppler**

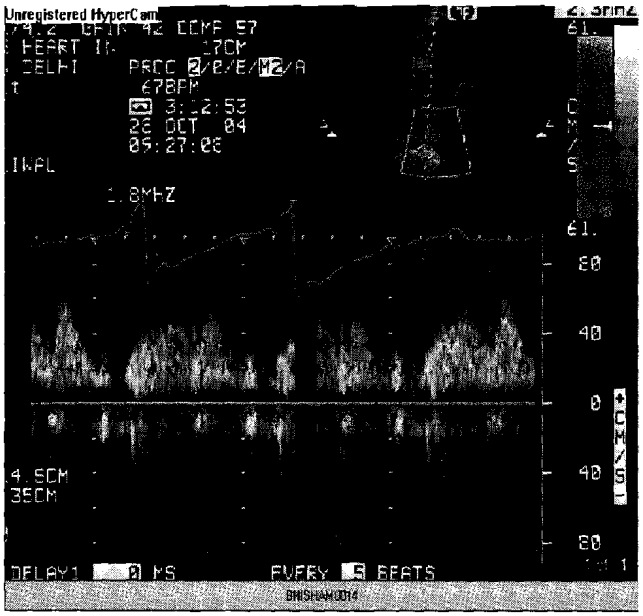


**Fig. 1.24 (b): Pulse wave Doppler across pulmonary vein**

Diastolic dysfunction can be graded as follows according to diastolic filling pattern:

Grade I—impaired relaxation

Grade II—Pseudonormal pattern

Grade III—Reversible restrictive pattern

Grade IV—Irreversible restrictive pattern

During grade I diastolic dysfunction E-wave is reduced with a shallow deceleration slope and A-wave becomes more tall and sharp and the isovolumetric relaxation time gets prolonged. When the LA pressure increases as in failure the elevated pressure opens the mitral valve earlier in diastolic (short IVRT) and sharp drop in gradient occur because of increased LVEDP. The E-wave becomes tall with steep deceleration slop, A-wave amplitude is diminished. This is called restrictive pattern on mitral trace. There may be a phase in transition where E to A ratio and IVRT drops back to normal so called psuedonormalization. Value of identifying such a defect can make considerable change in management.

A relaxation abnormality (A > E) indicated a possible benefit with B blockers despite presence or absence of LV systolic dysfunction. Restrictive pattern. (E >>> A) neccesitates use of preload and afterload reduction—NTG, diuretic and ACE inhibitors. These patients are likely to deteriorate with B blockers. The restrictive pattern indicates worse prognosis. [Fig. 1.25 (a), (b) and (c)]

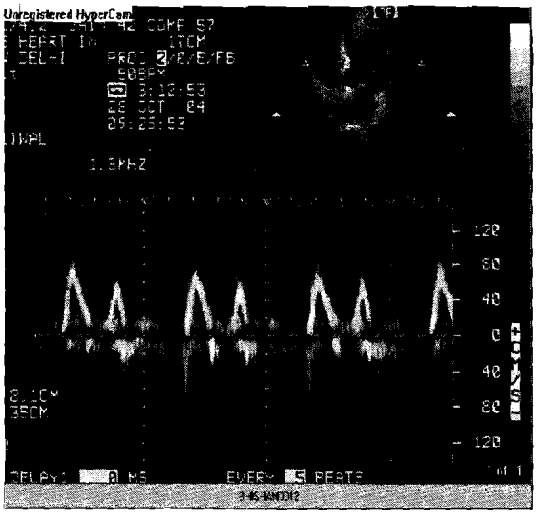

**Fig. 1.25 (a): Normal pattern**

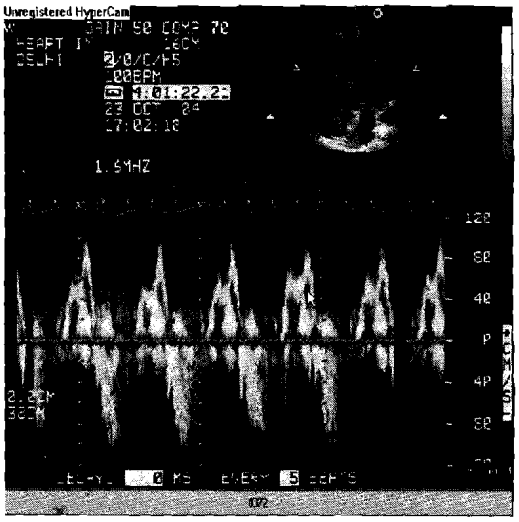

**Fig. 1.25 (b): Diastolic relaxation impairment**

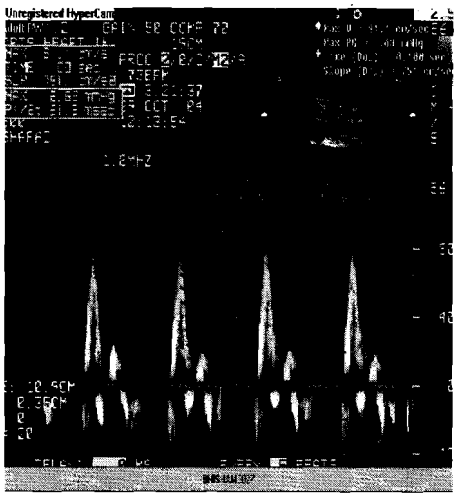

**Fig. 1.25 (c): Restrictive physiology (for detail see text)**

(Pulse wave Doppler across mitral valve for assessing diastolic function)

The classification of diastolic dysfunction and its main characteristics are tabulated below. (Table 1.6)

**Table 1.6: Classification of Diastolic Filling**

**Normal Filling**
- DT 160-240 msec (but can be lower, especially in young persons)
- IVRT 70-90 msec; E/A 1-2
- Mitral A duration ≥ PVa duration
- PVs2 ≥ PVd (PVs2 can be smaller than PVd in young persons)
- No anatomic abnormalities

**Impaired (or abnormal) relaxation**
- DR > 240 msec
- IVRT > 90 msec
- E/A < 1.0
- PVs2 >> PVd
- Mitral A duration ≥ or < Pva duration (depending on LVEDP)

**Pseudonormal pattern**
- DT 160-200 msec
- IVRT < 90 msec; E/A 1-1.5
- PVs2 < PVd
- Mitral A duration < PVa duration
- PVa velocity ↑ (> 35 cm/sec)
- 2 D echocardiographic evidence of structural heart disease (↓ EF, ↑LA,LVH)
- Reversal of E/A ratio (to < 1.0) with preload reduction (e.g. Valsalva maneuver)

**Restrictive filling**
- DT < 160 msec
- IVRT < 70 ms; E/A > 1.5
- PVs2 << PVd
- Mitral A duration < PVa duration
- PVa velocity ↑ (≥ 35 cm/sec, usually but not always)
- 2 D echocardiographic evidence of structural heart disease
- decreased E/A ratio with preload reduction (e.g. Valsalva)

***Source**: Oh J.K.*, Seward J.B., Tajik, A.J., *The Echo Manual,* 2nd edn., Little Brown and Company, 1994, p. 54.

**Check Your Progress 5**

1) Where do you put the cursor for taking mitral inflow pattern?

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2) Define grading of diastolic dysfunction and draw E/A waveform in relation to various grades.

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3) What is the normal deceleration time?

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## 1.7 LET US SUM UP

In this unit you have learnt about the fundamental physics of ultrasound imaging in echocardiography, position of patient for transthoracic scanning, various views for from thoracic canning and basics of cardiac doppler. You have also learnt about the assessment of diastolic functions.

## 1.8 ANSWERS TO CHECK YOUR PROGRESS

**Check Your Progress 1**

1) Echocardiography works on principle of ultrasound. The transducer has a Peizo electric crystal which emits sound waves of given frequency which is reflected from heart and other structures and is returned to the transducer which is displayed as image on monitor screen.

2) Peizoelectric crystal is used in the echcardiographic probe.

   Commonly used frequencies are

   - 2.5 MHz for adult echo
   - 7.5 –10 MHz for pediatric echo

3) (d) 10 MHz has best resolution. Higher is the frequency, better is the resolution but lesser is the penetration.

4) (a) Because lesser is the frequency better is the penetration.

**Check Your Progress 2**

1) (a) The blood flowing towards the transducer is encoded in red and blood flowing away is encoded in blue.

2) (a) The pulse wave Doppler probe has one crystal which sends and receive sound waves.

3) Pulse wave Doppler

**Check Your Progress 3**

Use continuity equation

$A_1V_1 = A_2V_2$

(LVOT) (Aortic Valve)

$\pi r_1^2 \times V_1 = \pi r_2^2 \times V_2$

$$\text{Area} = \frac{3.14 \times 1.1}{4 \times 4} = .21 \text{ cm}^2$$

**Check Your Progress 4**

PASP = 4 V2 + RA pressure

V = Velocity of TR jet

$= 4 \times 5 \times 5$

=100

if RA pressure is 10 mmHg

PASP = 110 mmHg

**Check Your Progress 5**

1) Place the pulse sample at the level of tips of mitral leaflets in their fully open diastolic position with direction of beam parallel to direction of blood flow.

2) There are four goals of diastolic dysfunction

   a) Grade I impaired relaxation

   b) Pseudonormal pattern

   c) Reversible restrictive pattern

   d) Irreversible restrictive pattern

3) Normal deceleration time is 160-240 msec2.