بِسْمِ اللَّهِ الرَّحْمَٰنِ الرَّحِيمِ

رَبِّ اشْرَحْ لِي صَدْرِي وَيَسِّرْ لِي أَمْرِي
وَاحْلُلْ عُقْدَةً مِنْ لِسَانِي يَفْقَهُوا قَوْلِي

My Lord! Open my heart, and make my task easy for me, loosen the knot in my tongue, so that they may understand my speech." (20:25-29)

ڈاکٹر رحم با چا

The most pleasurable moment of my life

Dr. Raham Bacha

Ph.D. Diagnostic Ultrasound

Associate Professor

The University of Lahore

What is
an Echocardiography?

The imaging of heart with the help of ultrasound pulse sent to thee body and reflected sound waves (echo) received; is termed as echocardiography.

Echocardiography is the morphologic evaluation of the heart; with the help of which one of the following?

A. X-Rays
B. Gama rays
C. Electromagnetic waves
D. Sound waves

MCQ

PRINCIPLES OF ULTRASOUND

- Sound is a mechanical disturbance produced by passage of energy through a medium which may be gas, liquid or solid.
- Sound waves has a particular frequency, a wavelength, its own velocity and an intensity

- Sound energy is transmitted through a medium in the form of cycles or waves. Each wave consists of a peak and a trough. The peak coincides with adjacent group of molecules moving towards each other (compression phase). The trough coincides with adjacent group of molecules moving away from each other (rarefaction phase)

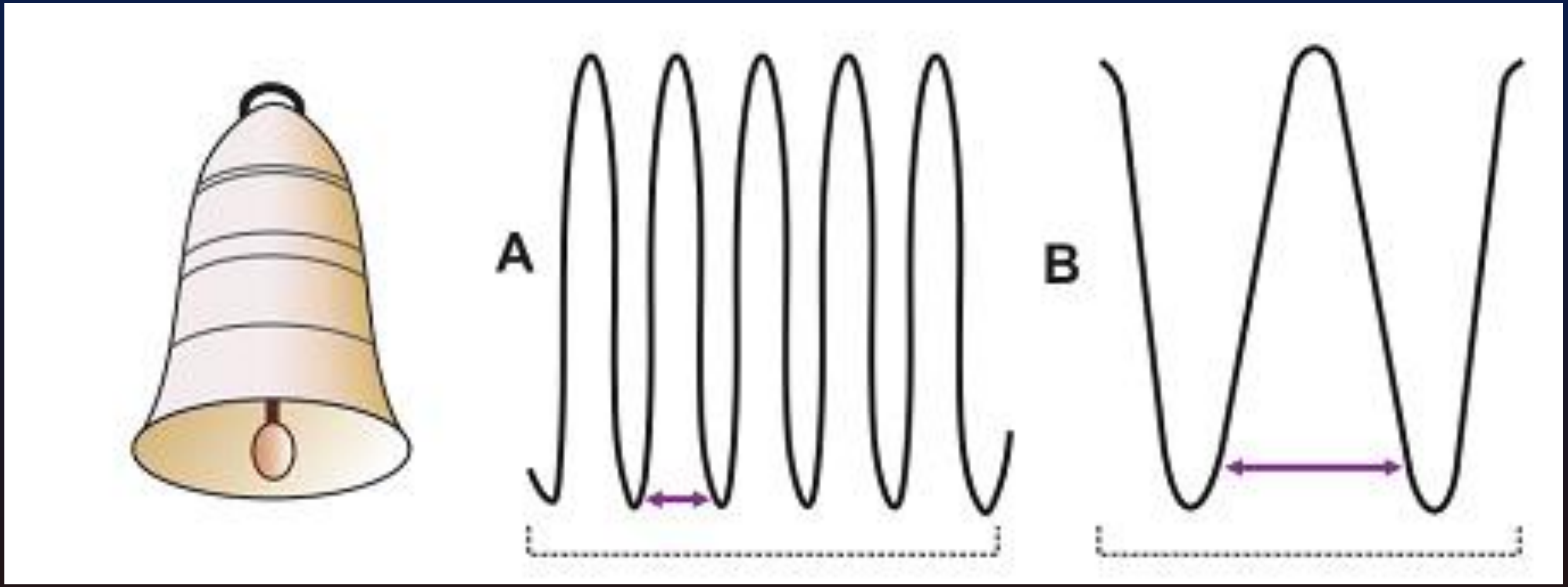
- Frequency of sound is the number of times per second, sound undergoes a cycle of rise and fall. It is expressed in cycles per second, or hertz (Hz) and multiples thereof.
- 1 hertz (Hz) = 1 cycle per second
- 1 kilohertz (KHz) = 10^3 Hz = 1000 Hz
- 1 megahertz (MHz) = 10^6 Hz = 1000000 Hz

- Frequency is appreciated by the listener as pitch of sound. Wavelength is the distance travelled by sound in one cycle of rise and fall. The length of the wave is the distance between two consecutive peaks.

Relationship between frequency and wavelength:

A. High frequency, short wavelength

B. Low frequency, long wavelength



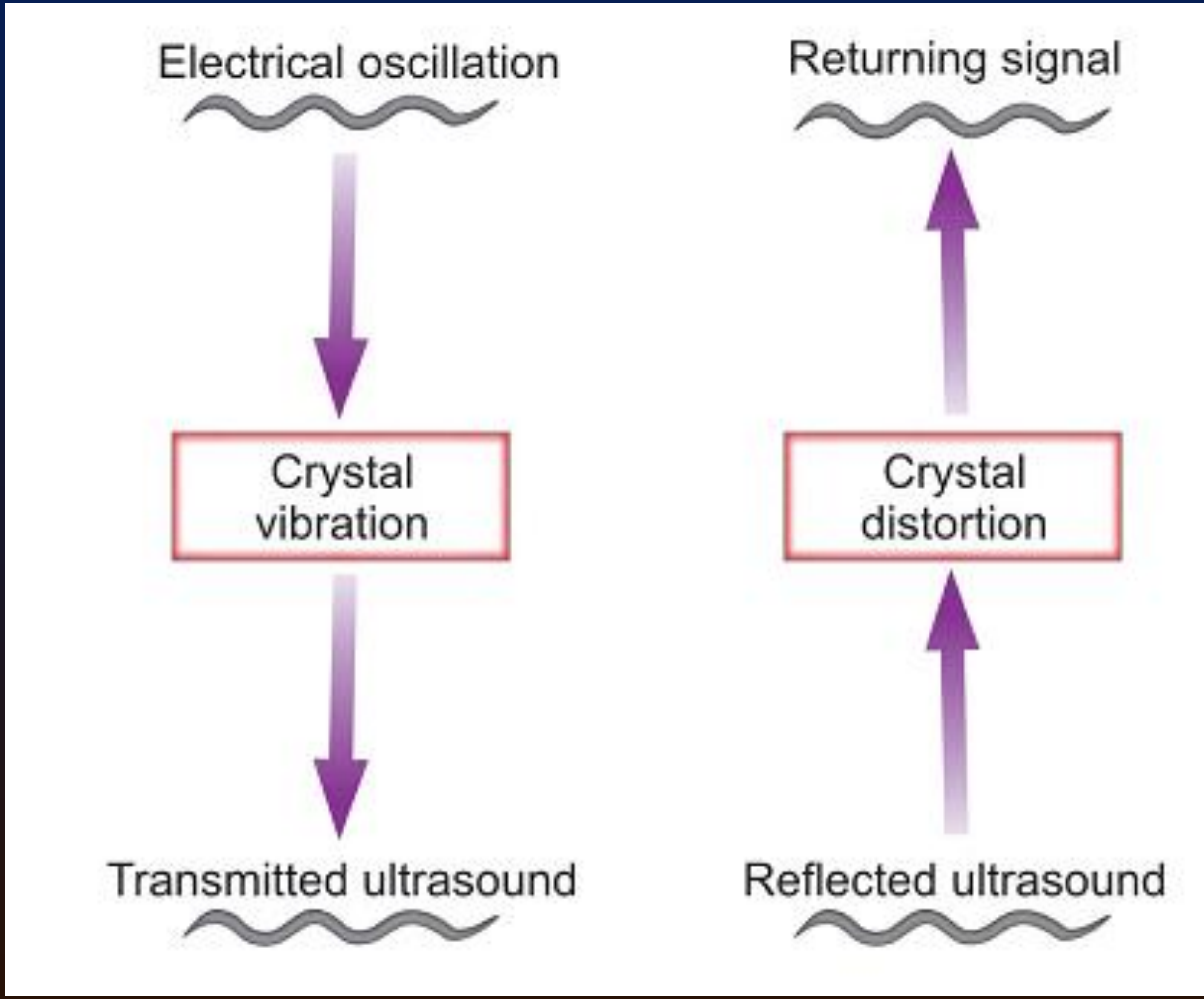
- Frequency and wavelength are inter-related. Since, sound travels a fixed distance in one second, more the cycles in a second (greater the frequency), shorter is the wavelength

- Therefore, Velocity = Frequency × Wavelength.
- • Velocity of sound is expressed in meters per second (m/sec) and is determined by the nature of the medium through which sound propagates. In soft tissue, the velocity is 1540 m/sec.
- • Intensity of sound is nothing but its loudness or amplitude expressed in decibels. Higher the intensity of sound, greater is the distance upto which it is audible.

- The normal audible range of sound frequency is 20 Hz to 20 KHz. Sound whose frequency is above what is audible to the human ear (more than 20 KHz) is known as ultrasound.
- • The technique of using ultrasound to examine the heart is known as echocardiography or simply echo.

- • Electricity and ultrasound are two different forms of energy that can be transformed from one to the other by special crystals made of ceramic such as barium titanate.
- • Ultrasound relies on the property of such crystals to transform electrical current of changing voltage into mechanical vibrations or ultrasound waves. This is known as the piezoelectric (pressure-electric) effect

The piezoelectric effect in ultrasound



- When electrical current is passed through a piezoelectric crystal, the crystal vibrates. This generates ultrasound waves which are transmitted through the body by the transducer which houses several such crystals.
- Most of these ultrasound waves are scattered or absorbed by the tissues, without any obvious effect. Only a few waves are reflected back to the transducer and echoed.

- Reflected ultrasound waves again distort the piezoelectric crystals and produce an electrical current. These reflected echoes are processed by filtration and amplification, to be eventually displayed on the cathode-ray-tube.
- The reflected signal gives information about the depth and nature of the tissue studied. Most of the reflection occurs at interfaces between tissues of different density and hence a different echo-reflectivity.

Echo-reflectivity of various tissues on the gray-scale

Tissue	*Reflectivity*	*Shade*
Bone	High	White
Muscle	Low	Gray
Air	Nil	Black

- The magnitude of electrical current produced by the reflected ultrasound determines the intensity and brightness on the display screen.
- On the gray-scale, high reflectivity (from bone) is white, low reflectivity (from muscle) is gray, and no reflection (from air) is black.
- The location of the image produced by the reflected ultrasound depends upon the time lag between transmission and reflection of ultrasound.

- Deeper structures are shown on the lower portion of the display screen while superficial structures are shown on the upper portion. This is because the transducer is at the apex of the triangular image on the screen.
- When ultrasound is transmitted through a uniform medium, it maintains its original direction but gets progressively scattered and absorbed.

- When ultrasound waves generated by the transducer encounter an interface between tissues of different density and thus different echo-reflectivity, some of the ultrasound waves are reflected back.
- It is these reflected ultrasound waves that are detected by the transducer and analyzed by the echo-machine.
- The wavelength of sound is the ratio between velocity and frequency (Wavelength = Velocity/Frequency).

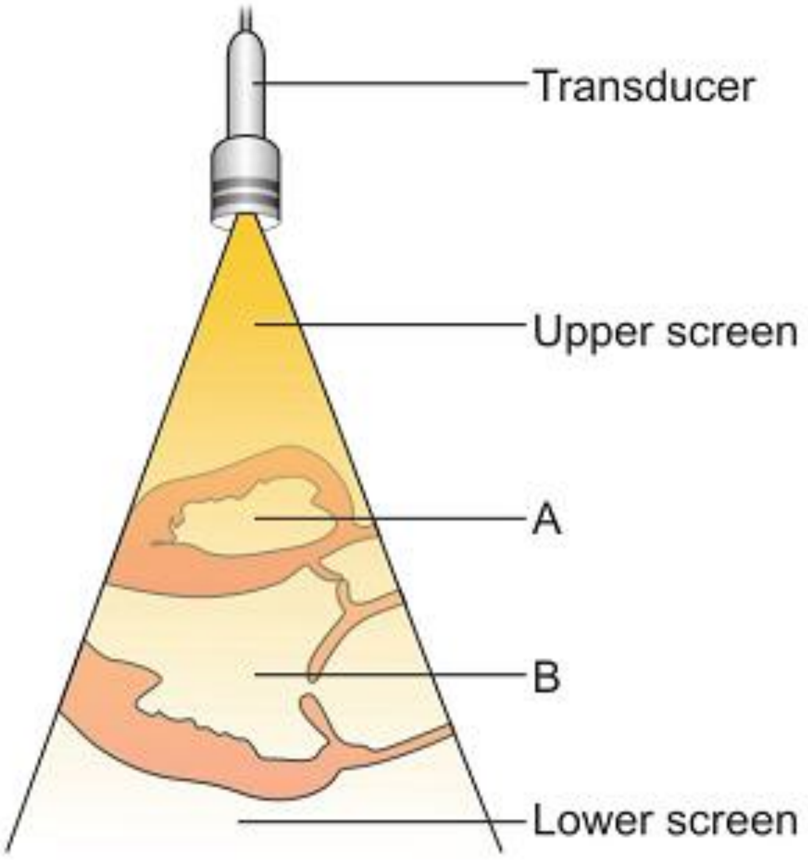


Fig. 1.3: Transducer is at the apex of visual display:
A. Right ventricle in the upper screen
B. Left ventricle in the lower screen

- Since wavelength and frequency are inversely related, higher the frequency of ultrasound, shorter is the wavelength.
- Shorter the wavelength, higher is the image resolution and lesser is the penetration.
- Therefore, high frequency probes (5.0–7.5 MHz) provide better resolution when applied for superficial structures and in children.

Features and applications of probes having different frequency

Frequency (MHz)	*Penetration in tissue*	*Resolution of image*	*Study depth*	*Age group*
2.5–3.5	Good	Less	Deep	Adults
5.0–7.5	Less	Good	Superficial	Children

- Conversely, lower the frequency of ultrasound, longer is the wavelength. Longer the wavelength, lower is the image resolution and greater is the tissue penetration.
- Therefore, low frequency probes (2.5–3.5 MHz) provide better penetration when applied for deeper structures and in adults

PRINCIPLES OF DOPPLE

- • The Doppler acoustic effect is present and used by us in everyday life, although we do not realize it. Imagine an automobile sounding the horn and moving towards you, going past you and then away from you.
- The pitch of the horn sound is higher when it approaches you (higher frequency) than when it goes away from you (lower frequency).

- This means that the nature of sound depends upon the relative motion of the listener and the source of sound.
- The change of frequency (Doppler shift) depends upon the speed of the automobile and the original frequency of the horn sound.
- Ultrasound reflected back from a tissue interface gives information about the depth and echo-reflectivity of the tissue.
- On the other hand, Doppler utilizes ultrasound reflected back from moving red blood cells (RBCs).

- The Doppler principle is used to derive the velocity of blood flow. Flow velocity is derived from the change of frequency that occurs between transmitted (original) and reflected (observed) ultrasound signal.
- • The shift of frequency (Doppler shift) is proportional to ratio of velocity of blood to speed of sound and to the original frequency.

- It is calculated from the following formula:

$$F_D \quad \frac{V}{C} \quad F_O$$

F_D : Doppler shift

F_o : Original frequency

V : Velocity of blood

C: Speed of sound

Therefore, velocity of blood flow is:

$$V \quad \frac{F_D \quad C}{F_O}$$

Further refinement of this formula is:

$$V = \frac{F_D \times C}{2F_O \times \text{Cos } \theta}$$

- The original frequency (Fo) is multiplied by 2 since Doppler shift occurs twice, during forward transmission as well as during backward reflection.
- Cosine theta (Cos θ) is applied as a correction for the angle between the ultrasound beam and blood flow. The angle between the beam and flow should be less than 20o to ensure accurate measurement.

- Cos θ is 1 if the beam is parallel to blood flow and maximum velocity is observed. Cos θ is 0 if the beam is perpendicular to blood flow and no velocity is detected.
- It is noteworthy that for Doppler echo, maximum velocity information is obtained with the ultrasound beam aligned parallel to the direction of blood flow being studied.
- This is in sharp contrast to conventional echo, where best image quality is obtained with the ultrasound beam aligned perpendicular to the structure being studied.

- Since, the original frequency value (2×Fo) is in the denominator of the velocity equation, it is important to remember that maximum velocity information is obtained using a low frequency (2.5 MHz) transducer.
- There is a direct relationship between the peak velocity of blood flow through a stenotic valve and the pressure gradient across the valve.

- Understandably when the valve orifice is small, blood flow has to accelerate in order to eject the same stroke volume. This increase in velocity is measured by Doppler.
- The pressure gradient across the valve can be calculated using the simplified Bernaulli equation: Δ P = 4 V2 P: pressure gradient (in mm Hg) V: peak flow velocity (in m/sec)

- This equation is frequently used during Doppler evaluation of stenotic valves, regurgitant lesions and assessment of intracardiac shunts.
- The velocity information provided by Doppler complements the anatomical information provided by st andard M-mode and 2-D Echo.

- Analysis of the returning Doppler signal not only provides information about flow velocity but also flow direction.
- By convention, velocities towards the transducer are displayed above the baseline (positive deflection) and velocities away from the transducer are displayed below the baseline (negative deflection

- The returning Doppler signal is a spectral trace of velocity display on a time axis. The area under curve (AUC) of the spectral trace is known as the flow velocity integral (FVI) of that velocity display.

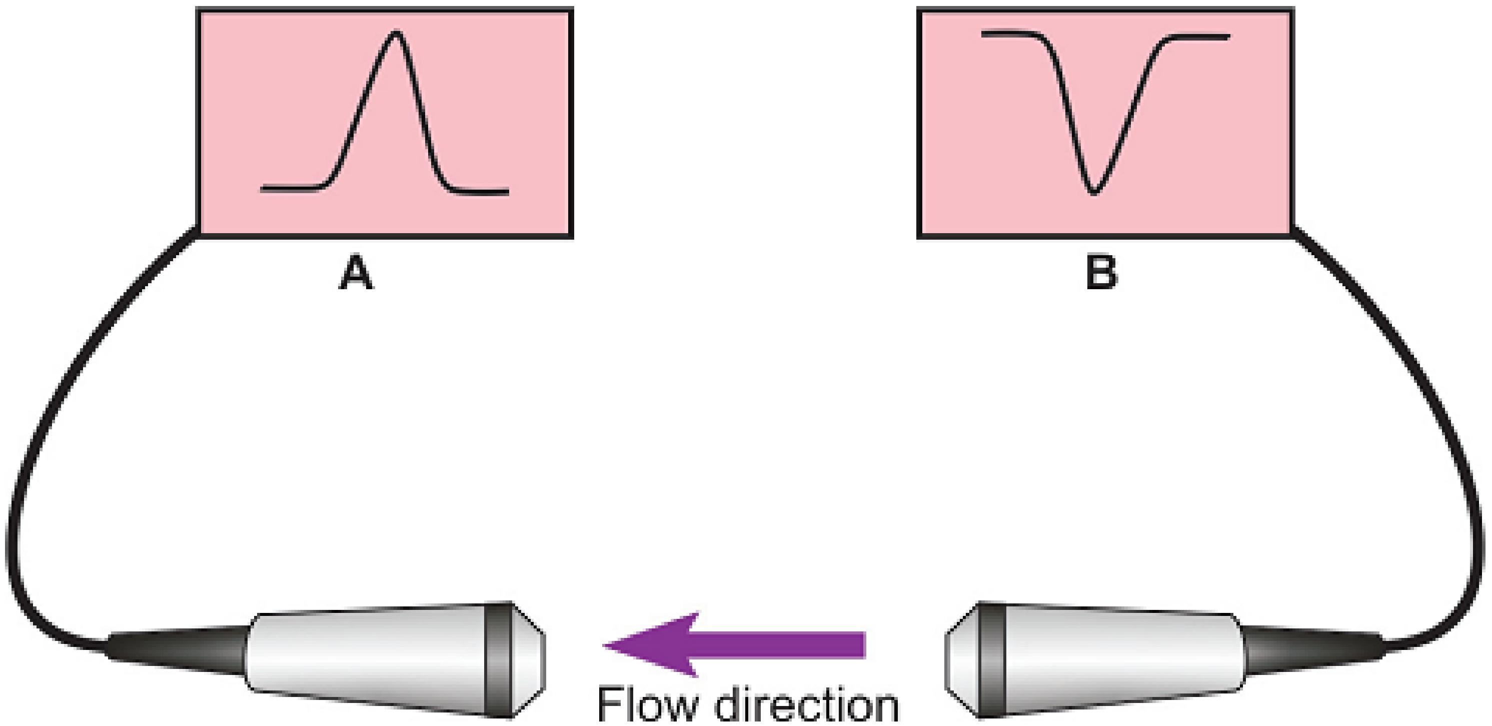


Fig. 1.4: Direction of blood flow and the polarity of deflection:
A. Towards the transducer, positive deflection
B. Away from transducer, negative deflection

- The value of FVI is determined by peak flow velocity and ejection time. It can be calculated by the software of most echo machines.
- Careful analysis of the spectral trace of velocity also gives densitometric information. Density relates to the number of RBCs moving at a given velocity.
- When blood flow is smooth or laminar, most RBCs travel at the same velocity, since they accelerate and decelerate simultaneously.

- The spectral trace then has a thin outline with very few RBCs travelling at other velocities (Figs 1.5A and C). This is known as low variance of velocities.
- When blood flow is turbulent as across stenotic valves, there is a wide distribution of RBCs velocities and the Doppler signal appears "filled in" (Fig. 1.5B). This is known as high variance of velocities, "spectral broadening" or "increased band width".

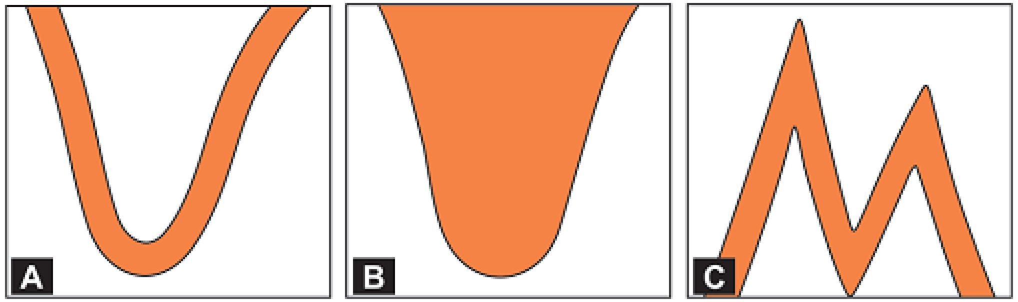


Fig. 1.5: Various patterns of blood flow seen on Doppler:
A. Laminar flow across a normal aortic valve
B. Turbulent flow across stenotic aortic valve
C. Normal flow pattern across the mitral valve

- It is to be borne in mind that turbulence and spectra broadening are often associated but not synonymous wit high flow velocity.
- The intensity of the Doppler signal is represented on the gra scale as darker shades of gray.
- Maximum number of RBCs travelling at a particular veloci cast a dark shade on the spectral trace. Few RBCs travellin at a higher velocity cast a light shade.

- This is best seen on the Doppler signal from a stenotic valve. The spectral display is most dense near the baseline reflecting most RBCs moving at a low velocity close to the valve.
- Few RBCs accelerating through the stenotic valve are at a high velocity. The Doppler echo modes used clinically are continuous wave (CW) Doppler and pulsed wave (PW) Doppler.

- In CW Doppler, two piezoelectric crystals are used, one to transmit continuously and the other to receive continuously, without any time gap.
- It can measure high velocities but does not discriminate between several adjacent velocity components. Therefore, CW Doppler cannot precisely locate the signal which may originate from anywhere along the length or breadth of ultrasound beam.

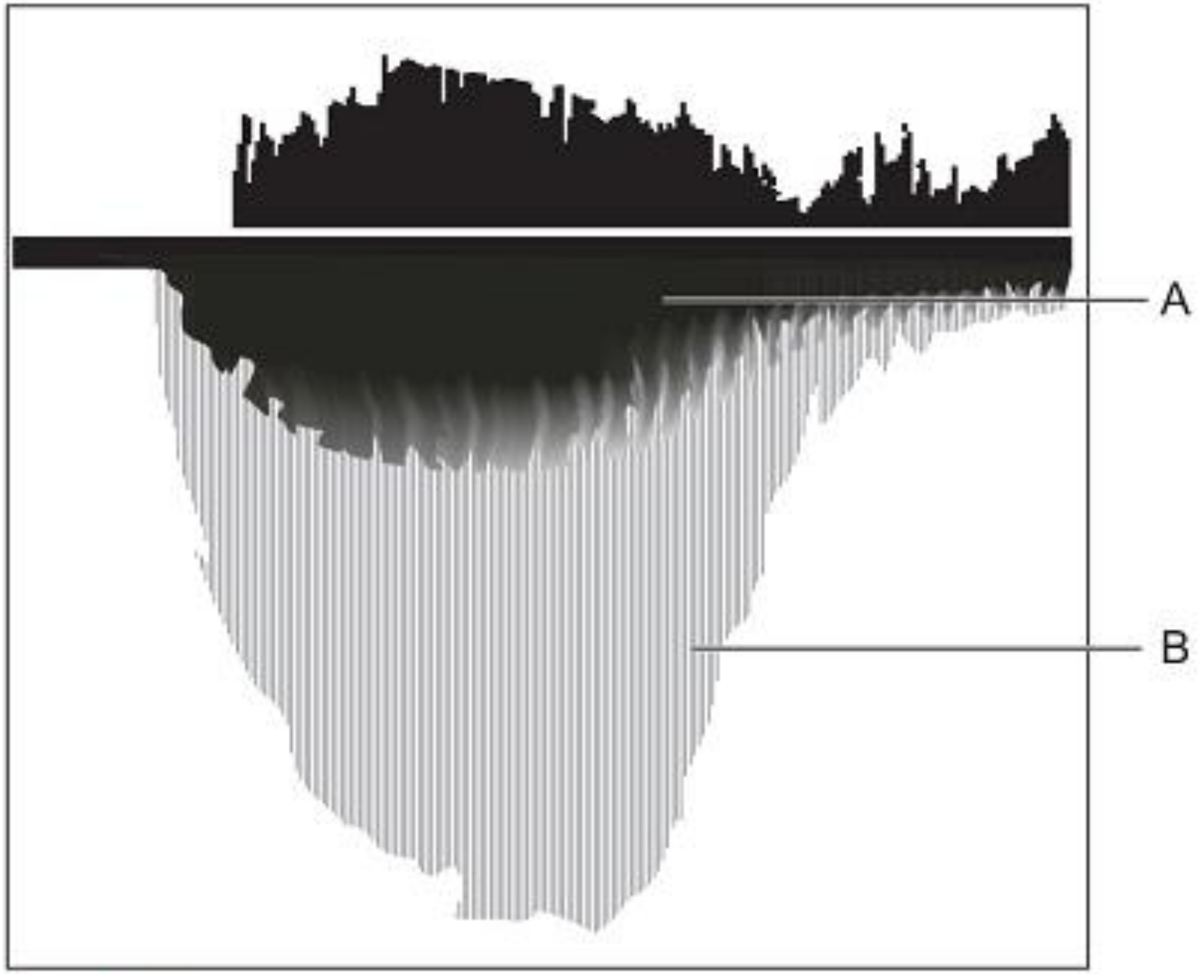


Fig. 1.6: Doppler signal across a stenotic aortic valve:
A. Most RBCs moving at low velocity
B. Few RBCs moving at high velocity

- In PW Doppler, a single piezoelectric crystal to first emits a burst of ultrasound and then receives it after a preset time gap. This time is required in order to switch-over into the receiver mode.
- To locate the velocity, a ‘sample volume’ indicated by a small box or circle, is placed over the 2-D image at the region of interest. The ‘sample volume’ can be moved in depth along the path of PW beam indicated as a broken line, until a maximum velocity signal is obtained.

- PW Doppler can precisely localize the site of origin of a velocity signal, unlike CW Doppler.
- Because of the time delay in receiving the reflected ultrasound signal, PW Doppler cannot accurately detect high velocities exceeding 2 m/sec.

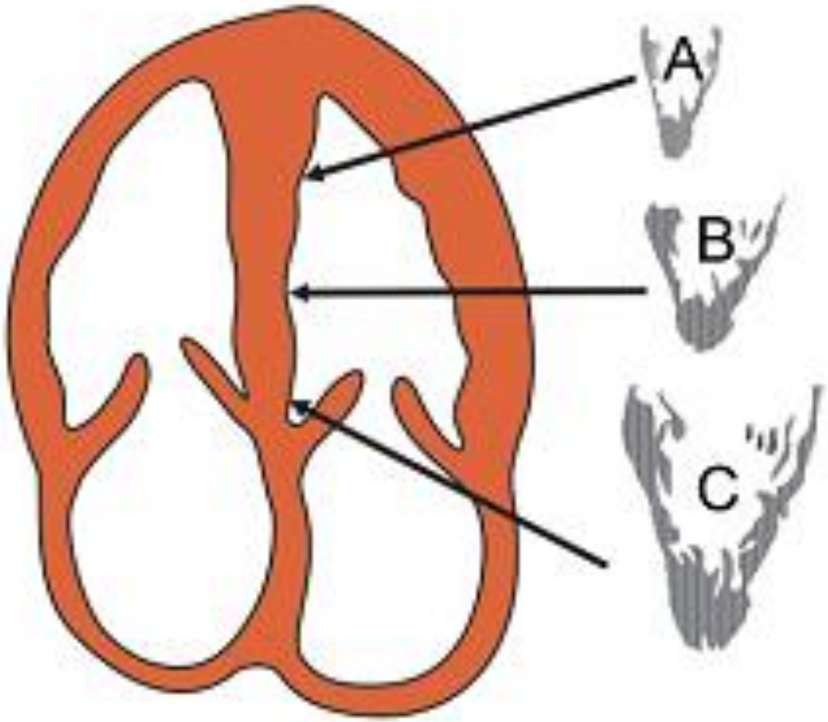


Fig. 1.7: Doppler signal from various levels of LV:
A. LV apex
B. Mid LV
C. Sub-aortic

- However, PW Doppler provides a spectral tracing of better quality than does CW Doppler.
- The single crystal of PW Doppler can emit a fresh pulse only after the previous pulse has returned. The time interval between pulse repetition is therefore the sum of the time taken by the transmitted signal to reach the target and the time taken by the returning signal to reach the transducer.

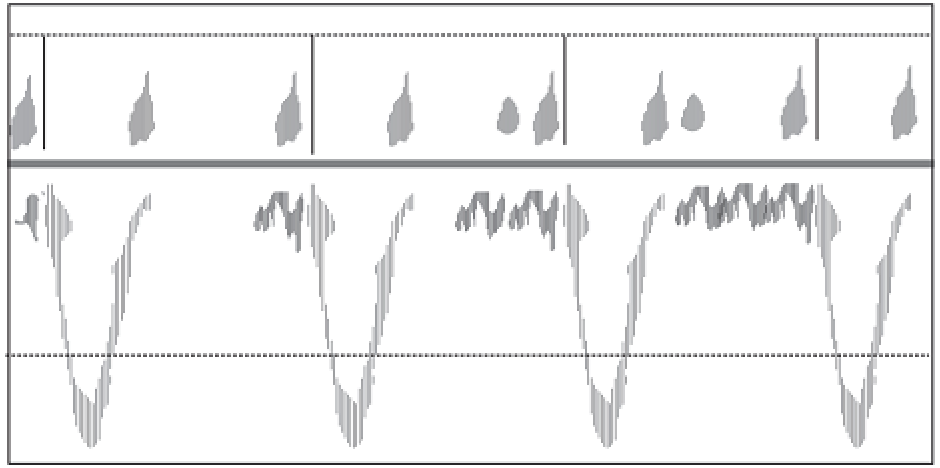


Fig. 1.8: Doppler signal from a regurgitant aortic valve showing laminar flow

- The rate at which pulses are emitted is known as the pulse repetition frequency (PRF). Obviously, greater the depth of interrogation, more is the time interval between pulse repetition and lower is the PRF.
- Pulse repetition frequency (PRF) should be greater than twice the velocity being measured. The PRF decreases as the depth of interrogation increases.

- The maximum value of Doppler frequency shift that can be accurately measured with a given pulse repetition frequency (PRF) is called the Nyquist limit.
- The inability of PW Doppler to detect high-frequency Doppler shifts is known as aliasing. Aliasing occurs when the Nyquist limited is exceeded.

- Aliasing is an artificial reversal of velocity and distortion of the reflected signal. The phenomenon of aliasing is also called “wrap around.”
- Aliasing can be tackled by one of these modifications:
- – high pulse repetition frequency
- – multigate acquisition technique
- – reduced depth of interrogation
- – shifting of display baseline.

Thank You