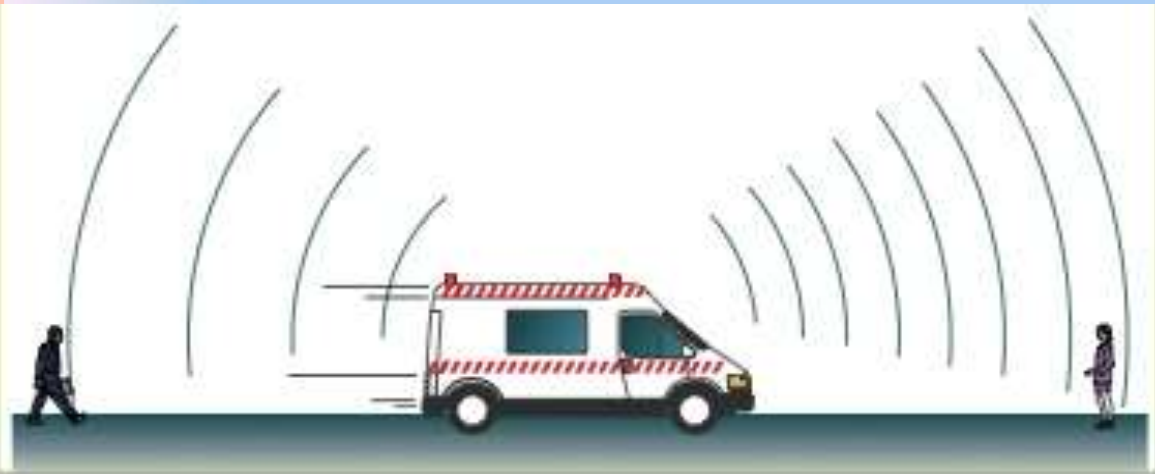


INTRODUCTION

- **Doppler effect**: Change in the perceived frequency of sound emitted by a moving source.
- First described by Christian Doppler in 1843.
- Same effect that causes a siren on a fire truck to sound high pitched as the truck approaches the listener (the wavelength is compressed) and a shift to a lower pitch sound as it passes by and continues on (the wavelength is expanded).



- In ultrasound, the Doppler effect used to measure blood flow velocity.
- Ultrasound reflected from red blood cells will change in frequency according to the blood flow velocity.
- When direction of blood flow is towards the transducer, the echoes from blood reflected back to the transducer will have a higher frequency than the one emitted from the transducer.
- When the direction is away from the transducer, the echoes will have a lower frequency than those emitted.
- The difference in frequency between transmitted and received echoes is called the **Doppler frequency shift**, and this shift in frequency is proportional to the blood flow velocity.



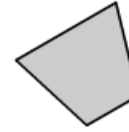
Ultrasound probe



Blood cell



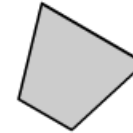
Ultrasound probe



Blood cell



Ultrasound probe



Blood cell



DOPPLER FREQUENCY SHIFT

- The Doppler shift is the difference between the incident frequency and reflected frequency.
- When the reflector is moving directly away from or toward the source of sound, the Doppler frequency shift (f_d) is calculated as

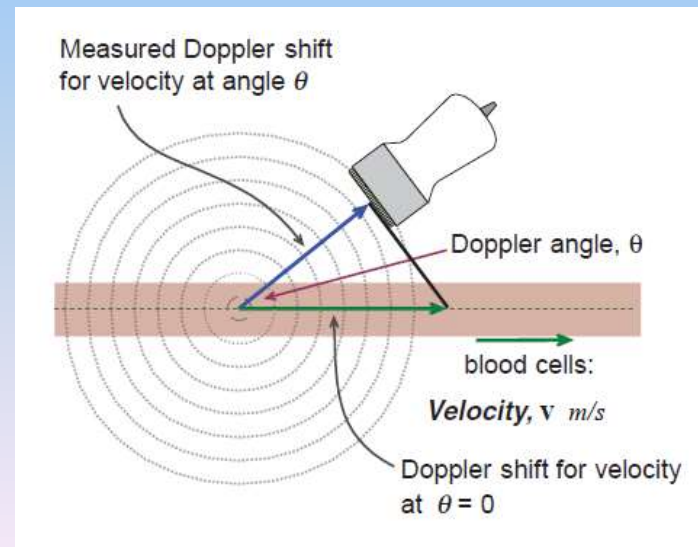
$$f_d = f_r - f_i = \frac{\text{reflector speed}}{\text{reflector speed} + \text{speed of sound}} \times 2 \times f_i$$

where f_i is the frequency of the sound incident on the reflector and f_r is the frequency of the reflected sound.

- Thus, the Doppler shift is proportional to the velocity of the blood cells.

- When the sound waves and blood cells are not moving in parallel directions, the equation must be modified to account for less Doppler shift.
- The angle between the direction of blood flow and the direction of the sound is called the **Doppler angle**.
- This reduces the frequency shift in proportion to the cosine of this angle. If this angle is known then the flow velocity can be calculated.

$$f_d = \frac{2 f_i v \cos(\theta)}{c}$$



FACTORS AFFECTING DOPPLER SHIFT

1. Doppler angle
2. Transducer frequency
3. Scattering of US by blood
4. Blood flow characteristic



1. DOPPLER ANGLE

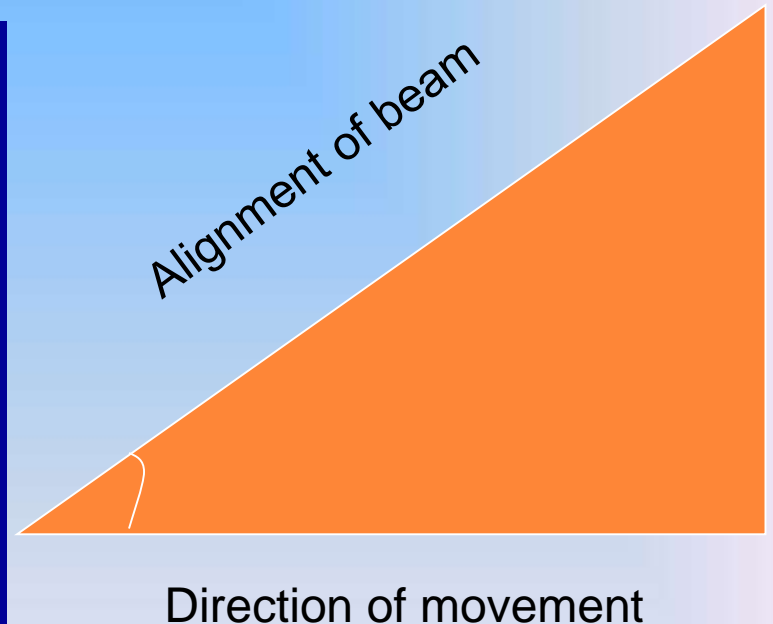
- Also known as the angle of insonation.
- Estimated by a process known as angle correction, which involves aligning an indicator on the duplex image along the longitudinal axis of the vessel.
- Few considerations that affect the performance of a Doppler examination:
 - The cosine of 90° is zero, so if the ultrasound beam is perpendicular to the direction of blood flow, there will be no Doppler shift and it will appear as if there is no flow in the vessel
 - The angle of insonation should also be less than 60° at all times, since the cosine function has a steeper curve above this angle, and errors in angle correction will be magnified

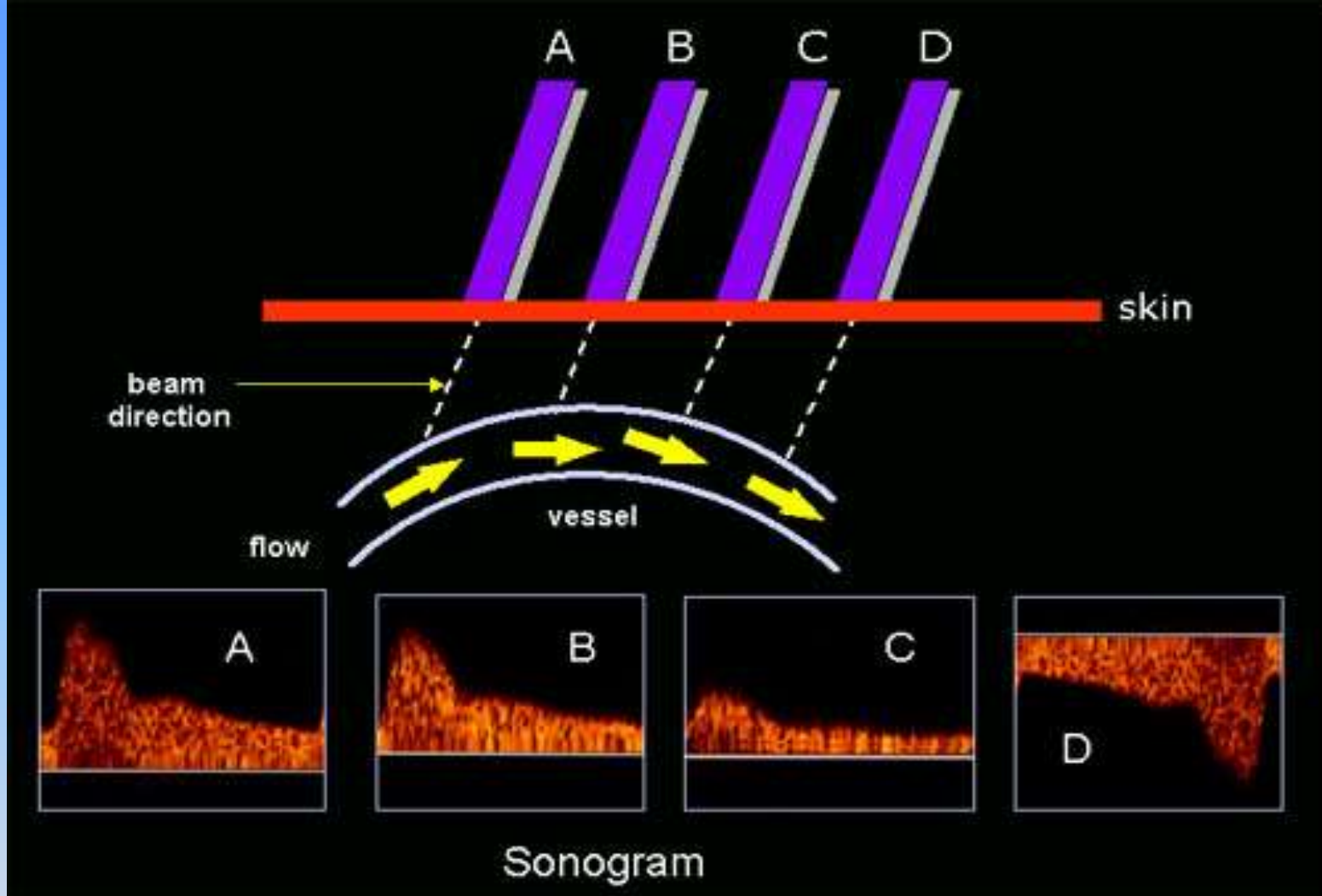


ANGLE EFFECTS

- Maximum Doppler shift at 0 degrees minimum at 90 degrees – proportional to the Cosine of the angle between the beam and direction of travel.

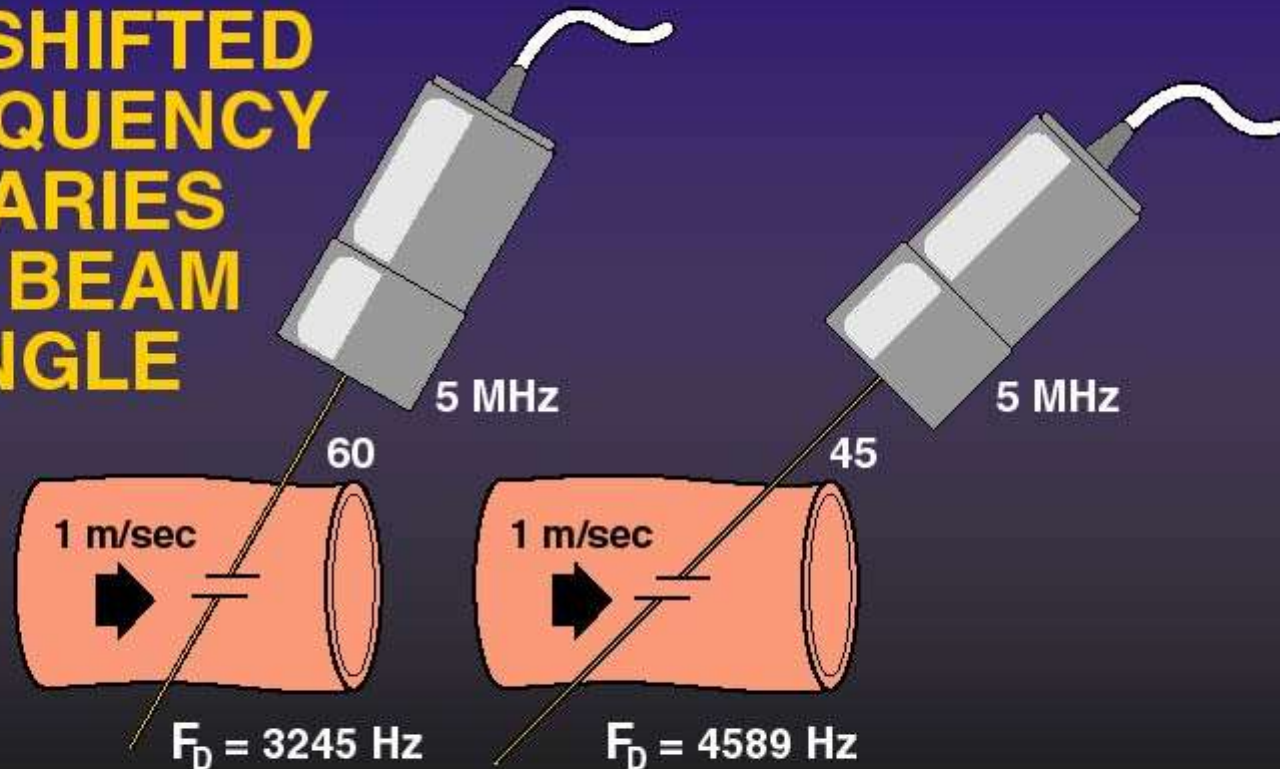
- | | |
|-----------------------------------|--------------------------|
| • Ideally should be zero | Usually not possible |
| • Smallest angle possible | Not under our control |
| • Do not use angle > 60 | Great error in velocity |
| • Angle 90 | Complete loss of flow |
| • Transducer position | Obtain smaller angle |
| • Different US systems | May be different results |





Effect of the Doppler angle in the sonogram. Higher-frequency Doppler signal is obtained if the beam is aligned more to the direction of flow. In the diagram, beam **(A)** is more aligned than **(B)** and produces higher-frequency Doppler signals. The beam/flow angle at **(C)** is almost 90° and there is a very poor Doppler signal. The flow at **(D)** is away from the beam and there is a negative signal.

**THE DOPPLER
SHIFTED
FREQUENCY
VARIES
WITH BEAM
ANGLE**



If the beam direction is perpendicular to the direction of flow, the Doppler frequency is ZERO!

2. TRANSDUCER FREQUENCY

- Increase in transducer frequency causes increased doppler frequency shift.
- At frequencies between 2-10 MHz, doppler shift comparatively small & in audible range (shift from 0-10 KHz) for most physiological motion (for velocity range from 0-100 cm/s).
- Change of frequency → measurable → movement of reflector towards/away from transducer.
- Depending on ↑ or ↓ in frequency → direction of movement.



EFFECT OF TRANSMITTED FREQUENCY ON DOPPLER SIGNAL FREQUENCY



$$F_D = 3.9 \text{ KHz}$$



$$F_D = 6.5 \text{ KHz}$$



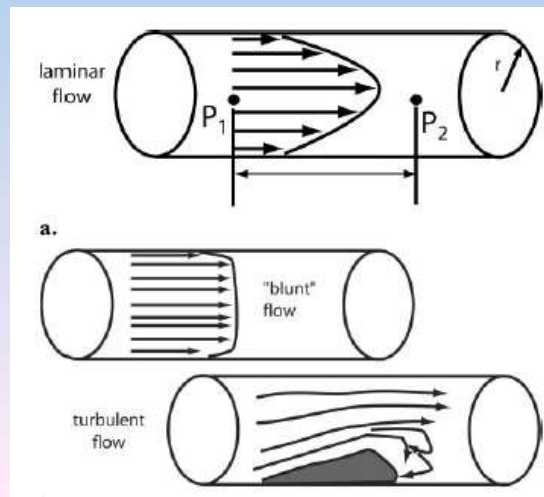
3. SCATTERING OF US BY BLOOD

- Smooth wall of blood vessel → specular reflection → strong echoes.
- Us wavelength $>$ size of RBCs → scattering of wave in all directions (Rayleigh-Tyndall scattering). Size of echo from blood → ↓.
- Intensity of scattered us ↑ with 4th power of frequency as images of vessel lumen differ significantly with instruments of different frequency.



4. CHARACTERISTICS OF BLOOD FLOW

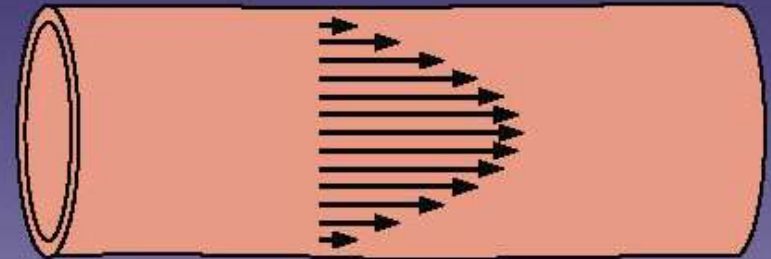
- Blood (viscous medium) → wall exerts drag effect on moving blood → slow movement near the wall than center.
- Non pulsatile flow with low velocity → parabolic velocity profile → laminar flow.
- Fast /accelerated flow → same velocity all over → plug flow.
- Major artery → plug flow during systole & laminar flow during diastole. Venous flow → laminar.



FLOW PATTERNS

- Laminar flow
 - Highest in center
 - Zero at wall
- Turbulent flow
 - Larger distribution of velocities

Laminar Flow



Turbulent Flow



BASIC EQUIPMENT

- Same probe can be used for Doppler Scanning.
- High Q transducer material (transducer will produce narrow range of frequency)
- Air backing can be used for maximal sound reflection from backing layer.
- Lower frequency probe. Usually 3.5MHZ probe.