ISUOG Basic Training

The Principles of Doppler Ultrasound

Learning objectives

At the end of this session, you will be able to understand the principles of:

- Doppler effect
- Doppler shift
- Pulsed wave Doppler
- Colour flow Doppler
- Power Doppler
- Indices
- Safety

Key questions

1. How is the Doppler shift related to flow velocities?
2. What is the importance of the insonation angle?
3. Why do we use indices such as the pulsatility index (PI)?
4. Which ultrasound application has the highest energy?
5. Should Doppler be used in the first trimester?

Doppler principle

Christian Johann Doppler

Austrian physicist

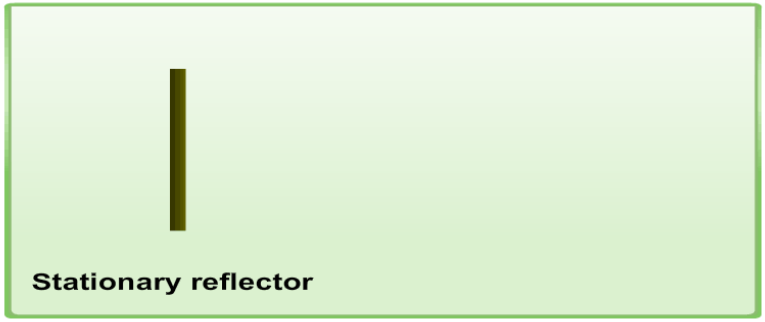
(1803 - 1853)

Doppler effect

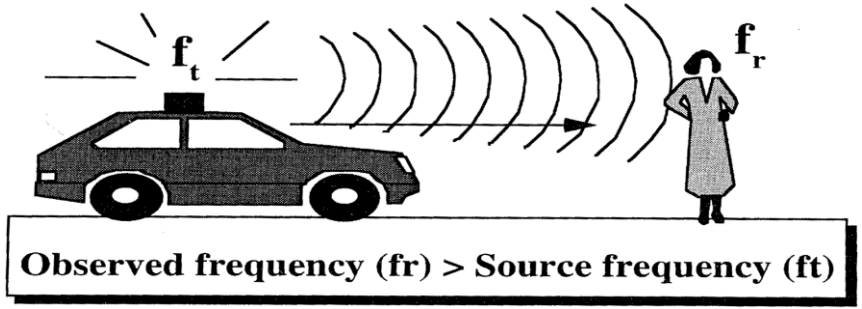
An effect found in all types of waves, where the source & the receiver are moving relative to each other

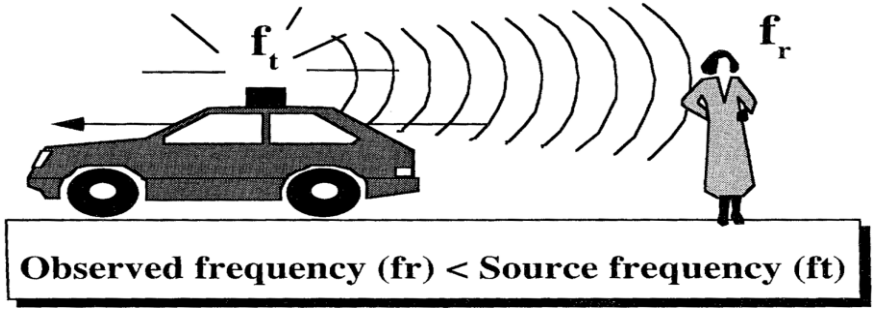
Doppler shift

Change in frequency produced by a moving reflector



Doppler principle





Car stationary relative to target

The person is “hit” by a constant number of wave fronts per time unit

Car moving towards target

The person is “hit” by additional wave fronts per time unit

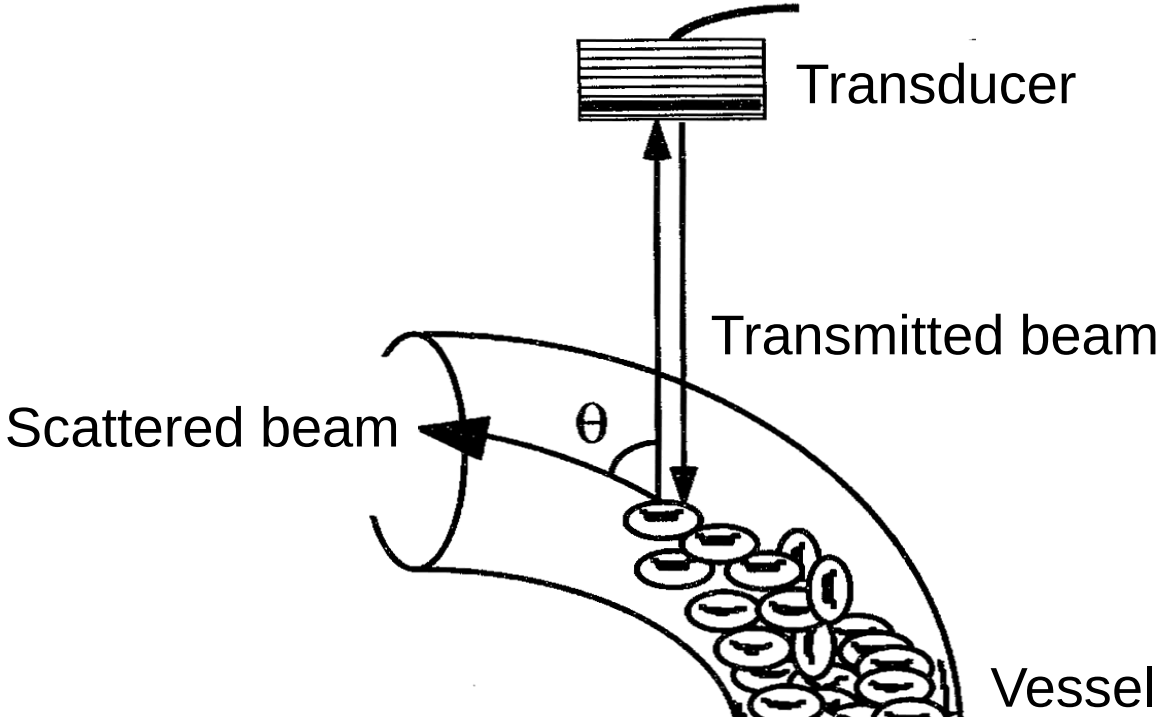
Car moving away from target

The person is “hit” by fewer wave fronts per time unit

What made Christian Doppler famous?

- The change in frequency between emitted & returned sound waves is proportional to the velocity of the moving reflector
- The change in frequency is called the Doppler shift
- High pitched Doppler shift means high velocity

Blood velocity measurement



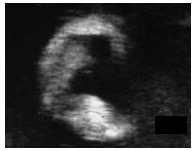
Abuhamed, A. Ultrasound in Obstetrics and Gynecology: A Practical Approach (1st ed), 2014.

Doppler equation

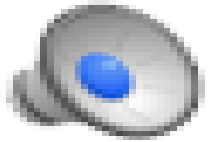
$$\Delta_f = \frac{2 \times fo}{v} V \cos \alpha$$

Δ_f : Change in frequency
fo : Frequency of transmitted sound (1-3 mHz)
v : Velocity of sound in the medium (1540 m/s)
V : Velocity of the reflecting surface (1-250 m/s)
α : Angle between the sound beam & the direction of motion of the reflecting surface

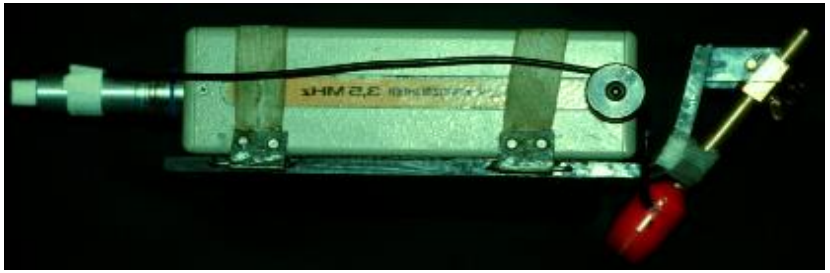
Δ_f is proportional with the velocity of the moving reflector

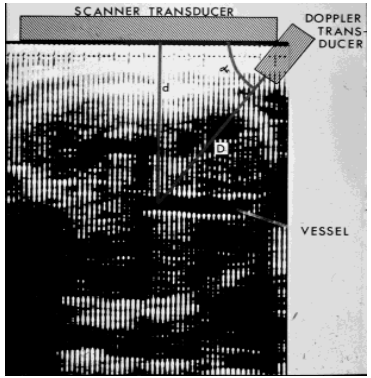


You can hear Doppler ultrasound

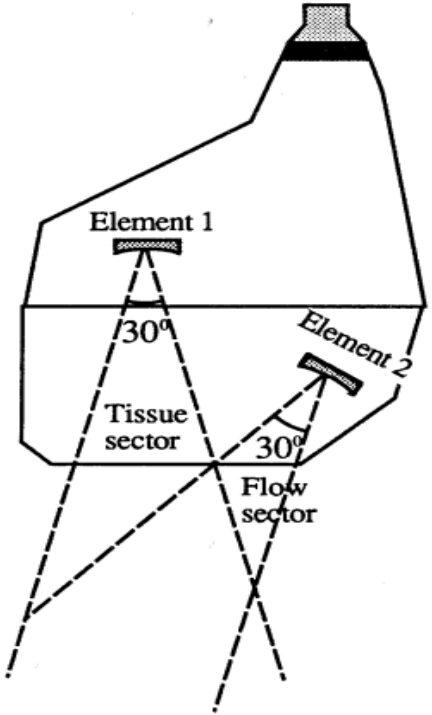


Duplex transducer



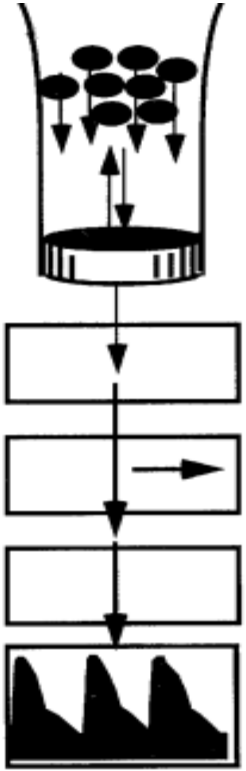


Insonation of umbilical vein at fixed angle (1979)



Eik-Nes et al. BMJ, 1980 .

Doppler signal processing



Moving scatterers

Produces frequency change

Transducer

Converts sound to energy

Amplifier

Demodulator

Determines direction of flow

Spectral processor

Sorts frequencies

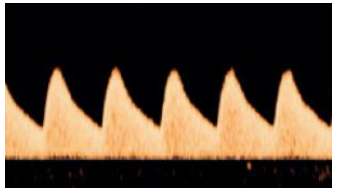
Video screen

Displays Doppler waveforms

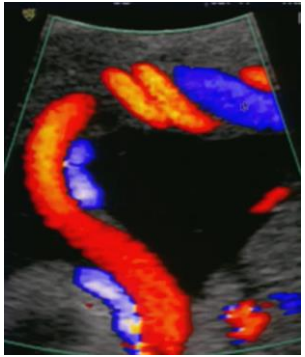
Basic Doppler techniques

- Continuous wave Doppler

- Pulsed wave Doppler

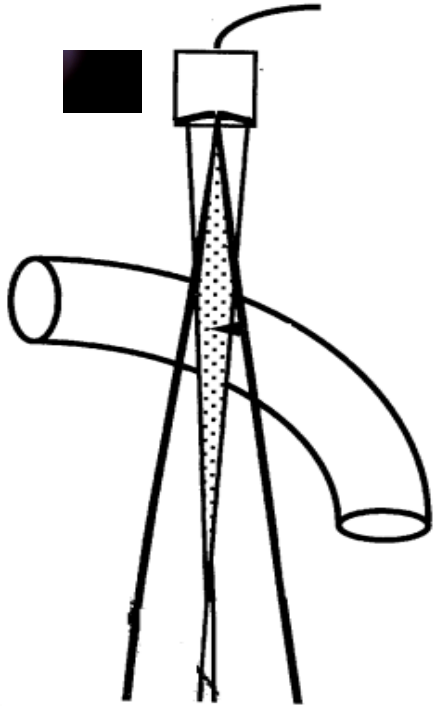


- Colour flow mapping



Continuous wave Doppler

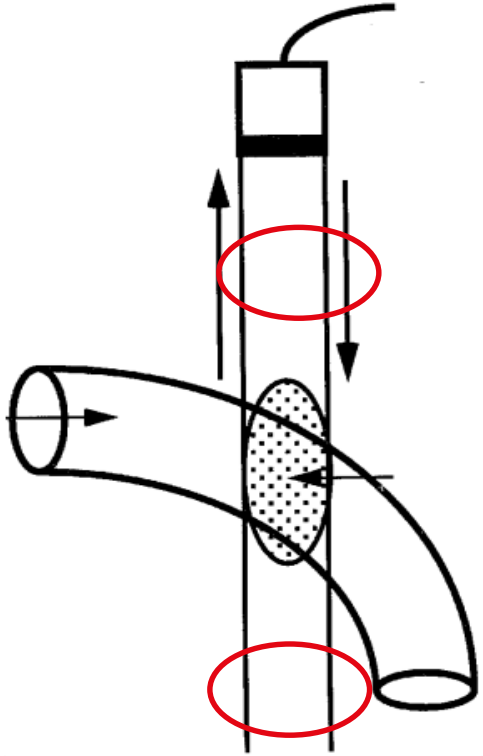
- Two transducers
- Sending & receiving continuously
- Cardiotocography (CTG)



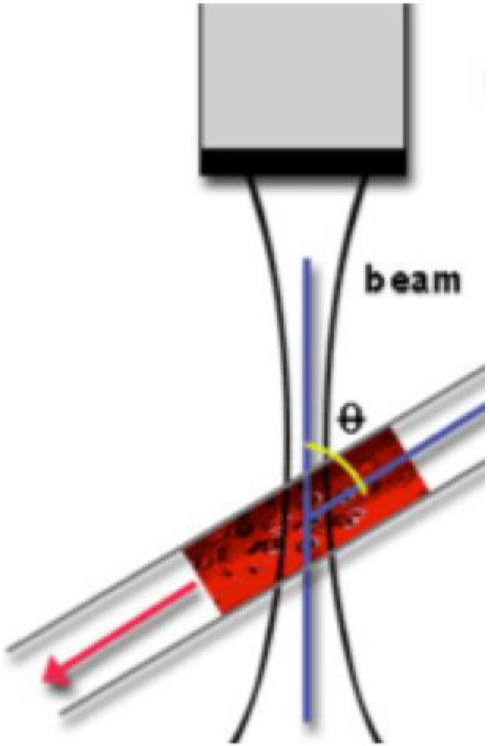
Abuhamed, A. Ultrasound in Obstetrics and Gynecology: A Practical Approach (1st ed), 2014.

Pulsed wave Doppler (PW)

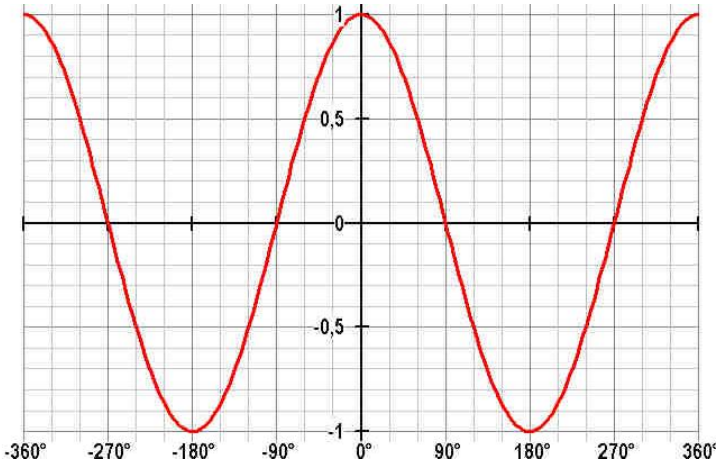
- One transducer
- Sends a pulse
- Gate closes
- Gate opens after a time
- Gates remains open briefly
- Gate closes



Insonation angle

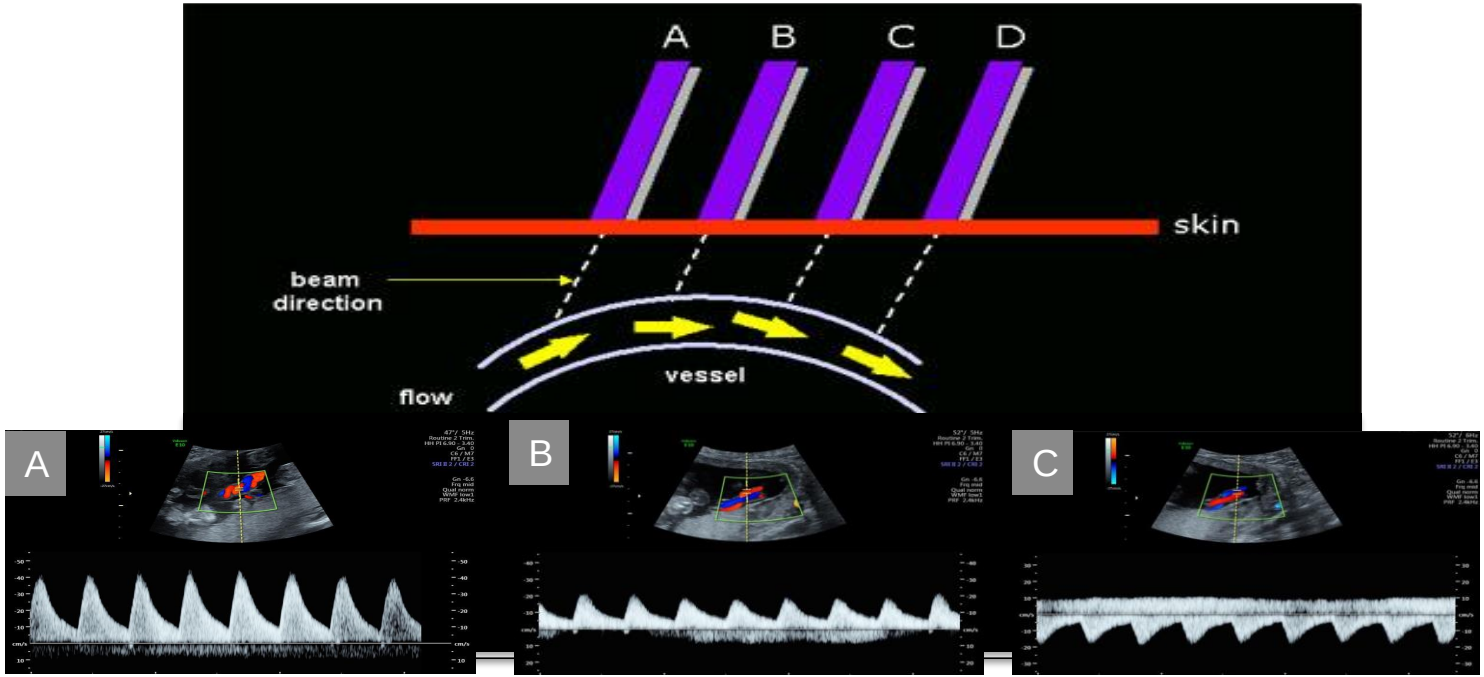


The velocity is dependent on the insonation angle (cosine of the angle)



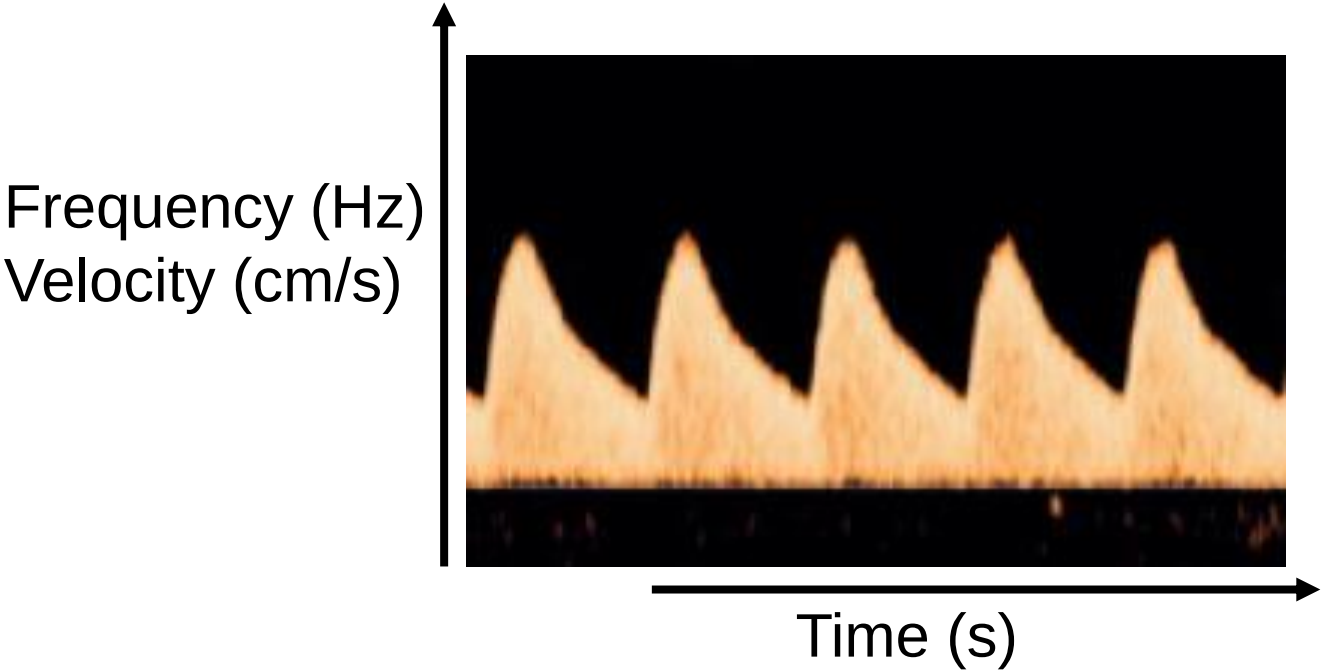
Value of the cosine of the angle

Flow direction and frequency

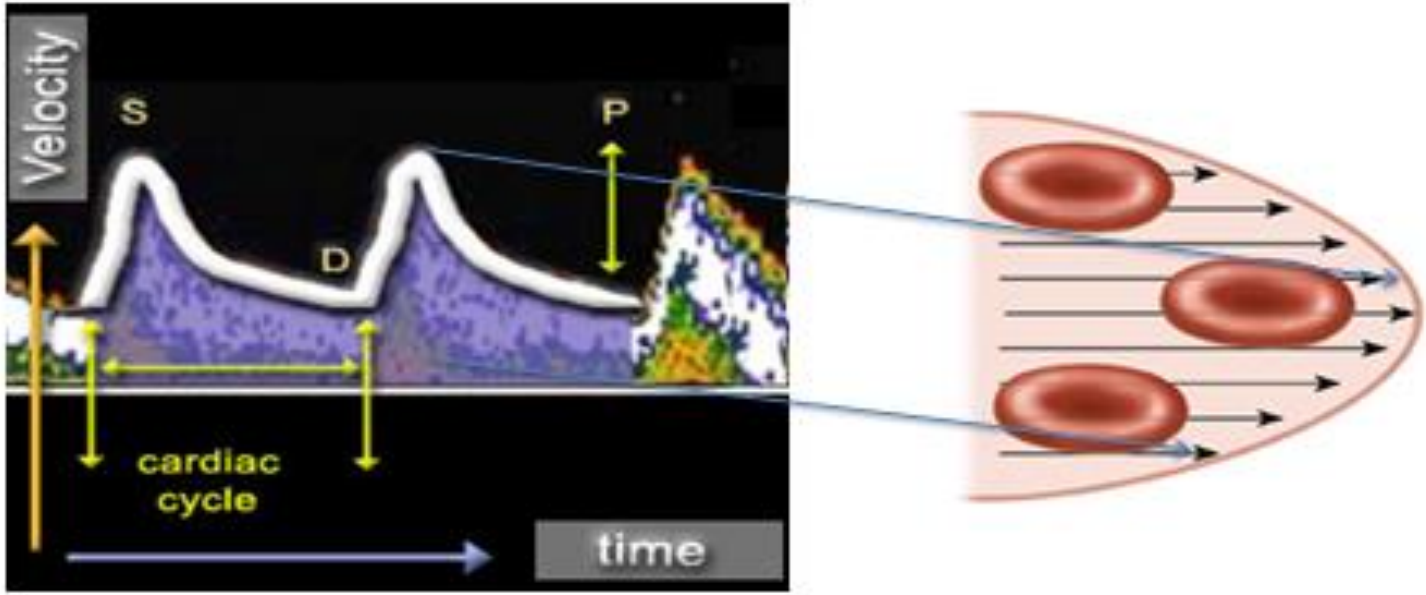


The height of the Doppler spectrum changes according to the insonation angle (compare A to B & C) & the direction of flow (compare A & B to C)

Frequency spectrum

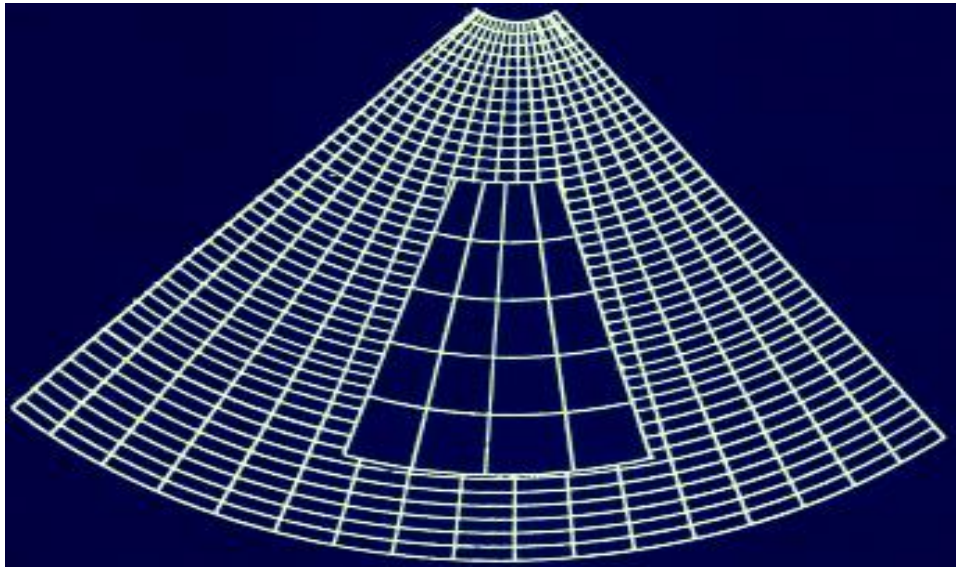


Doppler shift & velocity spectrum

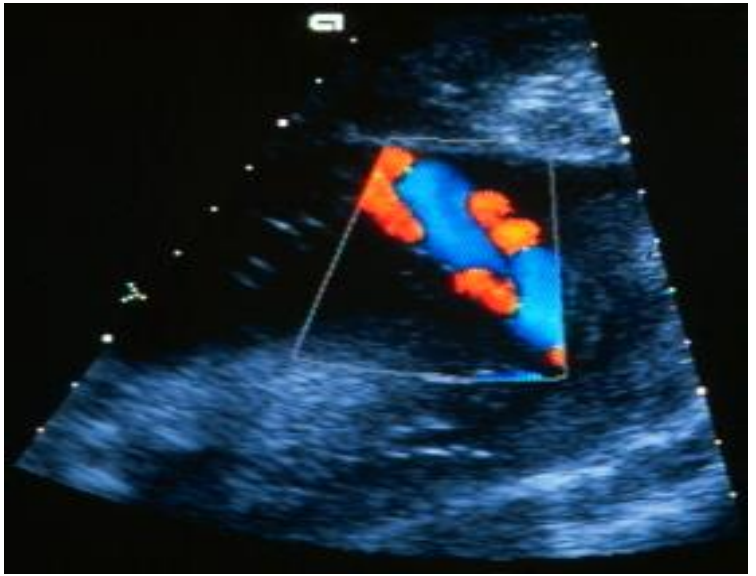


- Flow velocity waveform = spectrum of velocities within the vessel
- Maximum envelope = fastest red blood cells in the middle of the vessel

Basic principle of colour flow mapping (CFM)



Area with multiple sample volumes

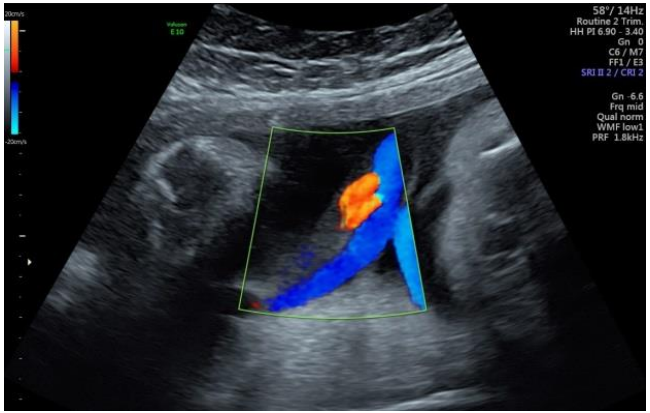


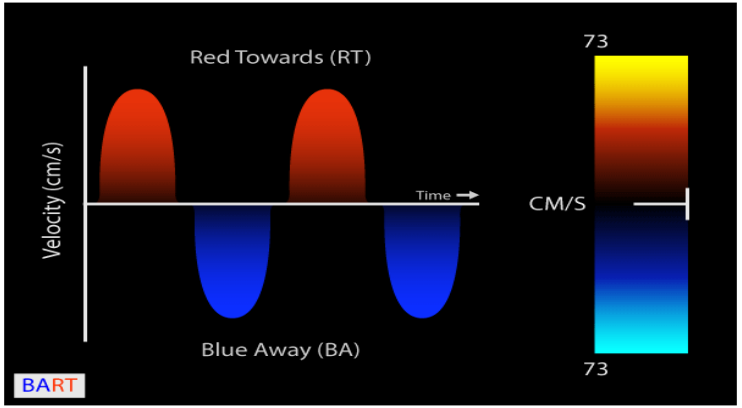
Same area colour coded

Colour Doppler

Principle:

- Translation of PW information into pixels of different colours, which are superimposed onto the 2D image
- *Flow towards the transducer – red*
- *Flow away from the transducer – blue*

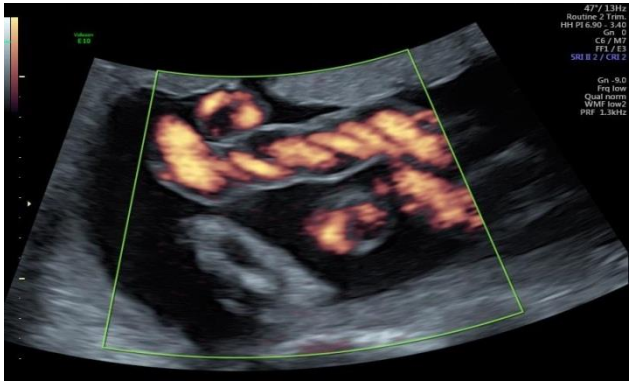




Power Doppler

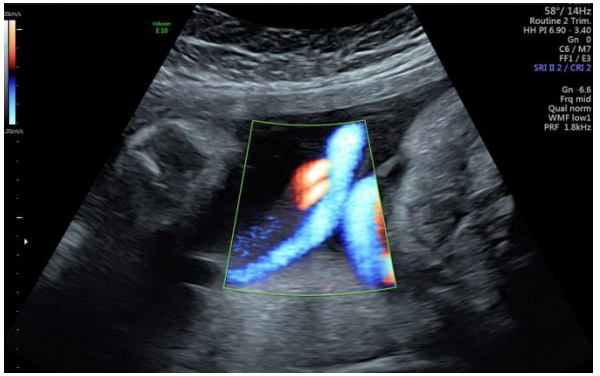
Power Doppler:

- Does not display velocity information
- Displays the amplitude of the returning Doppler shifted echoes
- Less dependent on angle of insonation



Directional power Doppler

- Modern machines incorporate directional flow into power Doppler mode



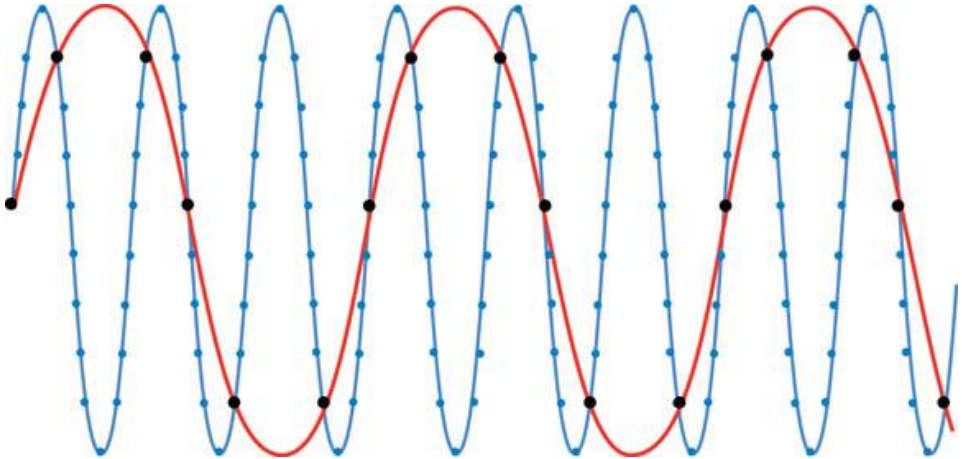
Colour coding

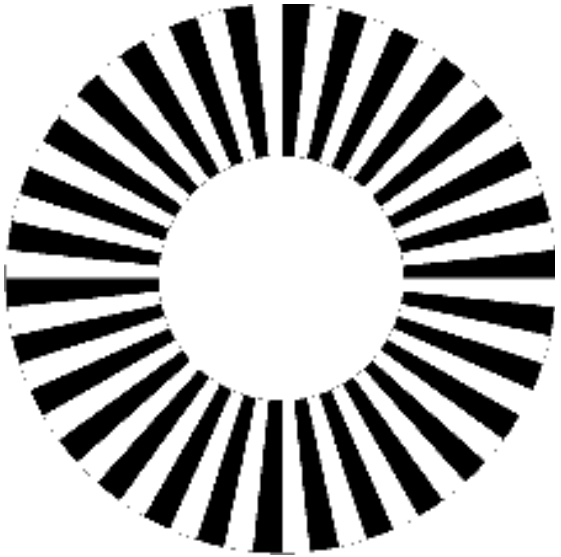
- Velocities away from transducer shades of blue
- Velocities towards transducer shades of red
- Aliasing shades of bright blue or bright yellow

Doppler controls

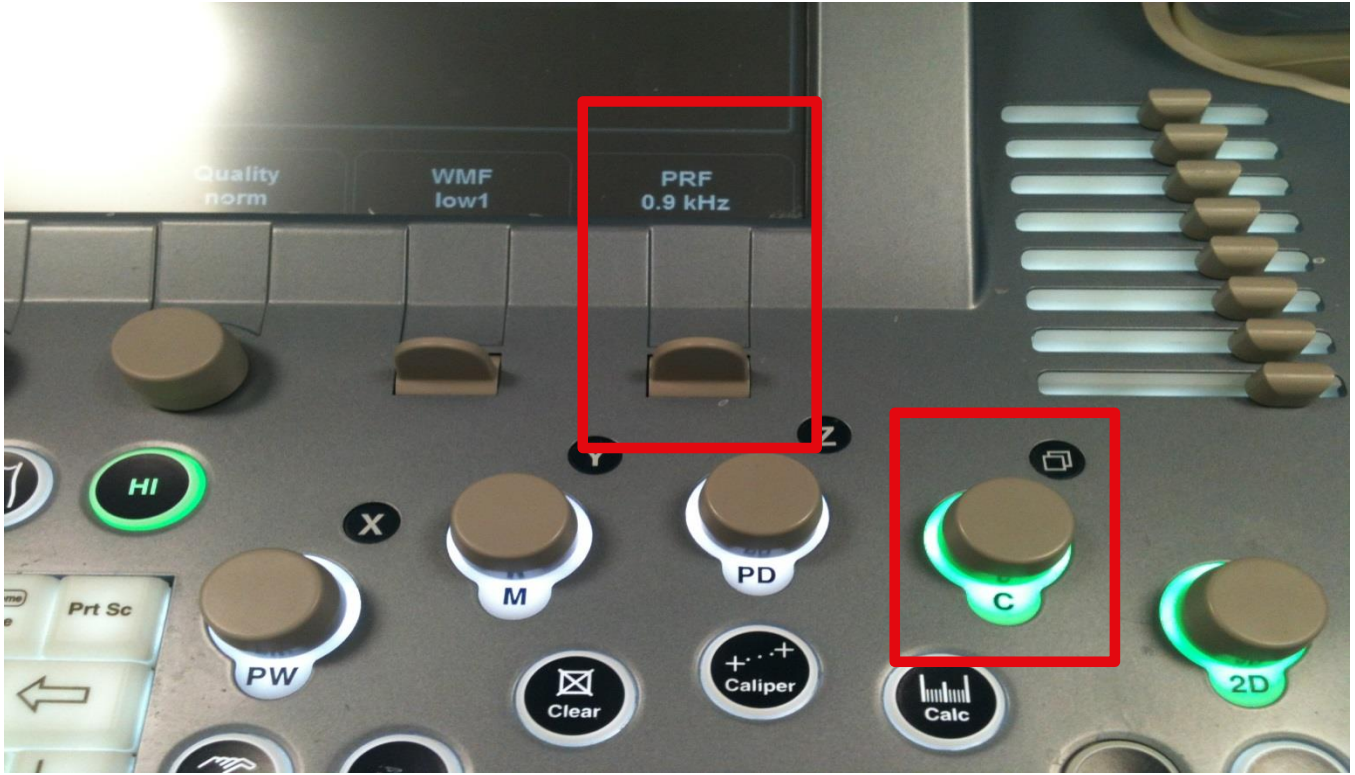
- Sample gate width
- Pulse repetition frequency (PRF)
- Baseline
- Sweep speed
- High-pass filter (min)

Pulse Repetition Frequency (PRF)



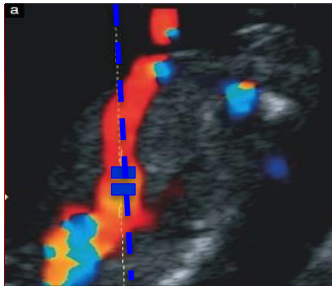


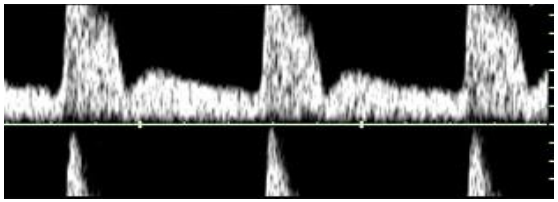
Use of colour or power Doppler

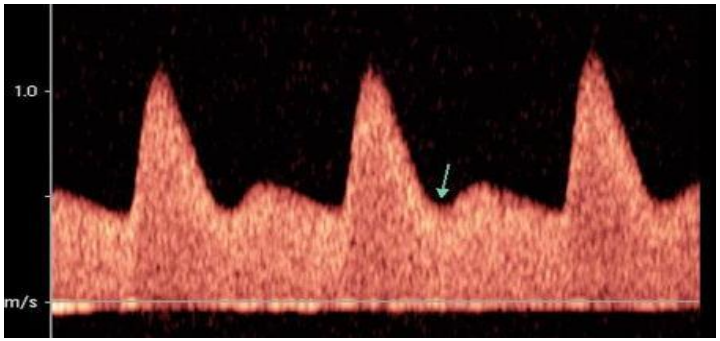


Doppler controls

- Adjust sample gate to cover the vessel, to avoid interferences from nearby vessels
- Increase PRF to correct for aliasing (2 x max velocity)
- Or modify the baseline



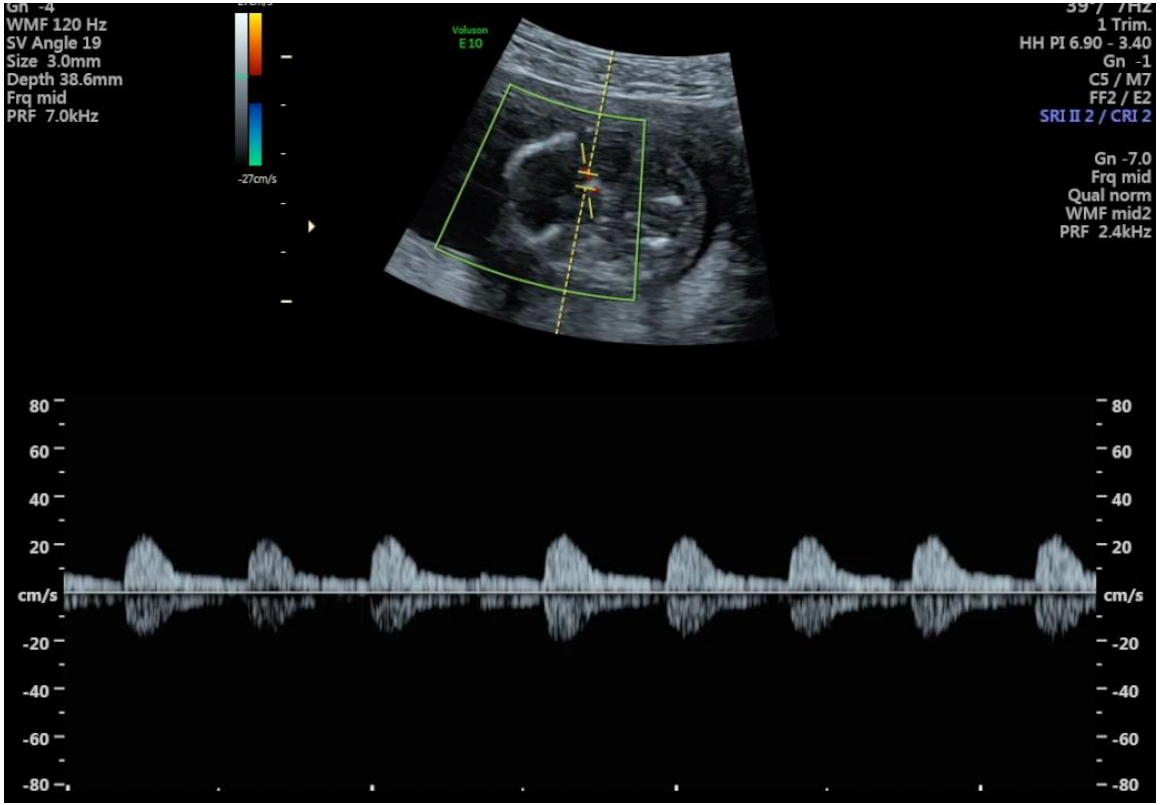




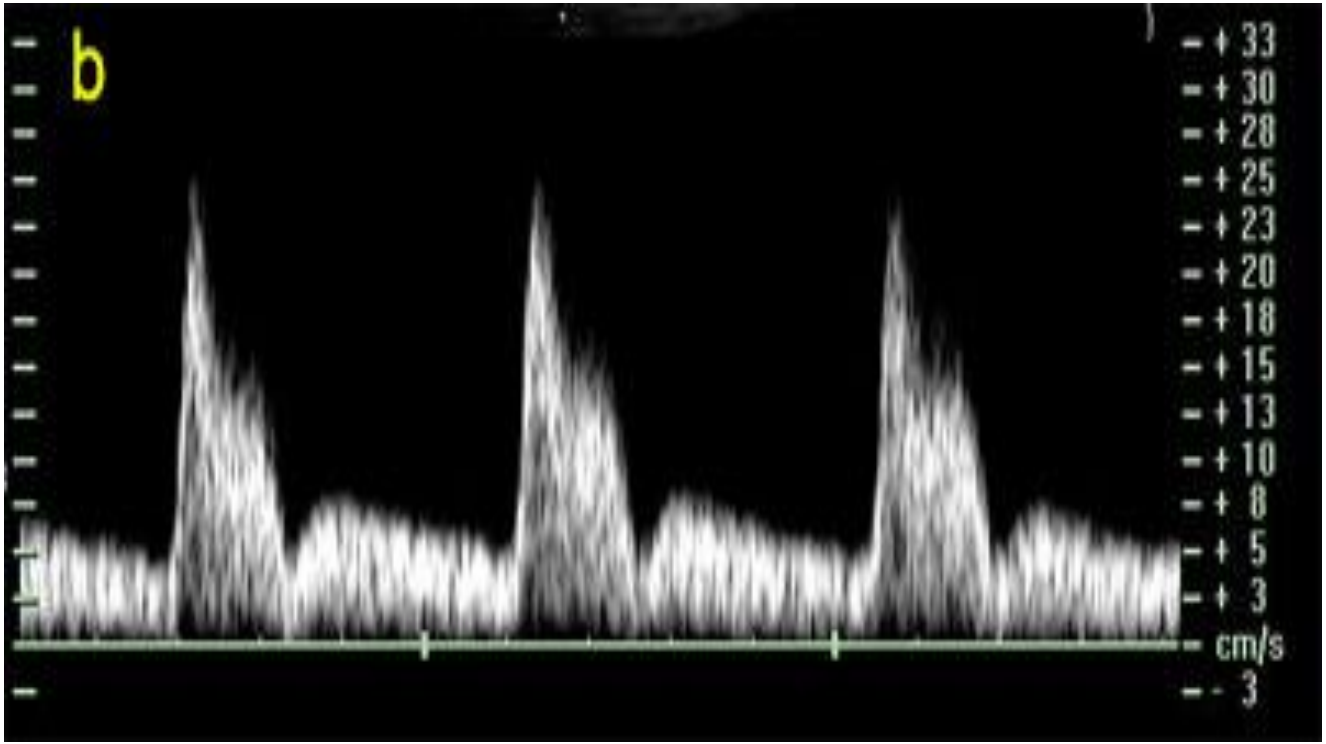
Aliasing

- When pulses are transmitted at a given sampling frequency (PRF), the maximum Doppler frequency (fd) that can be measured unambiguously is HALF the PRF
- If the blood velocity & beam/flow angle measured combined give a fd greater than half the PRF, ambiguity in the Doppler signal occurs. This ambiguity is called ALIASING.
- To measure high velocities (arterial), increase PRF
- To measure low velocities (venous), reduce PRF

Example of aliasing



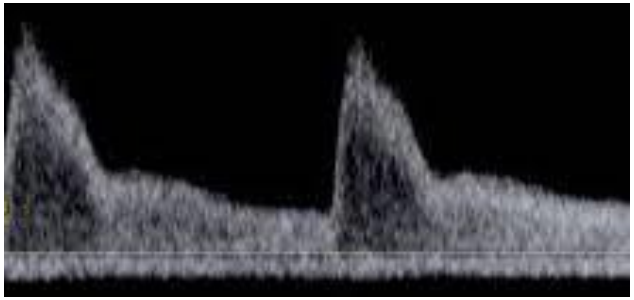
To correct - increase PRF & adjust baseline



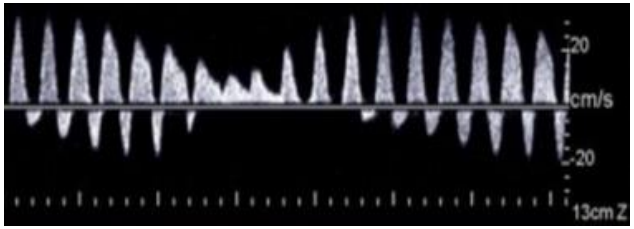
Sweep speed

The horizontal sweep speed setting alters the speed in which spectral doppler *x* axis is displayed on the screen.

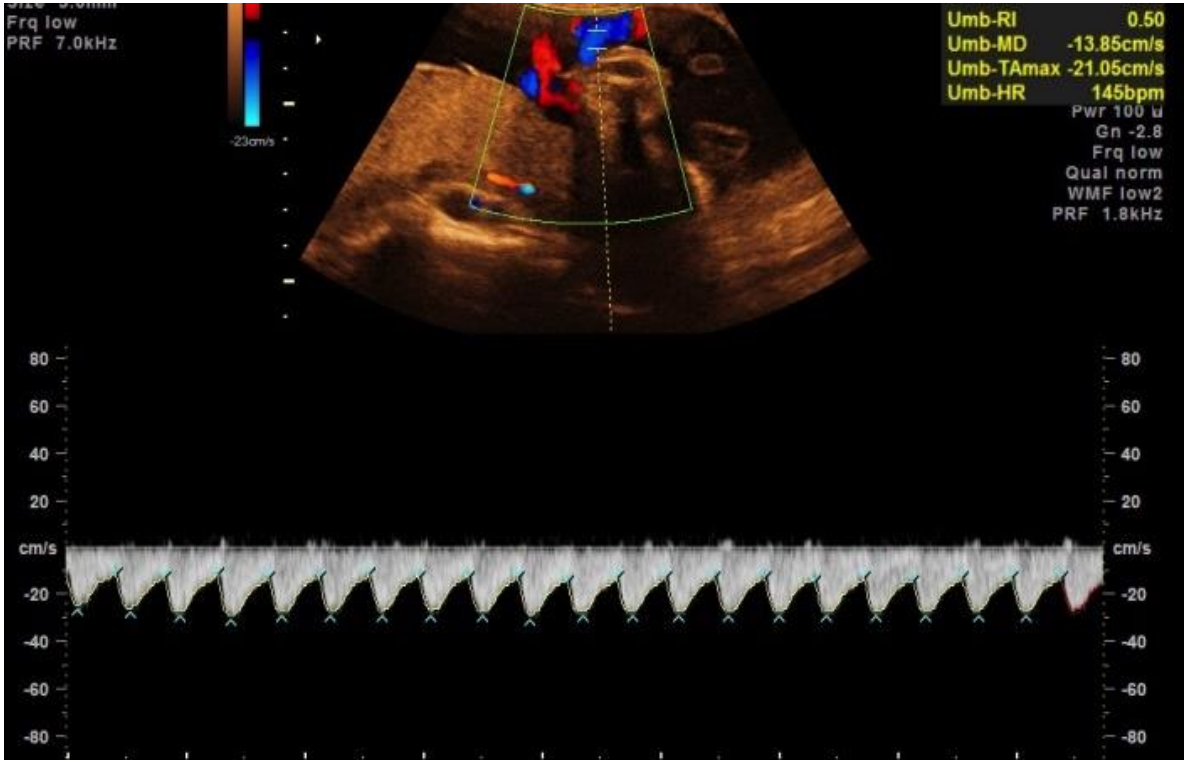
- A higher sweep speed displays fewer waveforms but provides greater details of individual waveforms, for example to investigate the presence of an early diastolic notch in the uterine arteries.



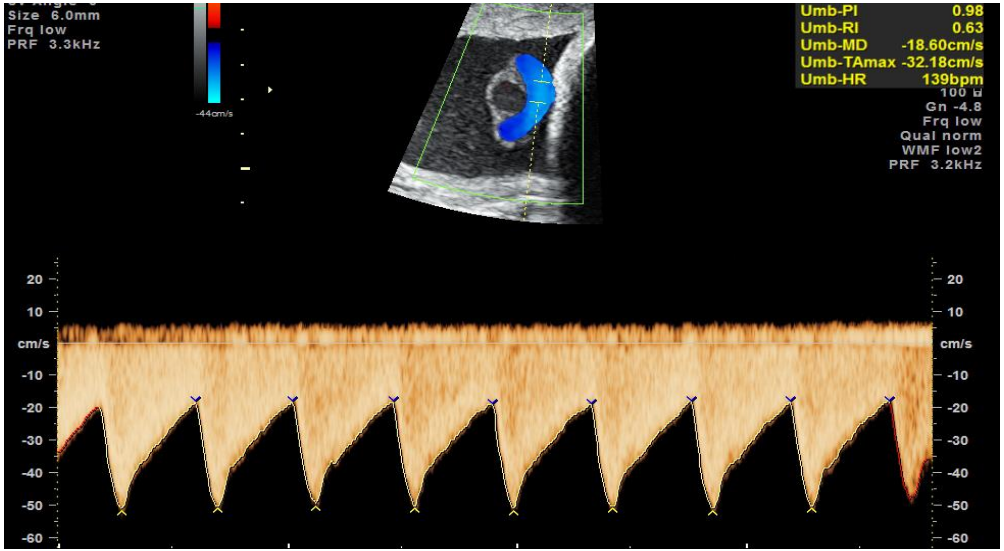
- A lower sweep speed displays more waveforms to better illustrate pathology related to variation, such as bi directional flow in arterial to arterial anastomosis in twin to twin transfusion syndrome.

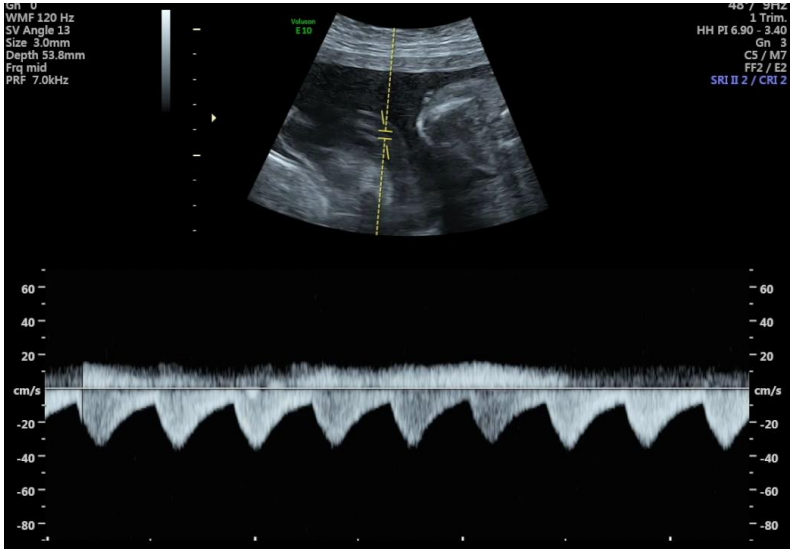


Sweep speed & PRF - incorrect



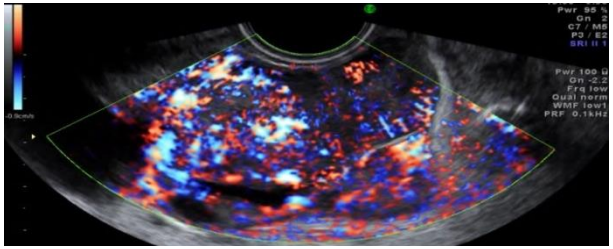
Sweep speed PRF - correct for UA



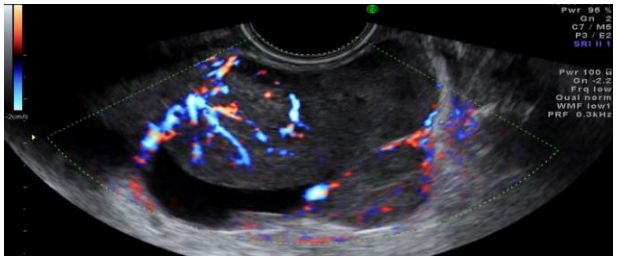


Use of Pulse Repetition Frequency (PRF)

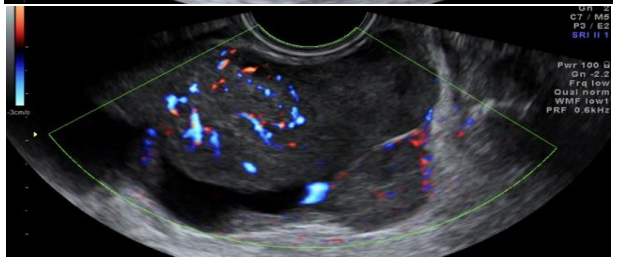
0.1

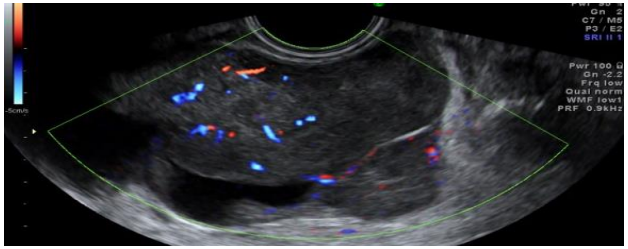


0.3

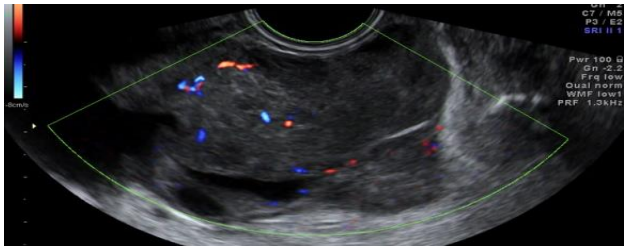


0.6

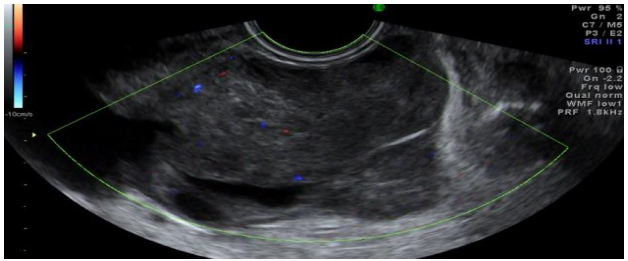




0.9

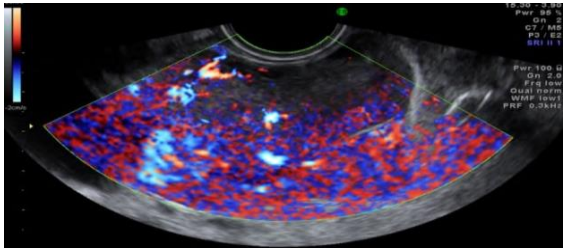


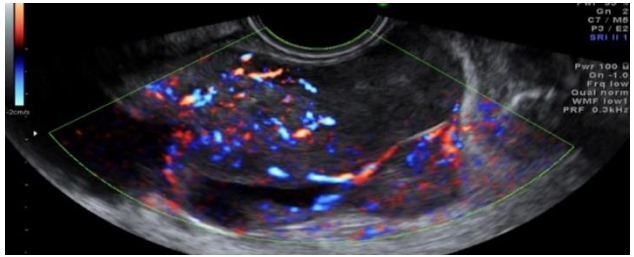
1.3

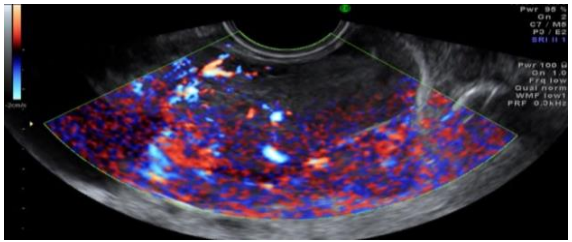


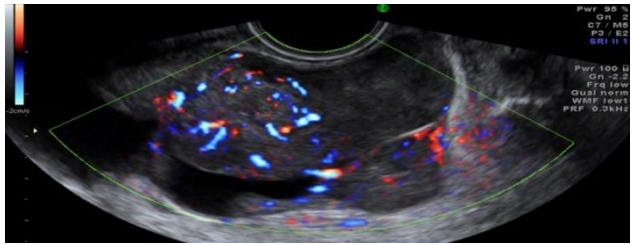
1.8

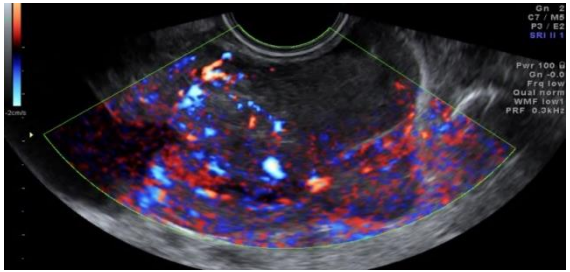
PRF fixed at 0.3, lower GAIN…

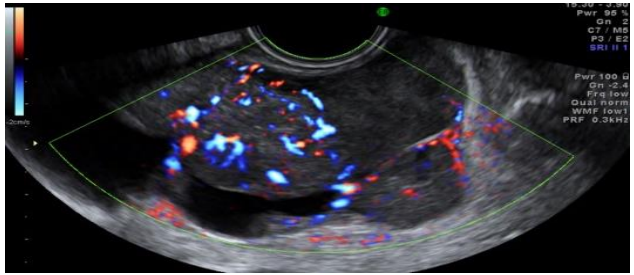




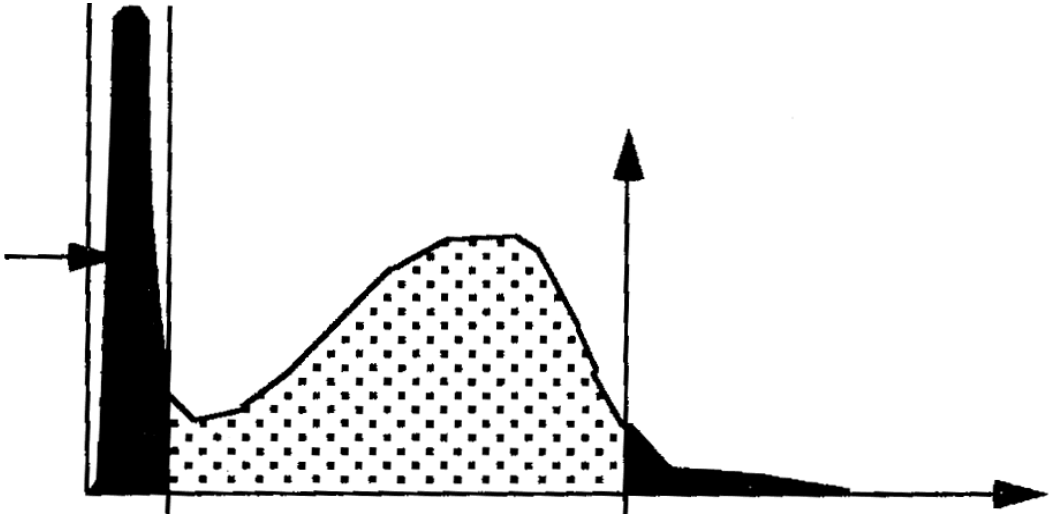






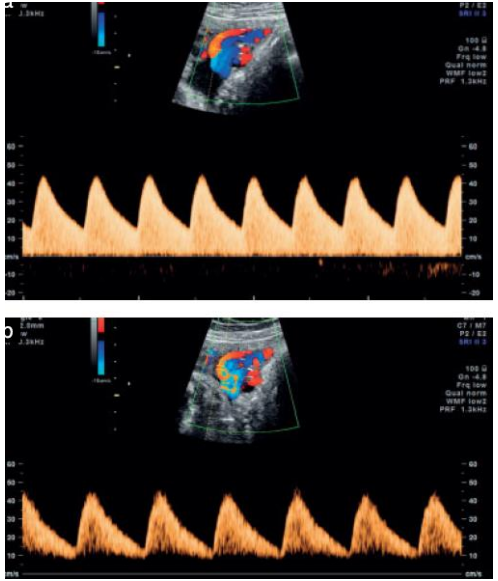


High/low pass filter



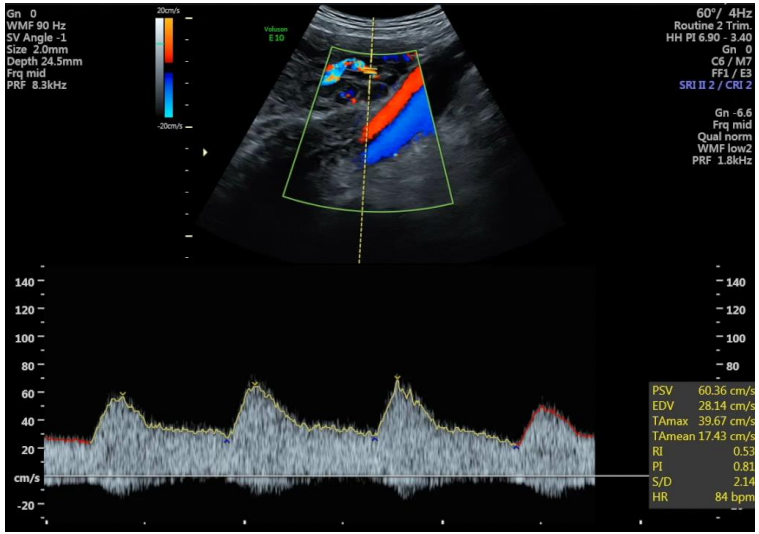
High pass

Low pass



Importance of a clear Doppler spectrum

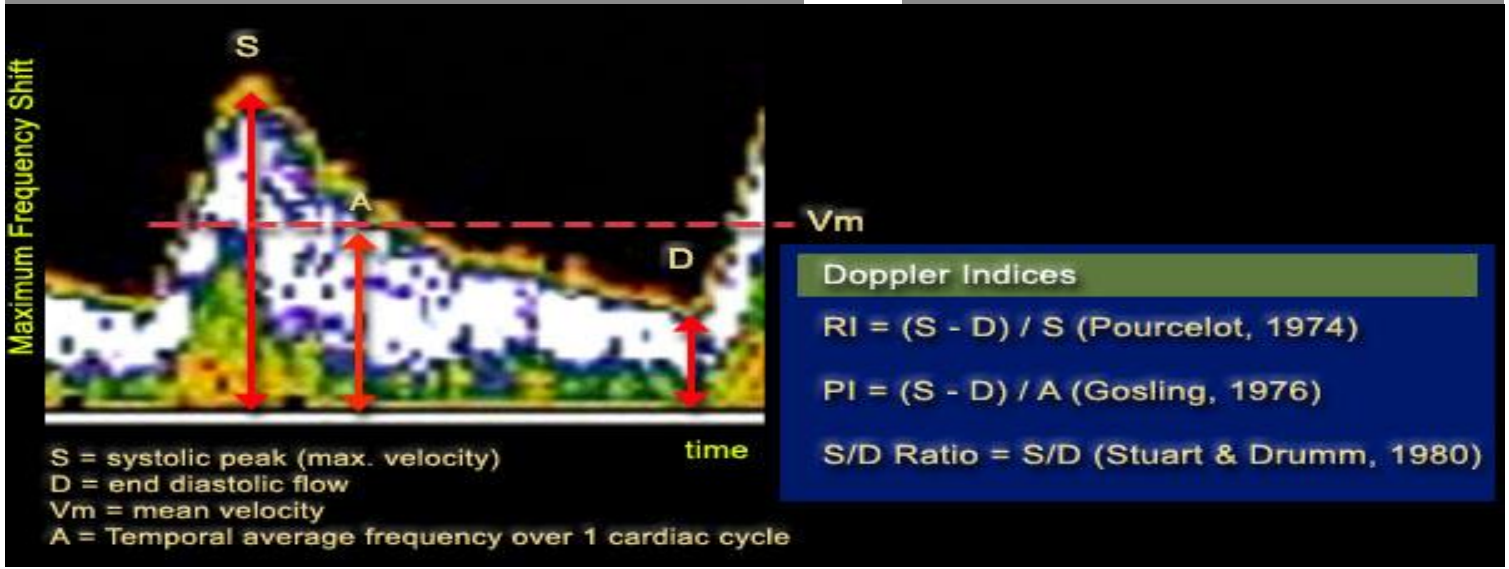
- Prevents erroneous interpretation of PI by automatic measurement modality
- Automatic measurements can be accepted only if Doppler spectrum is clear & trace follows the envelope



Which measurement to use?

Angle independent indices

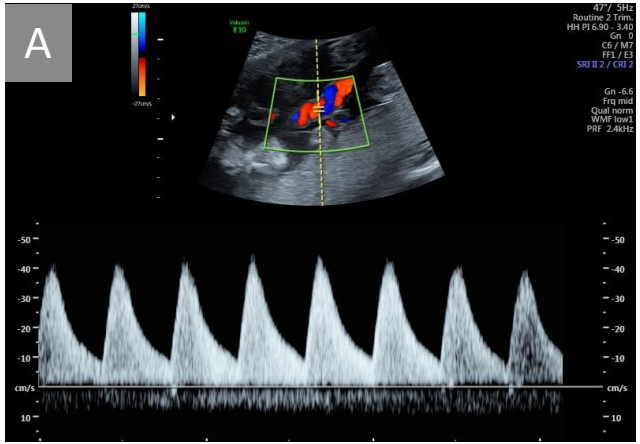
Angle < 90 degrees

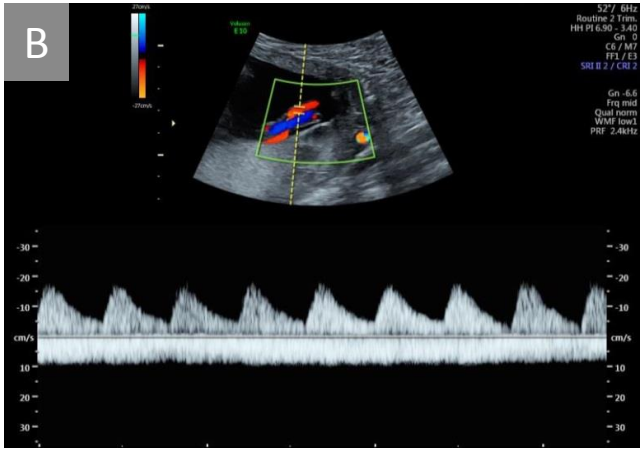


Pulsatility index (PI) preferred

Insonation angle

- PI is angle independent
- Dimensions of the spectral trace vary with angle of insonation (cosine ɵ)
- Cosine of $90^0 = 0$, therefore no flow detectable when sampled vessel lies at 90^0 to insonant beam

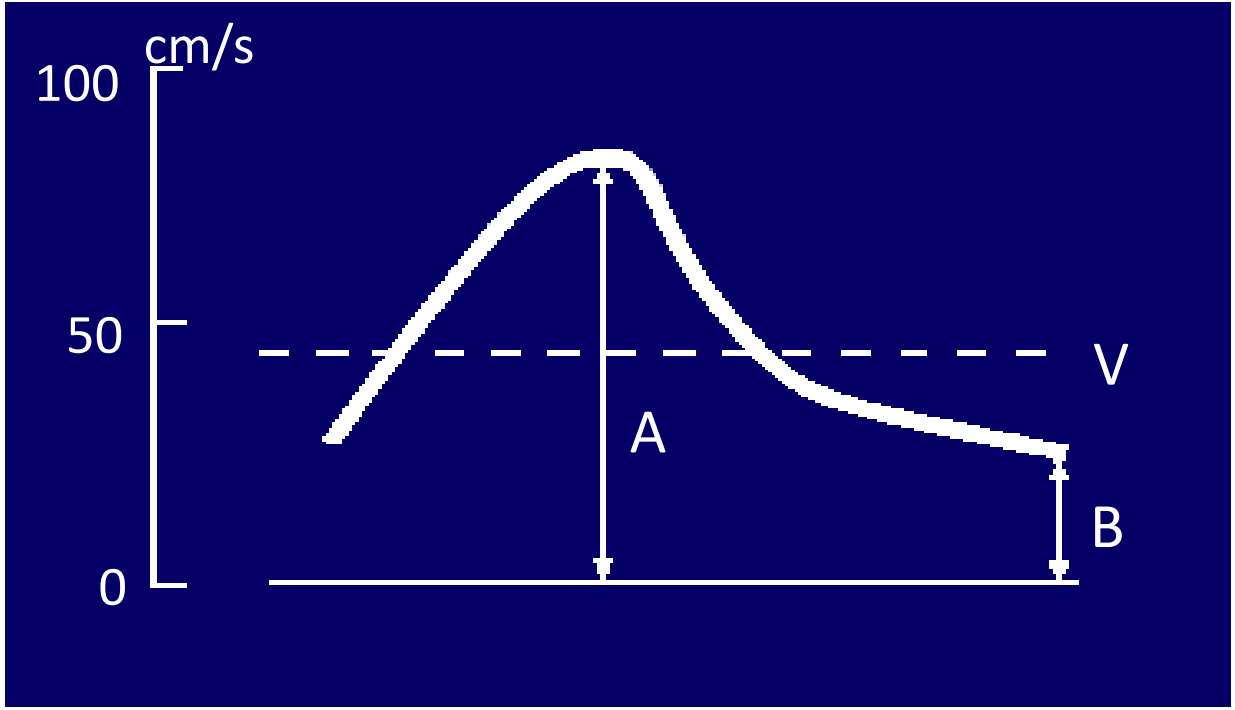




- The closer the angle of sampling is to the vertical (A), the ‘higher’ the trace
- The close the angle of sampling is to the horizontal (B) the ‘smaller’ the trace

Pulsatility index = PI

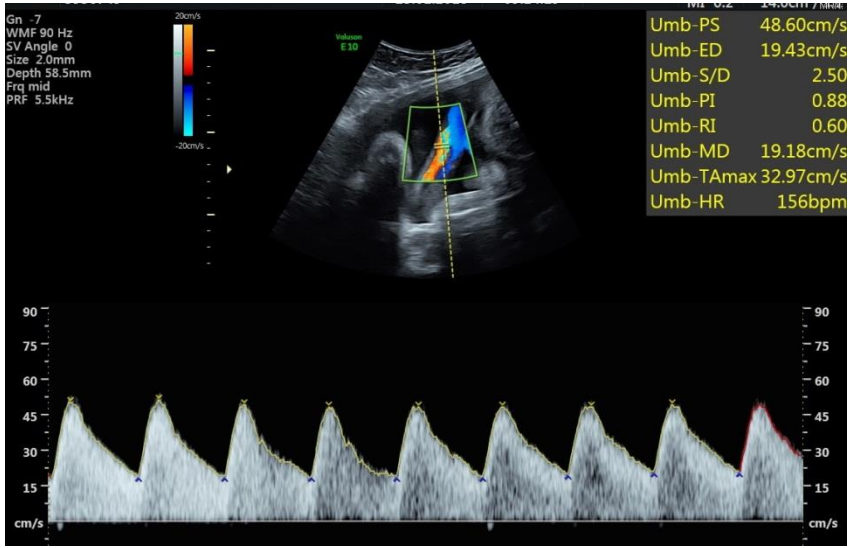
$$PI = \frac{A - B}{\nabla}$$



What does the PI reflect?

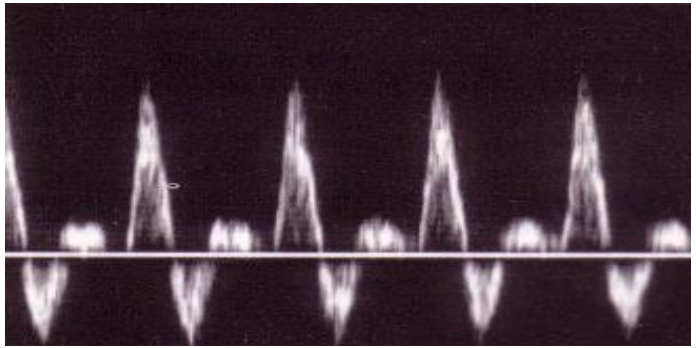
Relationship between pressure & flow in the interrogated vessel, dependant on:

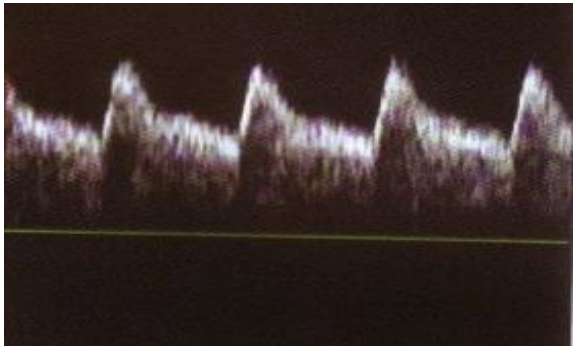
- Distance from the heart
- Peripheral resistance
- Vessel wall elasticity
- Blood viscosity



Pulsatility → downstream impedance

Femoral artery

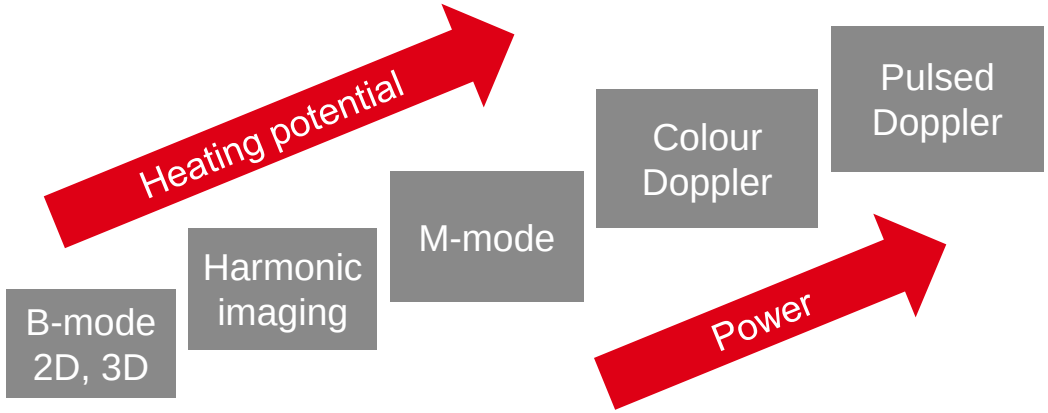




Rest: High peripheral resistance

Exercise: Low peripheral resistance

Safety issues - power levels



ISUOG Statement

The safe use of Doppler in the 11^{+0} to 13^{+6} week fetal ultrasound examination

- Pulsed Doppler (spectral, power & colour flow imaging) ultrasound should not be used routinely

- Pulsed Doppler ultrasound may be used for clinical indications such as to refine risks for trisomies

- When performing Doppler ultrasound, the displayed thermal index (TI) should be ≤ 1 & exposure time should be no longer than 5–10 min, and should not exceed 60 min (ALARA principle)

Examination of the embryo?

Do not use Doppler!

Key points

1. The Doppler effect is found in waves where the source & receiver are moving relative to each other
2. Pulsed wave Doppler & colour flow Doppler are the most frequently used techniques
3. Doppler techniques make the non-invasive assessment of fetal hemodynamics possible
4. Do not use Doppler in the 1st trimester unless clinically indicated