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

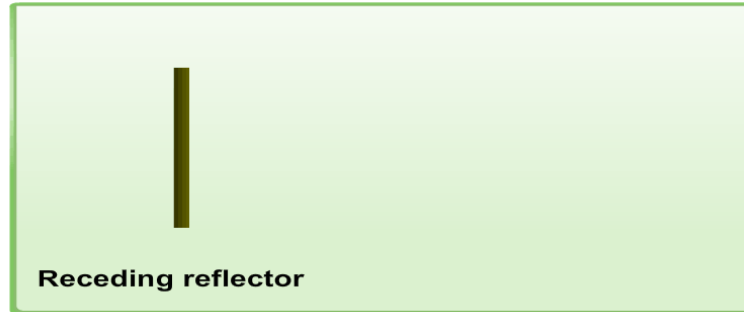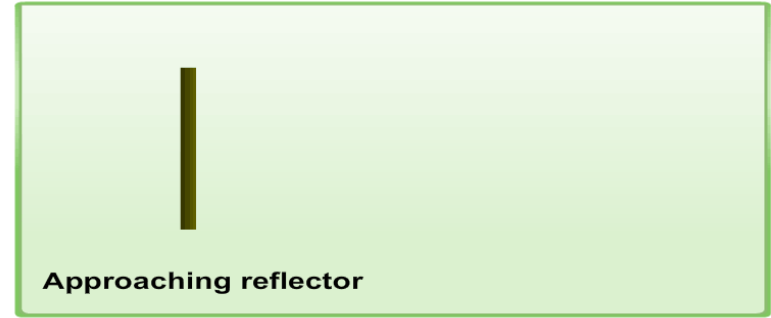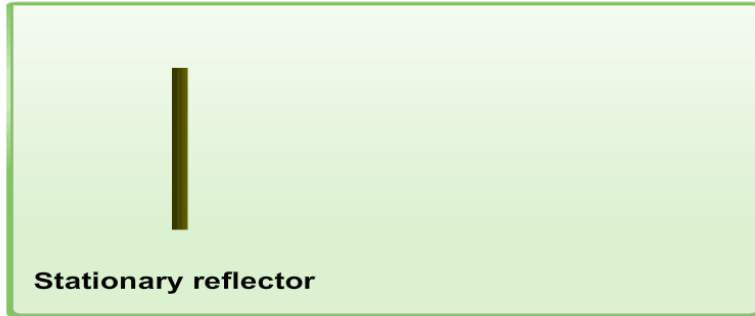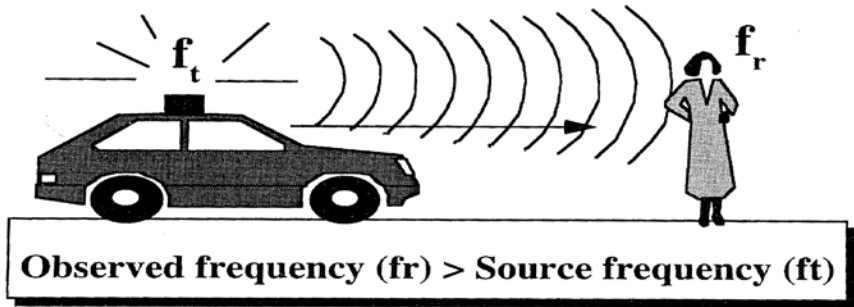Christian Johann Doppler

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

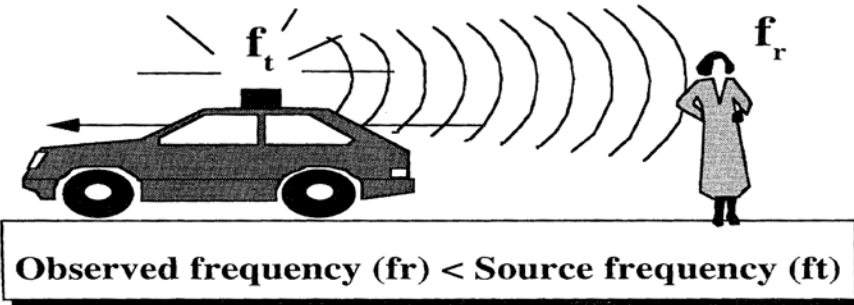## Change in frequency produced by a moving reflector

Stationary reflector

Approaching reflector

Receding reflector

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Doppler principle

Observed frequency (fr) > Source frequency (ft)

Observed frequency (fr) < Source frequency (ft)

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

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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

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Blood velocity measurement
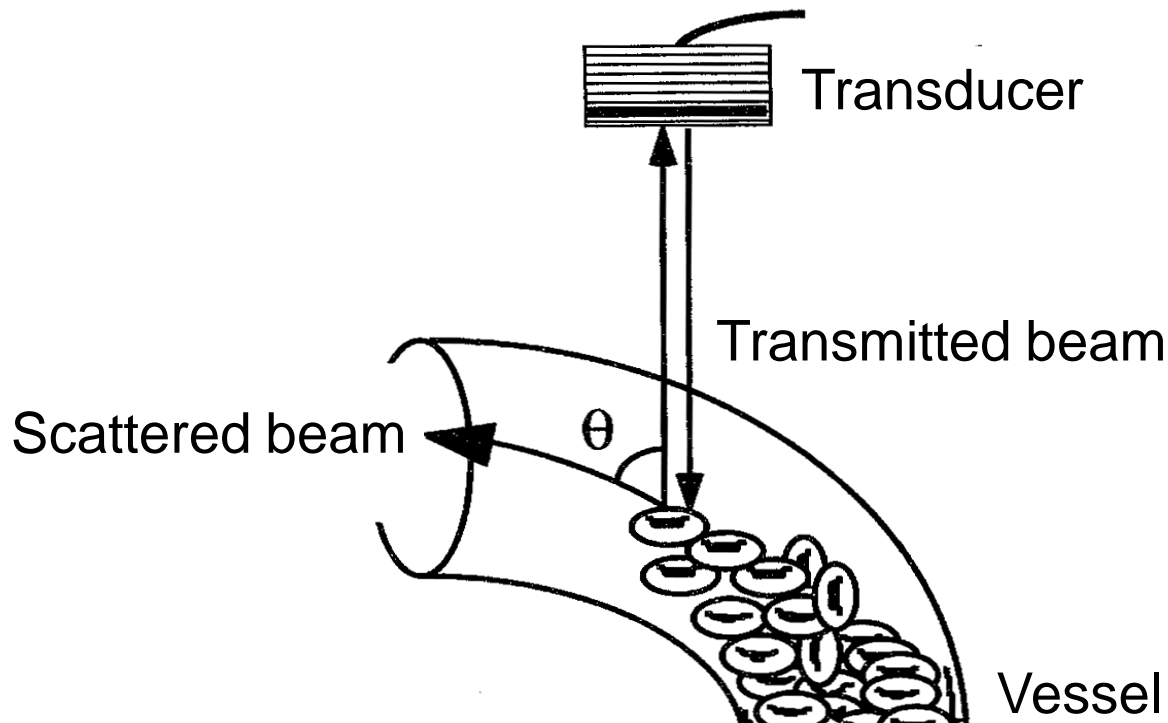
Transducer

Transmitted beam

Scattered beam

θ

Vessel

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

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Doppler equation

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

Δ_f : Change in frequency
f_o : 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
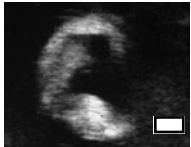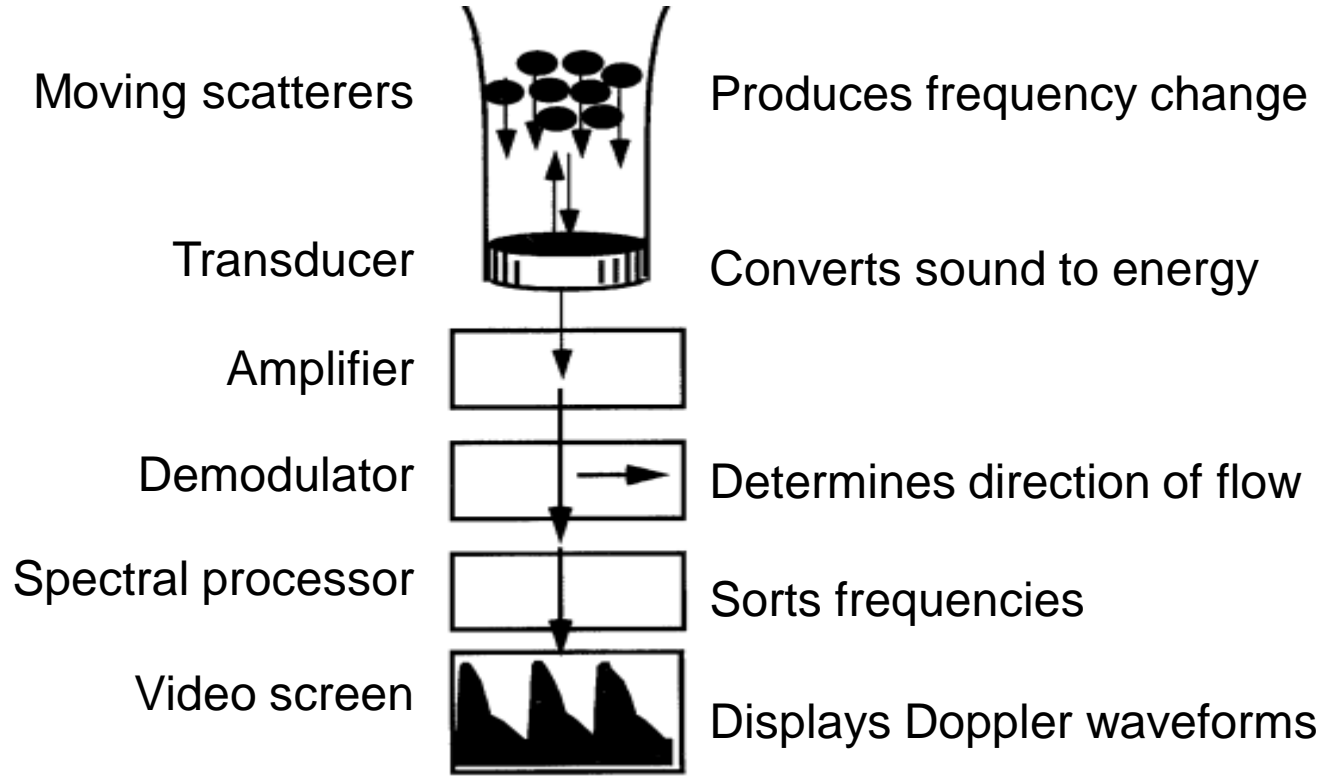
You can hear Doppler ultra ▶

Duplex transducer
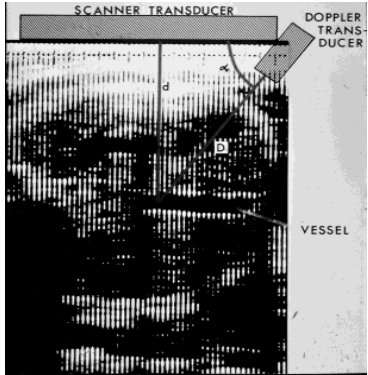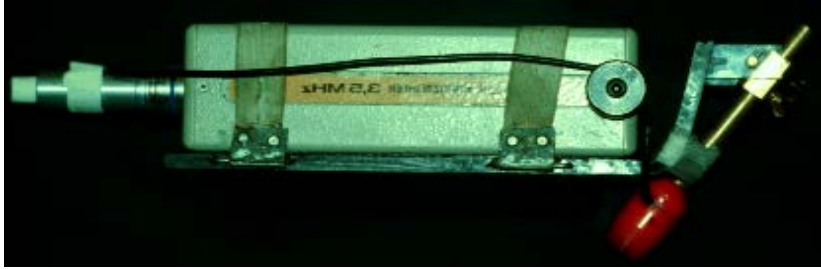

Insonation of umbilical vein at fixed angle (1979)

Element 1

30°

Tissue sector

Element 2

30°

Flow sector
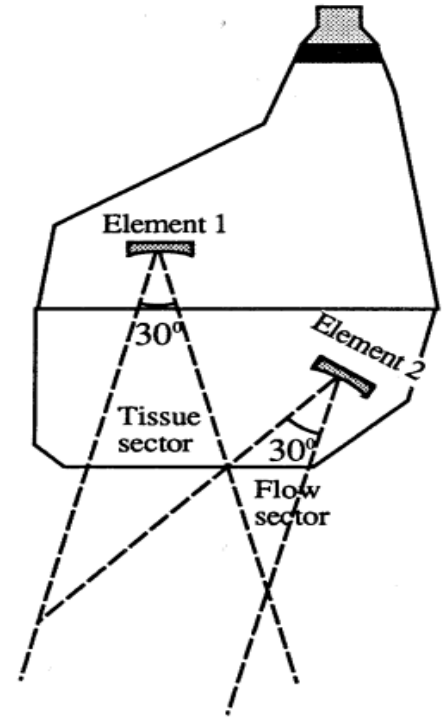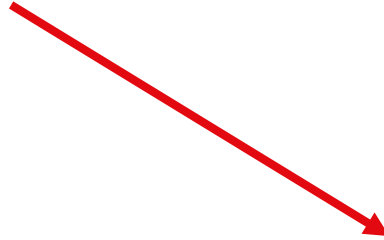
Eik-Nes et al. BMJ, 1980 .

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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
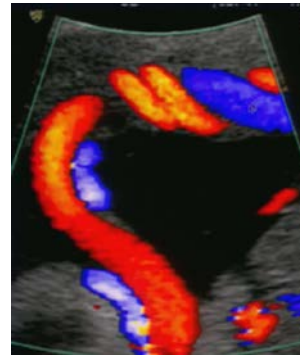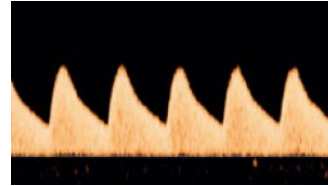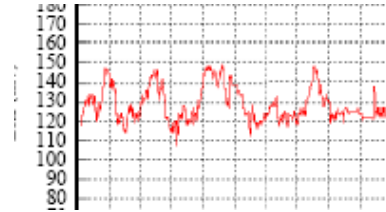
Continuous wave Doppler

- Two transducers

- Sending & receiving continuously

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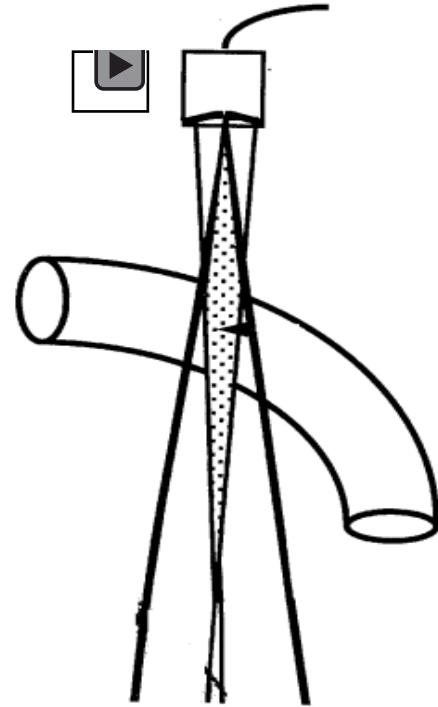
Abuhamed, A. Ultrasound in Obstetrics and Gynecology: A Practical Approach (1st ed), 2014.

Pulsed wave Doppler (PW)

- One transducer

- Sends a pulse

- Gate closes

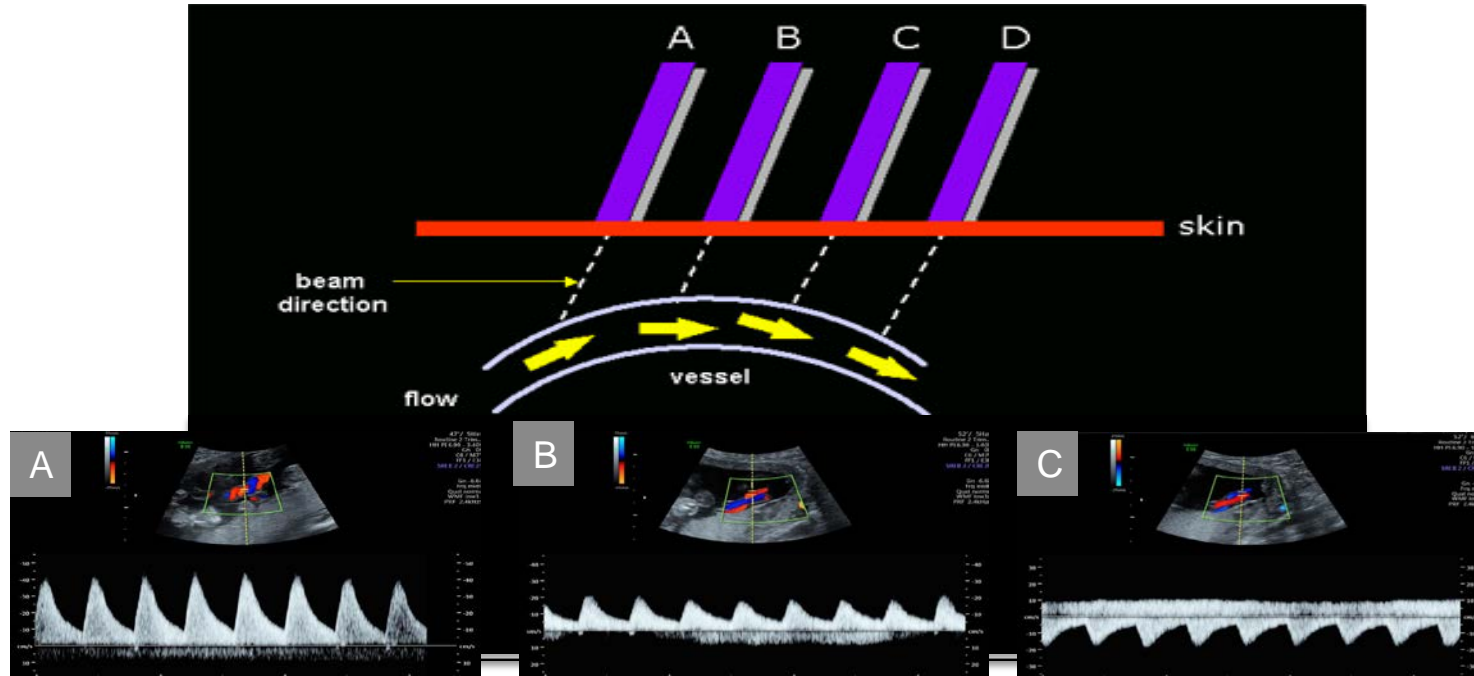- Gate opens after a time

- Gates remains open briefly

- Gate closes
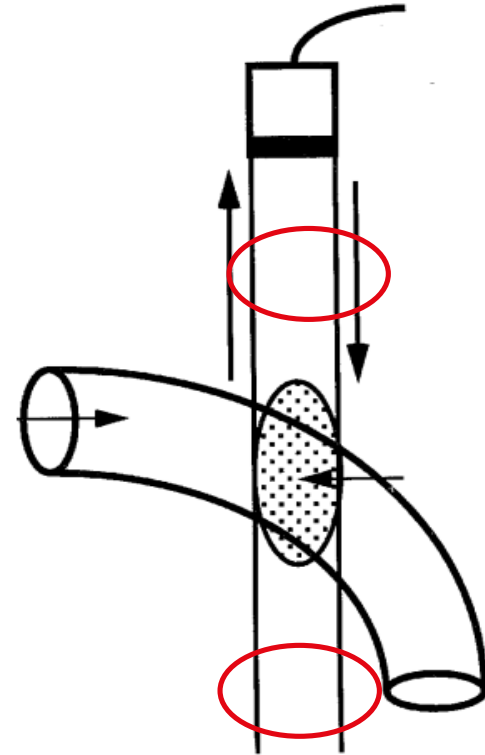
Insonation angle

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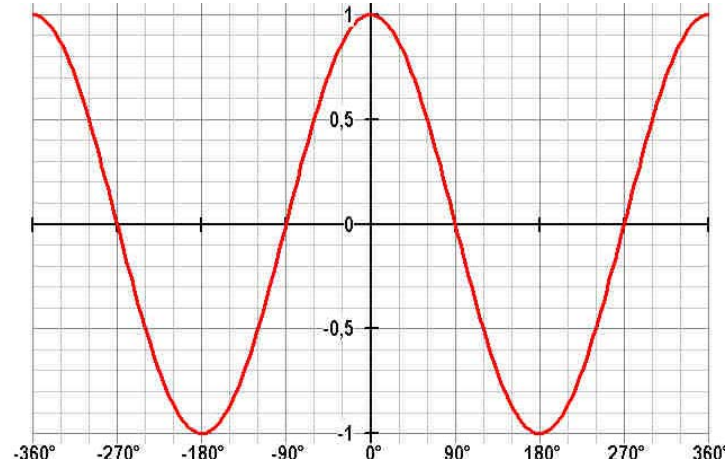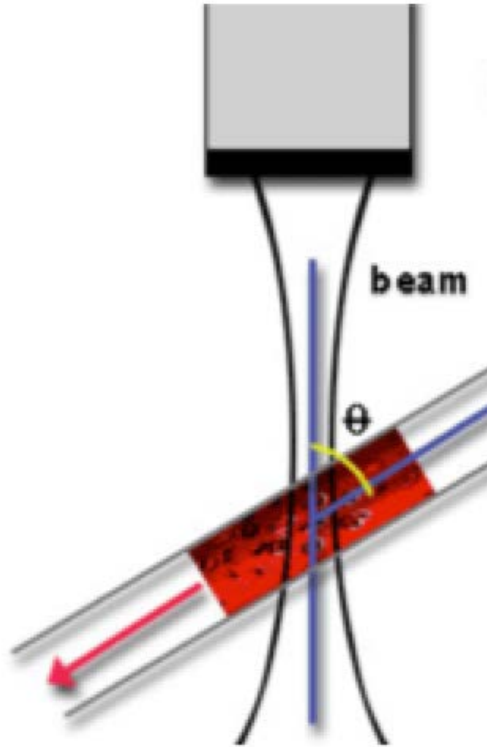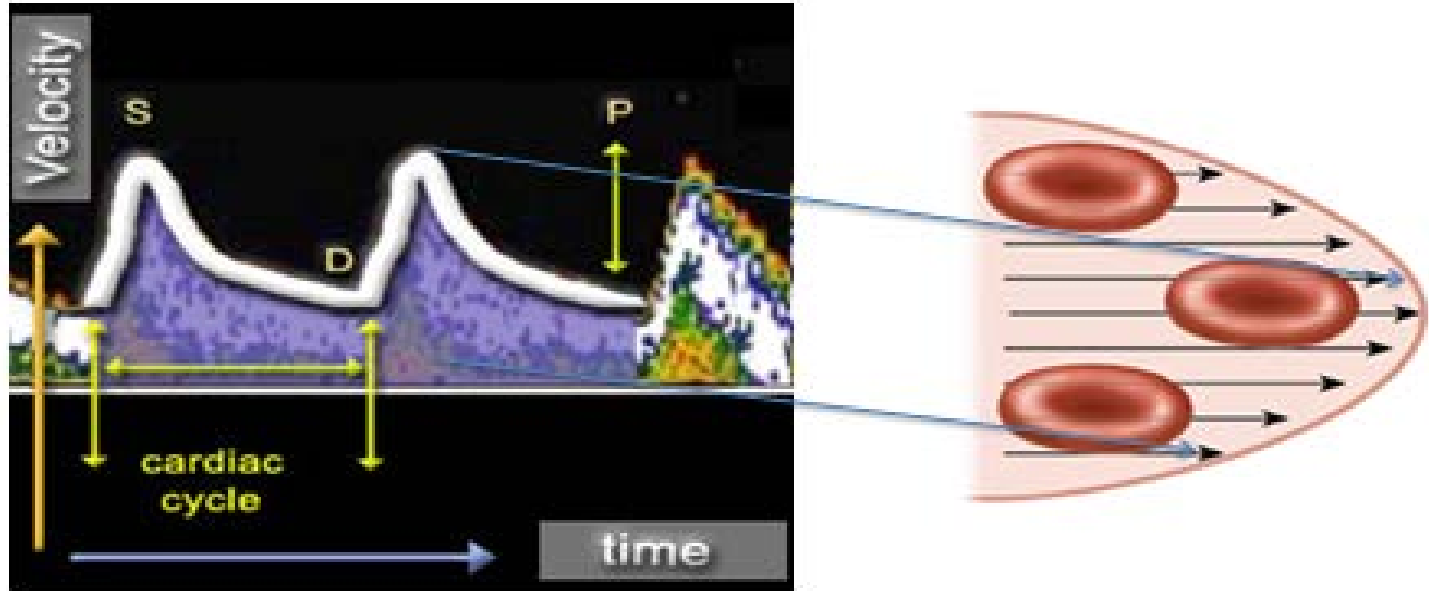

Value of the cosine of the angle

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)
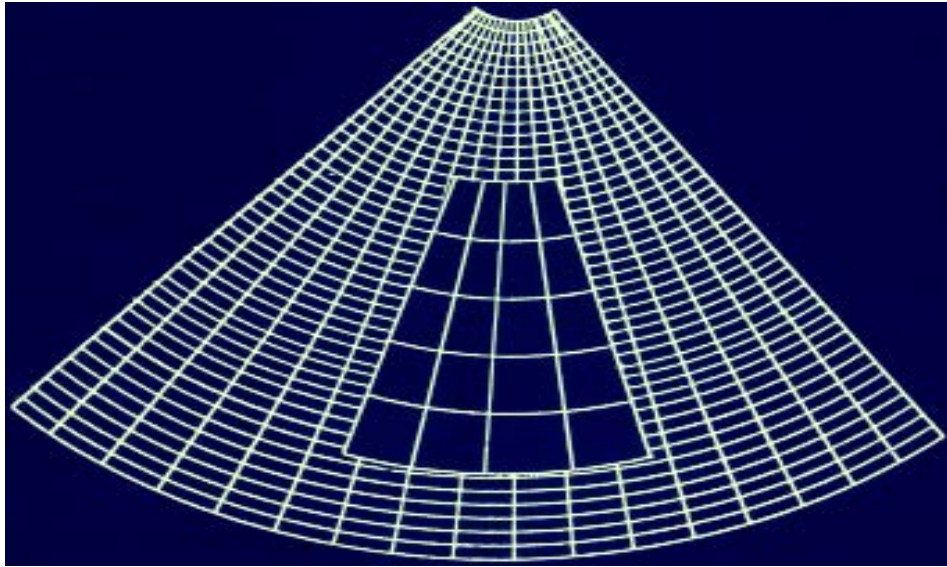
Frequency spectrum

Frequency (Hz)
Velocity (cm/s)

Time (s)
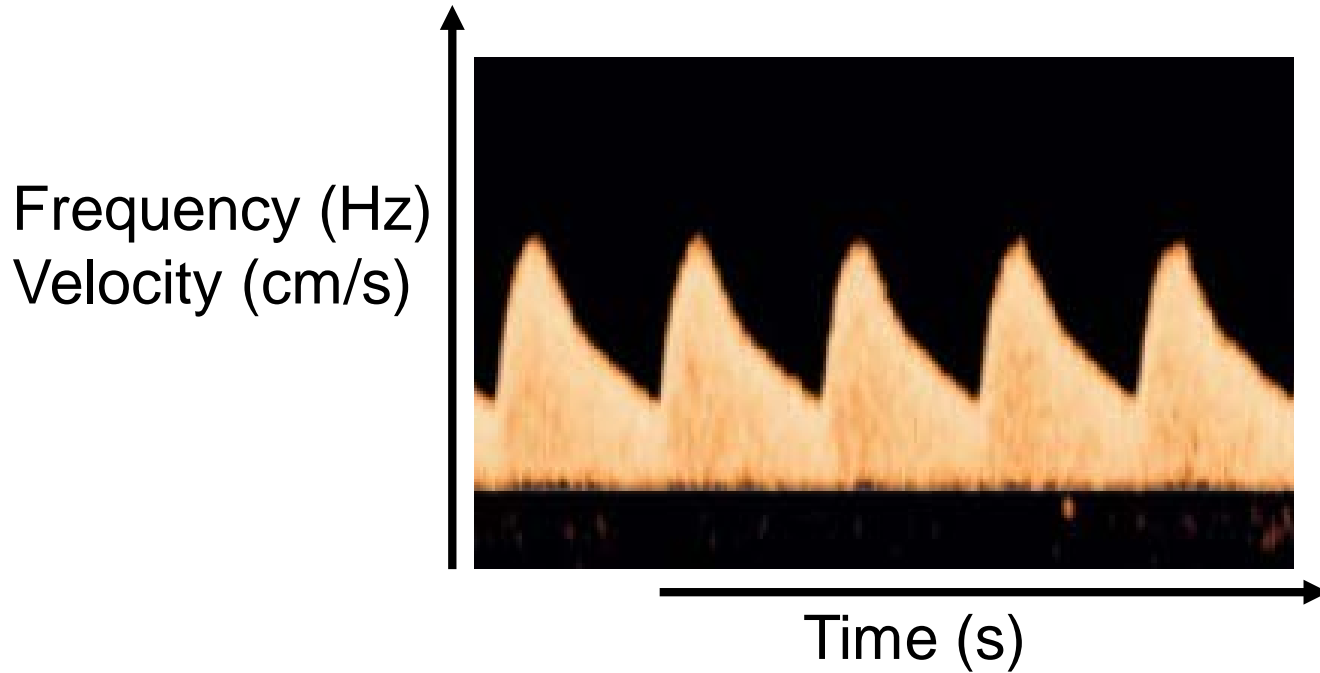
Doppler shift & velocity spectrum

- Flow velocity waveform = spectrum of velocities within the vessel

- Maximum envelope = fastest red blood cells in the middle of the vessel

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Basic principle of colour flow mapping (CFM)

Area with multiple sample volumes
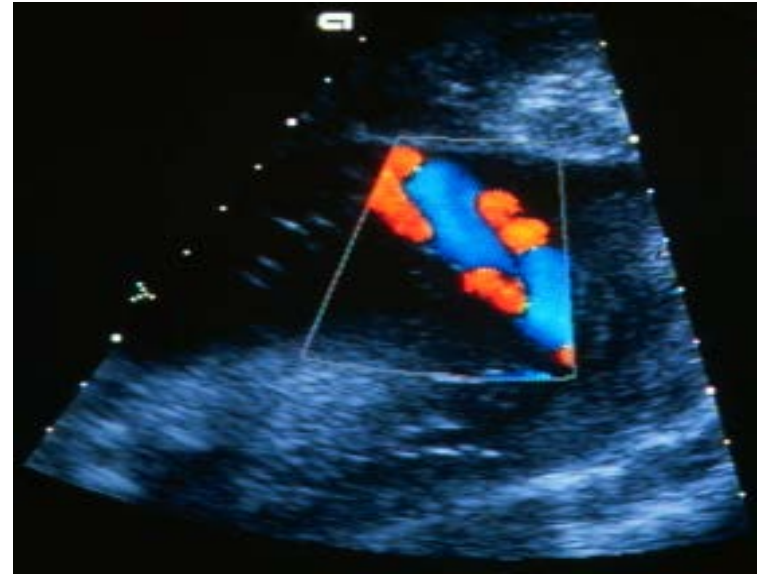
Same area colour coded

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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*
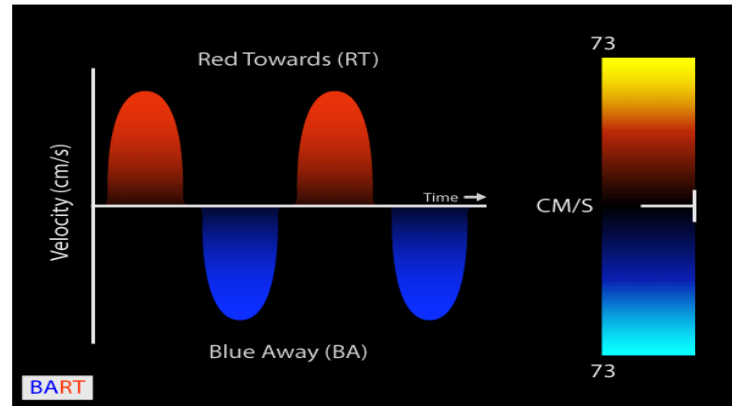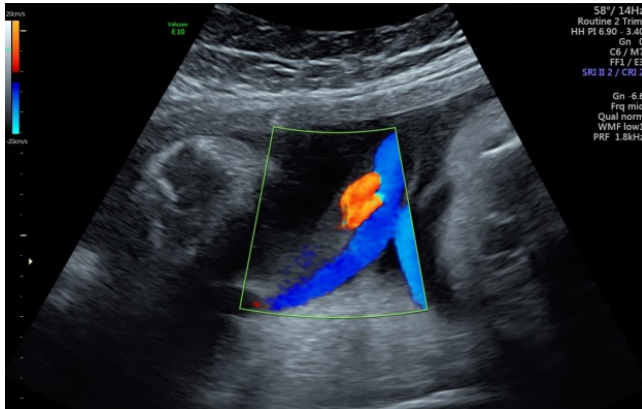
Power Doppler

Power Doppler:

- Does not display velocity information

- Displays the amplitude of the returning Doppler shifted echoes

- Less dependent on angle of insonation
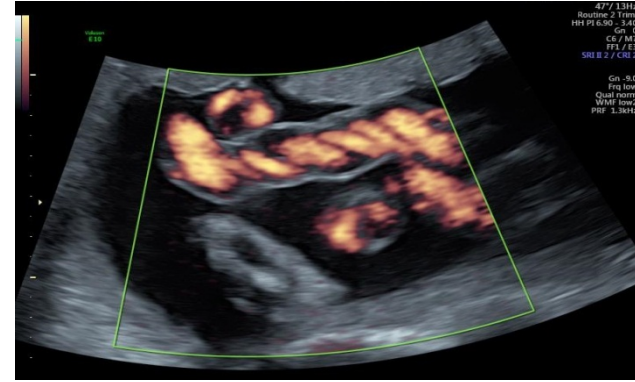
Directional power Doppler

- Modern machines incorporate directional flow into power Doppler mode
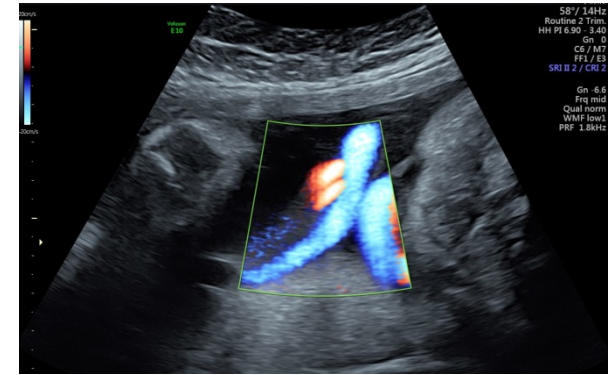
Colour coding

- Velocities away from transducer shades of blue

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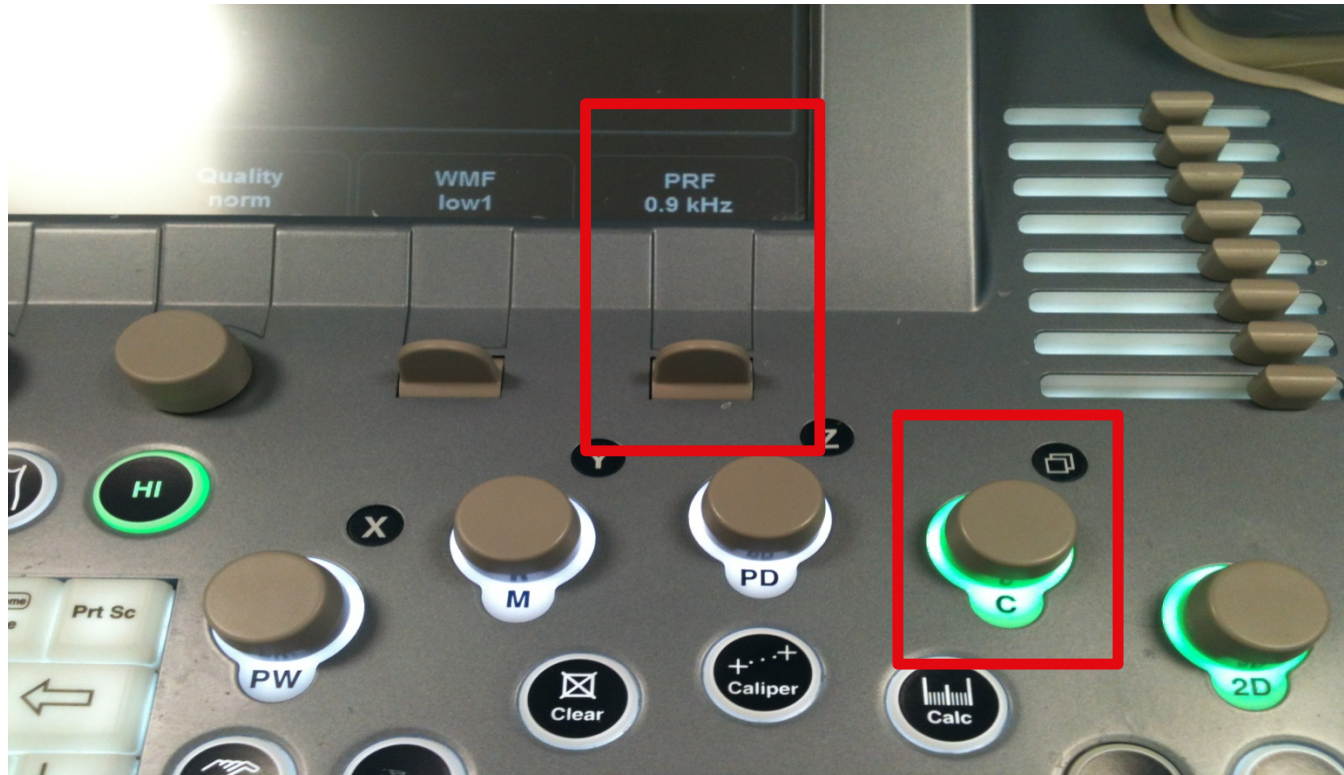
- Aliasing shades of bright blue or bright yellow

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Doppler controls

- Sample gate width

- Pulse repetition frequency (PRF)

- Baseline

- Sweep speed

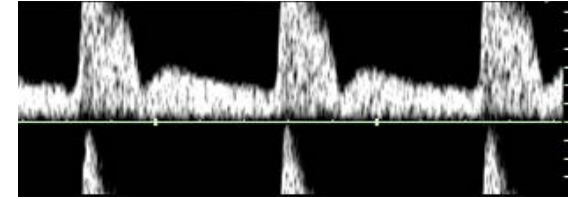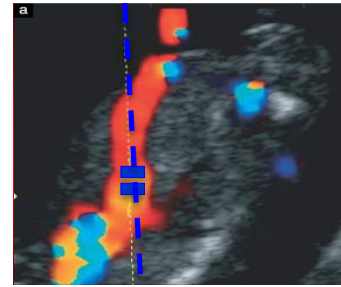- High-pass filter (min)

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Pulse Repetition Frequency (PRF)
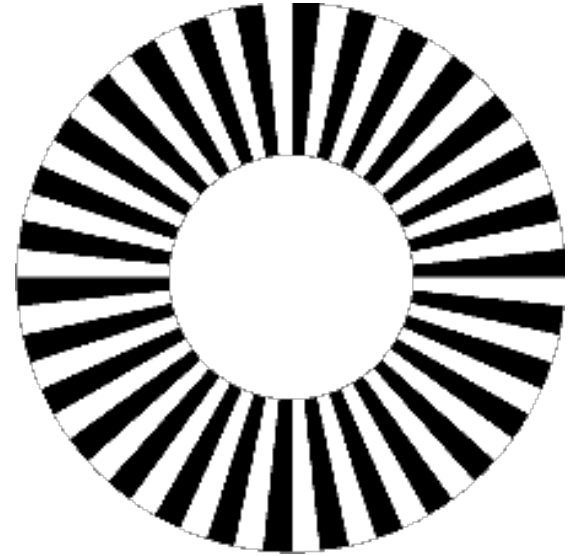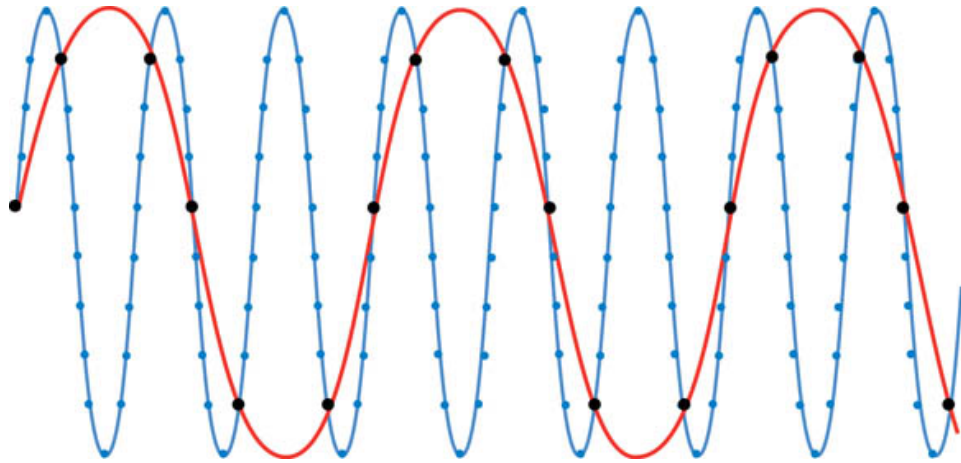
Use of colour or power Doppler

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
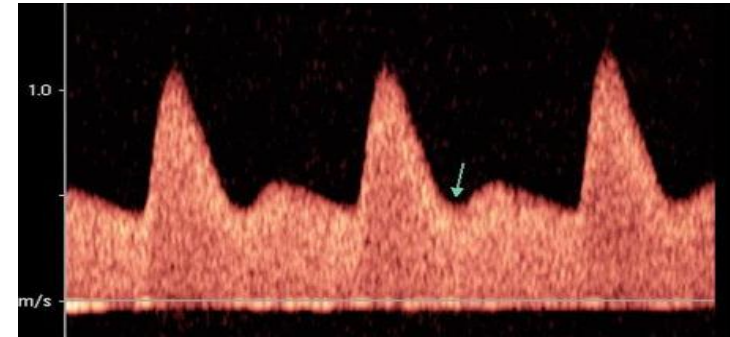
Aliasing

- 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

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Example of aliasing
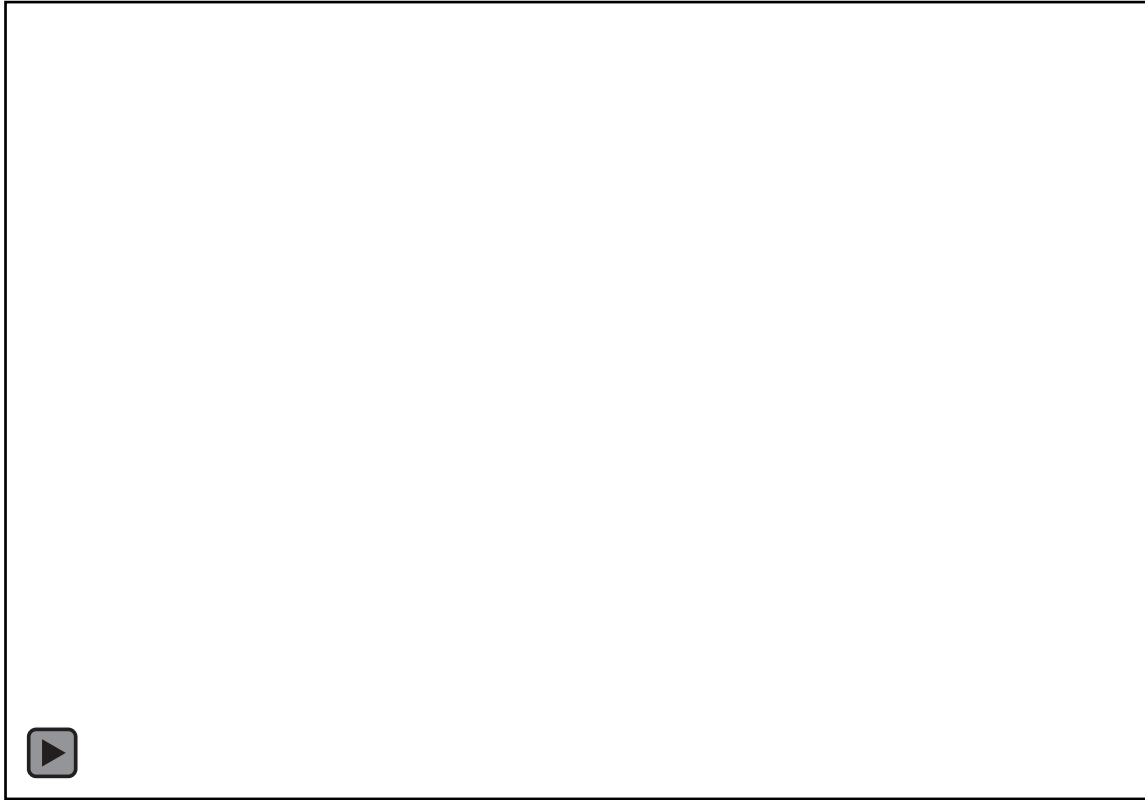
To correct - increase PRF & adjust baseline
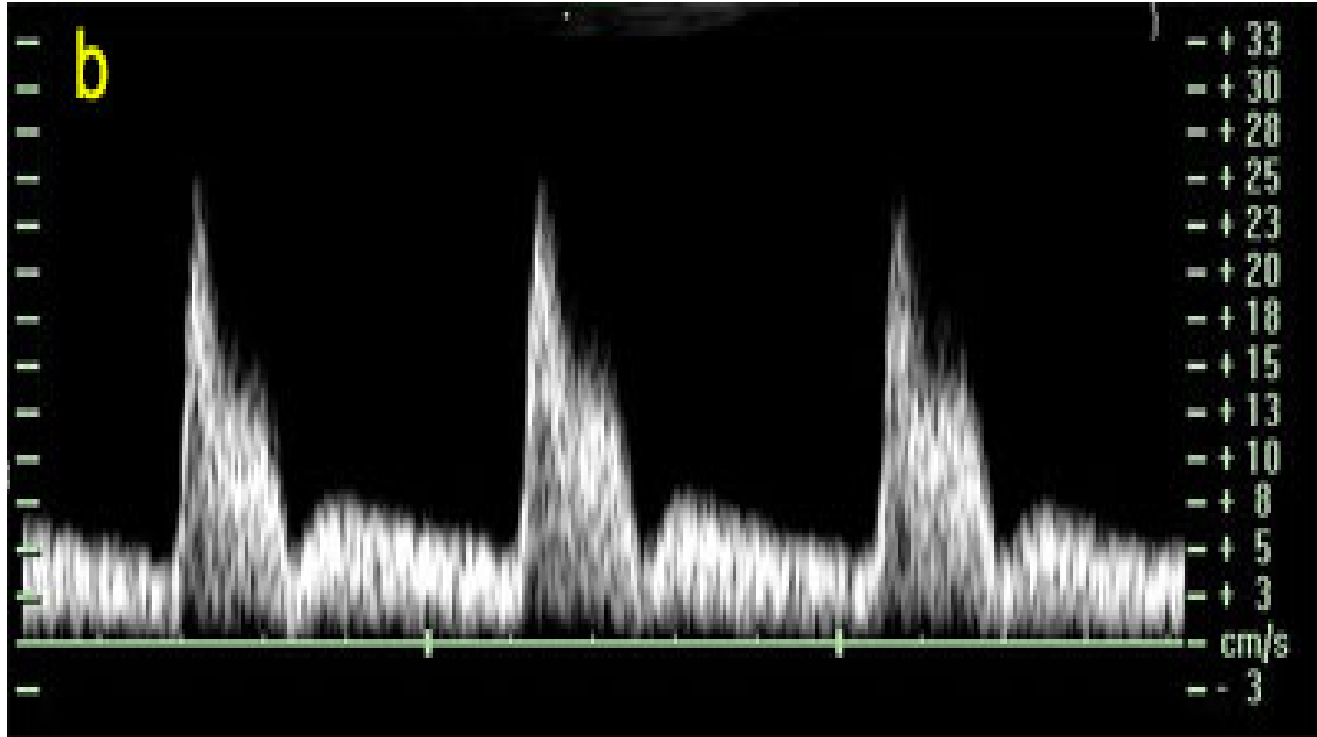
Sweep speed

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.
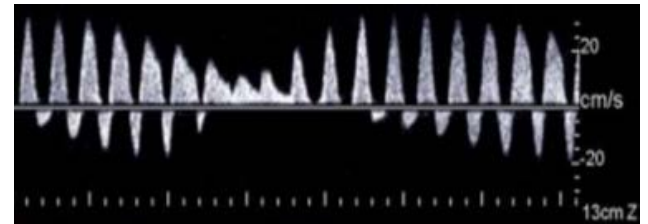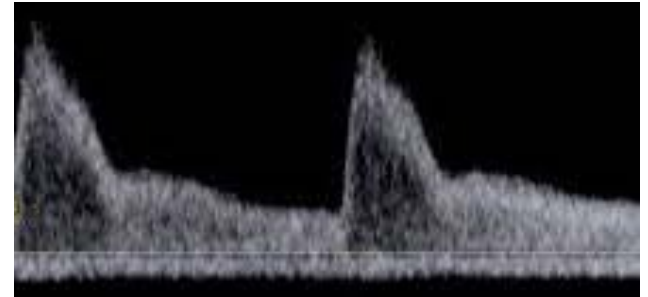
Sweep speed & PRF - incorrect
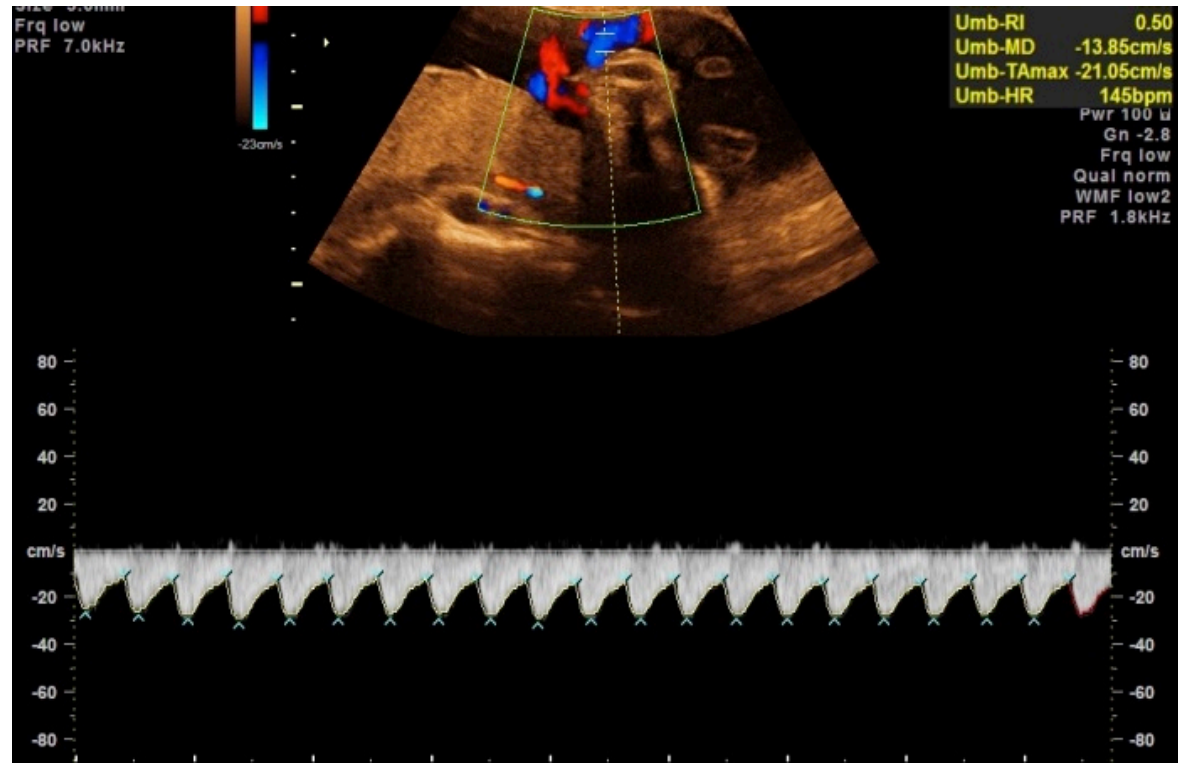
Sweep speed PRF - correct for UA
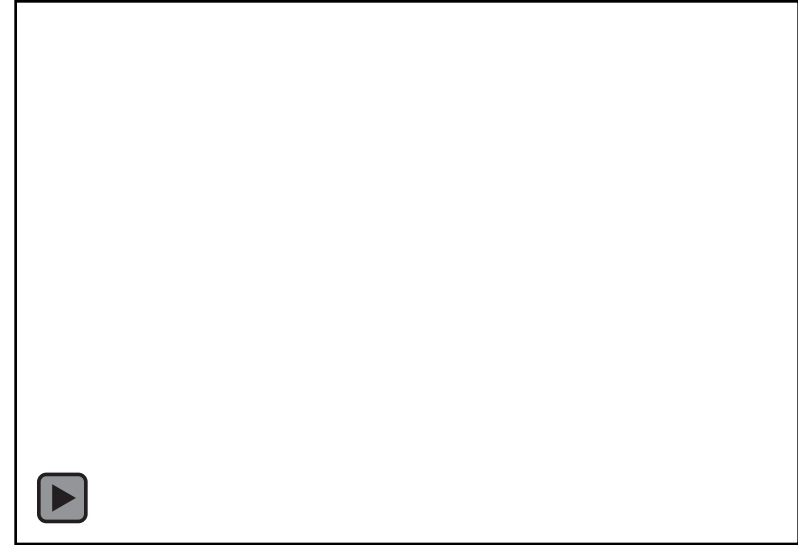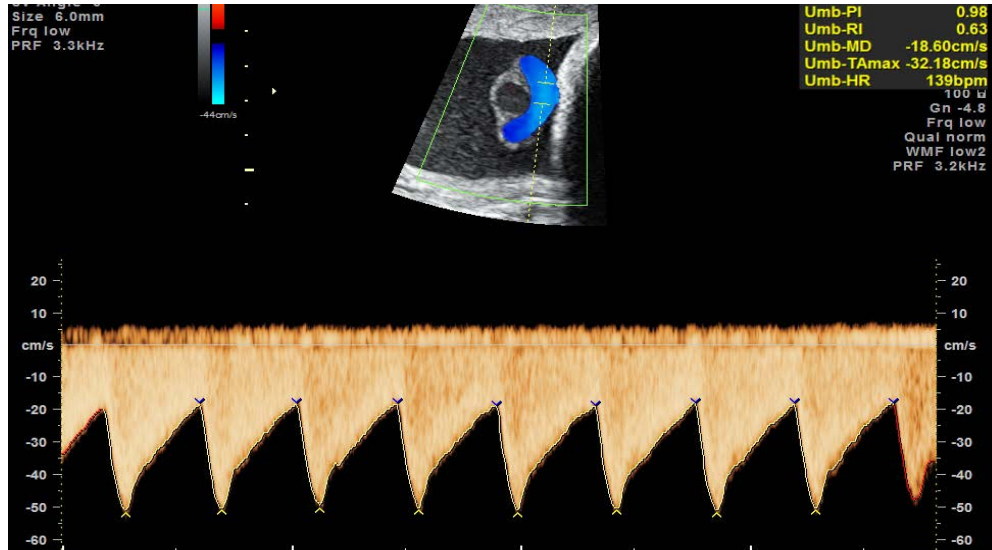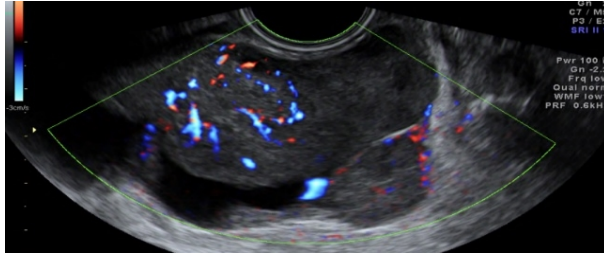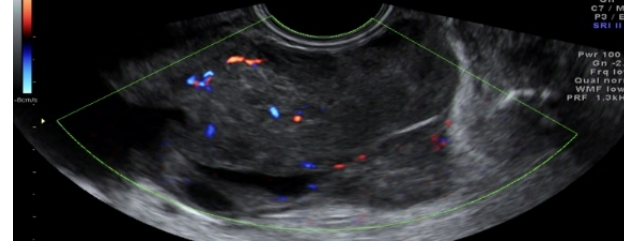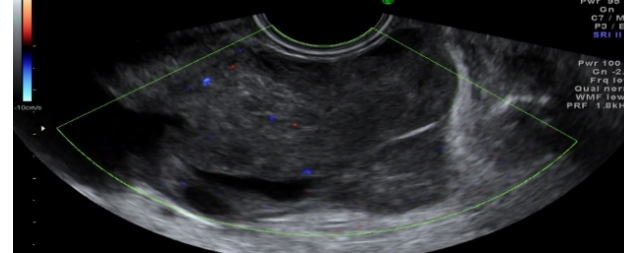
Use of Pulse Repetition Frequency (PRF)

0.1

0.9

0.3

1.3

0.6

1.8

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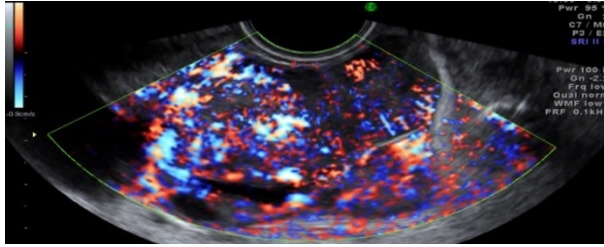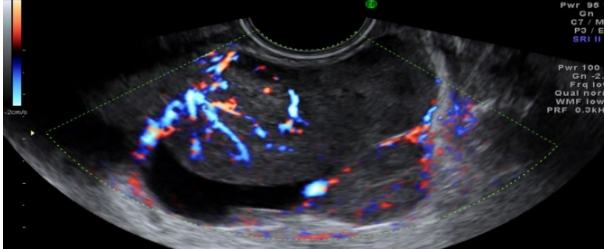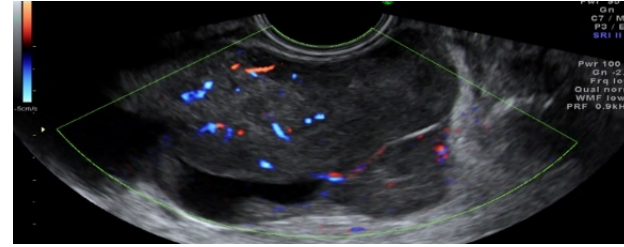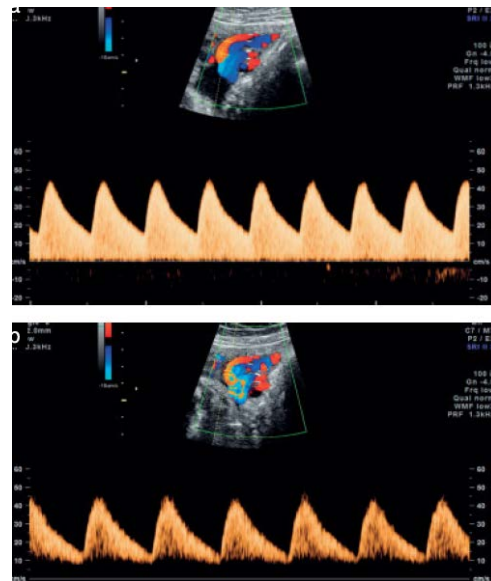
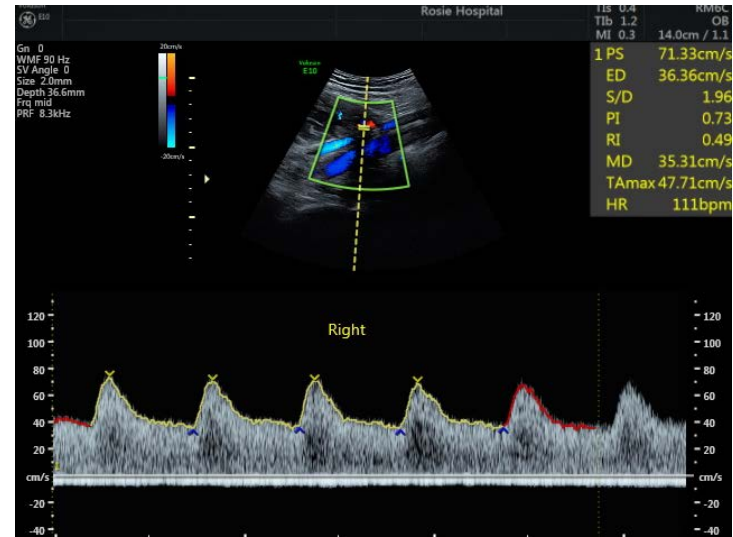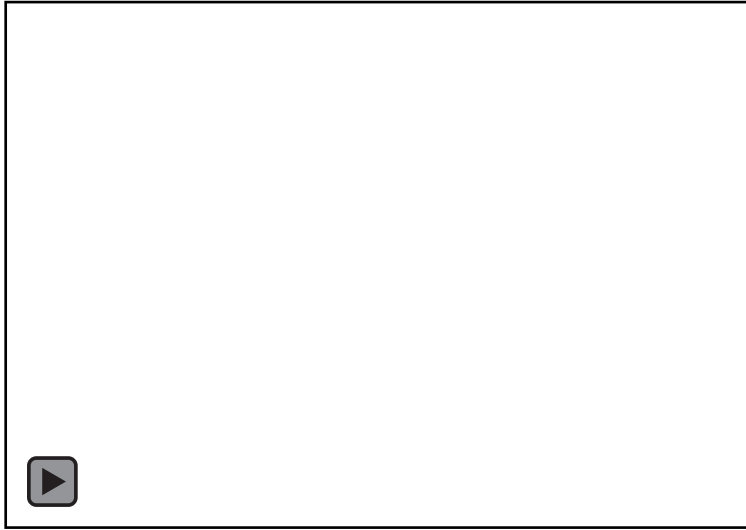# PRF fixed at 0.3, lower GAIN…
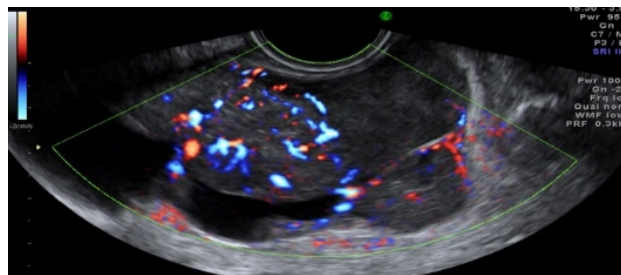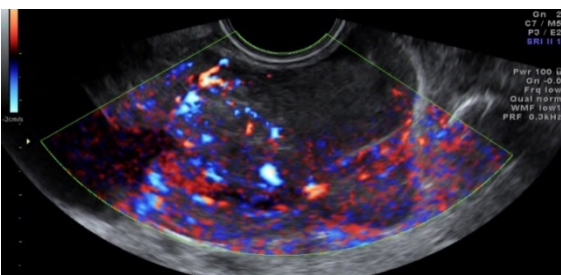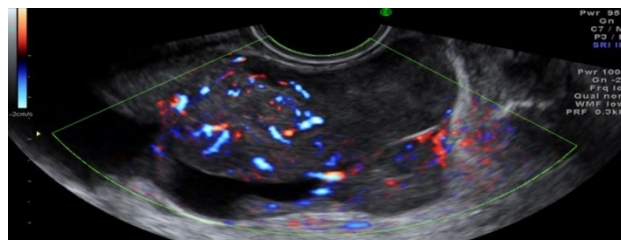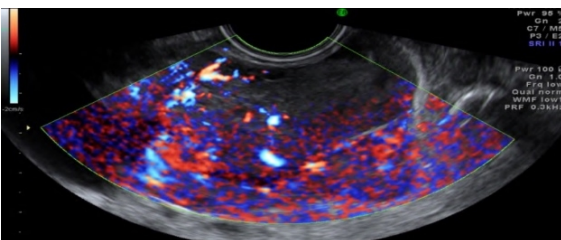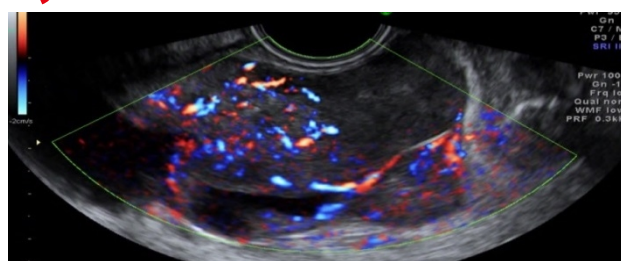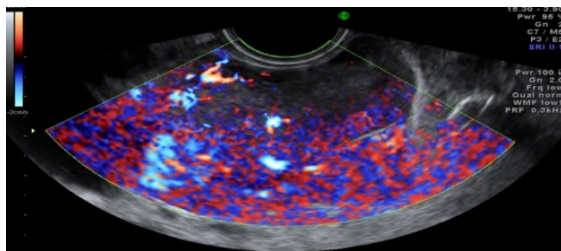
High/low pass filter

High pass   Low pass
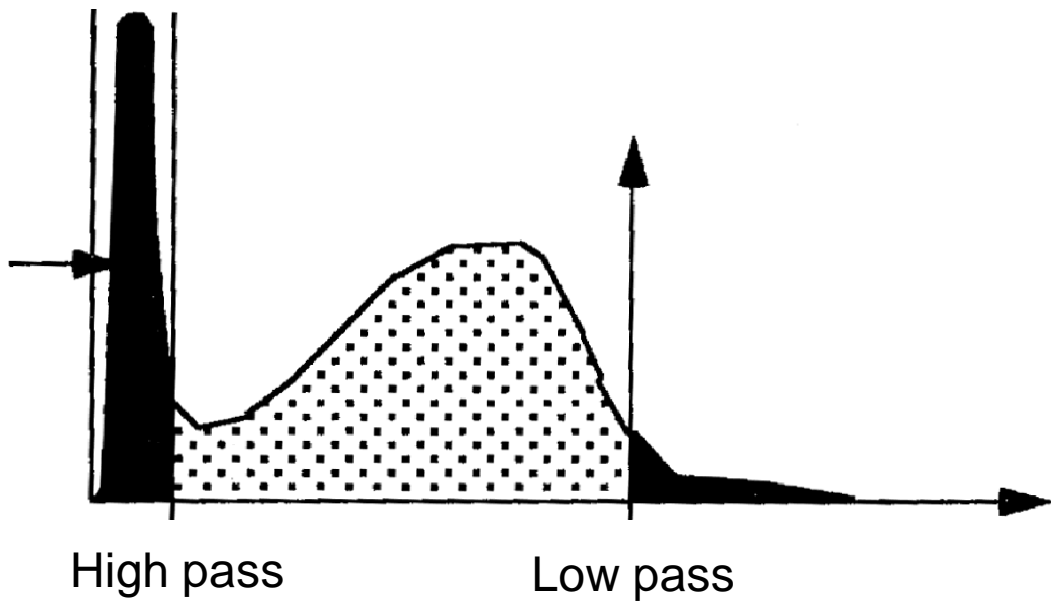
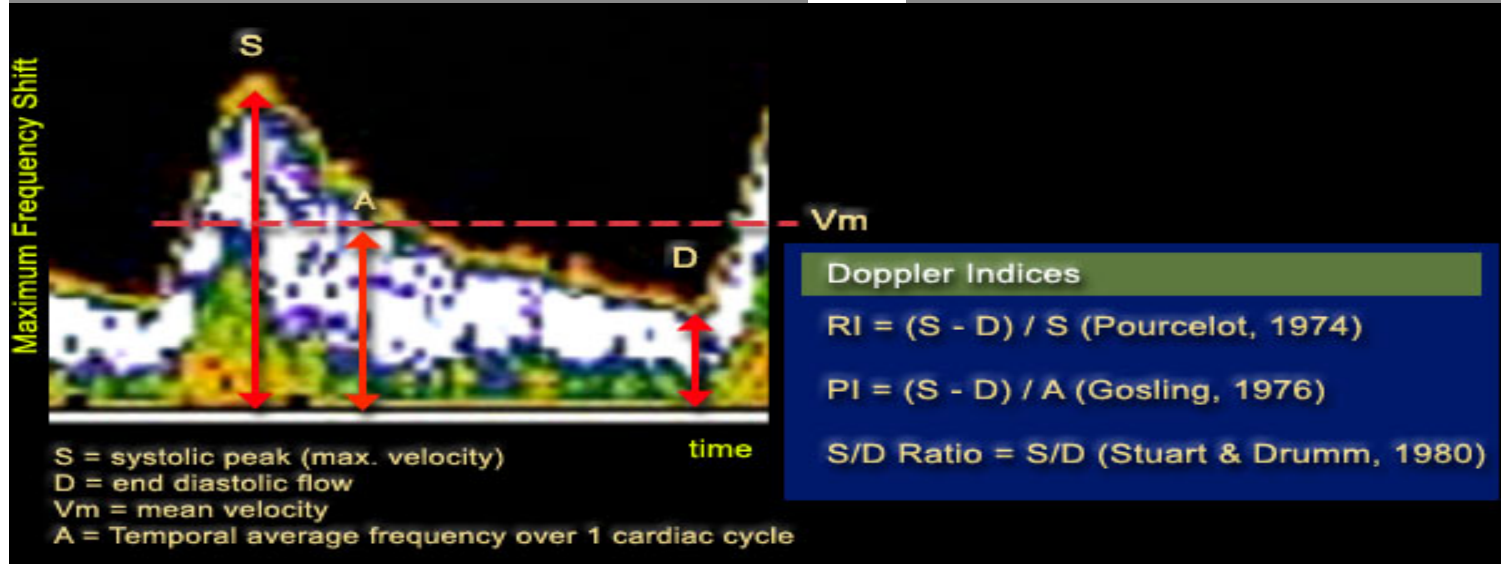# Importance of a clear Doppler spectrum

- 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?
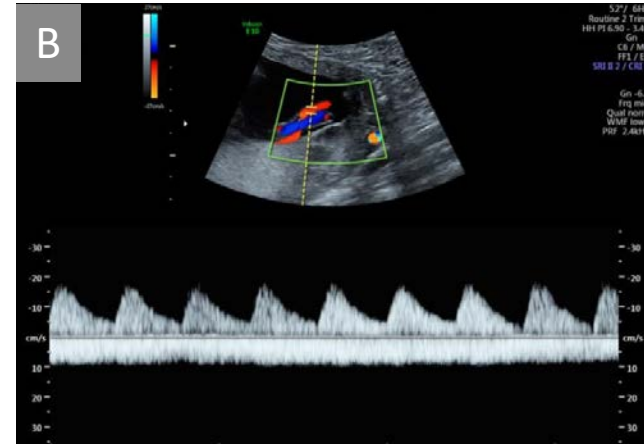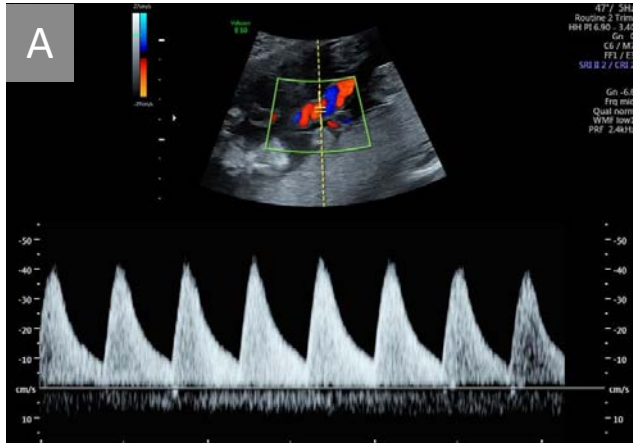
Angle independent indices   Angle < 90 degrees

Pulsatility index (PI) preferred

Insonation angle

- PI is angle independent
- Dimensions of the spectral trace vary with angle of insonation (cosine ө)
- 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
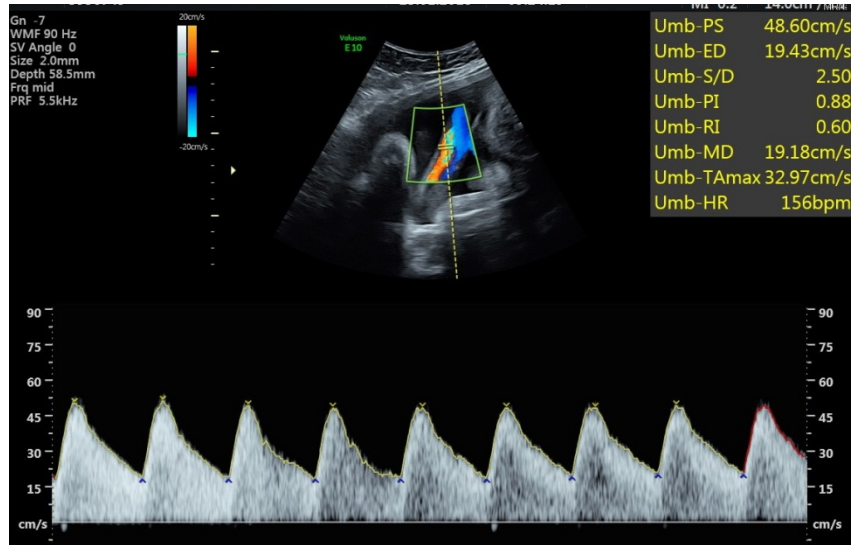
$$PI = \frac{A - B}{\nabla}$$
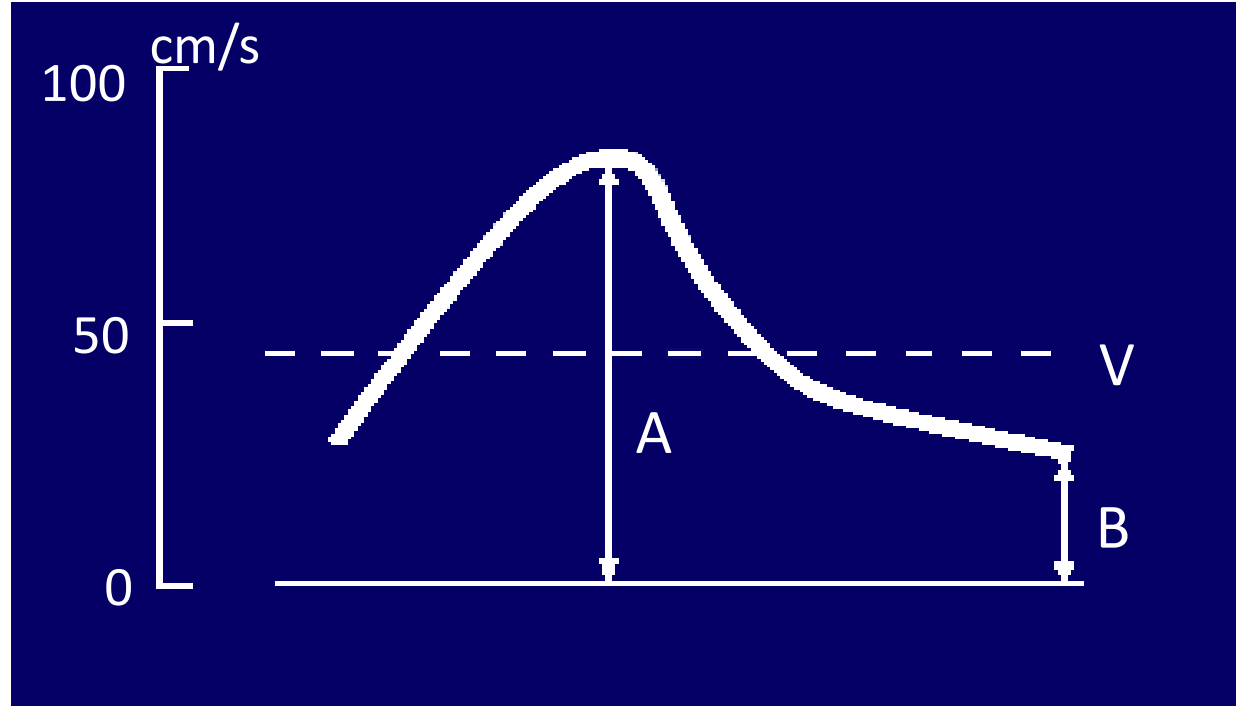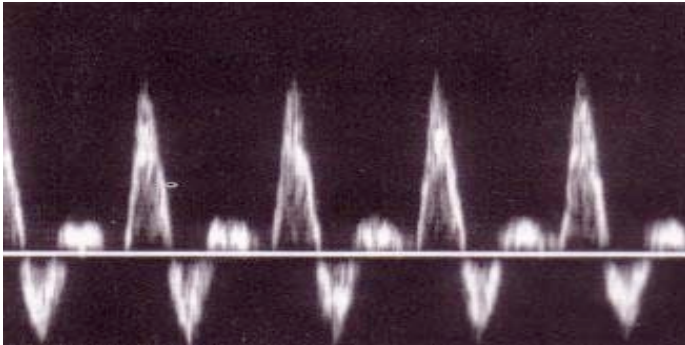
What does the PI reflect?

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

- Distance from the heart

- Peripheral resistance

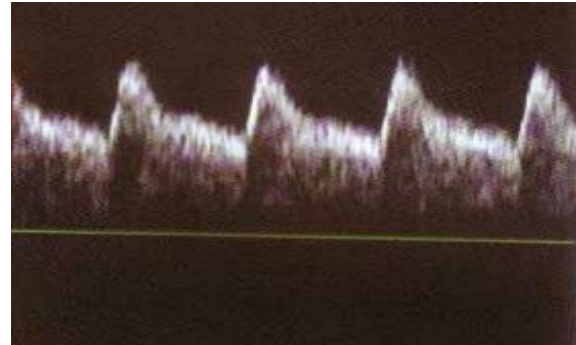- Vessel wall elasticity

- Blood viscosity

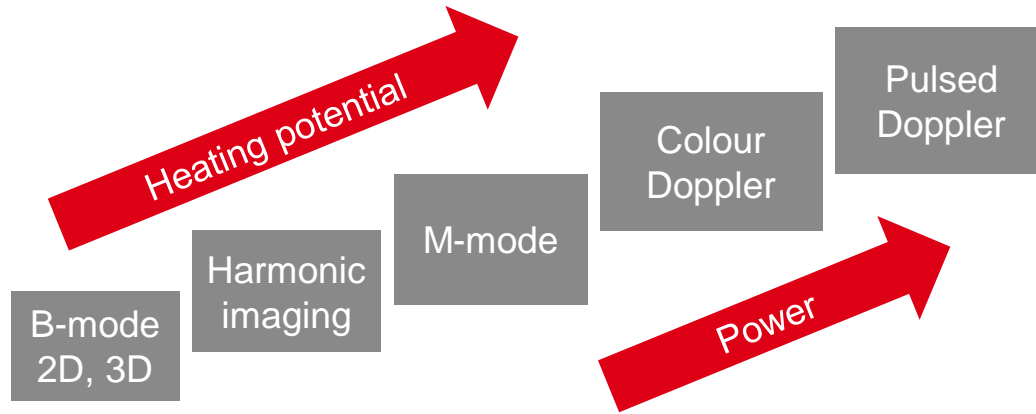# Pulsatility → downstream impedance

Femoral artery

Rest: High peripheral resistance

Exercise: Low peripheral resistance

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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)

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Examination of the embryo?

Do not use Doppler!
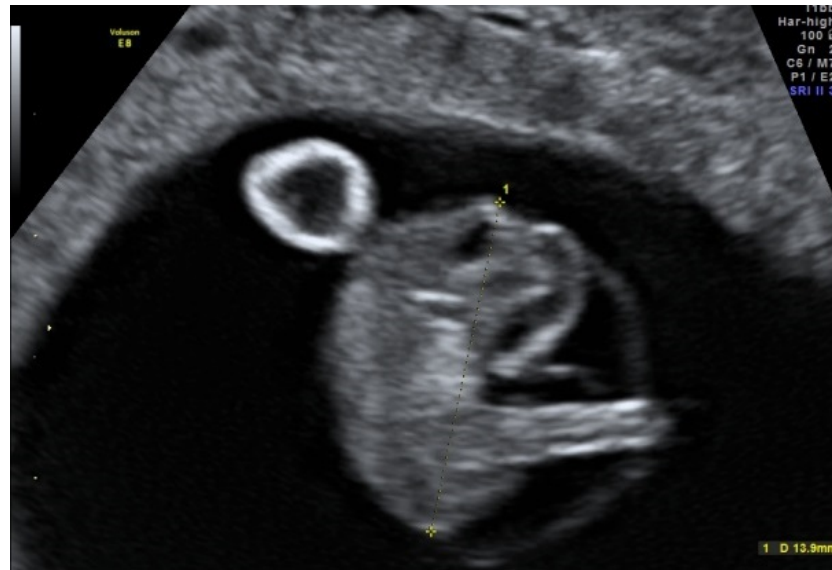
Key points

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

Basic Training