Doppler Principles and Vascular Ultrasound Techniques

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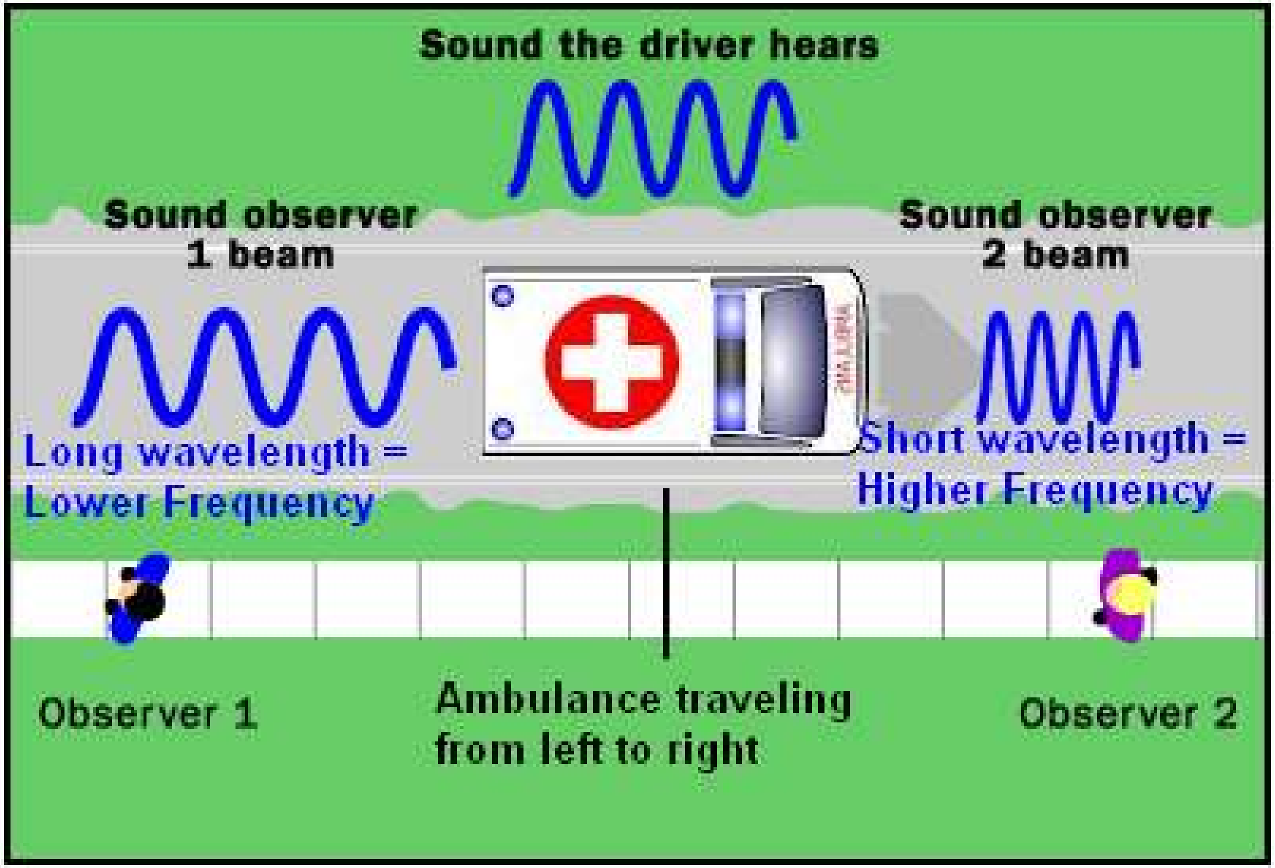
Learning Outcomes

- Review the Doppler principle and it's application in diagnostic ultrasound
- Optimising Doppler for venous imaging
- Tips and Tricks for Scanning lower limb veins
- Optimising Doppler for arterial imaging
- Tips and Tricks for Scanning the carotid arteries

Doppler Identifies

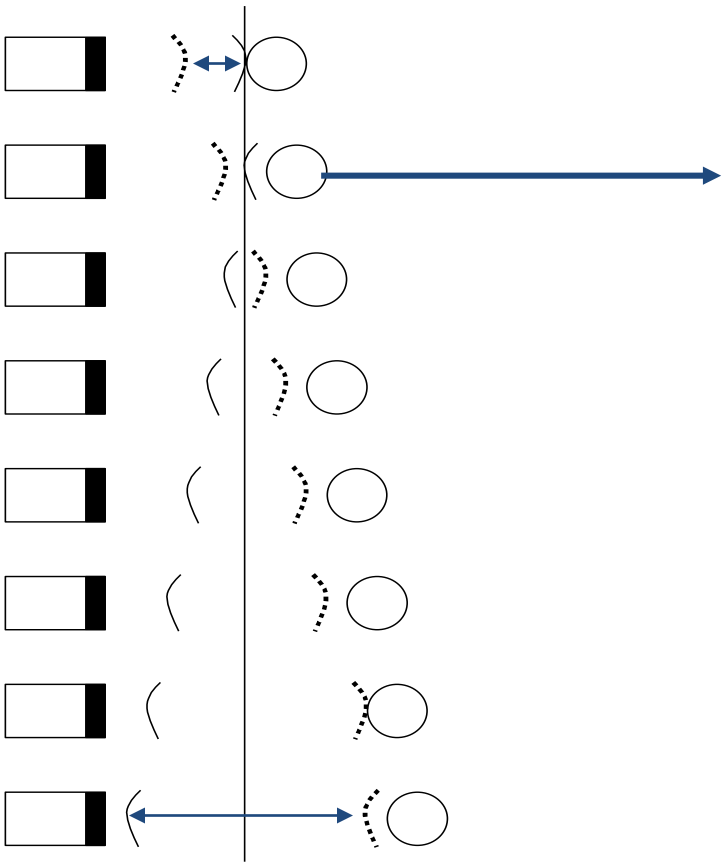
- Presence of blood flow
- Speed of blood flow
- Changes in flow over time
- Direction of flow
- Quality of flow (laminar or turbulent)

The Doppler Effect



$$f_{Doppler} = f_{recieved} - f_{transmitted}$$

Red blood cells moving away from ultrasound beam



Red blood cell moving away from sound beam

The Doppler Equation

$$f_D = \frac{2 f_t v \cos\theta}{c}$$

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$$f_D = \frac{2 f_t v \cos\theta}{c}$$

- f_d = Doppler shift frequency
- v = blood velocity
- f_t = transmitted frequency
- c = speed of ultrasound
- θ = angle between ultrasound beam and blood vessel

f_d can be +ive or –ive indicating an increase or reduction in frequency

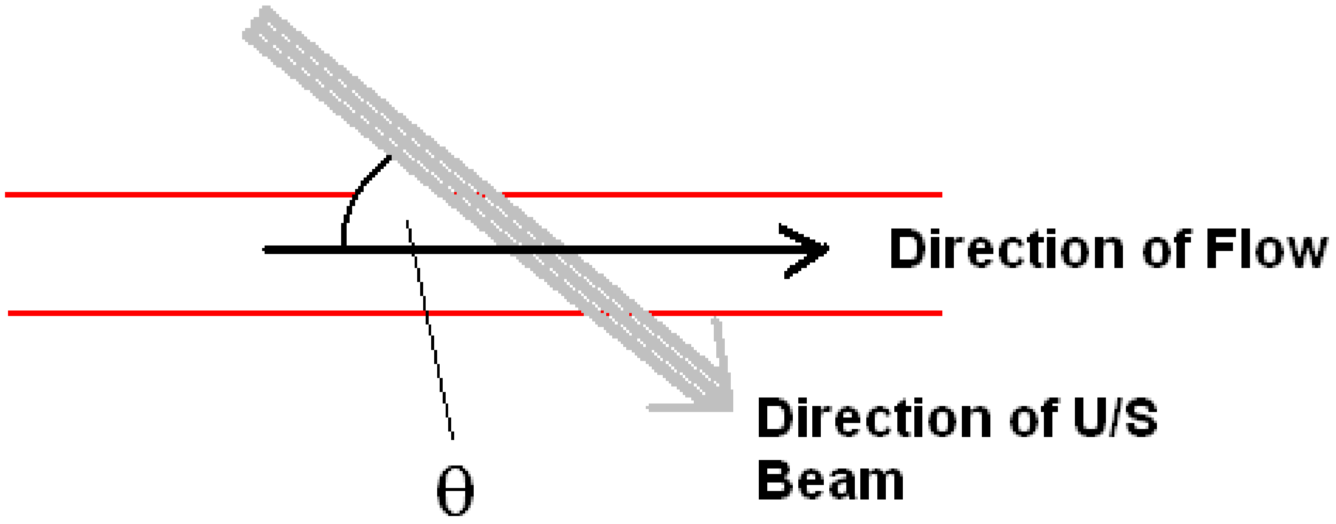
The 2 is important as we must consider outward & return passage of sound

The Doppler Equation

$$f_D = \frac{2 f_t v \cos\theta}{c}$$

• If you use a higher transmit frequency:	Doppler frequency INCREASES
• If the blood is flowing faster:	Doppler frequency INCREASES
• If you increase the Doppler angle:	Doppler frequency DECREASES
• If the speed of sound increases:	Doppler frequency DECREASES

Doppler Angle



As θ increases cos θ decreases and the Doppler frequency is reduced

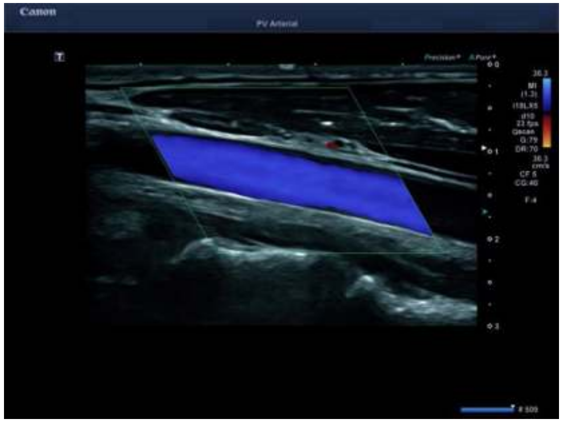
When θ = 90, cos $\theta = 0$ and there is no Doppler shift.

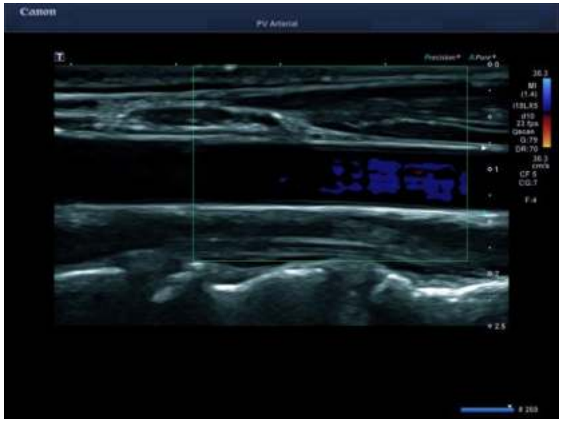
Doppler Angle

- Strongest Doppler signals are obtained when the ultrasound beam is in line with the blood flow
- Weakest Doppler signals are obtained when the ultrasound beam is perpendicular to blood flow.
- For practical purposes the angle between the ultrasound beam and blood flow is 30^0 - 60^0 .

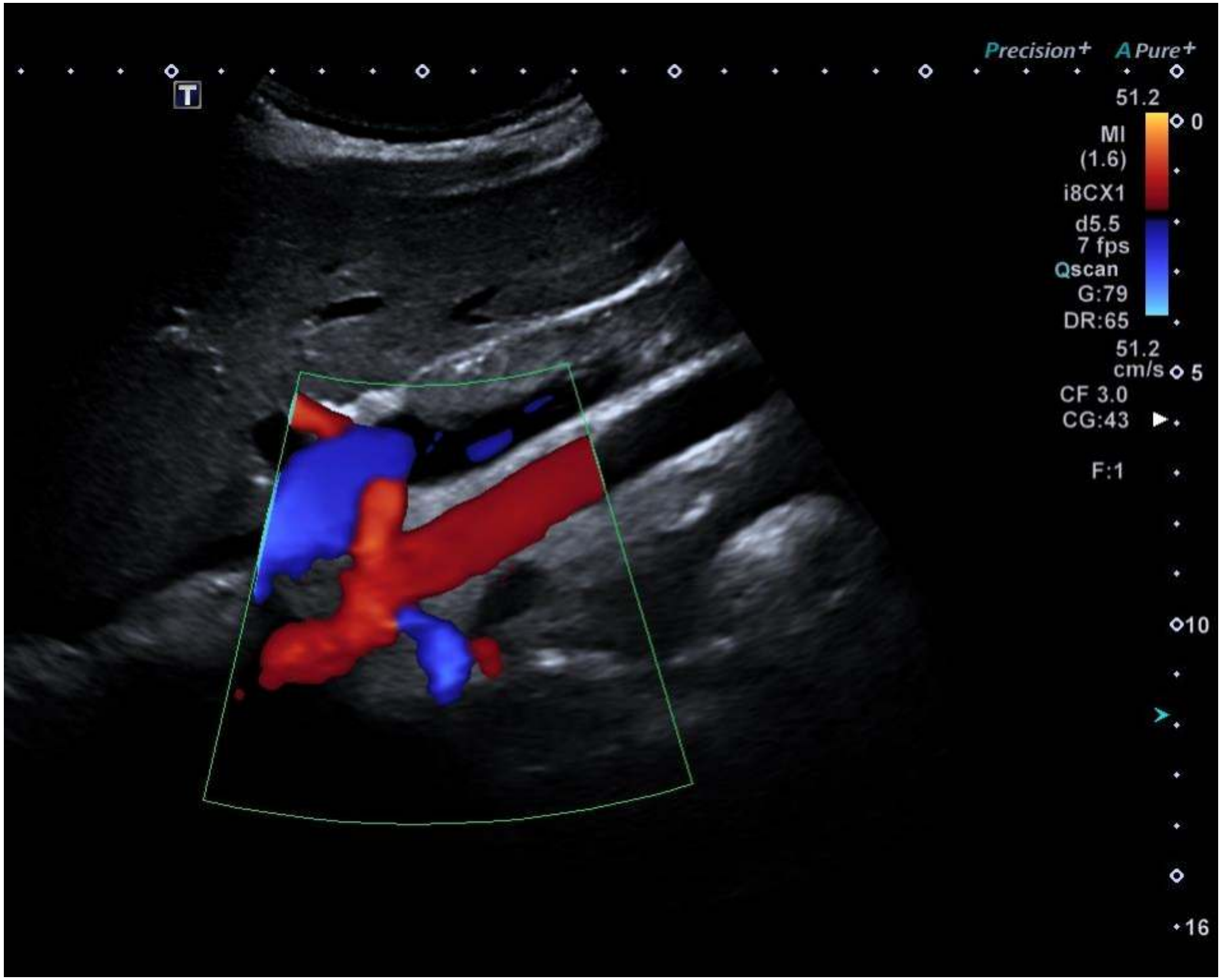
Beam Angle

- The shift in frequencies, which is detected by the machine and used to generate the colour image is dependent on the Doppler shift.
- The Doppler shift is caused by the red blood cells, which reflect the beam back to the probe moving either towards or away from the probe.
- If the ultrasound beam is at 90 degrees to the direction of the blood flow then there is no Doppler shift and we will not see any colour filling, even in the presence of good blood flow.





Colour Direction



Colour Doppler Technique

Optimise The Colour Doppler Settings

- Adjust the colour gain so that colour image fills the vessel lumen without bleeding into the surrounding image.
- Adjust the scale (PRF) so that the signal is just beginning to show signs of aliasing and then increase it slightly
- Steer the beam, either manually with the transducer position or electronically by adjusting the angle of the colour box.
- Adjust Doppler frequency. Higher frequencies result in better resolution, but poorer penetration.

Doppler in Venous Imaging (Venous Insufficiency Assessment)

- Venous reflux is highly positional dependent

- Patient Positioning
  - Standing with their weight on the contralateral leg
  - On a tilt table with a foot plate and an incline >30°

When this is not possible, limitations of the scan must be documented in the report

Protocol Outline

- Assess the following areas for reflux
  - Saphenofemoral junction
  - Greater saphenous vein
  - Saphenopopliteal junction
  - Short saphenous vein
  - All lower limb deep veins

- Follow varices and identify where they are filling from

- Assess any areas where competent veins become incompetent or vice versa

- Follow the muscle fascia identifying and assessing perforator veins

Long Saphenous Vein Anatomy

Bifid saphenous veins
Two veins within saphenous sheath

LSV arises anterior to medial maleolus

Communication to SSV

Cockett preforators, 7,13, 18cm above sole foot (LSV to PTV)

Boyd's perforators

Dodd's perforators hand's breadth above knee (LSV to femoral vein)

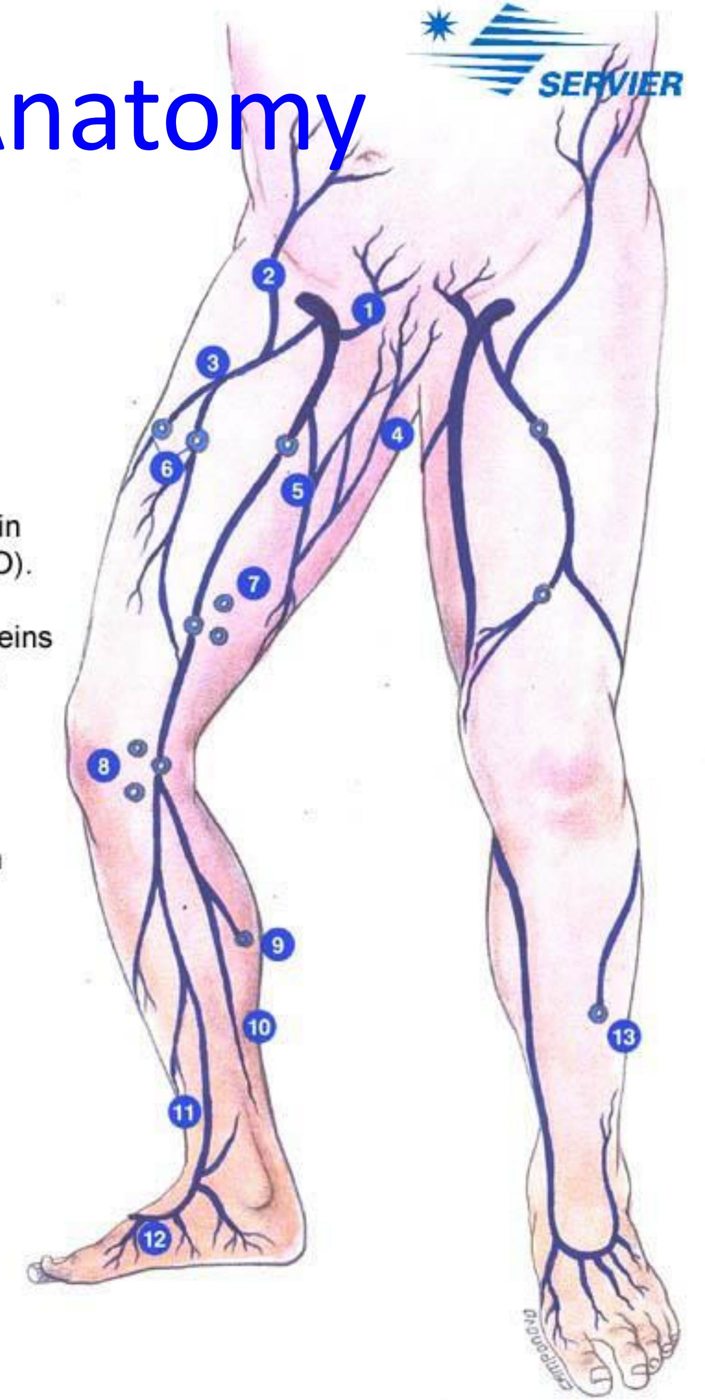
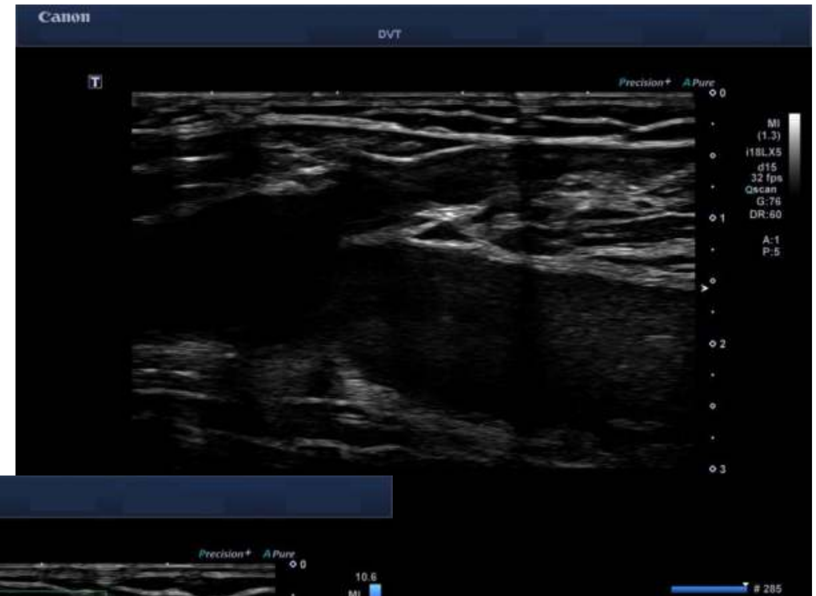


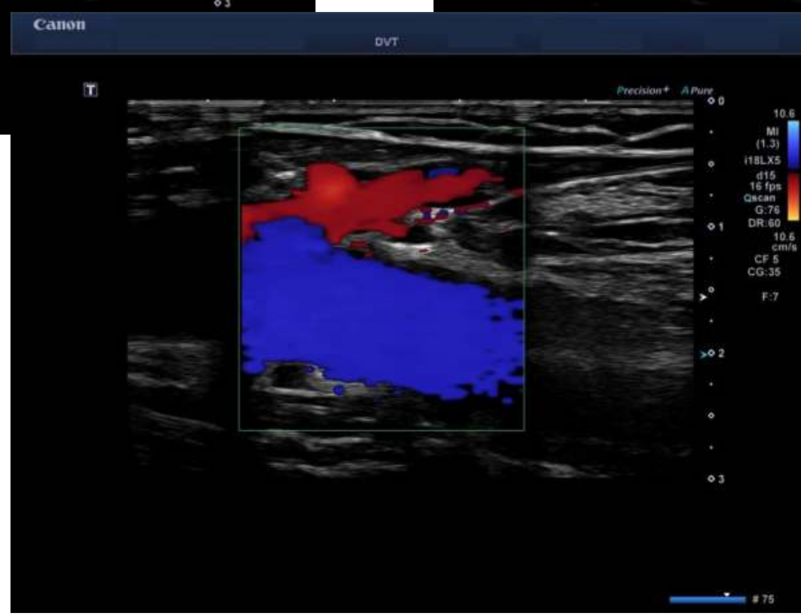
Figure 3. The long saphenous vein (perforating veins are shown by O).

1 Superficial external pudendal veins
2 Abdominal subcutaneous veins
3 Anterior branch
4 Perineal veins
5 Posterior branch
6 Perforating veins over the anterolateral vein of the thigh
7 Dodd's perforators
8 Boyd's perforators
9 Medial gastrocnemial perforating vein
10 Posterior crural arch vein
11 Long saphenous vein
12 Medial marginal vein
13 Peroneal perforating vein

http://www.phlebologia.com/en/main.asp

Saphenofemoral Junction (SFJ) (Mickey Mouse)





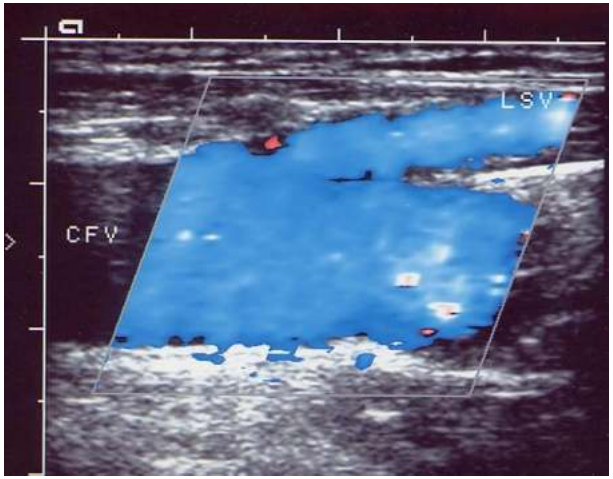
Augmenting flow

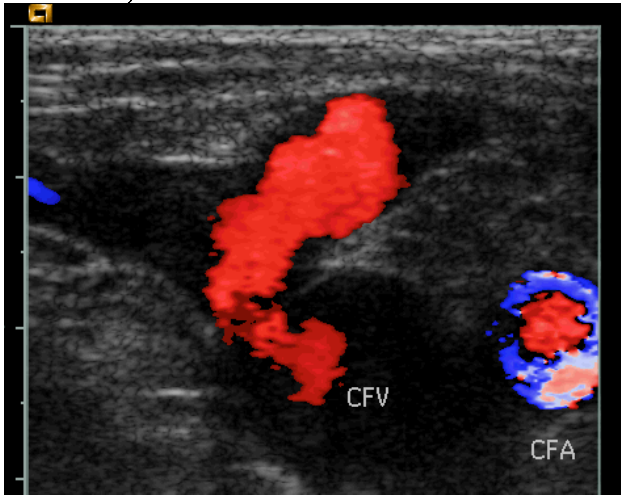
- By squeezing the calf muscle we can mimic the effects of the calf muscle pump, resulting in an increase in venous return
- When the calf is released the bicuspid valves should close preventing retrograde flow
- In the presence of venous insufficiency the valves will fail to close and reflux will be detected due to a change in the Doppler shift

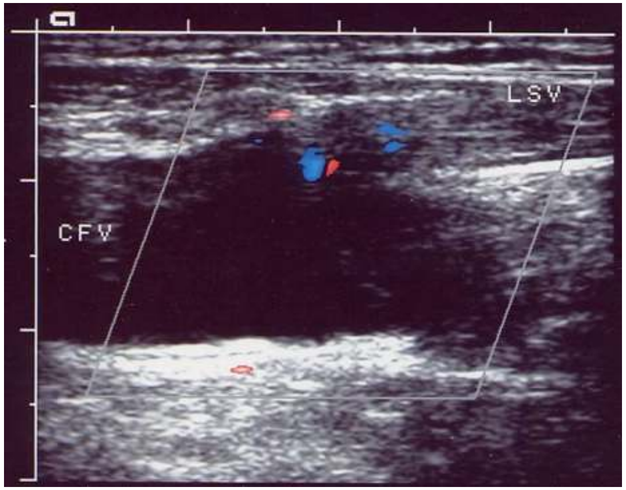
Reflux

- Scan in transverse
  - Colour to determine reflux and duration
- Longitudinal
  - Spectral to determine duration

(equivocal, about 0.5 to 1.0 second)

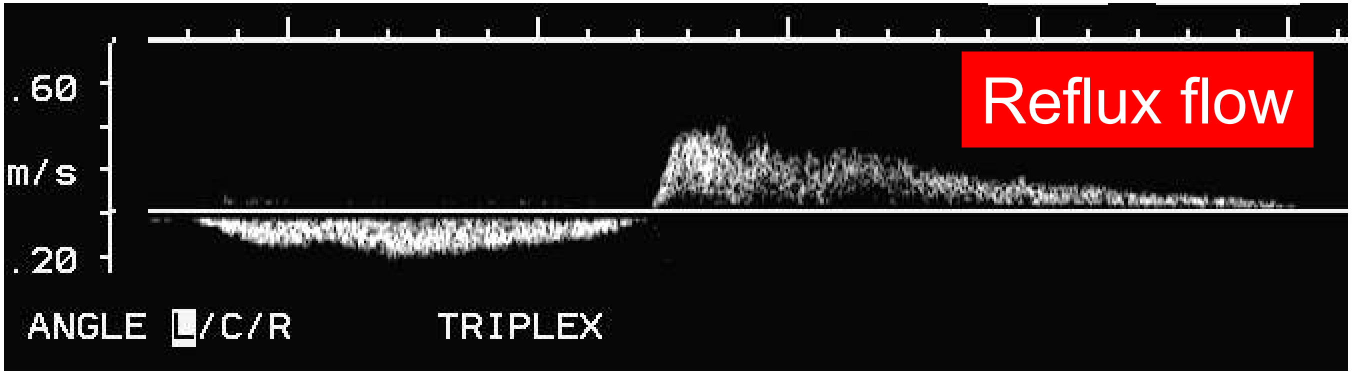






Reflux

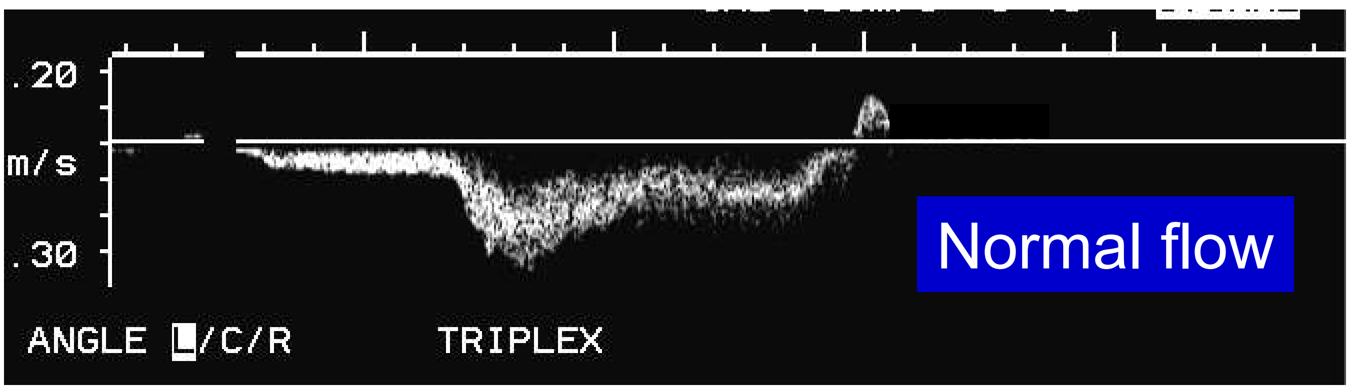
Reflux flow



Flow towards transducer

Flow away from transducer

Normal flow



Flow towards transducer

Flow away from transducer

Calf compression
flow up vein

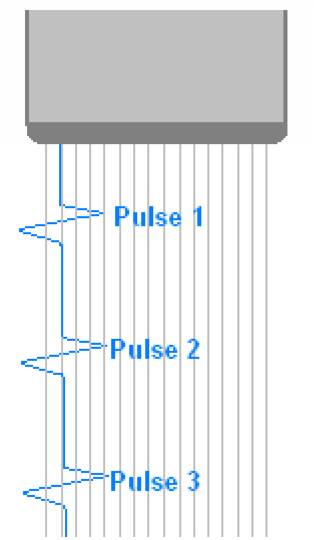
Release compression
flow down vein with incompetence

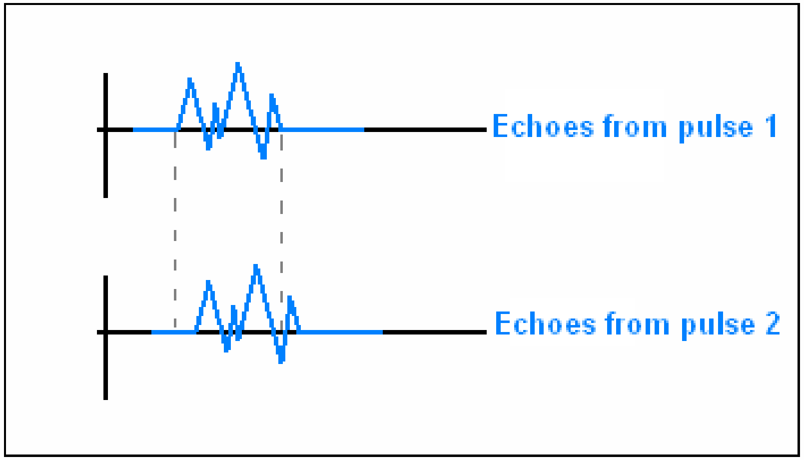
Augmenting flow

- In most cases you will be able to maintain antegrade flow for the duration of the squeeze

- If you are not seeing satisfactory flow consider the following:
  - PRF
  - Doppler Gain
  - Doppler frequency
  - Beam Angle
  - Augmentation technique
  - Patient positioning
  - Proximal obstruction

Colour Doppler



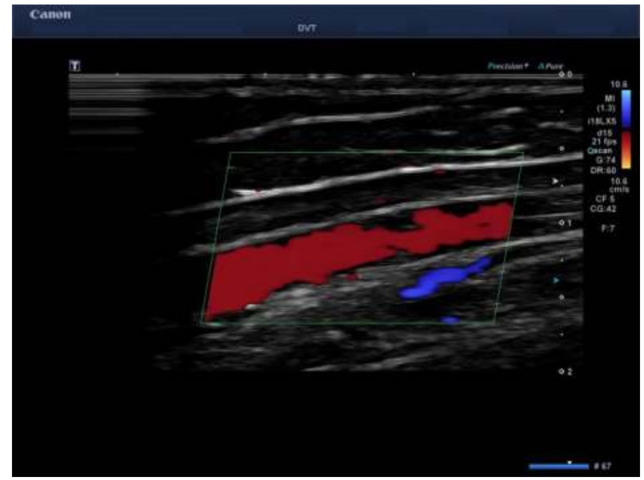


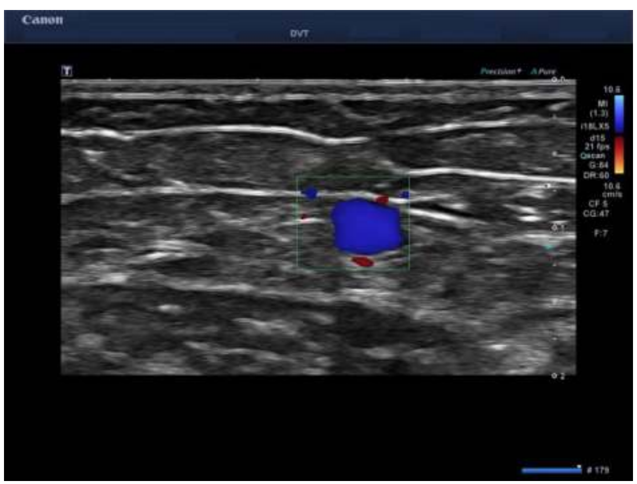
- Multiple pulses are sent along each colour scan line.
- The strong echoes from stationary reflectors are subtracted leaving only low amplitude echoes from moving scatterers.
- The phase shift between echoes from consecutive pulses are used to calculate the relative movement of reflectors in the time between pulses.
- This information is translated into directional velocity information and displayed on the colour map.

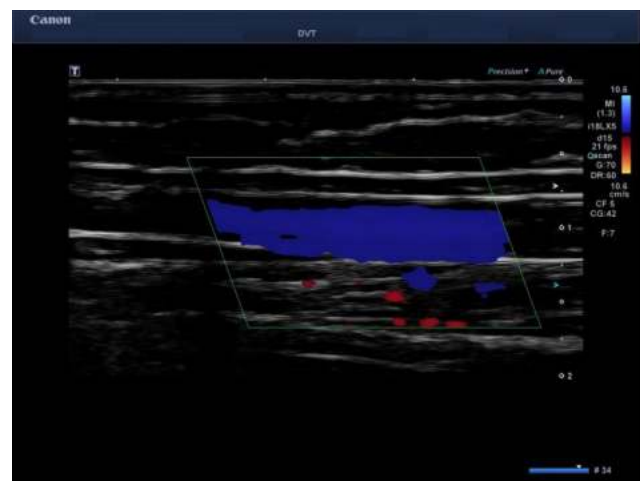
Pulse Repetition Frequency (Scale)

- For low velocity (venous) flow it is essential to set the PRF to an appropriate level
- If the PRF is too high the phase shift between successive pulses will be very small, resulting in poor colour sensitivity
- If PRF is too low aliasing will occur, resulting in direction being misrepresented on the colour image
- Remember to alter the PRF as appropriate during the scan!

Longitudinal or Transverse Images?







Spectral Doppler Quantification

- Spectral Doppler allows us to quantify the length of time a vein refluxes for following augmentation, and also gives us an indication of the volume of refluxing blood.

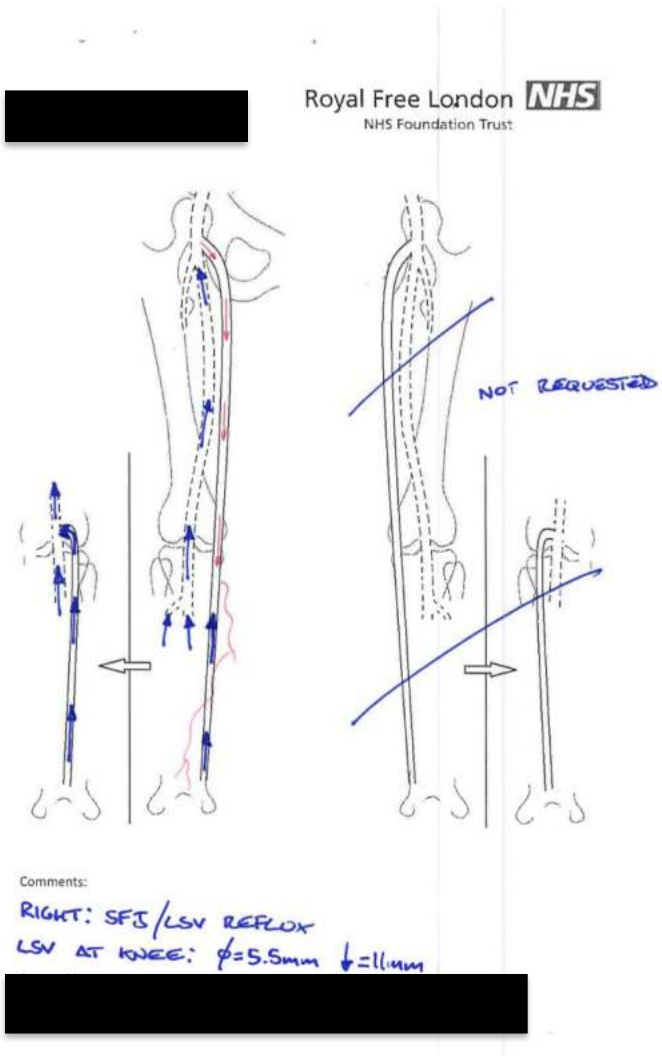
- Both of these variables are highly dependent on patient positioning and scanning technique and are poorly reproducible.

- This does not mean that spectral Doppler analysis is not useful!

Reporting

- Why was the scan requested?
- What treatment is the patient likely to receive?
- Can the findings be more clearly summarised as a diagram?

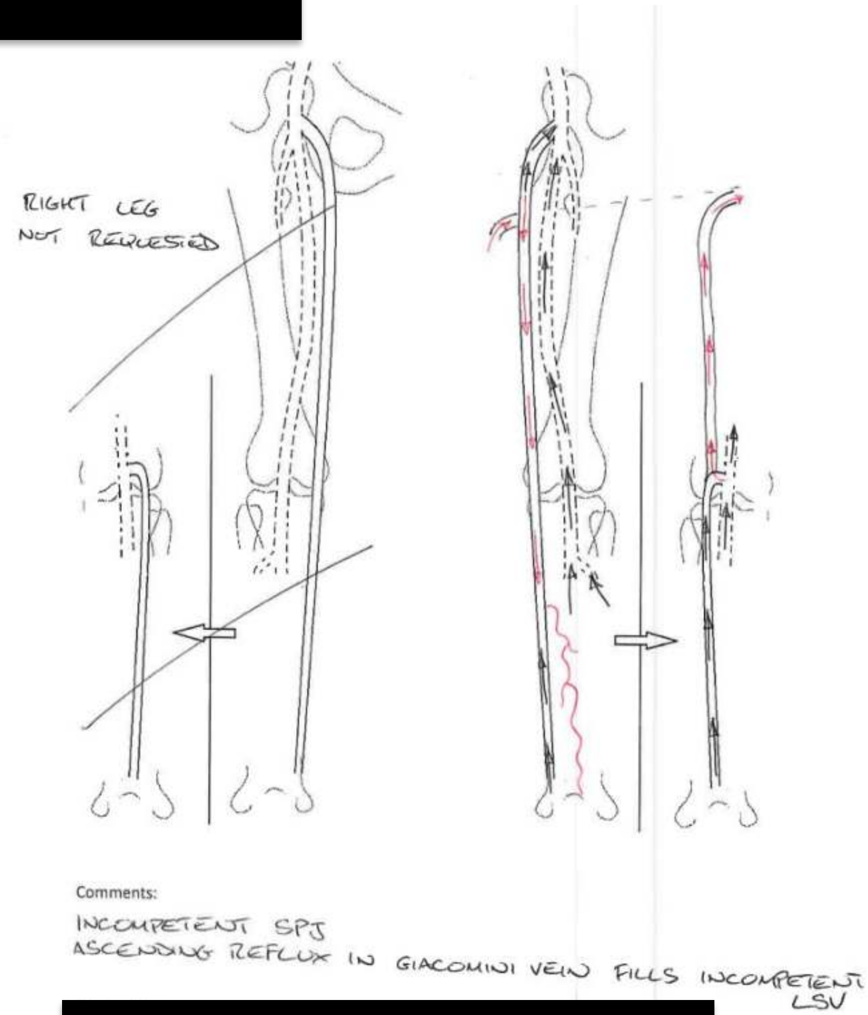
Example report



- Source of reflux
- Vessel filling varices
- Depth and diameter of vessel likely to be targeted for thermal ablation

Ascending Reflux

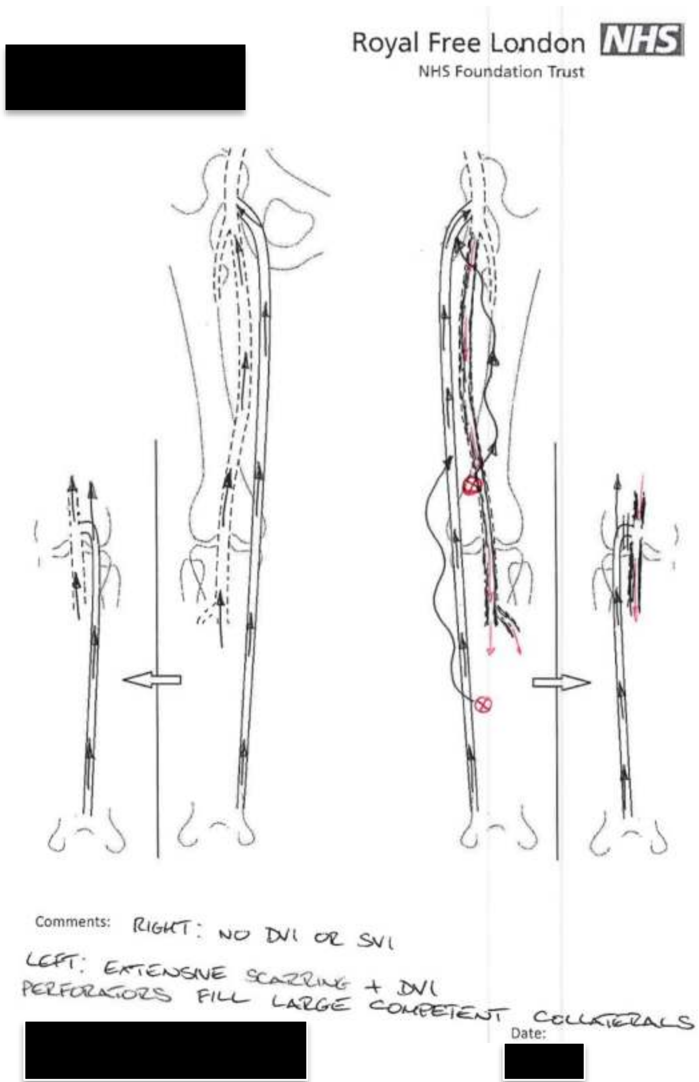
[redacted]



[redacted]

- The GSV was incompetent from the proximal thigh, but the SFJ was competent.
- The SPJ was incompetent, filling ascending reflux up the Giacomini vein, which drained into the GSV.
- This was most likely caused by a syphoning effect from the large calf varices filling from the GSV.

Competent Collateral Veins



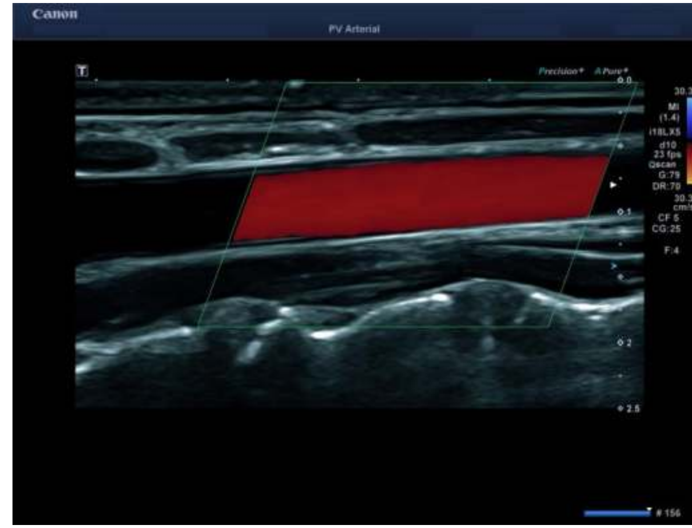
- The apparent varices all showed antegrade flow and drained into the competent SFJ

Doppler in Arterial Imaging (Carotid Artery Assessment)

- Traditional angiography imaging techniques often result in poor quantification of arterial stenoses.

- Doppler ultrasound allows us to quantify the haemodynamic impact of an arterial lesion, offering a more reliable method of assessing the severity of disease.


Canon
PV Arterial
Precision+
A Pure+
MI
(1.3)
i18LX5
d10
46 fps
Qscan
G:79
DR:70
A:4
P:4
196


Canon
PV Arterial
Precision+
A Pure+
30.3
MI
(1.4)
i18LX5
d10
23 fps
Qscan
G:79
DR:70
30.3
cm/s
CF 5
CG:25
F:4
156


Canon
PV Arterial
Precision+
A Pure+
MI
(1.3)
i18LX5
d10
45 fps
Qscan
G:74
DR:70
A:4
P:4
362


Canon
PV Arterial
Precision+
A Pure+
25.9
MI
(1.1)
i18LX5
d10
19 fps
Qscan
G:74
DR:70
25.9
cm/s
CF 5
CG:52
F:4
68

Detection of Arterial Stenoses

- B-mode – We can often visualise areas of narrowing on a B-mode image, however trying to quantify an irregular 3D plaque on a 2D image results in large errors

- Colour Doppler can be used to visualise narrowings in the vessel lumen, and also to detect changes in flow velocities in the presence of arterial disease

- Spectral Doppler enables us quantify these changes in flow and this information can be used to quantify the degree of narrowing

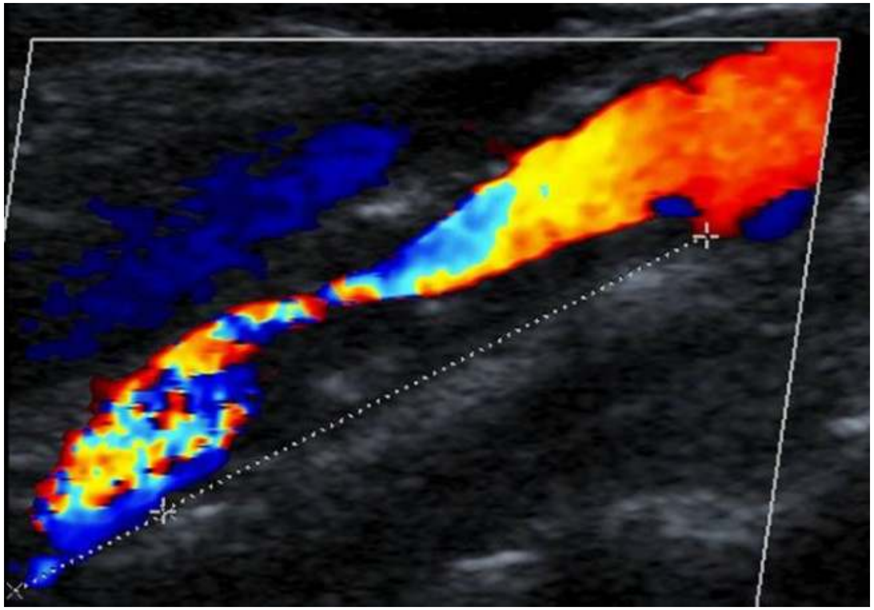
Aliasing

- Aliasing occurs when the Doppler sampling frequency (usually called PRF or Scale) is insufficient to accurately measure the Doppler shift.
- The faster the blood is moving the greater the Doppler shift and therefore the more likely it is that aliasing will occur.
- Although aliasing is an artefact and is displaying information, which does not correctly correspond to the direction and velocity of the blood, it is in fact very useful.
- When an artery becomes narrowed blood must flow faster (in order to get the same amount of blood through a smaller vessel).
- If we have our scale (PRF) set correctly then aliasing will highlight regions where the blood’s velocity has increased and this can be used to locate a stenosis.

Aliasing

- Adjust the scale (PRF) so that the signal is just beginning to show signs of aliasing in a healthy segment of the vessel and then increase it slightly.

- Any further increases in flow velocity will result in aliasng of the colour Doppler image.



Spectral Doppler Technique

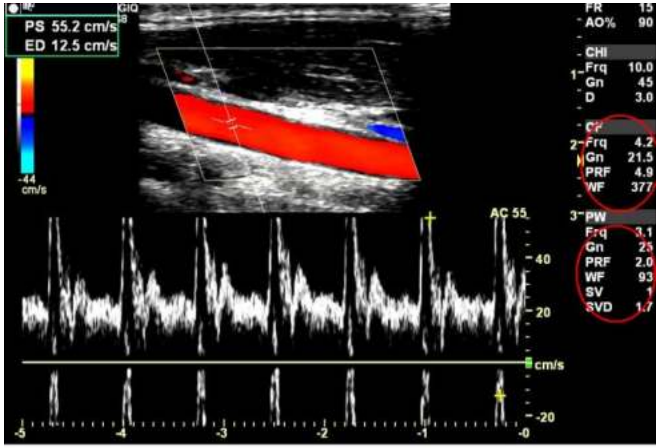
Optimise The Doppler Waveform Trace

- Adjust the scale (PRF) so that the waveform fills the window without cutting off the top of the trace.
- Adjust the PW (spectral) gain so that the trace can be clearly visualised, but the background remains black
- Adjust the sample volume (gate) size so that you are only collecting Doppler information from the appropriate region
- **Use the angle correct, so that the machine knows which direction the blood is moving in**
- Adjust Wall filter to remove noise from adjacent veins and vessel wall movement

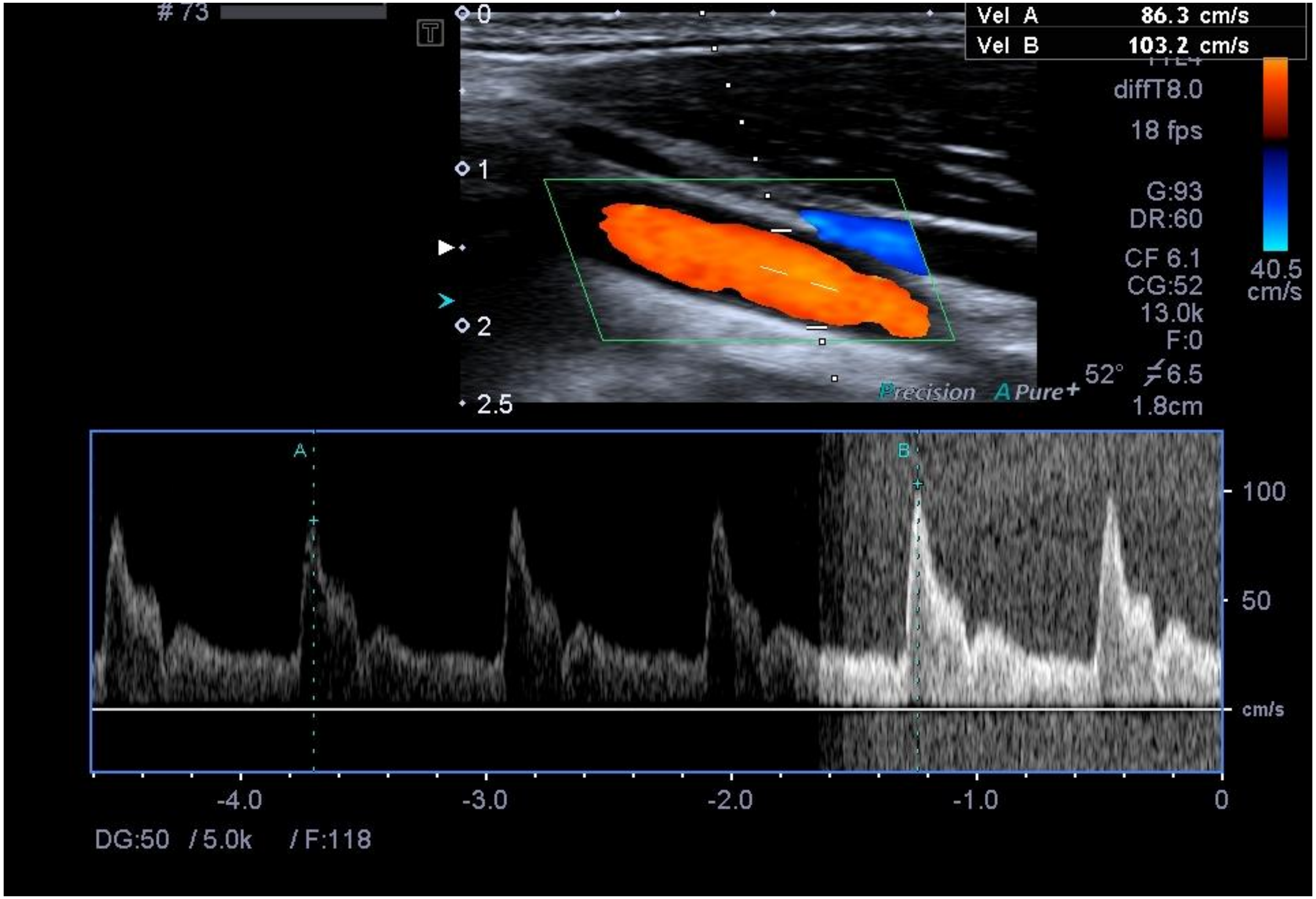
Aliasing

- The Spectral Doppler frequency and scale (PRF) are adjusted independently of the colour Doppler. (Colour and spectral Doppler infromation are produce by separate ultrasound beamms)

- Unlike Colour aliasing, spectral Doppler aliasing is of no use to us and should be avoided by:
    - Increasing the PRF
    - Decreasing the frequency
    - Lowering the spectral base line
    - Increasing the Doppler angle (Steer the beam)

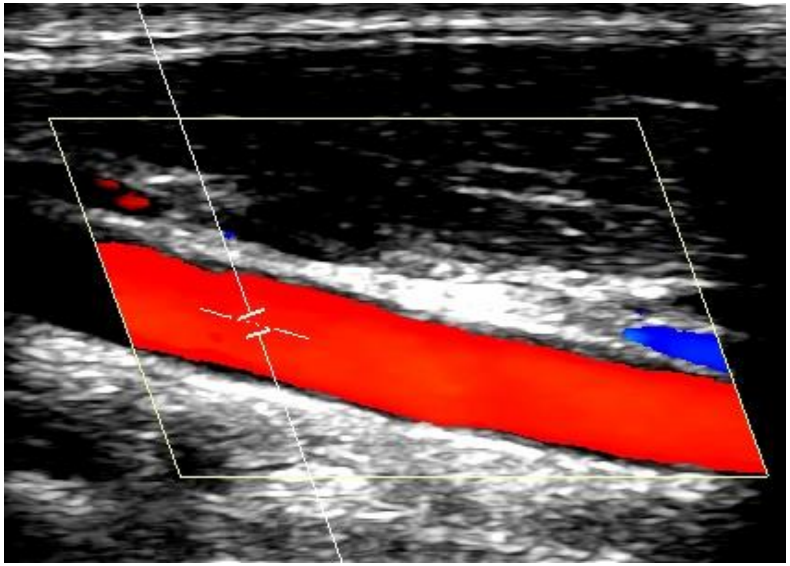


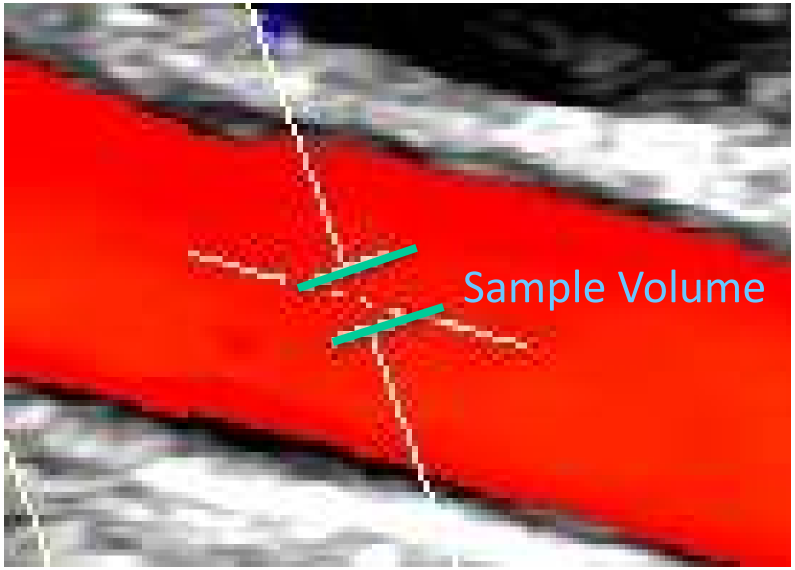
Spectral Doppler Gain



Sample Volume (Gate)

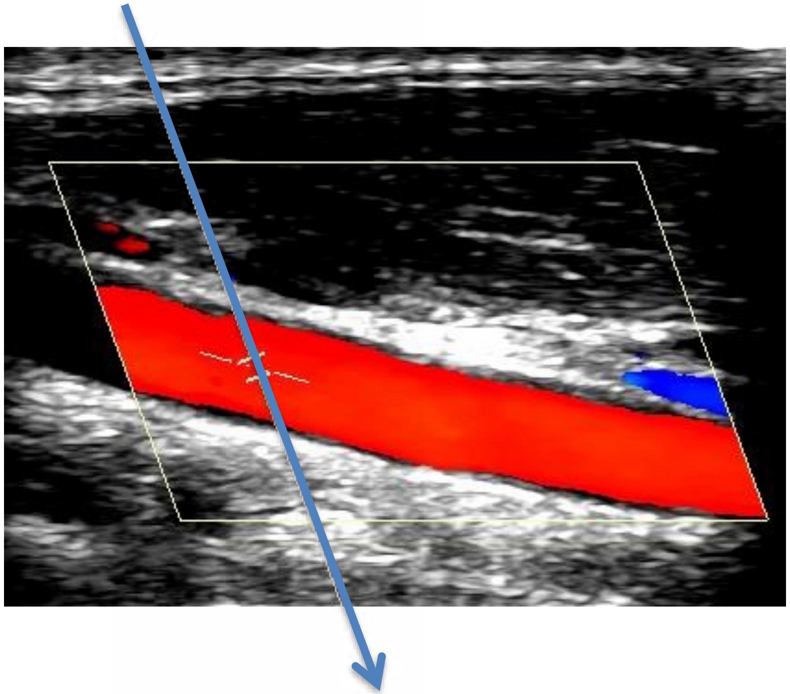
- The sample volume (or gate) is used to select the region from which the spectral Doppler information should be recorded.
- The size of the sample volume can be changed.
- For carotid arteries we are generally interested in maximum velocities, so the sample volume should be kept small and placed in the centre of the vessel lumen.

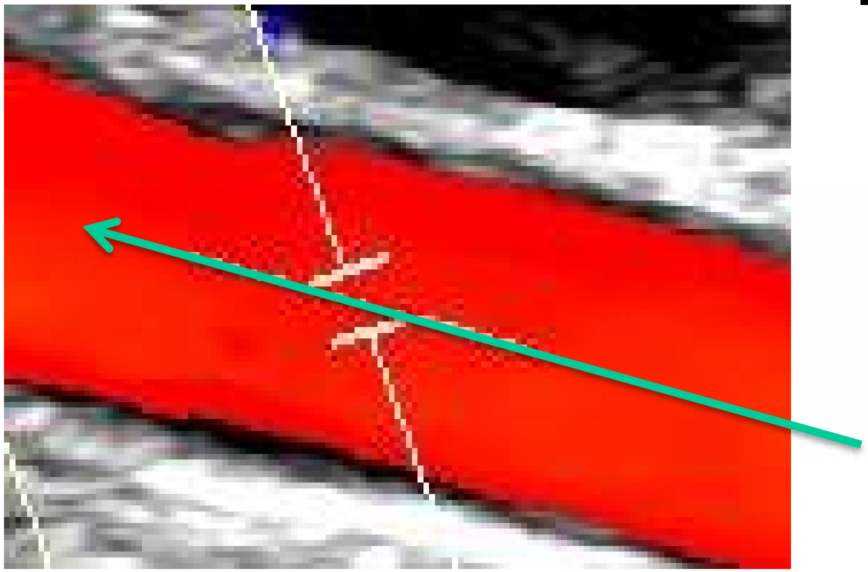




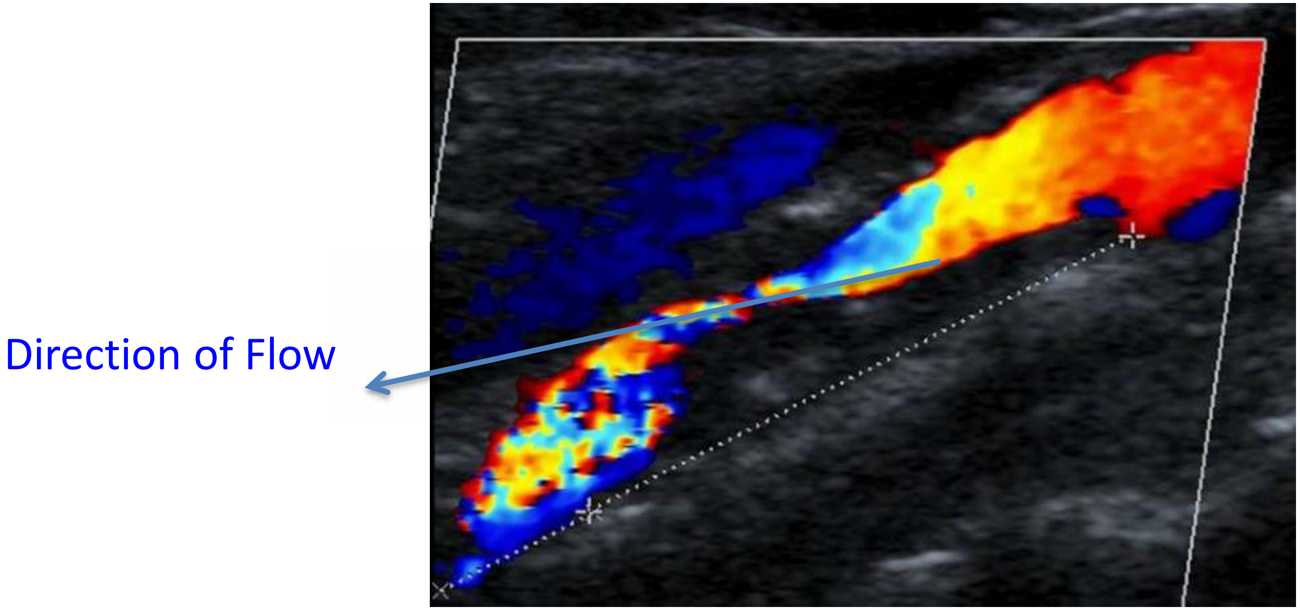
Angle Correction

$$f_D = \frac{2 f_t v \cos\theta}{c}$$





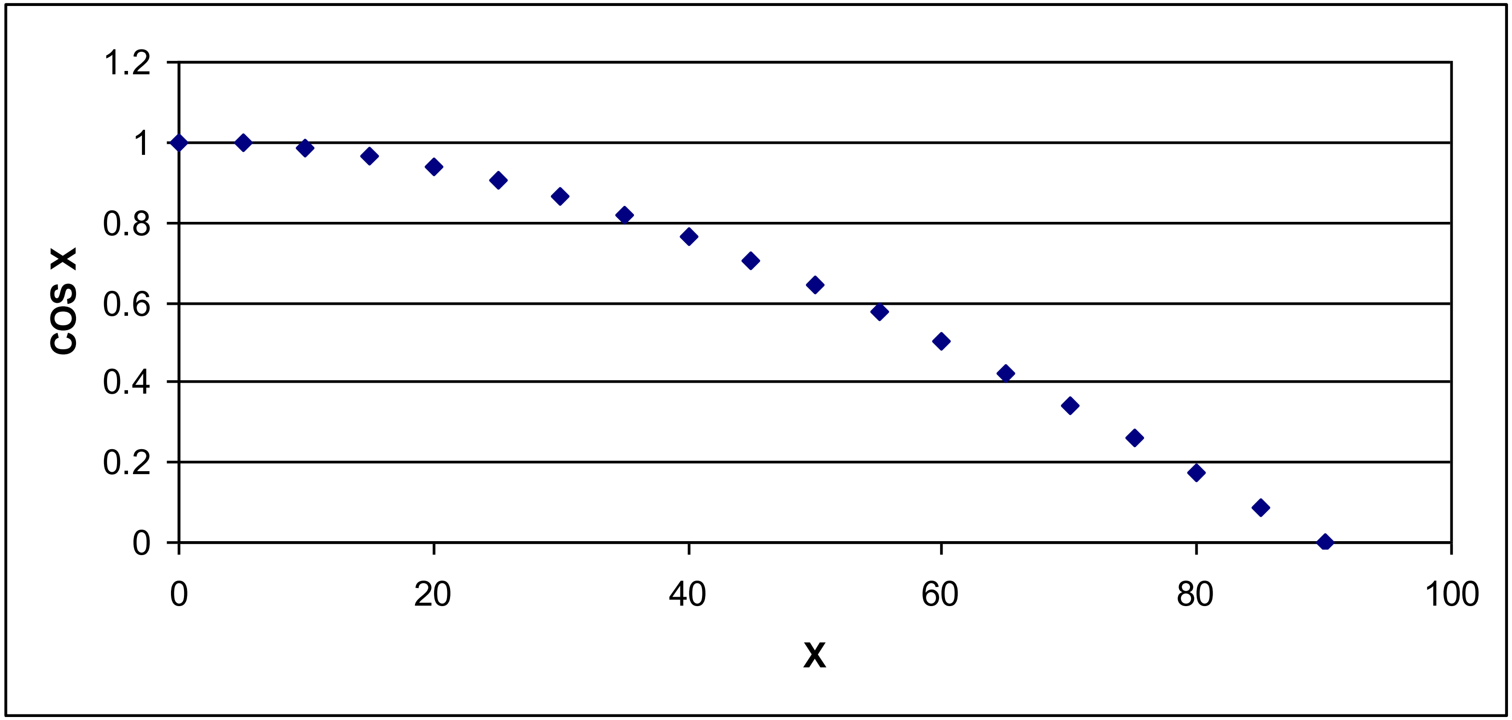
Angle Correction



- Angle correct to the direction of flow within the stenosis
- This may be different from the orientation of the vessel

As the Doppler angle increases a 1 degree error in the angle will result in a higher %error in the calculation of the Doppler frequency.

For the purposes of Doppler ultrasound the angle should always be less than or equal to 60 degrees!



Quantification of stenosis

- Optimise B-mode image
- Use colour Doppler to identify direction of stenotic jet
- Ensure an angle of insonation of $\leq 60°$
- Measure maximum velocity in or just beyond stenosis
- Calculate velocity ratio

Quantification of stenosis

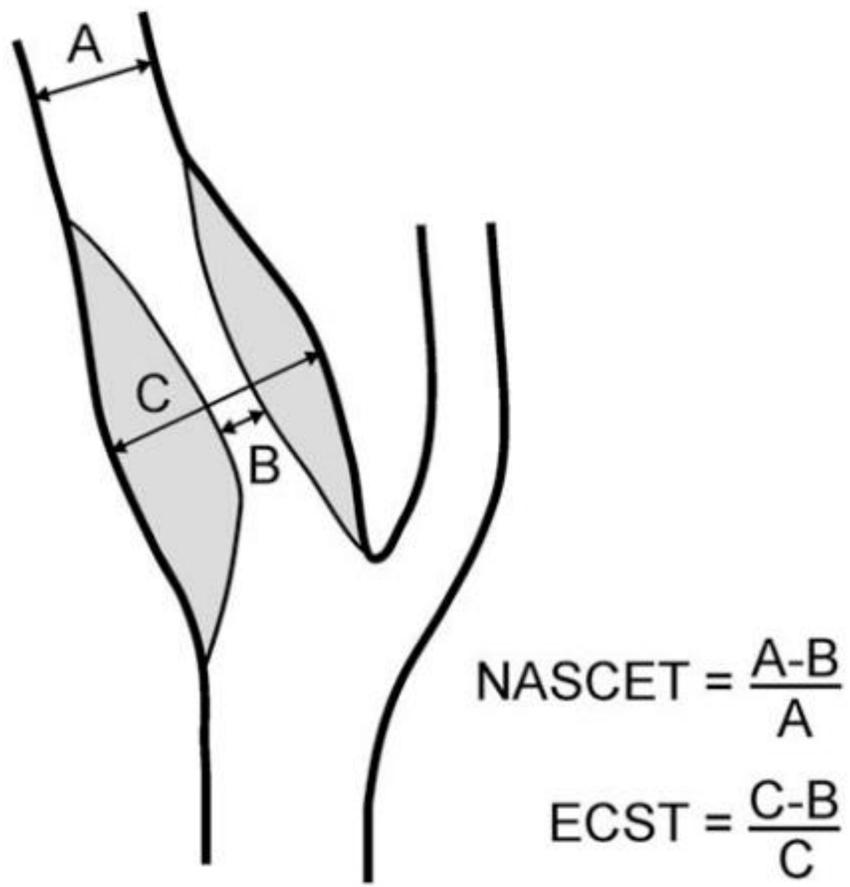
Table 1 Diagnostic criteria to be applied

Percentage stenosis (NASCET)	Internal carotid peak systolic velocity cm/sec	Peak systolic velocity ratio ICA_{PSV}/CCA_{PSV}	St Mary's ratio[c] ICA_{PSV}/CCA_{EDV}
<50	<125[a]	<2[a]	<8
50–59	>125[a]	2–4[a]	8–10
60–69			11–13
70–79	>230[a]	>4[a]	14–21
80–89			22–29
>90 but less than near occlusion	>400[b]	>5[b]	>30
Near occlusion	High, low – string flow	Variable	Variable
Occlusion	No flow	Not applicable	Not applicable

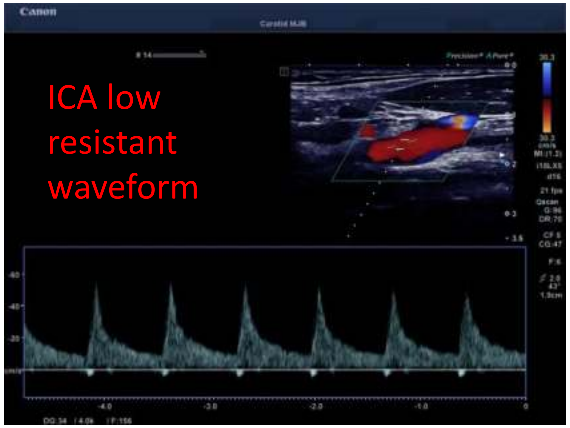
[a] NACC[17].
[b] Filis et al.[37].
[c] Nicolaides et al.[33].

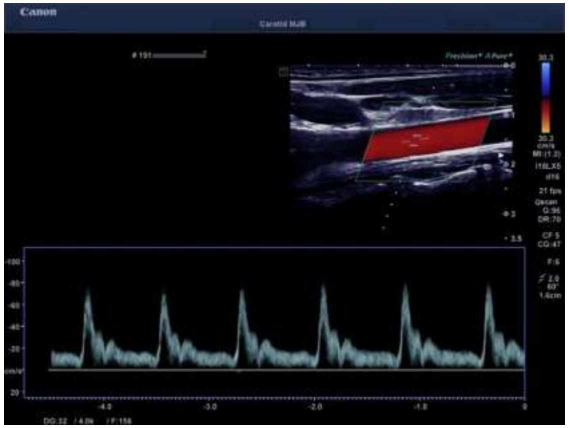
Joint recommendations for reporting carotid ultrasound investigations in the United Kingdom.
Oates et al
Eur J Vasc Endovasc Surg (2009) **37** 251-261

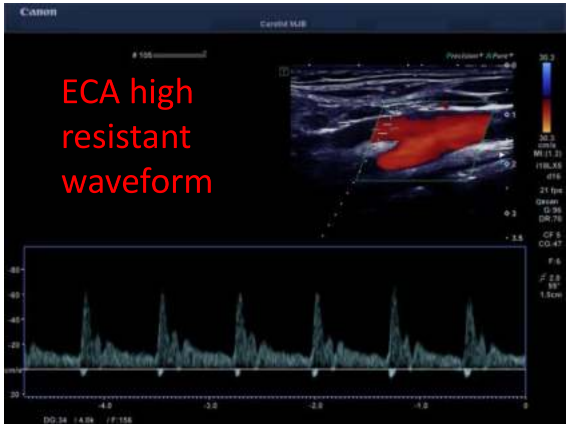
NASCET vs ECST



Qualitative Waveform Assessment

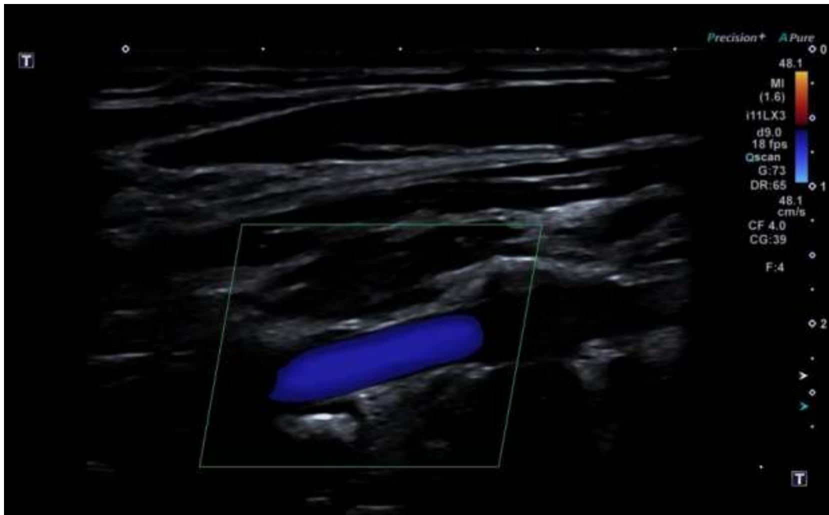






- The CCA waveforms looks like a combination of the ICA and ECA waveforms, as it feeds both distal vessel beds
- Unexpected changes in waveforms can indicate the presence of proximal or distal disease

Vertebral Arteries

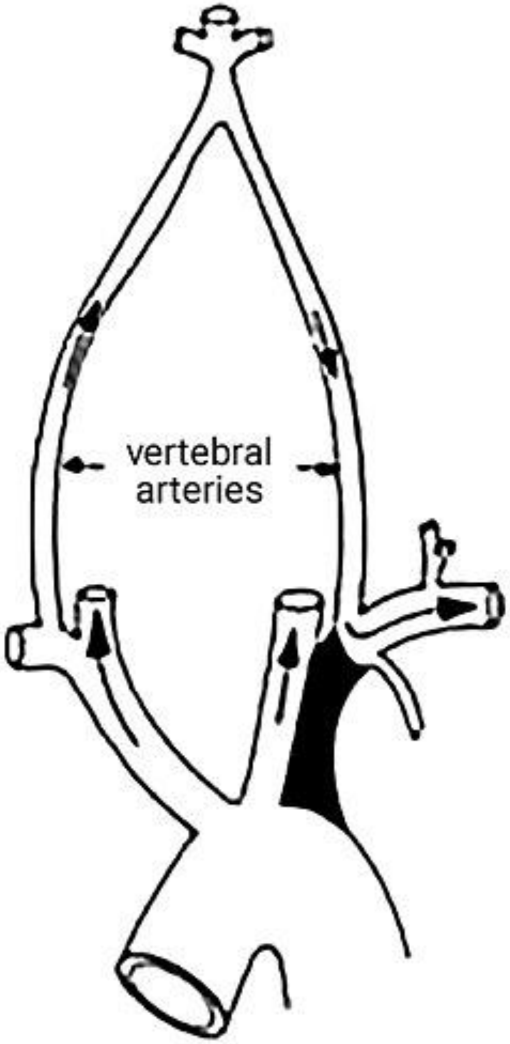


Which image shows reverse flow in the vertebral artery?

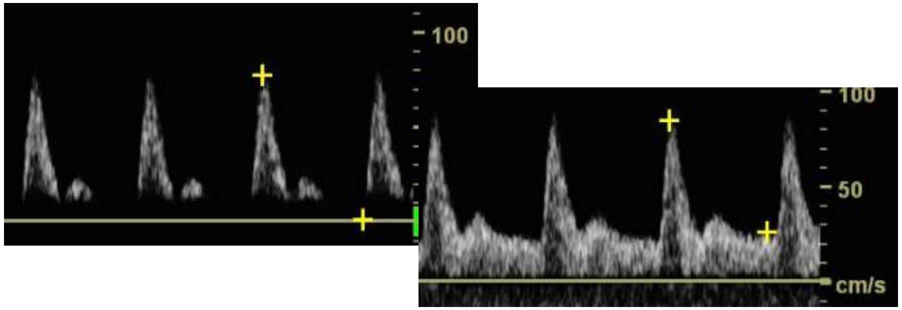
Why might the flow be reversed?

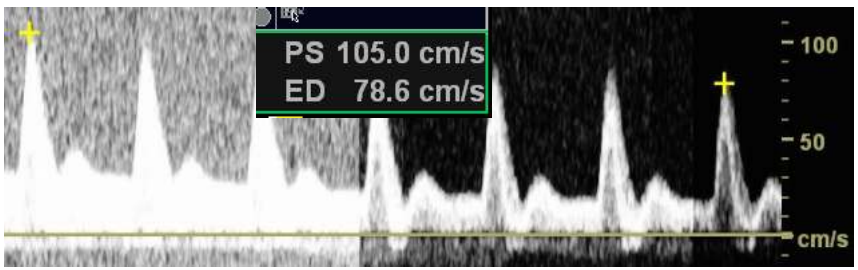
Subclavian Steal

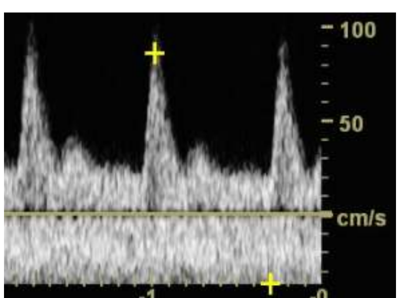
- Narrowed or blocked segment in the proximal subclavian artery
- Low pressure in the upper limb arteries
- Blood flows up the contralateral vertebral artery and back down the ipsilateral vertebral artery to supply the arm

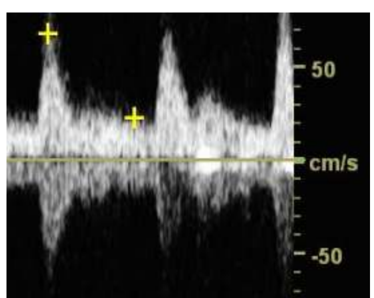


Waveform Optimisation – Don't Get Lazy









- PRF / Scale
- Gain
- Wall Filter
- Doppler Frequency
- Angle correct
- Spectral Trace Speed
- Caliper Positioning
- Sample Volume Size &Position