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Abdominal Ultrasound Level 2 Mini Series

Session Two: A guide to Doppler Ultrasound

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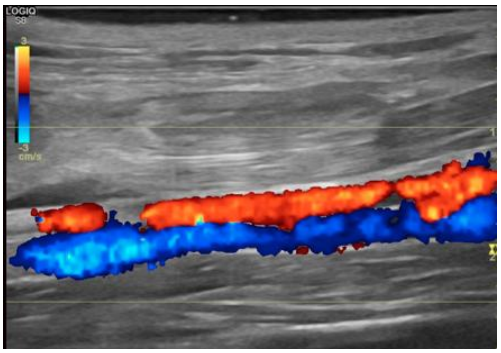
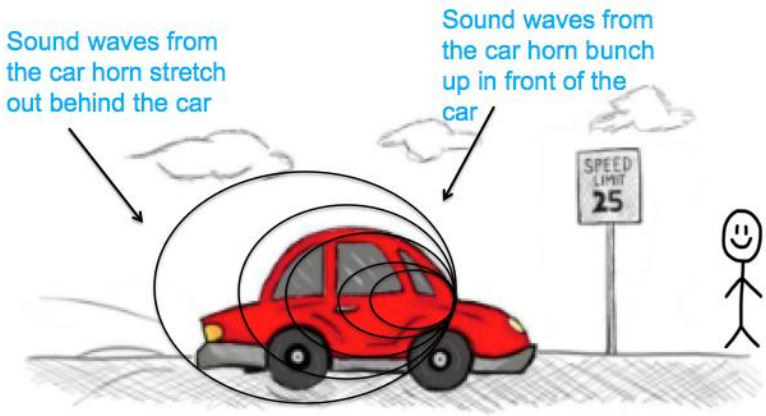


The Doppler Effect

The Doppler effect occurs due to the apparent change in frequency of a wave caused by relative motion between the source of that wave and the observer. It is most commonly observed in life with sound. As an object emitting a sound moves closer to the observer, the sound waves become bunched together in front of the object resulting in a reduction of the wavelength and an increase of the observed frequency. This higher frequency results in the observer hearing a higher-pitched sound. Once the source of the sound has passed the observer and starts moving away from them, the sound appears to change to a much lower pitch. This occurs because the sound waves are stretched out behind the source and hence have a longer wavelength, lower frequency and thus lower pitch. The actual emitted frequency of the sound wave by the source never changes.



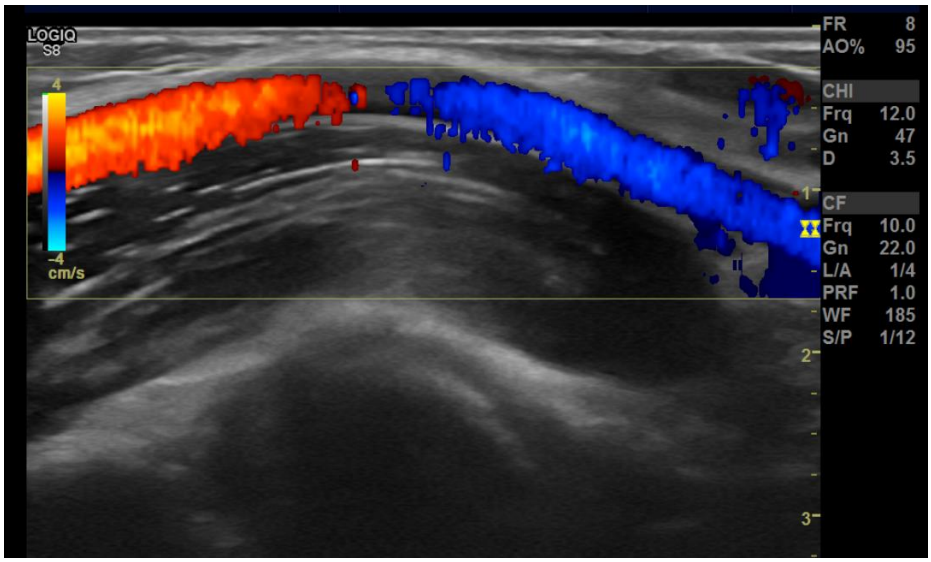
Application in Ultrasound

In Doppler ultrasound, the source of the ultrasound waves (the transducer) is stationary. It is the reflectors, in this case red blood cells within vessels that are moving. Red blood cells moving towards the transducer will result in echoes returning to the transducer with a greater frequency than those emitted. Conversely, echoes reflected from red blood cells travelling away from the transducer, will have a lower frequency than those originally sent out. By comparing the frequency of the echoes with that of the outgoing ultrasound pulses, the ultrasound machine can determine whether blood is flowing towards or away from the transducer. The difference between the two frequencies is known is the Doppler shift. Positive and negative Doppler shifts indicate flow towards and away from the transducer respectively. The machine can also determine the speed of blood flow from the magnitude of the Doppler shift since faster blood flow results in a larger Doppler shift and vice versa. There is one caveat to this however. In order for the machine to calculate blood flow speed accurately, we must tell it the angle between the outgoing ultrasound pulses and the blood vessel. This is because if we measure the blood flow in the same vessel but from different angles, we will obtain different Doppler shifts. The maximum Doppler shift is achieved if the ultrasound pulses are parallel with the direction of flow. Zero Doppler shift occurs if the direction of flow is perpendicular to the emitted ultrasound pulses as essentially there is no blood flow towards or away form the transducer. Ideally we should try to measure Doppler shift with the emitted pulses parallel with the vessel. In practice, this is rarely achievable with abdominal vessels and we normally aim for an angle <60 degrees as a compromise. Above 60 degrees, small errors in the estimation of the Doppler angle result in large errors in the calculated flow speed.

There are two main types of Doppler: colour Doppler and spectral Doppler. The names simply refer to the way in which blood flow information is displayed on screen.

Colour Flow Doppler

The machine displays flow as a variation in colour over a wide area of the image within a colour box (also know as a colour window) superimposed onto the grey-scale image. Within the colour box, there are multiple small sample volumes although only the outline of the colour box is presented on screen. A colour map (sometimes referred to as a colour bar) is provided which maps colour to average blood flow speed and direction. Different maps are usually available however by convention, blood flow towards the transducer is displayed as red and flow away from the transducer is displayed as blue. As blood flowing towards the transducer increases in speed, the colour changes from dark to bright red to yellow. Flow away from the transducer turns from blue to cyan as it increases in speed. The number or scale at either end of the colour bar is the flow speed corresponding with the maximum Doppler shift that can be accurately measured. The ultrasonographer can adjust this number. Increasing the scale improves accuracy with regards to determining the speed of fast-flowing blood however it also reduces the sensitivity of the system to slow flow. The result of the latter is that colour may not appear in vessels with slow flow and hence an absence of flow may be incorrectly assumed. Conversely, reducing the scale results in a system that is more sensitive to slow flow but is poor at determining high blood flow speeds and vulnerable to a phenomenon known as aliasing (discussed below).

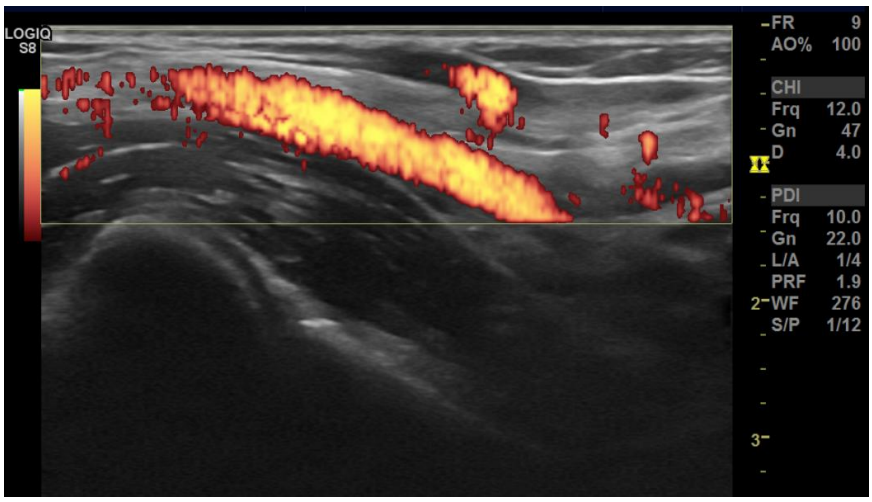


Use of Colour Doppler to assess flow in a blood vessel. Flow is from left to right. The colour red is used to indicate flow towards the transducer and blue signifies flow away from the transducer.

Power Doppler

Similar to Colour Doppler, Power Doppler also uses colour within a colour box superimposed onto a grey-scale image to depict flow. Power Doppler displays the total strength of the Doppler shift signal (rather than the average Doppler shift used in colour Doppler), which is determined by the number of red blood cells flowing at a particular point. It does not usually provide any information regarding direction, speed or character of flow (although some more modern systems may provide some of this information). However, it has the advantage of being almost completely angle independent and does not suffer from aliasing. Since it is more

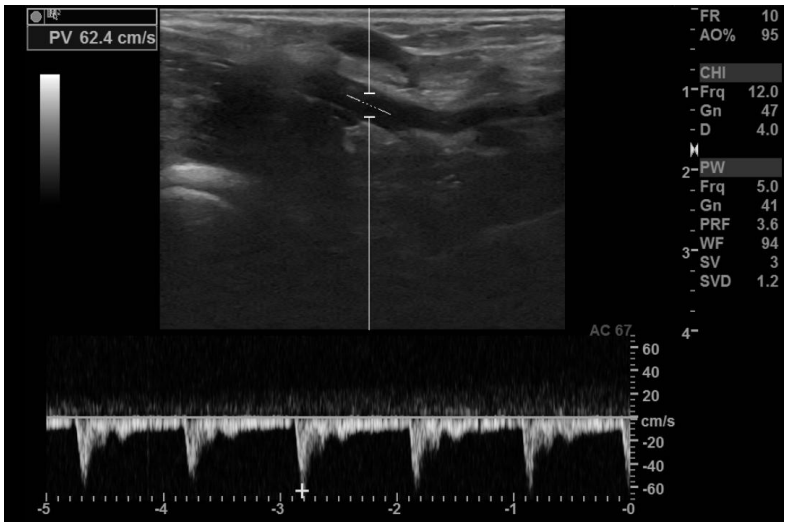
sensitive than colour Doppler to slow-flowing blood, or blood in small and/or deep vessels, it is ideal for use under these circumstances.



Use of Power Doppler to indicate flow within vessels.

Spectral Doppler

Blood flow information is displayed as a graph of time on the x-axis versus blood flow speed on the y-axis. The Doppler shift spectrum is depicted as white on a black background. Blood flow towards the transducer is displayed above the baseline and conversely, flow away from the transducer is displayed below the baseline. The width of the waveform represents the variation in Doppler shifts at a given point in time. The brightness of the spectrum represents the amplitude of the Doppler signal, which is in turn proportional to the concentration of blood cells. As for colour Doppler, the scale can be adjusted manually and determines the maximum velocity that can be displayed.



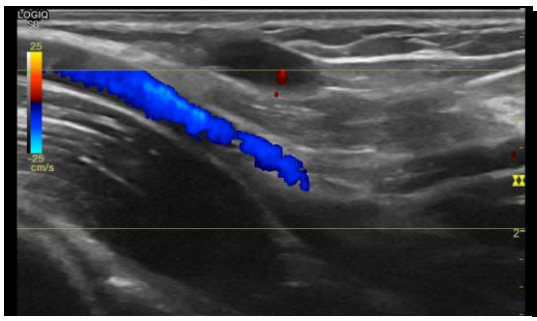
At the top of the screen, the B-mode image is provided. Notice the indicator line, range gate and angle correction line. At the bottom of the screen, the Doppler spectrum is displayed as a graph of time along the x-axis versus flow speed along the Y-axis.

Gain

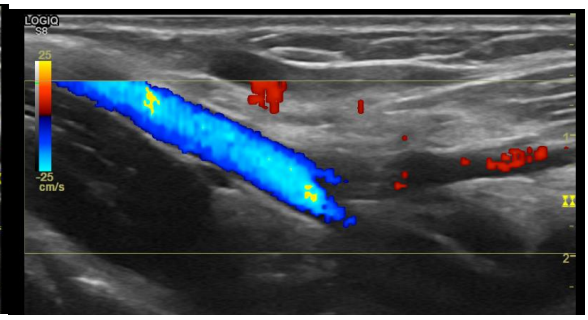
Gain can be adjusted separately from the gain control used for the grey-scale image and is used to amplify the returning Doppler shift signal. As a general rule of thumb when using colour Doppler, the gain should be increased until there is a small amount of speckle in the tissues surrounding the vessel of interest and then reduced until colour is seen only within the vessel lumen. Care should be taken not to increase gain excessively, since this can result in excessive colour outside vessels. Increasing gain excessively on the spectral Doppler display can result in artefactual spectrum widening and can mimic turbulence.

Persistence

Persistence is used to average colour flow information from several sequential frames that is then presented in a single image resulting in improved colour filling of the vessel lumen and hence an overall smoother image with reduced noise. Noise is predominantly caused by speckle and is reduced because it is a random process. When several frames containing random signals are averaged, the random signal is reduced in strength. The disadvantage of this function is that frame rate is, by necessity, reduced and information regarding the dynamic nature of flow is lost.



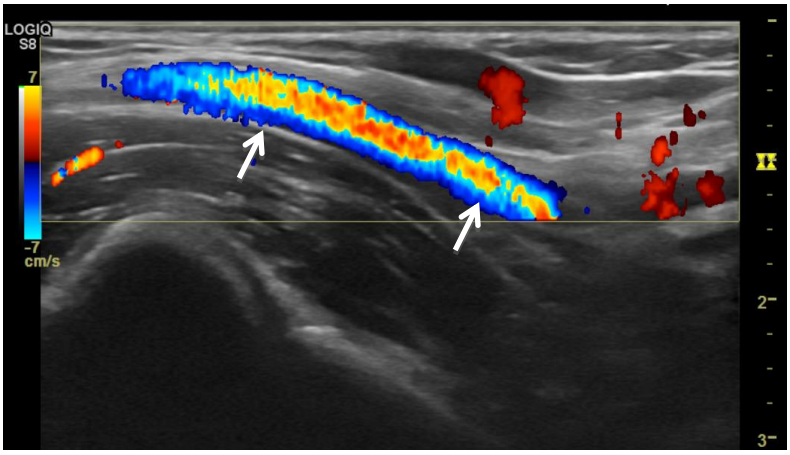
Without persistence



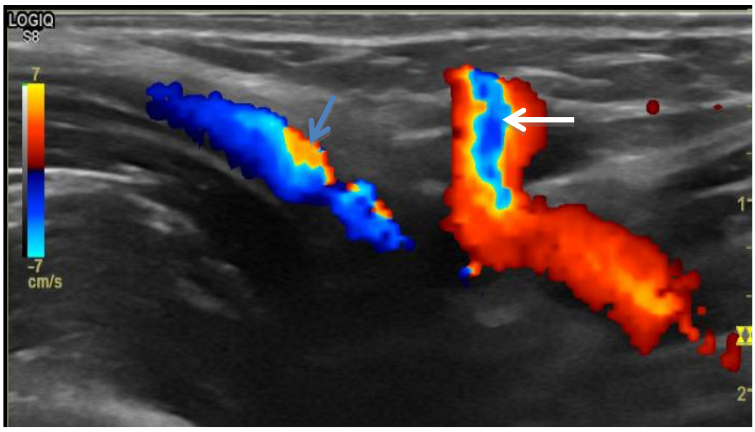
With persistence

Aliasing

When blood flow speed is higher than the system can cope with, aliasing can occur. In colour Doppler, aliasing results in flow being displayed with an incorrect colour. In simplified terms, this means that flow away from the transducer (which should normally be blue), when aliased, is displayed as red, incorrectly suggesting flow is towards the transducer. The opposite is also true in that aliased blood flowing towards the transducer is shown as blue.



Flow within a vessel (arrows) is depicted as blue colour at the periphery of the lumen where blood is flowing more slowly away from the transducer. Towards the centre of the lumen, blood speed is greater which in this instance, results in a Doppler Shift frequency that exceeds the maximum frequency that the system can cope with and aliasing occurs. This is shown as the colours red and yellow.



Example of aliasing in two vessels. In the vessel on the left, flow is away from the transducer however, a focal area of yellow/red colour within the vessel (blue arrow) occurs due to aliasing. Flow in the vessel on the right is towards the transducer however in the centre of the vertical portion of the blood vessel (white arrow), the colour blue is present due to aliasing. This part of the vessel is affected since blood flows fastest in the centre of a vessel with laminar flow and because the Doppler shift is greatest where blood is flowing parallel with the ultrasound beam axis.

Aliasing is undesirable since it can confuse interpretation and important flow information can be missed. There are several ways of eliminating aliasing. The velocity scale (numbers either side of the colour map) can be increased, although as mentioned previously, this will reduce the sensitivity of the system to slow-moving flow. The second way of eliminating aliasing is to simply move the baseline of the colour map up or down.

When aliasing occurs in flow shown as a spectral display, the peak flow velocities are wrapped around to the opposite side of the baseline. Again, increasing the scale and adjusting the baseline up or down, can be performed to eliminate aliasing.

References:

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