FUNDAMENTALS FOR INTERPRETING NONINVASIVE VASCULAR TESTING PART 1: BASICS OF DUPLEX ULTRASOUND EXAMINATIONS

PART 1: BASICS OF DUPLEX ULTRASOUND EXAMINATIONS

This series of articles about the use of duplex ultrasound to evaluate vascular structures and blood flow begins by reviewing the most basic principles, terminology and orientation to what is seen on a display screen. Before progressing to image and waveform analysis, and then moving along to case reviews, a general overview of terms makes for a good foundation.

The most fundamental question to ask is “why is it called duplex”? The term duplex implies that there are two of something involved. I ask this question often when teaching about how to read or perform vascular ultrasound studies, and too often get silence and looks of confusion. Maybe that is because it is such a fundamental term that it is assumed that we all know what it means. But it is important to break this down at the beginning as each of the two principle elements has both independent and combined applications to interpretation of these studies in vascular, or any other clinical area for that matter.

Duplex combines 1) B-mode imaging with 2) Doppler assessment of blood flow.

B-mode (brightness mode) is also called grayscale or pulse-echo reflection, with all of these terms used synonymously in different articles or everyday descriptions of ultrasound imaging. Ultrasound beams are transmitted into tissues in a pulsed manner and the reflections received back to the transducer are assigned depth placement from near to far field on the screen based on arrival time of the echo along with Brightness relative to the amplitude of the returning sound echo. This Brightness is mapped to a scale that is most often chosen to display a range of grays. The B-mode map may also be changed to display a range of colors. But the term “grayscale” is used widely as this was the original, and still most common, display selected.

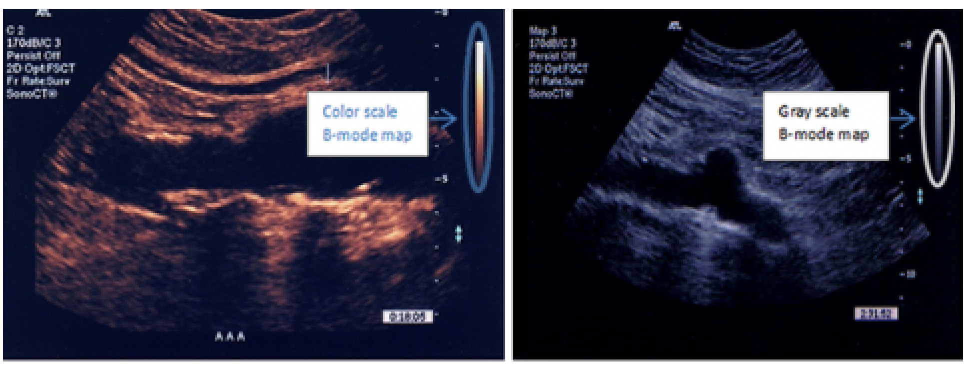


Figure 1 B-mode map examples using shades of color or shades of gray to display relative returning sound signal amplitude

Figure 1

To measure movement, or flow, ultrasound may utilize the Doppler effect to estimate the velocity and direction of the moving material, blood flow, in the cardiovascular system. Doppler is also used to visualize the motion of fluid in ureteral jets. In practice, getting a “Doppler signal” may mean that Continuous Wave (CW) or Pulsed Wave (PW) technology was employed to generate waveforms. Color Doppler is obtained using PW Doppler technology in combination with scanning that is used for B-mode ultrasound imaging to produce an image of flow, a representation of mean flow velocities and flow direction in a designated region of the overall display screen outlined by the “color box”. Color Doppler information is superimposed on the B-mode image and moving flow is seen within structures.

CW Doppler is used without imaging in the Vascular Laboratory. In Echocardiography studies, CW Doppler may be performed with an image to guide the path of insonation or with a transducer that is non-imaging. PW Doppler is most often used with an imaging transducer. However, for Transcranial Doppler studies, in particular, a non-imaging PW Doppler may be employed to acquire the waveforms. These variations can make it difficult for the physician or technologist who is learning how to perform or read duplex studies to differentiate what is being used, or could be used, and why.

Ultrasound transducers use piezoelectric crystals which respond to electrical voltage by producing sound: mechanical, longitudinal waves at characteristic frequency (actually frequencies). As the sound waves interact with structures in their pathway, the tissues reflect waves back to the transducer crystals and the energy received is converted back to electrical voltage and processed for display as image or waveform information. So, the same crystals can work to both send ultrasound waves and to receive them. The beams are directed into the tissue with the angle of insonation determined by how /where the transducer is placed on the skin and oriented by both electronic steering within the ultrasound machine and mechanical steering through angulation and rotation of the transducer by the hand of the clinician. Much like directing a flashlight beam that we can see, the sound beam we can’t see is fanned, or scanned, through the regions of interest to “see” our targets. The coordination of electronic and mechanical direction of the beam along with knowledge of the anatomy and disease processes makes duplex ultrasound a powerful tool.

In regard to using Doppler in assessing blood flow, it just so happens that the range of retuning frequencies are in the human audible range and we can hear signals that help immensely with our selection of the “right” waveforms to record as the most diagnostic. The transmitted (in MHz) sound is shifted by the moving blood flow components and the difference (in KHz) between the frequency transmitted and the returning frequency gives audible information that can be displayed as a spectrum of the shifted frequencies (on the vertical axis) and mapped over time (on the horizontal axis) on a graph. Higher and lower shifts, and direction of flow in relation to the zero baseline are displayed over time. The brightness of the different pixels in the display represents amplitude of the signal at different frequencies and points in time.

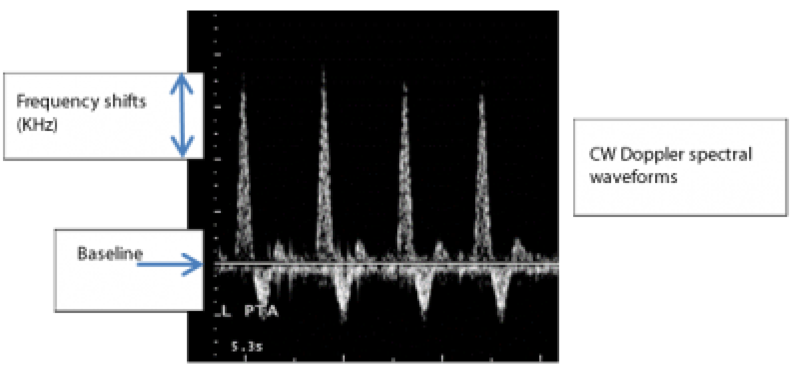


Figure 2 Spectral Doppler display of frequency shifts from arterial blood flow

Figure 2

Frequency shifts are translated to velocity of the moving blood flow through the Doppler equation when the angle of insonation to the vessel wall or the flow vector is known and entered by the clinician as a numerical value, estimated by lining up an angle correction cursor to the wall or flow as seen on the image (figure 3). By converting to velocity, our reports are given on a level playing field: speed is speed no matter what frequency transducer is being used.

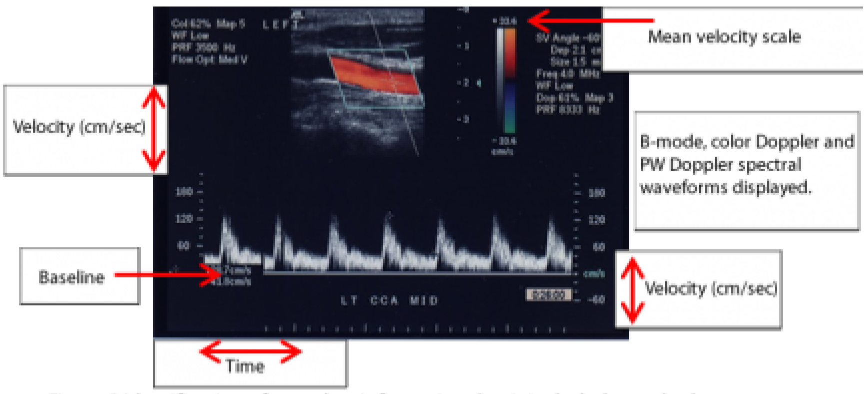


Figure 3 Identification of some key information that is included on a duplex image with color Doppler

Figure 3

CW Doppler uses 2 crystals with one always sending and one always receiving sound waves. If used without an image, and if the insonation pathway cannot be assumed to be parallel to the flow / vessel walls (0° angle), then waveforms with varying shape and frequency shifts may be displayed and analyzed for overall morphology, but velocity is not appropriately calculated. Here is a review of the effect of insonation angle on the Doppler shifts:

$$\Delta f = \frac{2 * f_{0} * V * \cos\theta}{C}$$

Frequency shift = 2 x operating frequency x velocity x cosine of the angle to flow / speed of sound in tissue

angle	cosine
0°	1.0
30°	0.86
45°	0.70
60°	0.50
90°	0

*The smaller the angle to flow, the higher the **frequency shift.***

Advantages of CW Doppler are excellent signal to noise ratio and the ability to display very high returning frequency shifts (high velocity flow). The major disadvantage is that the returning signals are from all points in the beam’s pathway; it is not depth sensitive. In the Vascular Laboratory, CW Doppler is most often used for waveform acquisition in extremity vessels and waveform morphology is assessed at

points along a limb in a blind fashion with vessel identification done by relative positons on the skin surface and relative position to other structures. Velocities are not calculated as the angle to flow is not known. The probe is angled to achieve the highest shifts possible (highest waveform height). In the heart, the beam transmitted with CW Doppler is directed to be at 0 degrees (parallel) to flow or very close to it for estimation of velocity. This may be done with a non-imaging transducer, Pedoff probe, that allows for access to narrow flow tracks and / or with very high velocities or CW may be engaged using the B-mode image for general guidance. High velocity jets out of the aortic valve, or other cardiac valves, with beam access through narrow rib spaces is where CW Doppler is the way to resolve the Doppler velocity waveforms without aliasing (peak cut off and not displayed accurately for measurement).
PW Doppler uses one crystal to send a pulse of sound waves and then receive the returning signals. The advantage here is being able to choose the placement of a sample volume within a flow stream instead of "listening" across the entire beam pathway; it is depth sensitive. So an isolated region of flow may be evaluated. Duplex combines PW Doppler with the image to evaluate a stenotic lesion, valve incompetency, or overall flow characteristics at a given location. The image below (figure 4) identifies important components of what is displayed when looking at a duplex screen shot that has image and PW Doppler being utilized together.

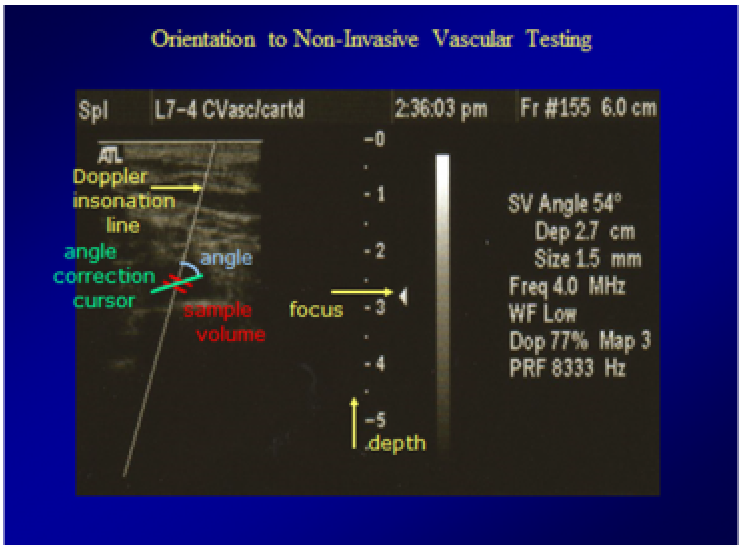


Figure 4 Breakdown of the different "lines" on the duplex image

Figure 4

The insonation line is placed and then the Doppler spectral display is scrolled over time. Angles of <60°, corrected to the vessel walls (most reproducible method for peripheral vascular work) or the flow jet, are accepted and have been used to generate the criteria charts that are in publication. PW Doppler waveforms may alias and so limited in maximum velocity that can be displayed at a given depth using a given operating frequency.

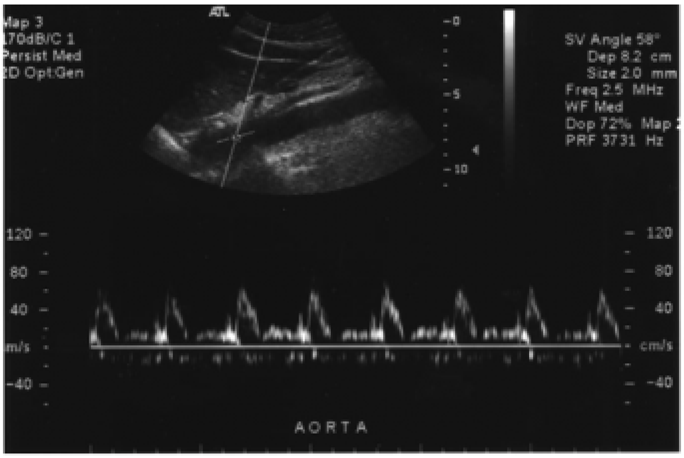


Figure 5 B-mode image and PW Doppler spectral waveforms

Figure 5

When the angle to flow is estimated by lining up the angle correction cursor to the vessel wall, we can move from reporting in frequency shift to reporting in velocity. This important change in approach makes it possible to report speed regardless of the operating frequency of the transducer, as long as the angle is correctly input by the sonographer by correctly adjusting the angle correction cursor. NOTE that the cosine of the angle is now in the denominator as opposed to being in the numerator when the frequency shift itself was the factor being reported (check out the earlier equation listed above). So now, as the angle correction that we input into the machine gets smaller the estimate of velocity goes down. Try inputting some simple numbers into the numerator and denominator of any equation to see how this works. I like to suggest using numbers related to our pay as that is always a very important calculation! The bigger the denominator is, the smaller the outcome will be.
Reminder for those who don't use the terms numerator and denominator every day, the numerator is everything above the dividing line and the denominator is everything below the line.

$$\text{my salary} = \frac{\textit{my hourly rate (numerator)}}{\textit{some number (demoninator)}} \text{ x the number of worked hours}$$

So, now look at the Doppler equation again with it solved for velocity instead of for frequency shift:

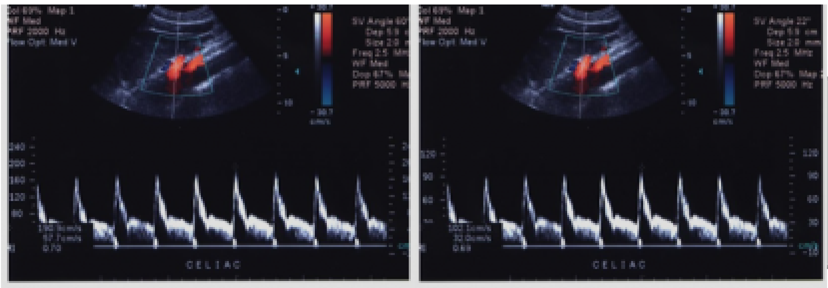
$$V = \frac{\Delta f * C}{2 * f_0 * cos\theta}$$

$$\text{Velocity} = \frac{\text{frequency shift x speed of sound in tissue}}{\text{2 x operating frequency x cosine of the angle to flow}}$$

angle	cosine
0°	1.0
30°	0.86
45°	0.70
60°	0.50
90°	0

The smaller the angle to flow, the lower the ***velocity calculation.***

This point is important in that you may determine if the velocity has been overestimated or underestimated when reviewing an image that has an obvious error in angle correction.



B-mode image, color Doppler and angle corrected PW Doppler spectral waveforms

Angle 60°, velocity 191/58 Angle 22°, velocity 102/32

Figure 6 Estimate of velocity changes with change in angle correction

Figure 6

The primary application of non-imaging PW Doppler is for Transcranial Doppler studies. In these examinations, the trajectory of the ultrasound beam is assumed to be zero, or close to zero, through windows that can be challenging to access in the cranium. Like using "blind" CW Doppler, this "blind" PW Doppler approach uses relative positon of the beam, but also includes sample volume depth, and the waveforms returning from surrounding vessels to identify the primary intracranial vessel(s) being interrogated.

The clinical diagnostic power of effectively combining ultrasound imaging with Doppler flow detection is truly remarkable. Each of the duplex components is strengthened by the other. When image alone is used to identify a lesion in the cardiovascular system, the hemodynamic significance of disease, from minimal effect to total occlusion, is largely missed. In the earliest days of employing CW Doppler alone to assess blood flow, vessel identification and the presence of anatomic variations (tortuosity, collateral pathways, aneurysm formation, congenital anomalies) led to some success along with a lot of inaccurate conclusions. Both the B-mode image and the Doppler waveforms are important to include in the generation and interpretation of a quality duplex ultrasound examination.

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