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The Doppler Velocity Waveform

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This is the fourth in a series of articles on ultrasound physics and instrumentation in Echo Rounds.[1–3] The purpose of this article is to describe information within the Doppler velocity spectral waveform, as well as clinically relevant factors that influence its appearance.

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Spectral Analysis and the Doppler Display

As we have previously described,[1,2] emitted ultrasound that has been reflected back to the ultrasound transducer by moving red blood cells creates a complex electrical signal due to the presence of multiple frequencies and amplitudes (Fig. 1). By the process of spectral analysis, a fast Fourier transform (FFT) analyzer repeatedly samples the Doppler signal, which it separates into component Doppler shift frequencies (a frequency "spectrum"), and

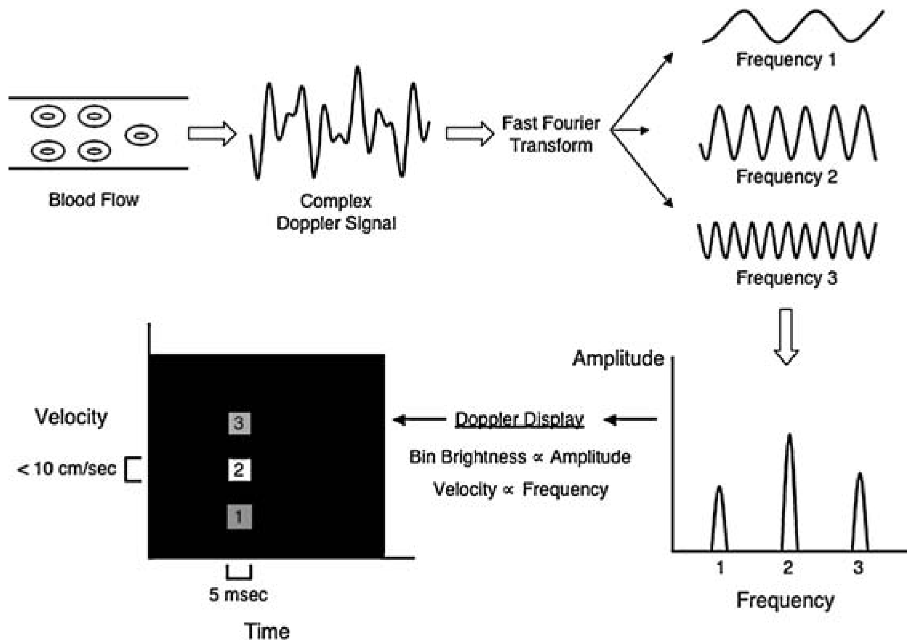

Figure 1. *Spectral analysis and the Doppler display. The fast Fourier transform (FFT) separates the Doppler signal into its component Doppler-shift frequencies and determines the amplitude at each frequency. Most ultrasound machines calculate Doppler-shifted frequencies over 5 msec increments and convert this to velocity information. These velocities are then displayed in a bin whose brightness is proportional to the amplitude of the signal.*

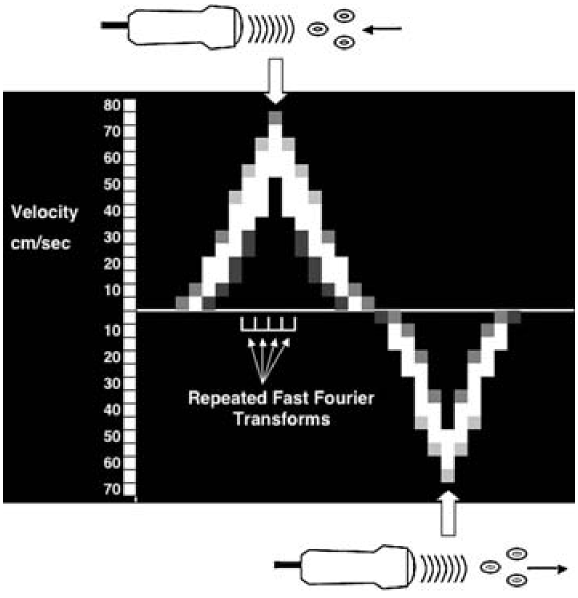

Figure 2. *The Doppler spectral waveform. Repeated calculation of FFTs generates a waveform that allows the display of flow velocities over time. Blood flow traveling toward the ultrasound transducer is displayed above the zero-velocity baseline, whereas flow away from the transducer is displayed below the baseline.*

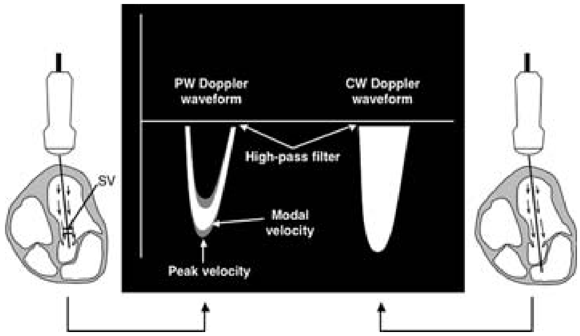

Figure 3. *A schematic of pulsed-wave (PW) and continuous-wave (CW) Doppler waveforms obtained from the apical five-chamber view. In the heart schematics, arrows of increasing length are indicative of increasing velocity as blood travels toward the left ventricular outflow tract in systole. The PW Doppler waveform typically displays a narrow band of velocities because velocity is only measured within the sample volume (SV). The CW Doppler waveform represents sampling over the entire length of the ultrasound beam, and thus has a wide range of velocities, appearing "filled-in." With PW Doppler, the brightest band of velocities represents the modal velocity, or the velocity at which the majority of red blood cells are traveling. A high-pass filter prevents very low velocities from being displayed for both PW and CW Doppler.*

determines the amount, or amplitude, of each frequency. An average Doppler shift frequency is calculated over a small increment of time (typically 5–10 msec) and then is converted to a velocity using the Doppler equation.[1] It is then displayed in a bin representing a small increment in velocity (<10 cm/sec). The brightness of each bin is determined by the strength of the Doppler signal, which is determined primarily by the volume of red blood cells traveling at that particular velocity (see below). The use of sequential FFTs creates a Doppler velocity waveform, displaying blood flow velocities over time (Fig. 2). Doppler waveforms displayed above the zero-velocity baseline indicate blood flow toward the ultrasound transducer, whereas waveforms displayed below the baseline are associated with blood flow away from the transducer.[4,5]

Pulsed-Wave Versus Continuous-Wave Doppler Waveforms

The pulsed-wave (PW) Doppler velocity spectral waveform normally displays a narrower range of velocities than does the continuous-wave (CW) Doppler waveform (Fig. 3). This occurs because PW Doppler measures blood flow velocities over a relatively small region (the sample volume), whereas CW Doppler measures blood flow velocities along the entire path of the ultrasound beam. The brightest, most distinct portion of the PW Doppler velocity waveform represents the modal velocity, or the velocity at which the majority of red blood cells are traveling.[4,5] When measuring velocities with PW Doppler, the outer edge of the modal velocity envelope should be used, despite the fact that the peak velocity of some red blood cells represented by a darker shade of gray is higher. To determine velocities from a CW Doppler waveform, the outer border of a well-defined spectral envelope should be used.[6]

Spectral Broadening

A PW Doppler spectrum is narrowest when all red blood cells are traveling at nearly the same velocity, a situation approximated by blood flow through a normal cardiac valve. The dark area beneath the modal velocity envelope (the spectral window) fills in (spectral broadening) when the range of blood flow velocities within the PW Doppler sample volume increases (Fig.4). This may occur in the presence of normal flow if the sample volume is placed

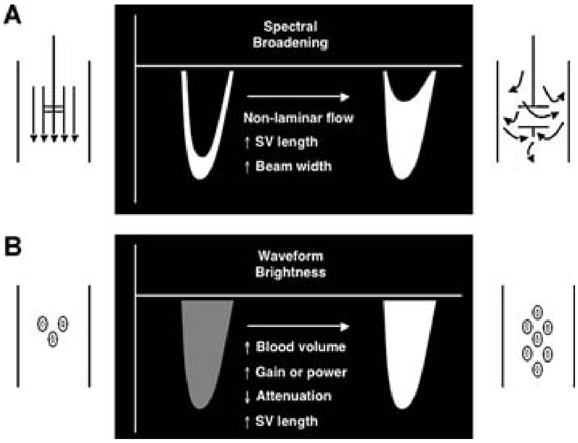

Figure 4. ***A*** *Spectral broadening. When all blood flow velocities measured in a sample volume are the same (plug flow) or nearly so (as occurs with laminar flow), a narrow velocity spectrum results. If blood velocity is sampled at a site of disorganized or turbulent flow, in which a wide range of velocities occurs, the spectrum broadens. Spectral broadening may also be associated with relatively long sample volumes (~5 mm) or increasing beam width, as occurs at greater imaging depths.* ***B*** *An increase in Doppler velocity spectral waveform brightness is associated with a greater volume of blood being sampled. The spectrum brightness also increases with increased Doppler gain or power, increased sample volume length (with PW Doppler), or reduced ultrasound beam attenuation, which occurs with lower emitted ultrasound frequencies.*

"off-center" in the blood flow stream. In addition, a decreased peak blood flow velocity and a muffled (not crisp) sound will be evident. Spectral broadening may become "complete" with turbulent flow, as occurs with flow across stenotic and regurgitant valves. Spectral broadening also occurs with an increasing sample volume size, which increases the range of blood flow velocities sampled.

Waveform Brightness

The shade of gray (brightness) of a Doppler velocity spectrum is influenced by the Doppler signal amplitude, which is primarily determined by the volume of blood sampled. To achieve the brightest spectrum, the ultrasound beam should be aligned with the axis of blood flow, and should not unnecessarily pass through cardiac structures, such as the interventricular septum, which weakens the ultrasound beam. Waveform brightness is also increased by increasing the Doppler power or gain. Finally, an increase in the PW Doppler sample volume may increase the spectrum brightness due to the resulting increase in the number of blood cell reflectors.[4] This will often improve the appearance of low-amplitude velocity spectra, such as from the pulmonary veins.

In summary, we have discussed the creation of the Doppler velocity spectral waveform and factors that influence its appearance. An understanding of these principles improves the ability of the ultrasound user to diagnose cardiac disease using Doppler echocardiography.

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