Spectral Doppler Sonography: Waveform Analysis and Hemodynamic Interpretation

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The spectral Doppler power waveform contains an immense amount of hemodynamic information from the sampled circulation. As we saw in Chap. 3, the spectral information consists of three fundamental variables: frequency, amplitude, and time. Spectral frequency reflects the speed of blood flow. The amplitude approximately represents the number of scatterers traveling at a given speed and is also known as the power of the spectrum. Amplitude depends on the quantity of moving red blood cells (RBCs) in the sample and therefore reflects the volume of blood flow. The time over which the frequency and amplitude vary is the third variable. A comprehensive depiction of the Doppler spectrum is therefore three-dimensional (see Chap. 3). Such a display is complex, however, and not particularly useful for clinical application. Fortunately, there are alternative approaches for effectively characterizing the spectral waveform, including two-dimensional sonograms and various frequency envelope waveforms. These approaches can be utilized to evaluate various aspects of hemodynamics of flow, ranging from the presence and directionality of flow to downstream impedance. This chapter discusses these subjects and other related issues.

Spectral Doppler Sonogram

A typical two-dimensional sonographic display of Doppler frequency shift waveforms from the umbilical circulation is shown in Fig. 4.1. Each spectrum of the Doppler shift is depicted in a vertical line whose vertical dimension represents the magnitude of the

![Fig. 4.1. Spectral Doppler waveform from the umbilical arteries. Vertical axis represents the magnitude of the Doppler frequency shift. Horizontal axis represents time. Brightness of the tracing indicates the amplitude of the Doppler spectrum. Note that the recording is scrolled from right to left as new information is continuously added to the right end of the spectral display.](image)
frequency; the image intensity or brightness represents the amplitude. Each successive spectrum is added to the right of the previous spectrum as the display is scrolled from right to left. Thus the horizontal axis indicates the temporal dimension of the Doppler recording. When sampled from an arterial circulation, a Doppler waveform depicts one cardiac cycle. The left limit of the wave corresponds with the onset of systole, the zenith of the wave with peak systole, and the right limit with the end of diastole. In a two-dimensional Doppler sonogram, only the frequency and time are quantitatively depicted, whereas the amplitude, or power of the spectrum, is expressed only qualitatively. The directionality is depicted in terms of whether the flow is toward or away from the transducer. The flow toward the transducer is shown as an upward deflection from the baseline and flow away as a downward deflection; this configuration may be reversed in the display. The hemodynamic interpretation and utilization of the various characteristics of the Doppler wave sonogram are discussed later in this chapter.

Doppler Frequency Shift Envelopes

Although the full power spectral display of the Doppler signal as described above provides a comprehensive account of the dynamics of flow velocity, often more limited and focused spectral information based on the various envelope definitions of the Doppler frequency shift waveform is used (Fig. 4.2). Of the various envelopes, the maximum and mean frequency shift waveforms are most commonly used for clinical applications. These envelopes and an additional one, the first moment, are discussed here.

Maximum Frequency Shift Envelope

The maximum frequency shift envelope may be derived manually by outlining the spectral waveform or electronically by analog or digital techniques. Many devices allow superimposition of the maximum frequency envelope over the spectral display waveform. It should be noted that most Doppler descriptor indices are based on the maximum frequency shift values (see below), although most indices are usually determined without defining the total envelope. This envelope is not significantly affected by uneven insonation so long as the ultrasound beam includes the fastest flow within the lumen. It is also resistant to the flow velocity profile of the circulation, the attenuation variation between blood and soft tissue, the signal-to-noise ratio, and the high-pass filter. The maximum frequency envelope is susceptible to spectral broadening as the definition of maximum frequency in relation to the spectral power becomes imprecise, and the maximum frequency values form a gradual slope at the various cutoff levels of peak power (see Fig. 3.6).

Mean Frequency Shift Envelope

Under the ideal circumstances of complete and uniform insonation of the target vessel, the mean frequency provides an indirect estimate of mean flow velocity; corrected for angle of insonation, it yields actual velocity values. The accuracy of the mean frequency depends on the velocity profile and is compromised when a vessel is incompletely insonated. The envelope is affected by the differential attenuation of sound between blood and tissue, which favors transmission of Doppler signals from the center of the vascular lumen; it results in false elevation of the mean frequency. It is also susceptible to high-pass filtering, which increases the mean frequency estimate by eliminating low-frequency signals along with the tissue-derived clutter signals. The mean frequency has the advantage of being unaffected by spectral broadening because of the symmetric nature of the spectral spread.