Sonographic Color Flow Mapping: Basic Principles

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Color flow mapping consists of real-time depiction of two-dimensional flow patterns superimposed on cross-sectional pulse echo images of anatomic structures [1–3]. The flow patterns are color-coded to present a variety of hemodynamic information. Doppler color flow mapping is based on the estimation of mean Doppler-shifted frequency and does not provide information on peak frequency shift or actual flow. Furthermore, the hemodynamic information provided is qualitative rather than quantitative. Nevertheless, color flow mapping has proved useful for elucidating structural and functional abnormalities of the circulatory system. The technique was first introduced in cardiology practice and has revolutionized noninvasive diagnosis of cardiac pathology. The use of this method has since been extended to other medical disciplines. In obstetrics and gynecology, color flow mapping has been used to investigate fetal and maternal hemodynamics during pregnancy and pelvic vessels in non-pregnant women. Color flow has been found to be useful for elucidating complex cardiac malformations of the fetus, directing spectral Doppler interrogation of fetal cerebral, renal, and other circulations, diagnosing ectopic pregnancy, and assessing pelvic tumor vascularity. It should be recognized, however, that the information generated by Doppler color flow mapping is significantly influenced by the instrumental setting and characteristics. The reliability of the method thus depends on the appropriate use of the device by the operator, who should have a clear understanding of the basic principles of Doppler color flow mapping and its implementation.

In this chapter we describe the basic principles, instrumentation, and limitations of Doppler color flow mapping and present practical guidelines for its use. We also discuss an alternative sonographic color flow mapping technique based on the time domain processing analysis.

Principles of Doppler Color Flow Mapping

Multigated Doppler Interrogation

Doppler color flow mapping is based on multigated sampling of multiple scan lines using bursts of short pulses of ultrasound (Fig. 6.1). Many range-gated samples are obtained for each emitted pulse of ultrasound along a single scan line by opening the receiving gate sequentially to the echo signals arriving from various depths along the scan line. The time needed for the return journey of the echo is used to determine the spatial origin of the returning echoes. Assuming a sound propagation speed of 1,540 m/s in tissue, the echo return time for an emitted sound pulse in 13 ms/cm of tissue depth. Thus a signal from a depth of 5 cm takes 65 ms from the moment of transmission to its return to the transducer. If the second sample is to be obtained from a depth of 10 cm, the range gate is opened at 65 ms after reception of the first sample (130 ms after transmission of the pulse). In reality, many samples are collected, and the consecutive sampling of the signals along the

![Image](image-url)
scan line is timed according to the depth of the sampling location.

Each returning echo is referenced to its range gate, which identifies it with the spatial location of its origin, and is electronically stored using delay circuitry. After all the echoes from the first pulse are received, a second pulse in phase with the first pulse is sent along the same scan line. Appropriate timing of the pulse repetition is a critical consideration for pulsed Doppler, as transmission of a pulse before the return of the echo from the previous pulse causes range ambiguity (see Chap. 3). With two-dimensional Doppler color flow mapping, range ambiguity is not permissible. The backscattered echo signals of the second pulse are collected from range locations identical to those of the first pulse and are referenced to their respective range gates. To determine the mean Doppler shift, each echo signal from each pulse sampled from a given range gate is compared with that from the previous pulse sampled from the same gate. Because an enormous amount of samples are collected, the comprehensive spectral processing techniques (see Chap. 3) cannot be implemented in Doppler color flow mapping. Instead, the autocorrelation technique is utilized to obtain the mean Doppler phase shift (see below).

Each scan line is repeatedly sampled using multiple pulses. The latter ranges from 3 to 32, although usually 8–10 pulses are used. The signals from the identical range gates are collected and compared to obtain mean Doppler shifts, which are averaged for each gate. The number of pulses per scan line is called the ensemble length (Fig. 6.2). There are several reasons for this repeated sampling of a single scan line. The most important is the fact that blood flow is a continuously changing phenomenon, and the duration of each pulse in Doppler color flow mapping is too short (<2 ms) to provide an acceptable mean value. As the number of pulses per scan line is increased, the quality of flow information improves in terms of reliability and completeness. Another distinct advantage of increasing the samples is the enhancement of Doppler sensitivity to detect low-velocity circulations. This ability may be useful for gynecologic applications, specifically for detecting ovarian, uterine, or tumor blood flow, where it is more important to detect flow than to be concerned with the temporal resolution. Moreover, as the samples are repeated and averaged against a constant background of noise, the signal-to-noise ratio improves. Multiple sampling also contributes to stabilization of the high-pass filter.

Once sampling of a scan line is completed, the next scan line is interrogated in the same manner as described above. The color flow map is completed by multiple scan lines sweeping across the imaging field (Fig. 6.1).

**Color Doppler Signal Analysis**

Multigated sampling of multiple scan lines of the color flow imaging field generates an enormous amount of data. Color flow mapping requires real-time processing and display of these data. The demands of processing such a vast flow of information cannot be met by the currently available comprehensive spectral analytic techniques, such as fast Fourier transform (see Chap. 3). For example, during the time the Fourier spectral analyzer processes signals from one sample volume, thousands of samples must be processed for color flow mapping. Obviously, color flow mapping requires an alternative approach for Doppler signal analyses [4, 5], which is usually achieved by the autocorrelation technique (Fig. 6.3), which generates mean Doppler shift information, rather than the comprehensive power spectral data generated by full spectral processing. It is important to note that the autocorrelation method does not estimate the peak frequency shift.

The mean Doppler shift is based on phase differences between the echoes generated from consecutive sound pulses transmitted in the same direction and sampled from the same location. *Phase* is defined in physics as a specific degree of progression of a cyclic phenomenon. When two waves are in step, they are in phase. The movement of the scatterer during the elapsed time between the two consecutive pulses causes the resulting echoes to be out of step or phase. The autocorrelator measures this phase difference by multiplying the successive signals. The mean Doppler shift is related to the phase difference, as shown in the following equation:

\[
\phi = 360 \times \frac{M F_d}{PRF}
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