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RESEARCH ARTICLE

# Clinical Applications of Doppler Ultrasound in Obstetrics

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## Abstract

Ultrasound images of flow, whether color flow or spectral Doppler, are essentially obtained from measurements of movement. In ultrasound scanners, a series of pulses is transmitted to detect movement of blood. Echoes from stationary tissue are the same from pulse to pulse. Echoes from moving scatters exhibit slight differences in the time for the signal to be returned to the receiver. These differences can be measured as a direct time difference or, more usually, in terms of a phase shift from which the 'Doppler frequency' is obtained. They are then processed to produce either a color flow display or a Doppler sonogram.

## Introduction

In recent years, the capabilities of ultrasound flow imaging have increased enormously. Color flow imaging is now commonplace and facilities such as 'power' or 'energy' Doppler provide new ways of imaging flow [1]. With such versatility, it is tempting to employ the technique for ever more demanding applications and to try to measure increasingly subtle changes in the maternal and fetal circulations [2].

To avoid misinterpretation of results, however, it is essential for the user of Doppler ultrasound to be aware of the factors that affect the Doppler signal, be it a color flow image or a Doppler sonogram. Competent use of Doppler ultrasound techniques requires an understanding of three key components:

- The capabilities and limitations of Doppler ultrasound;
- The different parameters which contribute to the flow display;
- Blood flow in arteries and veins.

Doppler assessment of the placental circulation plays an important role in screening for impaired placentation and its complications of preeclampsia, intrauterine growth restriction and perinatal death [3]. Assessment of the fetal circulation is essential in the better understanding of the pathophysiology of a wide range of pathological pregnancies and their clinical management [4]. This paper provides a comprehensive account of Doppler ultrasound in Obstetrics and will be of value to those involved in antenatal care and fetal medicine.

As with the introduction of any new technology into routine clinical practice, [5] it is essential that those undertaking Doppler assessment of the placental and fetal circulations are adequately trained and their results are subjected to rigorous audit [6]. The Fetal Medicine Foundation, under the auspices of the International Society of Ultrasound in Obstetrics and Gynecology, has introduced a process of training and certification to help to establish high standards of scanning on an international basis [7].

The Certificates of Competence in Doppler assessment of the placental and fetal circulations are awarded to those sonographers that can perform these scans to a high standard, can demonstrate a good knowledge of the indications and limitations of Doppler and can interpret the findings in both high-risk and low risk pregnancies [8].

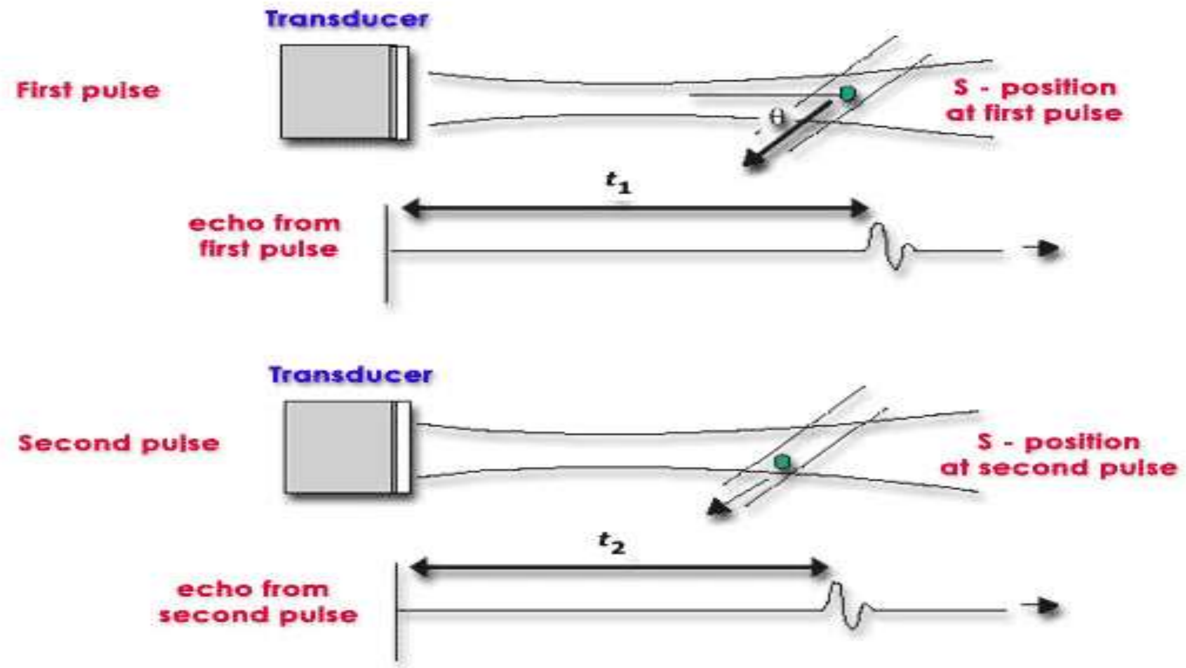


**Figure 1: Ultrasound velocity measurement. The diagram shows a scatterer S moving at velocity V with a beam/flow angle. The velocity can be calculated by the difference in transmit-to-receive time from the first pulse to the second (t2), as the scatterer moves through the beam.**

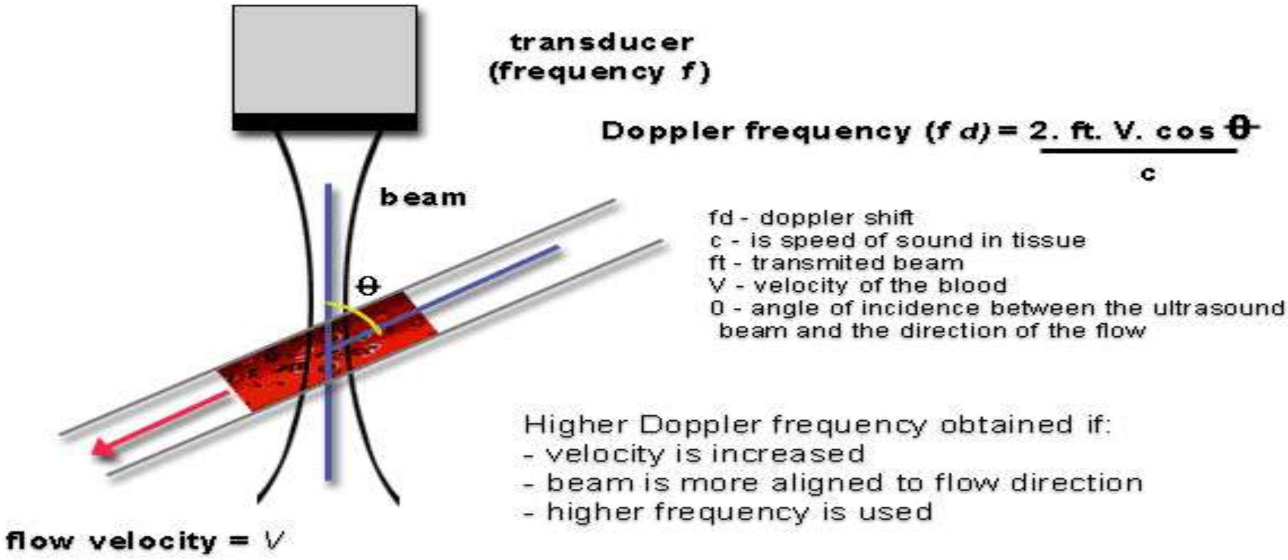


**Figure 2: Doppler ultrasound. Doppler ultrasound measures the movement of the scatterers through the beam as a phase change in the received signal. The resulting Doppler frequency can be used to measure velocity if the beam/flow angle is known**

As can be seen from Figures 1 and 2, there has to be motion in the direction of the beam; if the flow is perpendicular to the beam, there is no relative motion from pulse to pulse [9]. The size of the Doppler signal is dependent on:

- Blood velocity: as velocity increases, so does the Doppler frequency;
- Ultrasound frequency: higher ultrasound frequencies give increased Doppler frequency. As in B-mode, lower ultrasound frequencies have better penetration.
- The choice of frequency is a compromise between better sensitivity to flow or better penetration;
- The angle of insonation: the Doppler frequency increases as the Doppler ultrasound beam becomes more aligned to the flow direction (the angle between the beam and the direction of flow becomes smaller). This is of the utmost importance in the use of Doppler ultrasound [10]. The implications are illustrated schematically in Figure 3.

 

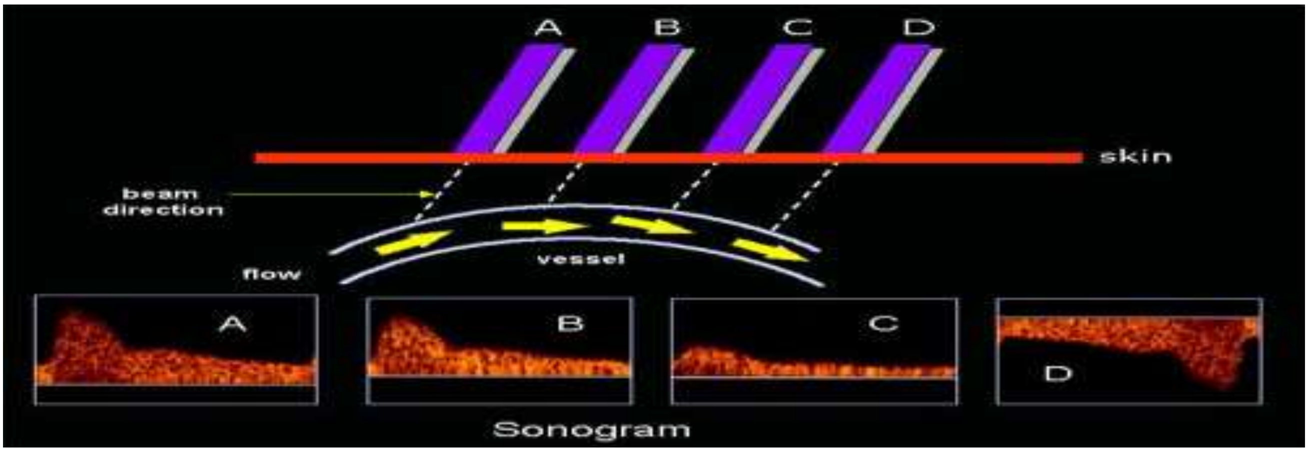


**Figure 3: Effect of the Doppler angle in the sonogram. (A) higher-frequency Doppler signal is obtained if the beam is aligned more to the direction of flow. In the diagram, beam (A) is more aligned than (B) and produces higher-frequency Doppler signals. The beam/flow angle at (C) is almost 90° and there is a very poor Doppler signal. The flow at (D) is away from the beam and there is a negative signal**

All types of Doppler ultrasound equipment employ filters to cut out the high amplitude, low-frequency Doppler signals resulting from tissue movement, for instance due to vessel wall motion. Filter frequency can usually be altered by the user, for example, to exclude frequencies below 50, 100 or 200 Hz. This filter frequency limits the minimum flow velocities that can be measured [11].

## Aliasing

Pulsed wave systems suffer from a fundamental limitation. When pulses are transmitted at a given sampling frequency (known as the pulse repetition frequency), the maximum Doppler frequency $f$d that can be measured unambiguously is half the pulse repetition frequency. If the blood velocity and beam/flow angle being measured combine to give a $f$d value greater than half of the pulse repetition frequency, ambiguity in the Doppler signal occurs. This ambiguity is known as aliasing [12]. A similar effect is seen in films where wagon wheels can appear to be going backwards due to the low frame rate of the film causing misinterpretation of the movement of the wheel spokes [13].

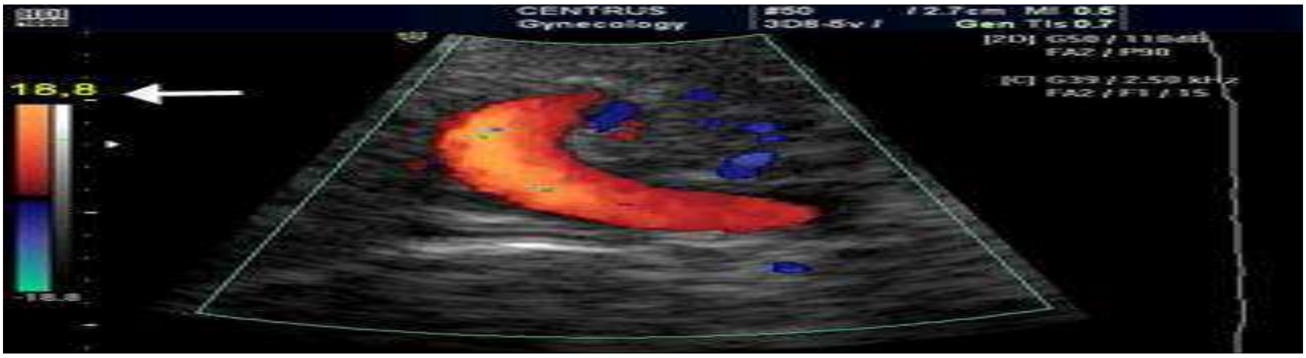


**Figure 4: Aliasing of color doppler imaging and artefacts of color. Color image shows regions of aliased flow (yellow arrows)**

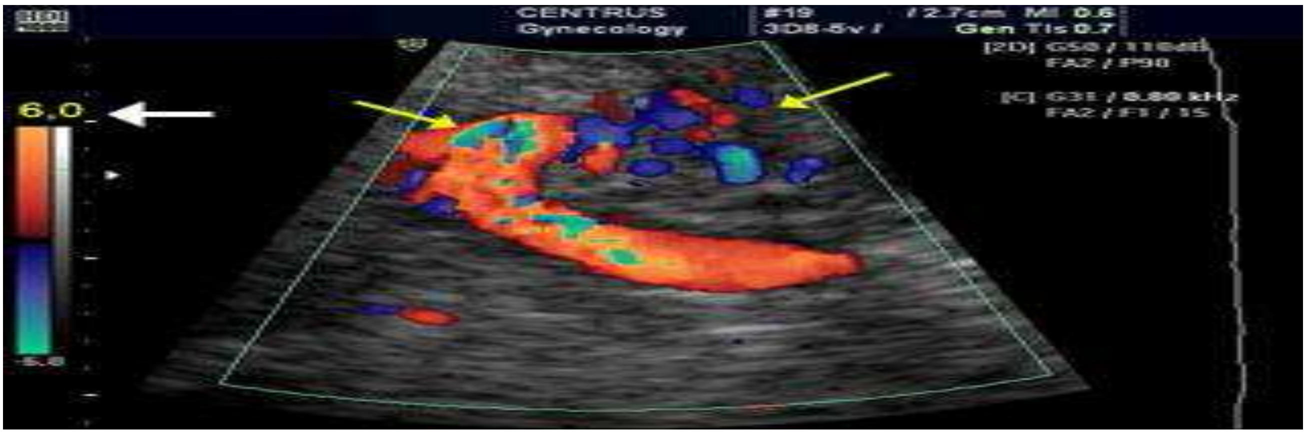


**Figure 5: Reduce color gain and increase pulse repetition frequency**

## Ultrasound Flow Modes

Since color flow imaging provides a limited amount of information over a large region, and spectral Doppler provides more detailed information about a small region, the two modes are complementary and, in practice, are used as such [14]. Color flow imaging can be used to identify vessels requiring examination, to identify the presence and direction of flow, to highlight gross circulation anomalies, throughout the entire color flow image, and to provide beam/vessel angle correction for velocity measurements. Pulsed wave Doppler is used to provide analysis of the flow at specific sites in the vessel under investigation.

When using color flow imaging with pulsed wave Doppler, the color flow/ B mode image is frozen while the pulsed wave Doppler is activated .Recently, some manufacturers have produced concurrent color flow imaging and pulsed wave Doppler, sometimes referred to as triplex scanning. When these modes are used simultaneously, the performance of each is decreased. Because transducer elements are employed in three modes (B-mode, color flow and pulsed wave Doppler), the frame rate is decreased, the color flow box is reduced in size and the available pulse repetition frequency is reduced, leading to increased susceptibility to aliasing. Power Doppler is also referred to as energy Doppler, amplitude Doppler and Doppler angiography. The magnitude of the color flow output is displayed rather than the Doppler frequency signal.

Power Doppler does not display flow direction or different velocities. It is often used in conjunction with frame averaging to increase sensitivity to low flows and velocities [15]. It complements the other two modes. Hybrid color flow modes incorporating power and velocity data are also available from some manufacturers.

These can also have improved sensitivity to low flow. A brief summary of factors influencing the displays in each mode is given in the following sections. Most of these factors are set up approximately for a particular mode when the application (e.g. fetal scan) is chosen, although the operator will usually alter many of the controls during the scan to optimize the image.

### Spectral Doppler

- Examines flow at one site
- Detailed analysis of distribution of flow
- Good temporal resolution – can examine flow waveform
- Allows calculations of velocity and indices

### Color Flow

- Overall view of flow in a region
- Limited flow information
- Poor temporal resolution/flow dynamics (frame rate can be low when scanning deep)
- Color flow map (diferent color maps)
- Direction information
- Velocity information (high velocity & low velocity)
- Turbulent flows

### Power/Energy/Amplitude Flow

- Sensitive to low flows
- No directional information in some modes
- Very poor temporal resolution
- Susceptible to noise

### Spectral or Pulsed Wave Doppler

Pulsed wave Doppler ultrasound is used to provide a sonogram of the artery or vein under investigation (Figure 5). The sonogram provides a measure of the changing velocity throughout the cardiac cycle and the distribution of velocities in the sample volume (or gate) (Figure 5). If an accurate angle correction is made, then absolute velocities can be measured.

The best resolution of the sonogram occurs when the B-mode image and color image are frozen, allowing all the time to be employed for spectral Doppler. If concurrent imaging is used (real-time duplex or triplex imaging), the temporal resolution of the sonogram is compromised [16].

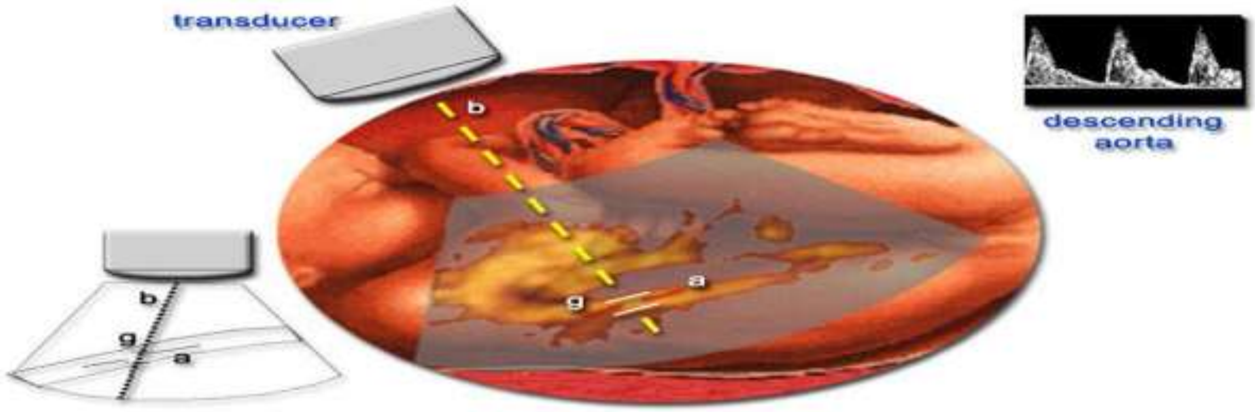


**Figure 5: Setting up the sample volume. (b) - direction of the Doppler beam, (g) - gate or sample volume (a) - angle correction Sonogram of the descending aorta. With the angle correction the peak velocities could be measured.**

## Blood Flow Measurements

### Velocity Measurement

Theoretically, once the beam/flow angle is known, velocities can be calculated from the Doppler spectrum as shown in the Doppler equation. However, errors in the measured velocity may still occur.

Errors can arise in the formation of the Doppler spectrum due to:

- Use of multiple elements in array transducers;
- Non-uniform insonation of the vessel lumen;
- Insonation of more than one vessel;
- Use of filters removing low-velocity components.

Errors can arise in the measurement of the ultrasound beam/flow velocity angle.

- Use of high angles (ϴ> 60°) may give rise to error because of the comparatively large changes in the cosine of the angle which occurs with small changes of angle (Figure 6).
- The velocity vector may not be in the direction of the vessel axis.

Errors can arise in the calculation packages provided by the manufacturers for analysis of the Doppler spectrum (for instance, of intensity weighted mean velocity).

- While efforts can be made to minimize errors, the operator should be aware of their likely range. It is good practice to try to repeat velocity measurements, if possible using a different beam approach, to gain a feel for the variability of measurements in a particular application. However, even repeated measurements may not reveal systematic errors occurring in a particular machine.
- The effort applied to produce accurate velocity measurements should be balanced against the importance of absolute velocity measurements for an investigation.
- Changes in velocity and velocity waveform shape are often of more clinical relevance when making a diagnosis. In this and other cases, absolute values of velocity measurement may not be required.


**Figure 6: Effect of high vessel/beam angles. (a) A scan of fetal aortic flow is undertaken at a high beam/vessel angle. Beam/flow angles should be kept to to 60° or less**

 

### Calculation of Absolute Flow

Total flow measurement using color or duplex Doppler ultrasound is fraught with difficulties, even under ideal conditions 5. Errors that may arise include:

- Those due to inaccurate measurement of vessel cross-sectional area, for example the cross-sectional area of arteries which pulsate during the cardiac cycle;
- Those originating in the derivation of velocity (see above).
- These errors become particularly large when flow calculations are made in small vessels; errors in measurement of diameter are magnified when the diameter is used to derive cross-sectional area. As with velocity measurements, it is prudent to be aware of possible errors and to conduct repeatability tests.

### Flow Waveform Analysis

Non-dimensional analysis of the flow waveform shape and spectrum has proved to be a useful technique in the investigation of many vascular beds. It has the advantage that derived indices are independent of the beam/flow angle. Changes in flow waveform shape have been used to investigate both proximal disease (e.g. in the adult peripheral arterial circulation) and distal changes (in the fetal circulation and uterine arteries).

While the breadth of possible uses shows the technique to be versatile, it also serves as a reminder of the range of factors which cause changes to the local Doppler spectrum. If waveform analysis is to be used to observe changes in one component of the proximal or distal vasculature, consideration must be given to what effects other components may have on the waveform.

### Flow Waveform Shape: Indices of Measurement

Many different indices have been used to describe the shape of flow waveforms. Techniques range from simple indices of systolic to diastolic flow to feature extraction methods such as principal component analysis [17]. All are designed to describe the waveform in a quantitative way, usually as a guide to some kind of classification. In general, they are a compromise between simplicity and the amount of information obtained.

The relative merits of indices used in uterine arteries have been discussed elsewhere. Commonly used indices available on most commercial scanners are:

- Resistance index (RI) (also called resistive index or Pourcelot's index);
- Systolic/diastolic (S/D) ratio, sometimes called the A/B ratio;
- Pulsatility index (PI).

These indices are all based on the maximum Doppler shift waveform and their calculation is described in Figure 5. The PI takes slightly longer to calculate than the RI or S/D ratio because of the need to measure the mean height of the waveform.

It does, however, give a broader range of values, for instance in describing a range of waveform shapes when there is no end-diastolic flow. In addition to these indices, the flow waveform may be described or categorized by the presence or absence of a particular feature, for example the absence of end-diastolic flow and the presence of a post-systolic notch [18].

Generally, a low pulsatility waveform is indicative of low distal resistance and high pulsatility waveforms occur in high resistance vascular beds (Figure 4), although the presences of proximal stenosis, vascular steal or arteriovenous fistulas can modify waveform shape. Care should be taken when trying to interpret indices as absolute measurements of either upstream or downstream factors. For example, alterations in heart rate can alter the flow waveform shape and cause significant changes in the value of indices [19].

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