Doppler Basics for a Gynecologist

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Abstract

Ultrasound is the first-line modality for the assessment of the patients with gynecological conditions and infertility. Doppler plays a very important role in the evaluation of these patients for a differential diagnosis of pathologies in patients with gynecological complaints as well as for understanding the changes occurring during the menstrual cycle and modifying the fertility treatment accordingly. However, this requires an optimum image quality, which can be achieved only by an adequate understanding of the various knobs and settings of the B mode and Doppler on the scanner. This article discusses these settings in a purely practical perspective.

Keywords: Doppler, Image quality, Scanner settings.

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What is Doppler?

Doppler is an effect produced on the frequency of a sound wave when it hits a moving object. This can most simply be explained by a difference in the sound quality perceived by an individual who is standing on a road and hears the voice of a siren of a moving ambulance. The intensity of the sound increases as the sound source moves towards the individual and decreases as it moves away from the individual. When the receiver and the sound source move towards each other, the frequency of the sound wave heard is higher than sent by the sound source, and if the two move away from each other, the frequency of the heard sound is lower than that produced by the sound source. The difference in the emitted and the received frequency is known as the Doppler shift. This effect was first described by Christian Johann Doppler in 1842. However, it was only in 1959 that Satumora demonstrated the use of this technology for demonstration of blood flows.

Translating the Doppler effect in the body for blood flow assessment: the sender and receiver are both static and the target (red blood cells (RBCs)) moves. The first frequency shift occurs when the sound beam hits the moving RBC and again the frequency shift occurs when it returns.

The shift depends on the angle at which the sound beam hits the moving object. Looking into the equation used for the calculation of the velocity from the frequency change on Doppler:

\[ f_d = \frac{2 \cdot f_t \cdot V \cdot \cos \theta}{c} \]

where \( f_d \) = Doppler shift, \( f_t \) = transmitted beam, \( V \) = the velocity of blood flow, \( \theta \) = the angle of incidence between the ultrasound beam and the direction of flow.

Considering this equation, it is important to notice that the frequency of the received beam is dependent on the frequency of the incident beam, the velocity of the moving object, and the angle of incidence. However, more importantly, it is not dependent on the absolute value of the angle of incidence; it is dependent on the “cos” value of this angle. Therefore, for correct calculation of the frequency, or for the calculation of any of the unknown variables out of these above-mentioned four, the cos value of the angle (cos \( \theta \)) should be within acceptable limits (Table 1).

The precise Doppler frequency is calculated, taking into account an angle correction factor of \( 1/\cos \theta \) (Table 2).

Table 1: Angle of incidence of the sound beam, their cos values, and the percentage deviation these lead to in the velocity value

<table>
<thead>
<tr>
<th>Angle (°)</th>
<th>Cos value</th>
<th>% deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>30</td>
<td>0.866</td>
<td>13</td>
</tr>
<tr>
<td>45</td>
<td>0.707</td>
<td>29</td>
</tr>
<tr>
<td>60</td>
<td>0.5</td>
<td>50</td>
</tr>
<tr>
<td>90</td>
<td>0</td>
<td>100</td>
</tr>
</tbody>
</table>

Table 2: Angle of incidence of the sound beam, correction factors used for calculation of velocity, and the correction error

<table>
<thead>
<tr>
<th>Angle (°)</th>
<th>Correction factor ( 1/\cos \theta )</th>
<th>Correction error (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>30</td>
<td>1.15</td>
<td>+3</td>
</tr>
<tr>
<td>45</td>
<td>1.41</td>
<td>+6</td>
</tr>
<tr>
<td>60</td>
<td>2.00</td>
<td>+9</td>
</tr>
<tr>
<td>70</td>
<td>2.92</td>
<td>+14</td>
</tr>
<tr>
<td>75</td>
<td>3.86</td>
<td>+21</td>
</tr>
<tr>
<td>80</td>
<td>5.76</td>
<td>+30</td>
</tr>
</tbody>
</table>

The Doppler effect can be displayed as color Doppler, power Doppler, and spectral Doppler.

Color Doppler

Doppler is the most commonly used term for the color Doppler. It displays the blood flow in two colors, which are conventionally red and blue. The color indicates the direction of the flow. The flow towards the probe is indicated in red and that away from the probe in blue (Fig. 1). However, these can be interchanged by...
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Using an invert switch (Fig. 2). When the flow is perpendicular to the sound beam, not towards or away from the probe, no color will be displayed in spite of the presence of the flow. The cause for this has already been explained earlier. When the flow is perpendicular to the sound beam, the Doppler angle is 90° and the \(\cos \theta\) value is 0; therefore, the flow cannot be displayed. The arterial flow is pulsatile and the venous flow is nonpulsatile. The brightness of the color depends on the velocity of the flow. The higher flow velocities display bright colors and the lower flow velocities display dull colors (Fig. 3). However, the color Doppler does not give exact velocity values. Therefore, it is a directional semiquantitative Doppler.

**Power Doppler**

Though a Doppler, the power Doppler is not an angle-dependent technology. It is known that movement of any object produces energy and this is used to depict the blood flow signals in the power Doppler. This means that wherever there is a movement of blood or of body tissues, color signals will be generated. It is not an angle-dependent technology and so the advantage is that it displays color signals even in vessels that are perpendicular to the sound beam.

However, the disadvantage is that it is a single color display and does not show the flow direction. It indigenously potentiates the signals and therefore is a useful technology for documentation of low-velocity blood flows. The main application of the power Doppler therefore is to pick up flow in low-velocity blood vessels and the blood flows in the vessels perpendicular to the sound beam (Fig. 4). Like color Doppler, the color display of the power Doppler signals also varies depending on the velocity of the moving object. High-velocity movements show a bright color and the low-velocity movements display a dull color (Fig. 5).

HD flow (high-definition flow) is a new addition to the basic power Doppler technology. It is a directional power Doppler. Apart from high-flow sensitivity, the HD flow also has a color coding for the flow towards or away from the probe as in the color doppler (Fig. 6). Like color and power Doppler, the brightness of the color correlates with the velocity of the moving object.

**Spectral Doppler**

Spectral Doppler is a spectral display of the flow/movement of a moving object. The trace above the baseline in the spectrum...
is the flow towards the probe and the trace below the baseline is the flow away from the probe (Fig. 7) on the spectrum. Like in the color Doppler, the invert switch can reverse the flow display. On the spectral Doppler, the arterial flow appears spiky and the venous flow appears flat. There is a scale on the side of the spectrum and it is by this scale that the exact velocities of the flows can be calculated (Fig. 8).

The spectrum can be displayed for a pulsed wave Doppler and a continuous wave Doppler. In the pulsed wave Doppler, the transducer is dedicatedly used for emitting the sound wave during one time interval and then dedicatedly to receive the sound wave during the following time interval of the same length alternatively. As the sound waves are emitted in pulses, it is called a pulsed wave Doppler. The limitation of the pulsed wave Doppler is that the maximum frequencies recorded correctly are smaller than half that of the pulse repetition frequency. This limit of any pulse repetition frequency (PRF) is called Nyquist limit/frequency. The PRF therefore should be set at least double the frequency to be measured. Therefore, to record different velocities, the pulse repetition frequencies have to be selected accordingly. The pulsed Doppler therefore has a limitation to maximum velocities that it can record. This can be overcome by the continuous wave Doppler. This uses dedicated elements for emitting and receiving sound waves and therefore has no higher limit for velocities recorded. This is used chiefly for adult echocardiography. Since the continuous wave Doppler is not used for the Doppler studies in gynecology and obstetrics, we shall not include it in the further discussion here.

To obtain the correct information about flow velocities with the Doppler, certain settings and adjustments on the scanner are required. Though most of these are set on the dedicated presets, it is important to understand how can we manipulate certain switches/knobs to achieve best flow information.

These are the Doppler box size, color gains, PRF, wall motion filter and balance on color and power Doppler and sample volume, gains, PRF, wall motion filter, and angle correction for the pulsed wave Doppler.

**Color/Power Doppler Settings**

**Box Size**

When one switches on the color Doppler, a box appears on the screen, on the B mode image. This box defines in which area of the B mode image that the blood flow information will be looked for. It is important to consider here that when the Doppler is switched on, the machine has to process the B mode information as well as the flow information; therefore, the frame rate significantly decreases. What is this frame rate?

The ultrasound scan that we are doing gives us continuous live, real-time information of the area scanned. We call this as real time because it matches with the live movements of the human body. This is done by a compilation of multiple B mode images.
Only if the B mode images are processed fast enough to match the real-time changes, this scan can be seen like a continuous scan as in a video. The number of B mode images produced in a unit time is called a frame rate. This clearly means that the higher the frame rate, the better would the scan quality be considered. This frame rate can be increased if the machine has to process less. Though it is known that starting the color Doppler decreases the frame rate, the frame rate with the color Doppler can be optimized if the color box size is planned just large enough to cover the area of interest.

I would add here that before switching on the color Doppler, the B mode image should also be optimized for its angle and depth to concentrate only on the area of interest. The color box can be moved all across the B mode image and the size can be altered based on the requirement (Fig. 9).

**Gains**

When the Doppler is switched on, it should show the blood vessels filled up with color and no color spilling out of the vessels. This is done by gain adjustment. When the gains are too high, the color will be seen spilling out of the vessels (Fig. 10). In contrast, when the gains are low, the color will not completely fill up the vessel (Fig. 11). This is because when the gains are low, the low velocity signals will not be picked up by the Doppler. It is important to mention at this stage that in a vessel the central stream has the highest velocity flow, whereas close to the walls the velocity is lower due to friction with the walls. The correct gain therefore is when the entire lumen of the vessel is filled with color and there is no spill outside.

How to set? Increase the gains to the maximum, there will be a lot of spill of color. Start decreasing the gains till the color is contained in the vessel, and further decrease the gains, there will be black (anechoic) areas between the color column and the vessel wall (Fig. 12). These mean over-reduced gains. Increase the gains till the vessel again fills up fully with color and this is your correct setting. Once set and placed in the presets, the gain settings for color and power Doppler are not to be changed.

**PRF**

It has already been discussed that the PRF decides what is the maximum receiving frequency of the sound wave (indirectly velocity) that is recordable at a particular setting (Niquist frequency). Therefore, it is important to select an optimum PRF for
the velocity of the blood vessels flow studied. If the high PRF is used for a low velocity flow, it will not be possible to pick up the color where there are flows (Fig. 13). Instead if low PRF is used for high velocity flows, there will be aliasing (mixing of red and blue colors), which appears like turbulence (Fig. 14). The PRF setting would be optimum when the color homogenously fills the entire vessel with single color-red or blue (Fig. 15).

Wall Motion Filter
It is known that Doppler produces color signals wherever there is a movement, and the brightness of the color depends on the velocity of the moving object. This means that the color signals are produced by the red blood corpuscles in the blood, but are also produced by the wall movement of the artery and also by the pulsations transmitted to the surrounding tissues. The color signals of the blood flow are the brightest, those of wall motion are dull, and those due to transmitted pulsations from the surrounding tissues are the dullest, for the reasons explained earlier.

However, these dull color signals produced by low velocity movements corrupt the flow information and can be eliminated only if a low velocity filter is used. This filter is named as wall motion filter (WMF). The WMF can be adjusted at various levels depending on the level of sound signals that need to be eliminated to produce clear flow velocity signals. For larger vessels with high velocity flows the arterial flow movement is more and a higher WMF is required, whereas for small vessels with low velocity signals, the arterial wall movements are less and so low wall filters are required. Using a higher wall filter for a low velocity blood flow vessel will eliminate the slow flow information. This will lead to a typical color flow signal with a color column seen in the center of the vessel; there is a black line seen on both the sides between the vessel wall and the color column, similar to that produced by low gains (Fig. 12).

Balance
As the name suggests, this is a balancing tool between the two modalities—the B mode and the color Doppler. As discussed earlier, when the Doppler is switched on, the scanner computer processing is doubled and therefore the scanner is to be advised as to which of the two modalities should be given predominance and should be highlighted. This can be decided by the balance. When a color/power Doppler is switched on, a gray bar and a color bar appear on the left side of the screen. On the gray bar is a green line (Fig. 16). This line indicates the balance adjustment. When the brightness of the gray scale on the image matches the brightness below the green line on the gray bar, the color predominates and the color filling is normal, but when the brightness on the gray scale image matches the brightness above the green line on the gray bar, the B mode predominates and therefore in these areas if the color is present
to show the flows, the color will be patched up with white (Fig. 17). Increasing color gains is surely not an answer to this problem.

Very importantly when this happens the correct thing to do is to change the balance to higher, which allows the color pick up even with the bright gray scale. However, the balance setting on many scanners are on the sub-menu of the color Doppler. This makes adjusting it clumsy because when the operator is assessing flow in a relatively small vessel on the scan, opening the sub-menu and changing the balance is difficult. Therefore, a practical solution to this is to reduce the B mode gains, which will match the brightness of the image to a gray shade below the green line on the gray bar and allows good color pick-up (Fig. 18).

**Settings for Pulsed Wave Doppler**

**Sample Volume**

Sample volume is the selected length of the vessel to assess the flow. When a pulsed wave Doppler is switched on, a dotted line appears on the screen. This line is parallel to the sound beam and can be swapped across the entire image. Two parallel short horizontal lines (= sign) appear on this line (Fig. 19). This “= sign” can be moved up and down on the dotted line anywhere. This sign is to be placed on the vessel in which the flow is to be measured. The distance between the two lines decide what length of the vessel will be evaluated for the flow assessment. If the vessel is not absolutely parallel to the sound beam (overlapping on the dotted line), the distance between the two line (sample volume) should be equal to the diameter of the vessel. A sample volume smaller than the diameter will lead to error in the velocity assessment because then it will not evaluate the flow in the entire stream (Fig. 20). When that happens, correct velocity readings are not possible because, as is known, flow velocities in the central stream and at the sides are not the same. If the sample volume is larger than the diameter of the vessel, the vessel wall movement or flow information from neighboring vessels may corrupt the flow information details (Fig. 21).

**Gains**

The gain settings on the pulsed wave Doppler should be such that it produces a clear, well-defined bold spectrum of blood flows (Fig. 22). If the gains are too high, the flow information with be corrupted by a lot of noise (Fig. 23). If the gains are too low, the entire spectrum will appear scarce and scattered (Fig. 24).

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**Fig. 17:** Color Doppler imaging showing color patched up with white due to low balance setting, or high gains on B mode

**Fig. 18:** Optimum balance setting or low B mode gains show normal color filling of vessels

**Fig. 19:** Power Doppler image with the spectral Doppler line and sample volume shown by the red circle

**Fig. 20:** Spectral Doppler image showing flow spectrum with small sample volume
PRF

As has been discussed earlier, the Nyquist frequency of a sound wave decides what maximum flow velocities can be recorded by a sound wave of certain frequency. Therefore, the PRF is adjusted according to flow velocity to be assessed. If high PRF is used for low velocity flow, it will not be possible to differentiate between the systolic and diastolic flows, as the systolic flow recordings will be subdued (Fig. 25). If low PRF is selected for high velocity blood flows, there will be an overlapping of systolic and diastolic signals and is known as aliasing (Fig. 26). The correct PRF setting would therefore be when the spectrum will fill up two-thirds of the spectral

Fig. 21: Spectral Doppler image with large sample volume showing hazy margins of the spectrum with extrashadows (noise)

Fig. 22: Bold spectrum of uterine artery flow with optimum gain settings

Fig. 23: High gain setting of pulsed doppler showing noise on the spectrum

Fig. 24: Low gain setting gives ill-defined blurred spectrum

Fig. 25: High PRF setting for low velocity flow will decrease the systolic peak and difference between systolic and diastolic flows

Fig. 26: Low PRF setting for high velocity flow on pulsed wave Doppler shows overshooting of systolic flow and overlapping of systolic and diastolic flows—Aliasing
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area (above the baseline) (Fig. 27). Though when there is a minimal adjustment required to achieve this, moving the baseline up or down would also serve the purpose.

Wall Motion Filter

Like in color and power Doppler, the function of a wall motion filter in pulsed Doppler also is to eliminate signals from low velocity movements, chiefly not to corrupt the image with wall motions and also with venous flows, adjoining the artery. Again like color and power Doppler, the settings are low for low velocity vessels and high for high velocity vessels. However, the wall filter setting in a pulsed Doppler spectrum is known to be correct only if the spectrum touches the baseline (Fig. 28). When there is a black line or a gap between the baseline and the spectrum (Fig. 29), this trace is not to be accepted, as this clearly indicates a high wall filter for the case. In that case, if we say it eliminates low velocity information, it means it interferes with the diastolic flow information and may lead to a false diagnosis of the absent end diastolic flow and naturally then wrong interpretations. The Spectral Doppler being a quantitative Doppler, the wall filter settings on this modality are in numbers—30, 60, 90 Hz, etc. Wall filters, as a rule for gynecological and infertility assessment, are set at the lowest (30 Hz) and for fetal echocardiography, this is set high (may be 90–120 Hz) depending on the fetal gestational age.

As discussed earlier considering the equation for calculation of the blood flow velocity from frequency of incident sound beam, frequency of received sound beam and cos of the angle of incidence, if the angle of incidence is 90°, then the cosθ being 0, the velocity value will be 0 and also that with increasing angle from more than 60°, the percentage of error in the calculation is highly significant and so the Doppler angle is always set between 0° and 60°, preferably <30°. When the pulsed wave Doppler is switched on, the dotted line and the “= sign” appears. The Doppler angle can be considered or set at 0 when the vessel is parallel to the dotted line. This is often times possible because the dotted line can be swapped across the entire B mode image and the probe manipulation may also help in the alignment of the two. However, if it is still not possible, after achieving the smallest angle between the vessel and the dotted line, angle correction is used. This deviates out a short line from the dotted line, and is tried to align this short line to the vessel (Fig. 30). In trying to do this, the angle between the dotted line and the short line is the Doppler angle. It is displayed on the screen or the touch pad of the scanner (Fig. 31). This angle is to set as <30° preferably and maximum of 60° may be allowed.

Setting the Speed of the Trace

An ideal spectral trace is when there are 4–5 cardiac cycles (Fig. 32) recorded on any one spectrum image. This can be done by scaling
the time axis, or in simpler words, setting the speed of the trace. For most scans, this is possible when the speed is set as 4 or 5. Higher speed gives a trace of too few cardiac cycles (Fig. 33) and lesser speed gives too many cardiac cycle traced (Fig. 34).

**Artifacts**

Inspite of all these settings used to optimize the Doppler images, certain artifacts still cannot be completely eliminated. These are aliasing, mirror image artifact, and artifacts due to electrical interferences.

**Aliasing**

When the Doppler frequency exceeds the Nyquist frequency, it results in aliasing. This is an overlapping effect of systolic and diastolic velocities across the baseline on both the sides of the spectrum. This effect is similar to what we have often observed, especially in movies. The car wheels suddenly appear to start rotating in the opposite direction when the car speeds up.

If the frequency of the oscillations is 5 Hz but the pulse repetition frequency is 2 per second and therefore this signal will see this movement only twice in a second and not only miss the intermittent information but also will interpret that the flow is in both directions. Adjusting the optimum PRF sorts out this problem.

**Mirror Image Artifact**

Mirror image artifact is when a similar spectrum is seen on both the sides of the baseline. This is especially possible when the sample
volume is large and is tracing the flow in two vessels or two loops of the same vessel positioned, side by side (Fig. 35). The second possibility is that a large sample volume is placed on the curve of the loop, when in the proximal half of the loop the blood flow is observed away from the probe by the transducer and in the distal half of the sample volume the flow is perceived towards the probe. Decreasing the sample volume and planning to place it on one vessel only sorts out this problem.

**Electrical Interferences**

These may appear as random signals on color, power or spectral Doppler, (Fig. 36) especially when the scanner is sharing the same electrical line as some high-voltage gadgets and the only way to get rid of this is to plan the electrical supply to the scanner wisely.

**Safety of Doppler**

There is a big scarcity against using the Doppler in the people who are aware of the ill effects of Doppler and a false sense of safety in those who are not aware of these side effects. The two major effects of sound wave when it passes through the human body are:

- Thermal effect: production of heat that may damage the cells;
- Mechanical effect: due to pressure changes on the molecule.

**Thermal Effects**

As the sound waves pass through the body tissues, there is absorption of energy and a transformation of ultrasound energy into heat. The energy absorption is minimal in the fluid and maximum in bones. It is also dependent on the frequency of the ultrasound waves. The absorption is higher with higher frequency waves, and lower with low frequency sound waves. A temperature rise of up to 1°C is considered absolutely safe, whereas if it is >2.5°C, it can lead to a significant tissue damage. This thermal effect is measured as thermal index, and is displayed on the screen. It is generally found that the temperature rise of 2°C is thermal index 2. We know that the temperature rise of 1°C is safe; therefore, the thermal index should be limited at maximum 1. Though it is important here to understand that with higher thermal indices also the damage can occur only after exposure for a certain period of time. Unfortunately, this time is difficult to define confidently. Moreover, since the energy-absorbing capacity of different tissues is different, the thermal index for soft tissues (TIs) and bones (TIB) is different.³

**Mechanical Effect**

When the sound wave passes through the body tissues, it leads to oscillations of the body molecules, resulting in a cavitating (low pressure) phase and a compressing (high pressure) phase. In the negative pressure phase or the cavitation phase, large microbubbles are formed. Once the oscillations reach a certain level, a fluid medium incorporating gas microbubbles is set in motion, which is called microstreaming. This generates a huge strong pressure and leads to bursting of cell membranes. This effect is pronounced if the high frequency, high intensity ultrasound is aimed on a small focus.¹

The second possible mechanism explained is as follows: existing microbubbles or cells undergoing cavitation inflate under the influence of a negative pressure and implode abruptly. This takes microseconds but causes a sudden rise in temperature/pressure and results in tissue destruction. This is transient cavitation and occurs only when energy levels are beyond certain thresholds. This threshold may be quantitatively documented as mechanical index. The mechanical index (MI) is defined as maximum estimated in situ rarefaction pressure or maximum negative pressure (in MPa) divided by the square root of the frequency (in MHz). MI of up to 0.3 can be considered safe and when more than 0.7, it can lead to cavitation.⁴

**Conclusion**

Doppler is a very useful modality for the assessment of circulation in the human body. Only correct settings on the scanner can give optimum results; therefore, it is very important to understand the basic principles and settings of the ultrasound scanner before starting to use the Doppler for interpretation of vascular flows and information of oxygenation in the human fetus. The Ultrasound and Doppler are generally safe modalities. Their safety can be related to the frequency used and the length of exposure. Therefore, the Doppler should not be used for a long time on a single focus and therefore the ALARA ⁵ (as low as minimum achievable) principle is now applied for all ultrasound scans.

**References**