Top Ten Doppler Errors and Artifacts

In virtually every ultrasound related credentialing exam, questions are asked regarding artifacts. In general, people perceive artifacts as inherently “bad.” There are times when artifacts hide or mask information, and as such are undesirable. However, there are times when the presence of artifacts reveals valuable clinical information when appreciated in the context of the underlying physics.

Now, in this short write-up on the Top Ten Doppler (Color and Spectral) Errors and Artifacts, I clearly will not be able to provide all of the contextual physics which makes artifacts valuable or most easily avoided when not beneficial, but I can at least give you a starting point for thought. So this is my list of the top ten errors and artifacts which occur in color and spectral Doppler.

10. Aliasing
9. Incorrect Color Steering/Angle
8. Overgaining Color
7. Undergaining Color
6. Spectral Mirroring
5. Incorrect Color Scales
4. Spectral Broadening
3. Incorrect Specification of Flow Direction (Doppler Angle)
2. Incorrect Doppler Operating Frequency
1. Believing 60 Degrees is Ideal
Aliasing occurs when the Doppler frequency shift exceeds the maximum detectable frequency (determined by the Nyquist Criterion equal to the PRF/2). The Doppler shift increases (as predicted by the Doppler equation) when the velocity is higher (narrowing, kinks, branches, twists, and increased flow), when using a higher operating frequency transducer, and as the cosine of the Doppler angle increases. The PRF decreases with increasing depth.

Key Points:
- Relatively easy to detect
- Reduced by using a lower operating frequency
- Often indicative of higher velocities (which result from vessel bends, kinking, twists, branches or narrowing)
- More likely with Doppler angles close to 0 or 180 degrees
- More likely to occur with deeper imaging depths

Figure 1. Aliasing in the distal ICA
Incorrect Color Steering/Angle

Since Color Doppler is angle dependent, the angle formed between the interrogating sound beams and the flow should be optimized. For sector transducers, the angle to flow is changed by either manually rocking the transducer or using a different imaging window. For linear transducers, in addition to manual manipulation and different imaging windows, the angle can be changed by electronic steering. As the angle approaches 90 degrees, no Doppler shift is detected and color may not present where flow exists.

**Key Points:**

- Poor angles result in poor color filling
- With linear transducers, the color box should be steered to make the angle to flow closer to 0 or 180 degrees and not close to 90 degrees

**Figure 2. Incorrect Color Steering**

**Figure 3. Appropriate Color Steering**
Overgaining Color

When you adjust the receiver gain with 2D imaging, there is a corresponding change in the brightness of the grayscale image. Color Doppler is a threshold-based technique such that a signal above a specific amplitude (color priority) is displayed as color, and below the specific amplitude is displayed as an absence of color, or grayscale data. At very low color gains, color signals from all flow regions will be below the threshold and no color will be displayed. When the color signal is amplified above the threshold, color is presented. Once color is presented, increasing the color gain potentially will cause very little change in the color image until the gain is high enough that the noise floor signals are amplified above the threshold. Once the noise is amplified above the threshold, color noise speckle becomes apparent in the image. Increasing the gain beyond this point serves only to increase the amount of color noise present in the image.

Key Points:

- Not always easily detected since overgaining generally presents differently superficially than deeper
- Deeper, or at sensitivity limit, overgaining is appreciated as color speckle in non-flow regions (random color speckle overlaid on tissue)
- Superficially, or when not at sensitivity limit, overgaining is appreciated by color presentation bleeding over in non-flow regions (such as overlapping vessel walls)
Undergaining Color

See discussion in Section 8 regarding color gain.

Key Points:

- Undergaining causes an under appreciation of flow
- In the worst case, no flow is appreciated even though flow exists
- Undergaining is rarely an issue with superficial flow
- Learning how to set color gain appropriately for “deeper” flow, when sensitivity could be an issue, is based on increasing the color gain until color speckle appears in non-flow regions and then decreasing the gain until the speckle just disappears

Figure 6. CCA with color undergained
Bi-directional Doppler allows for determination of blood flow direction. The processing chain in bi-directional Doppler systems has a forward channel (I channel) and a reverse channel (Q channel) so that forward flow can be differentiated from reverse flow. If some of a true signal “leaks” into the reverse channel, an artificial signal is presented reflected across the baseline. The artificial signal, referred to as a “spectral mirroring” is weaker in amplitude (not as bright) as the actual flow component, and is exacerbated by stronger (higher amplitude) Doppler signals.

**Key Points:**

- Spectral mirroring presents as artificial flow in the opposite direction of true flow (a spectral signal “mirrored” about the spectral Doppler baseline).
- Detecting spectral mirroring is obvious sometimes (when the artifactual signal is a perfect copy of the true signal) but difficult to detect at times when only certain components of the flow are mirrored.
- The easiest way to determine if spectral mirroring exists is to analyze the brightest (highest amplitude) aspects of the spectrum to see if there is a mirrored component of lower intensity (lower amplitude) symmetric about the baseline. If not, then mirroring is unlikely to exist.
- If the system Doppler circuitry is designed such that the gain and phase match of the forward (I) and reverse (Q) channels are not well matched, mirroring will occur quite frequently.
- Decreasing the transmit power and/or receiver gain can decrease the presence of spectral mirroring, but care must be taken as the actual signal can also be adversely affected (see Figure 7).
- Spectral mirroring can also occur when the Doppler angle is close to 90 degrees (as flow is detected as both towards and away simultaneously). The solution is obviously to stay far way from 90 degree Doppler angles.

**Figure 7. Spectral mirroring**
The color scales are also referred to as the pulse repetition frequency (PRF). The maximum possible PRF is determined by the imaging depth. Deeper imaging results in a lower maximum PRF (or lower maximum color scale). Since color gives an estimate of the mean velocity, the color encoding is based on the mean velocity of the flow detected. Therefore, the maximum of the color scale represents the highest mean velocity that can be presented without color aliasing (flow represented as colors wrapped around the color bar).

Key Points:
- When changing color scales (PRF), color wall filters automatically also change
- Lower scales (lower PRF) result in lower wall filters and hence, improved ability to detect low velocity flow
- Higher scales (higher PRF) result in higher wall filters and hence, can result in an inability to detect low velocity flow
- For cardiac imaging, color scales set too low will artificially increase color jet size
- For cardiac imaging color scales set too high will artificially decrease color jet size

![Figure 8. High scales/High wall filter](image1)
![Figure 9. Low scales/Low wall filter](image2)
Spectral Broadening

Artifactual spectral broadening should not be confused with the normal spectral spread which results from the normal varying flow velocities within a flow region. Spectral broadening results from varying angles to flow when the transmitting region of the transducer (the aperture) is not approximated by a point source. The spread in angles results in some velocities being “overcorrected” and other velocities being “undercorrected.” With respect to appearance of the spectrum, artifactual spectral broadening results in an increase in the detected peak velocity as well as a filling of a spectral window (when a spectral window exists). Since there is both an overestimation and underestimation, the mean velocity is not as significantly affected as is the peak velocity.

Key Points:

- Spectral broadening artifact results in a spreading of spectral signal, increasing peak velocities and potentially filling in a spectral window (when a spectral window does exist)
- Spectral broadening generally occurs with large, linear arrays
- Spectral broadening decreases with increasing depth
- Spectral broadening is exacerbated by larger Doppler angles
- Spectral broadening can result in significantly higher measured peak velocities resulting in spuriously large calculated pressure gradients

Figure 10. Correct angle

Figure 11. Incorrect angle
Incorrect Specification of Flow Direction (Doppler Angle)

Since the detected Doppler shift is angle dependent, it is important to be able to identify the Doppler angle. As already discussed, the angle is formed between the interrogating sound beam and the direction of flow. Some confusion generally arises when people cross between the vascular and cardiac fields as the vascular field teaches “angle correction” whereas the cardiac field generally does not. The primary reason that the cardiac field does not teach angle correction is that for most cardiac applications, the Doppler line can be steered directly parallel to the flow resulting in either 0 degrees or 180 degrees, implying that the entire Doppler shift is detected. With respect to vasculature, because of the anatomy, less optimal angles (such as 50 or 60 degrees) generally result. In these cases, the Doppler angle is specified by setting the flow indicator which goes through the Doppler sample volume. The system then measures the resulting angle between the Doppler steered line and the user set flow indicator.

Key Points:

- In cardiac imaging, the assumption is that the Doppler line is steered parallel to flow (such that the Doppler angle is either 0 degrees or 180 degrees – requiring no angle correction). If the Doppler is not aligned to flow, the Doppler angle is not the assumed angle, introducing error into the Doppler measurement. The further away from parallel to flow, the greater the error.

- In vascular settings, the system determines the Doppler angle based on the user’s setting of the flow indicator. If the flow indicator is not aligned to the flow, the angle “correction” is incorrect (See Figure 12).

- Even when there is a good color flow image, it is quite possible to be off by more than a few degrees from the true direction of flow when setting the flow indicator.

- Recall that there is a third dimension which is not visualized on the ultrasound monitor, therefore, proper alignment to flow in the third dimension (elevation) is not always obvious. For this reason, I believe that even with careful application, flow indicators are often off by $\pm 5$ degrees and sometimes off by as much as $\pm 10$ degrees.

Figure 12. Flow indicator clearly set incorrectly even though system says “60 degrees.” Actual peak systolic velocity is about 75 cm/sec or 50% error.
Incorrect Doppler Operating Frequency

The operating (or transmit) frequency is user selectable. Most modern transducers operate over a range of frequencies (the transducer bandwidth), and allow the user to select more than one frequency at which to image. Most ultrasound systems allow for choice of imaging frequency and color frequency and sometimes allow for choice of spectral Doppler frequency. Higher frequencies result in better resolution but significantly lower penetration. Choosing the correct operating frequency is therefore very important as inadequate penetration or resolution can result in non-diagnostic scans.

Key Points:
- Reflection from blood is based on a very weak mechanism of Raleigh scattering
- Attenuation of ultrasound increases exponentially with increasing frequency and depth
- With the exception of superficial Doppler imaging, the Doppler frequency should be as low as possible
- Using a Doppler frequency that is too high can result in inadequate sensitivity
- Using a Doppler frequency that is too high can result in Doppler velocity measurements that are much lower than reality

Figure 13. Imaging Frequency 4.0 MHz
Doppler Operating Frequency 1.8 MHz

Figure 14. Imaging Frequency 4.0 MHz
Doppler Operating Frequency 4.0 MHz
Believing 60 Degrees is Ideal

As already discussed, because of anatomy, achieving ideal Doppler angles of 0 or 180 degrees is generally not practical when imaging vasculature. Many years back, a Doppler angle of 60 degrees was specified as a “standard.” At that time, setting the standard to 60 degrees made sense based on repeatability and limitations of early imaging equipment. However, as equipment has become better with better steering capabilities, the 60 degree standard persists and the 60 degree angle has taken on mythical qualities of “goodness.”

Key Points:

- Early in duplex carotid imaging when equipment had very limited steering capability, in order to standardize measurements, 60 degrees became the standard angle correct
- Current equipment has greater steering capabilities, allowing for smaller Doppler angles to be achieved
- Realize that it is not always possible to specify the flow direction within plus or minus 10 degrees let alone 5 degrees (see Figure 12; incorrect specification of Doppler angle)
- A few degrees of error around 60 degrees can represent a pretty large deviation in measure peak velocity (the Doppler shift is based on the cosine of the Doppler angle, and the cosine is very nonlinear)
- This problem is exacerbated by the artifact of spectral broadening, which also gets worse with larger Doppler angles
- Smaller Doppler angles are better but consistency still matters. As a result many labs appropriately set a criterion of 45 to 60 degrees
- I generally suggest that labs set a criterion of 45 to 55 degrees, striving to measure velocities at 50 degrees whenever possible

If 90 degrees results in no detected Doppler shift, and hence, infinite error, and 80 degrees is considered unusable, and 70 degrees considered horrendous, why would 60 degrees be the ideal Doppler angle?

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Figure 15. Angle Correction Error (10 degree error) Reprinted with permission: Ultrasound Physics and Instrumentation, 4th Edition, Miele F p. 588
For questions or additional information

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