Doppler

Chapter 19

Doppler

- A moving train with a trumpet player holding the same tone for a very long time travels from your left to your right.
- The tone changes relative the motion of you (receiver) and the player (sound source)
- The *f* appears to increase as it approaches you from the left and decreases as it moves away from you on your right.
- This change in frequency is a Doppler shift and is called Doppler Frequency

Doppler Frequency

- The frequency only changes when there is a change in the source and receiver position.
- There is no change when the source and receiver remain constant.
- This is the primary physical principle which is used to measure the velocity of blood in a vessel

Doppler shift

- Defined as The *f* shift created between the transmitted and received *f* by an interface moving with velocity at an angle to the sound source.
- It is a low *f* that rides or uses as a carrier the higher transmitted *f*
- Separating the two frequencies is done in the system an is call?

Doppler shift

- Doppler shift (Hz) = reflected *f* – transmitted *f*
- A transmitted *f* has a of 5 MHz
- When its reflected off moving blood cells the measures 5.003 MHz
- What is the Doppler shift?
- Is reflects a positive shift because the frequency is higher than the carrier *f*

Doppler shift

- We already know this shift is created when the transmitted sound strikes moving vessels
- Positive shifts are created when the change is higher than the original *f*
- Negative shifts are created when the change is lower than the original *f*

Speed vs. velocity

- Doppler *f* only indicate velocity not speed
- Speed is measured in units or centimeters per second (cm/s) dist./ time
  - Measurement of the distance RBC's travel / s
- Velocity is defined as the speed and direction that the blood is moving

The Doppler equation

$$\text{Doppler shift} = \frac{2 \times \text{speed of blood} \times \text{transducer frequency} \times \cos\Theta}{\text{propagation speed}}$$

Also expressed as

$$f_D = \frac{2vf \cos\Theta}{c}$$

f shift and Blood cell velocity

- It is directly related
- The faster the velocity the higher the Doppler shift that is created
- If the Doppler study produces a shift of 10 kHz with the blood moving at a velocity of 6 m/s. What is the shift when it slows to 3 m/s?

Why is the # 2 in the Doppler equation

- Simply because there are two Doppler shifts In the US exam.
- The first occurs when the sound strikes the moving RBC's
- The second occurs when the reflection from the RBC's returns to the transducer

Hz vs. cm/s

- Current equipment measure the transmitted and received sound frequency and display the information in Hz
- The system computers have the Doppler equation programmed in it and utilize this to simultaneously display both numbers.
- This is important because 3 kHz Doppler in a vessel means nothing but a velocity of 0.4 m/s can mean a great deal to the clinician.

Example of a Doppler shift scale

How are Doppler shift and transmitted Frequency related?

- They are directly related
- If you double the transmitted frequency you so the same to the shift.
- Say a 3 MHz transducer produces a 5 kHz Doppler shift.
- If you change to a 6 MHz transducer what shift will you get?

Primary Beam Direction vs. Flow Direction

- Doppler frequency measurements depend on the direction of the flowing vessel and the direction the beam intersects it.
- If possible the best shift is obtained parallel to the moving RBS's
- This creates a 100% accurate velocity measurement

Primary Beam Direction vs. Flow Direction

- In reality an angle will almost always exist creating a measured velocity that is less than that of the true velocity
- To correct Cosine Θ is used
- By introduction of this into the equation a true velocity can be determined from almost any angle

Nondirectional Doppler

- Systems that measure the presence of moving RBC's by the Doppler shift
- Flow toward or away form the unit will be the same
- Used to detect flow in arteries after repair or fetal heart rate in L & D
- Since output is nondirectional a single speaker is used to hear the pulse

Bidirectional Doppler

- Most common Doppler in clinical use
- Distinguishes flow direction represented by a positive or negative shift in the spectrum
- Requires stereo one speaker is used for flow toward the transducer the second for flow away
- The Doppler spectrum is a graphic display of what is being heard

CW Doppler

- Requires two transducers one constantly transmitting while the other is always listening
- What is the greatest advantage of this type of Doppler?
  - Is can accurately measure extremely high velocities without aliasing
- The primary disadvantage of this Doppler is its inability to determine the exact location of the moving blood cells

CW Doppler

- Signals from the entire overlapping region are heard or displayed without knowing their depth
- This type of limitation is called range ambiguity
- There is also the inability to compensate for depth

CW Doppler

CW transducers

- This transducer contains 2 elements each in the shape of a semicircle.
- Does not produce anatomical images
- Pulses duration are continuous

CW transducers

- For this reason backing material is eliminated resulting in:
  - Undampened signal
  - Narrow band width
  - High quality factor
  - Higher sensitivity

CW transducers

- Matching layers are still necessary
- Why?
- They increase the percentage of sound transmitted into and out of the body

Pulse Wave Doppler

We use it almost every day so it is important that we know how it works

Pulse Wave Doppler

- Differs from CW in that it only has one PZT and uses it to send and receive
- The operator can select the depth at which to hear the Doppler shift by use of a gate
- The system knows where the gate is placed and only listens to the reflections that are within this calculation angle

Pulse Wave Doppler

Advantages
- Selection of location in which to listen to the Doppler shift
  - Decreases the artifact related with CW

Disadvantages
- Inaccurate measurement of high velocities
  - Aliasing results when the velocity is greater than the nyquist limit

Pulse Wave Doppler

- Imaging and Doppler are performed by the same transducer.
- When they are done simultaneously they are called duplex imaging
- Since the transducer is also used for imaging a backing is used resulting in the same characteristics as just imaging PZT's
  - Low quality factor
  - Lower sensitivity
  - Wide bandwidth pulses

Aliasing

- Only seen on pulsed Doppler
- Results from the sample rate is to low for the measured velocity of moving blood
- Results in the peak velocities being cut and wrapped around to the bottom half of the display below the baseline
- **The nyquist limit** is the highest Doppler frequency that can be displayed without aliasing

Aliasing

- When listening to the sound made by aliasing it sounds different. They come from the wrong speaker.

- Nyquist limit (Hz) = $\frac{\text{PRF (Hz)}}{2}$

Depth and aliasing

- More aliasing is created the deeper you go
- Velocities are interrogated many times a second
- This interrogation is directly related to the system's PRF
- When shallow the PRF is high providing a higher Nyquist limit
- When deep the PRF is low resulting in a lower limit

The effect of transmitted frequency on aliasing

- High frequencies create more aliasing because they create higher Doppler shifts
- Aliasing however is less common in lower frequency transducers
- But the trade off is that the image quality is not as good

Aliasing

Less Aliasing

- Slower blood velocity
- Lower frequency transducer
- Shallow gate (high PRF)

More Aliasing

- Faster blood velocity
- Higher frequency transducer
- Deep gate (low PRF)

Techniques to avoid aliasing

- Adjust scale to max.
- Use a lower frequency transducer
- Change to a different position that is closer
- Use CW
- Shift the baseline

Adjust scale to max

- Changes the Systems PRF to its max range
- Advantages
  - increases the nyquist limit less chance of aliasing
- Disadvantages
  - The high PRF decreases sensitivity to low velocities and aliasing can still persist

Use a lower frequency transducer

Advantage

- Since lower frequencies produce lower Doppler shifts you are less likely to exceed the Nyquist limit

Disadvantages

- No significant disadvantages for Doppler but the lower frequencies produce grayscale images of lesser quality

Change to a different position that is closer

Advantage

- New view can provide a closer sample volume resulting in a higher PRF and Nyquist limit

Disadvantage

- None to speak of the only limitation is the sonographer skill with obtaining alternate sites.

Use CW

Advantage
- Aliasing does not occur

Disadvantage
- Range ambiguity
- Overlapping vessels
- No anatomical image

Shift the baseline

- Advantages
- normally the baseline sits in the middle of the spectrum display flow toward the transducer appears above and flow away below.
- By adjusting the baseline to zero higher velocities are displayed in the proper direction

Shift the baseline

- Disadvantages
- The appearance on the display only changes
- The signal will still arise from the incorrect speaker
- It is ineffective when the shift is extremely high

Spectrum gray scale

- Related to the amplitude of all the reflected signals
- And or the number of RBC's creating the reflection

Color Flow Doppler

- Gray scale identifies anatomical structures while color identifies blood flow
- Provides information on flow location
  - To use pulsed Doppler
  - Assist in range resolution
  - But is also subject to aliasing

Color velocity

- Color Doppler uses a mean or average velocity
- Color maps provide a visual reference of how the system convert the velocities into a color image
- These are in a look up table (in the system) with the 2 most commonly use being
  - Velocity mode
  - Variance mode

Velocity mode

- Colors represent flow direction and peak average velocity
- The black is no flow
- Above is flow toward the transducer
- Below is flow away form the transducer
- Colors close to the black are slower that those further away form it

Variance Mode

- Provides additional information from velocity mode
- It disguises turbulent flow from laminar flow
- Colors on the Lt side of the map represent laminar flow
- Colors on the Rt represent turbulent flow

Doppler Packets

- What is it?
- To determine accurate blood flow velocities the area must be sampled with multiple pulses
- This group of pulses are referred to as a packet or ensemble
- The larger the packet the greater number of pulses

Doppler Packets

- This results in a more accurate velocity measurement.
- And provides an increased sensitivity to slow flow
- So why not always have very large packets?
- More time is needed to acquire the information

Doppler Packets

- Resulting in slower frame rates
- And decreased temporal resolution
- The packet size must be balanced with the all factors to provide a quality image

Power Doppler

- Identifies the presence of a Doppler shift
- Is non –directional
- All vessels are represented in the same color
- While CW, CD and Pulsed Doppler process velocity information Power Doppler process amplitude strength without regard to direction
- The amplitude is directly related to the number of moving RBC’s

Power Doppler advantages

- Aliasing does not occur since velocity is not processed
- It is not angle dependent unless it is 90°
- There is an increased sensitivity to low flow rates
  - Useful in a subtotal occlusion or determining venous patency

Power Doppler disadvantages

- The frame rate is slower than CD resulting in reduced temporal resolution
- Any motion will show on the monitor
- Traditional velocity or direction of flow cannot be measured

Doppler artifacts

- While Doppler shifts are mainly produced by moving blood some shifts may be produced by moving anatomical structures
- The most common are pulsatile vessels and the cardiac muscle.
- These low frequency shifts when present in the displayed spectrum are called clutter
- When they are present in the color image they are referred to as ghosting

Doppler artifacts

- How does one eliminate these?
- By the use of a wall filter
- When this filter is adjusted you can create or eliminate this artifact.
- Its only effect is on the low frequency shifts having no effect on the higher frequencies
- With CD it eliminates the color from slow moving reflectors

Crosstalk

- What is it?
- It's a form of mirror artifact that only occurs with spectral Doppler
- The spectrum appears to be bidirectional instead of the normal unidirectional pattern

Crosstalk

- Results from receiver gain set to high
- The angle of insonation is near 90 when the flow in the vessel is at the beams focus

Spectral Analysis

- All blood does not travel in a vessel at the same speed
- Instead it appears to be parabolic in shape
- The center of the vessel is the fastest
- While the slower is at the vessel wall.
- This produces many Frequencies
- Spectral Analysis is the tool used to understand the complex signals that arise and identify their individual velocities

Spectral Analysis

- Spectral Analysis is the tool used to understand the complex signals that arise and identify their individual velocities.
- Two currently methods used are
  - Fast Fourier Transformation
  - Autocorrection
- Older analog methods are no longer used but deserve to be mentioned.
  - Chirp Z transform, time interval histograms, zero crossing detectors

Fast Fourier Transformation

- A digital process used for both Pulsed Doppler and CW.
- Used because it is very accurate
- Displays the various components of the spectral velocity that make up the reflected signal

Fast Fourier Transformation

- So why do we need to display all these frequencies?
- We need to separate turbulent flow from laminar flow
- With laminar flow most RBC's travel at the same velocity so the trace has a narrow line.
- So the spectral window is clean

Image of good quality spectrum

Fast Fourier Transformation

- Turbulent flow is chaotic
- Blood is moving in many velocities and at times in more than one direction
- The spectrum now no longer has a clean line and well define window
- This type of flow is referred to as spectral Broadening

Autocorrection

- A digital technique that analyses color Doppler.
- Used because there are massive amounts of color data to process
- Less accurate than FFT but much faster

Diagnostic Indices

- The pulsatile spectral wave form seen in arteries show a distinction between the systolic and diastolic component of the cardiac cycle
- Two mathematical equations have been formulated to describe this waveform
  - Resistive Index
  - Pulsatility Index

Resistive Index

- This is a quantitative measurement of the Doppler waveform.
- It measures resistance in a segment of a arterial system
- Useful to diagnose stenosis or distal disease

- RI = $\frac{Vel_{max} - Vel_{min}}{Vel_{max}}$

Pulsatility Index

- Similar to RI but it requires one additional measurement
- PI = $\frac{Vel_{max} - Vel_{min}}{Vel_{mean}}$
- Most modern equipment provide the mean velocity measurements automatically

Advantages of RI and PI

- they are objective mathematical measurements not subjective observations
- They depend only on the wave form shape as the equation compares one velocity to another
- The calculation are not affected by the Doppler angle.