Ultrasound Physics

Fundamentals of 2D, Color and Spectral Doppler
Pitfalls and Artifacts

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Disclosures:

I have no disclosures
Objectives

Upon completion of this lesson the student will:

1. Identify how the 2D image is created, potential imaging pitfalls and artifacts, and changes required for image optimization

2. Identify ways the color image is created, potential imaging pitfalls and artifacts, and changes required for image optimization

3. Identify how the PW Doppler is used, advantages, disadvantages, pitfalls and artifacts

4. Identify when CW Doppler is used, advantages, disadvantages, pitfalls and artifacts
How is this image created?

We create an image from reflections that are placed horizontally and vertically based on physics, instrumentation and assumptions.

….so we need to talk about that a bit.
Depth

- Pulse-echo technique – US sent into body, reflects off structures and returns to the transducer
- Reflection return time determines depth
- Pulsing provides time/depth information – vertical axis

\[
\text{Depth (mm)} = \frac{C(\text{mm/us}) \times \text{Time (us)}}{2}
\]

- Pitfalls
  - Propagation speed error
  - Multipath
  - Reverberation
Scan Lines

• The beam is moved through the body in a sweeping action producing real-time

• Displayed reflections
  – Horizontal locations corresponding to the direction of the beam sent out

• Pitfalls
  – Grating lobes and side lobes
  – Refraction
Brightness

• The reflection brightness is based on the amplitude of the reflect
  – Higher amplitude = brighter reflection

• Pitfalls
  – Type of reflector
  – Angle of insonation
  – Attenuation
What does the instrument know?

- The instrument knows only 3 pieces of information about the reflection
  - Strength (amplitude)
  - Direction the beam was sent
  - Arrival time
What does the instrument assume?

• From the 3 pieces of information it KNOWS it ASSUMES the following
  – Strength (amplitude)
    • Strength is related to the anatomy or interfaces
  • Pitfalls
    – Attenuation is assumed to be a constant, which it is not
    – Strength of the beam is assumed to be a constant which it is not
  • Results in shadow, enhancement, focal banding at focal zone
What does the instrument assume?

- **Direction**
  - Assumes the beam went straight down and back once, and all US energy is within the beam
  - Pitfalls
    - May not go straight (refraction)
    - Side lobes or grating lobes
  - Results in echoes in the wrong place horizontally or in the elevation plane
What does the instrument assume?

– Arrival time
  • Assumes the beam went straight down and back once, and traveled 1540 m/s
  • Pitfalls
    – May not go once (reverberation or multipath)
    – May not travel 1540 m/s
  • Results in echoes in the wrong place vertically (depth)
Two outstanding resources for echo artifacts, including video examples, are:


Case

So many artifacts….😊

What about the one starting in the RV?

Shadow artifact – wrong amplitude/strength of reflector
Shadow Artifact

- Loss of image deep to a highly attenuating structure
  - Calcium
  - Catheter
  - Metal (prosthetic valve)
Shadow Artifact

- Remember color and spectral Doppler will shadow too

Mechanical prosthetic MV shadowing PW Doppler to Pulmonary Veins
Case

Is that pacer wire going through the RV free wall?

No

Grating lobe (aka side lobe) artifact
Sound outside of the primary beam, taking a path other than what the instrument assumed

Duplicate echoes placed incorrectly horizontally

Bertrand et al, JASE, May 2016
Grating/Side-Lobe

The ultrasound beam is 3 dimensional
Grating/Side lobe also come out in the elevation plane
Case

How many hearts?

Just 1

Mirror image artifact
Mirror Image

Sound does NOT go straight down and straight back to the transducer as expected.
Duplicate echoes in the wrong location, too deep.

Bertrand et al., JASE, May 2016
Resolved with Depth Correction
Mirror image with color Doppler

Slight angle change can improve the image and reduce the mirror image.
Case

I know, there is a lot going on here…

This is an apical 4 chamber

This patient has a Starr-Edward (Ball in Cage) mitral valve placed in 1986.

The RV and RA are severely dilated

Identify the phenomenon identified by the yellow arrow

Reverberation artifact
Sound make the path to the reflector more than once, this take more time
Duplicate echoes
• Equally spaced
• Decreasing in amplitude
• Deep to the second reflector

Bertrand et al., JASE, May 2016
Reverberation on pacemaker wire  

Reverberation in RV
Comet Tail

Comet tail (sometimes referred to as ringdown – inconsistent terminology) is a type of “short range reverberation.” Sound is bouncing between two closely spaced structures. Often seen at the lung/pleura interface and devices (pacemaker wires, MR clips, etc.)
Mitraclip
The consolidated lung results in no comet tail. Also you can see the lung.
Continuing with the Starr Edwards MV case…

What phenomenon do you expect related to the Silone poppet of the valve?
The propagation speed of the poppet is <1540 m/s

The poppet appears “oval” because the slow propagation speed displaced the deep side of the poppet further from the transducer

Can make the LA measure larger in A4ch
Case 5

Artifacts can be when something is MISSING that you should see.

Drop out artifact of the IAS

Must be perpendicular to see it well

Subcostal
The IAS is a specular reflector
Specular reflectors need to be insonated at 90 degrees to be seen well
Types of Reflectors

• Specular reflector
  – Large, flat, smooth boundary
  – Valves, vessel walls, endocardium, pericardium

• Scatter (Diffuse, non-specular)
  – Diffusion or redirection of sound in several directions
  – Small boundaries
  – Rough surface
  – Myocardium
  – Liver
Refections

Specular

Diffuse
Specular vs. Diffuse

- **Specular**
  - Perpendicular
  - Create artifacts
    - Missing reflections
    - Wrong location
    - Wrong amplitude

- **Diffuse**
  - Any angle
Refections

Brighter because it is at 90 degrees
Linear measurement are done in the PLAX to be perpendicular to the wall interface (specular)
Linear measurement are done in the PLAX to be perpendicular to the wall interface (specular)
Doppler Technique

- Doppler technique is the opposite of 2D
- Doppler shift is maximum at 0 degrees
- Doppler shift is zero at 90 degrees
- To report an accurate \textit{CALCULATED} velocity we must have an angle of less than 20 degrees
- Apical widow is most used for Doppler
Doppler

- Change in reflected frequency compared to frequency sent out when there is motion between source and reflector

\[
\text{Doppler frequency} = \text{reflected frequency} - \text{transmitted frequency}
\]

Doppler frequency = \((2 \times \text{transmitted frequency} \times \text{velocity} \times \text{Cos angle}) / \text{propagation speed}\)

Calculated Velocity = Doppler Shift \times \text{propagation speed}

2 \times \text{transmitted frequency} \times \text{Cos angle}
Doppler

- Amount of change dependent on velocity of reflector, transmitted frequency and angle between source and reflector
- **Doppler shift increases with:**
  - Increase velocity of reflector
  - Increase frequency of transducer
  - Make angle closer to 0 degrees (parallel)
- No Doppler shift at 90 degrees
In Echo we keep the angle $<20^\circ$ to minimize this effect.

This is what happens if the angle is 0 degrees.
The DS is maximum, Cos of angle is 1 so no effect on velocity calculation, accurate and maximum calculated velocity

$$\text{Velocity (m/s)} = \frac{\text{DS (MHz)} \times \text{C (m/s)}}{2 \times \text{Transmitted Frequency (MHz)} \times \text{Cos}}$$

(1)

This is what happen if you do NOT angle correct.
The DS decreased, no adjustment for Cos of angle, so calculated velocity

$$\text{Velocity (m/s)} = \frac{\text{DS (MHz)} \times \text{C (m/s)}}{2 \times \text{Transmitted Frequency (MHz)}}$$
FYI – other vascular imaging requires angle correction

This is what happens if the angle is 60 degrees and you angle correct. The DS is decreased, Cos of the angle is .5 to adjust for the DS reduction, so the calculated velocity increased (from what is would have been without angle correction) to a more accurate calculated velocity.

\[
\text{Velocity (m/s)} = \frac{\text{DS (MHz)} \times C (m/s)}{2 \times \text{Transmitted Frequency (MHz)} \times \cos(0.5)}
\]

Think of this as off-setting functions. The DS decreased the calculated velocity; the Cos of the angle increased the calculated velocity. So you’re left with a balanced equation with an accurate velocity.

No angle correction
- Displayed “velocity” approximately .5 m/s

With angle correction
- Calculated velocity is approximately 1 m/s
LOVT with Color – same scale

PLAX is 90 degree
Less Doppler shift
No aliasing

A5ch is close to 0 degree
More Doppler shift
Aliasing
Doppler Angle – Velocity Vector

- If direction of reflector is not parallel to direction of sound the DS will be reduced
- This will reduce the calculated velocity, underestimating pressure gradients
- We use different windows to get angles of <20 degrees to minimize this effect
- Angle of 60 degrees will result in 50% reduction in velocity calculation
- Angle of 45 degrees is roughly a 30% deduction

Use only the highest velocity to calculate the PG.
Velocity Error due to Angle

PLAX RV inflow is best angle

PLAXRV inflow is highest velocity
What is another scenario that we assess velocity from multiple windows?

Aortic stenosis must be evaluated with Pedoff transducer

- Smaller footprint provides for better angle to stenotic jet

From 3 windows
- Apical
- Right parasternal
- SSN

Highest calculated velocity from the window closest to 0°
Non-imaging CW

- Pedoff
  - Continuous wave (blind)
  - Smaller footprint to better angles
  - Used
    - AS – Apical, Rt Parasternal, SSN
    - All prosthetic or repaired valves
      - Aortic as above
      - MV apical only
Can you identify two artifacts with the color Doppler?
Color Aliasing

- Aliasing artifact occurs when the pulsing rate (PRF) is too slow for the DS frequency being sampled.
- Causes the flow to be displayed on the wrong direction.
- Aliasing occurs if the DS exceeds
  - **Nyquist Limit** – max DS that can be sampled accurately
  - \( NL = \frac{1}{2} \text{PRF} \)
- PRF is limited by depth.
- Increasing the depth will decrease the maximum PRF possible, resulting in aliasing at a lower DS.
Color Mirror Image

As we have already discussed
Case

What is the Doppler artifact?
Aliasing

- PRF is too slow for the DS frequency being sampled
- DS exceeds Nyquist Limit
- How to eliminate
  - Baseline (cut and paste)
  - Increase scale (PRF) – this is limited by depth
  - Decrease DS by decreasing the operating frequency of the TB (already decreased by design)
  - CW Doppler
  - HPRF
LVOT PW – Aortic Valve CW

Typical placement of sample gate for LVOT velocity, 0.5 cm proximal to the valve
LV Midcavity Obstruction

With LVOT or Midcavity obstruction the CW is used to identify the PEAK VELOCITY and the PW is used to identify the LOCATION (Depth).

5ch with CW, 5 m/s – but where?
“Step Through” with PW

PW at various locations to demonstrate LOCATION of the highest velocity
High PRF (HPRF)

- Doppler approach that intentionally pulses too fast, creating range ambiguity

- Advantages – eliminates aliasing and allows for velocity measurement with PW

- Disadvantage – multiple sample gates with risk of contamination

- Uses in echo are rare – LVOT or midcavity obstruction with concurrent AS
HOCM and AS
Case

Findings?

A Note about Amplitude

• The amplitude of the Doppler signal is represented by brightness
• Amplitude is determined by how many reflectors (RBC) are creating the DS
• Larger area = more RBC = higher amplitude
• Smaller area (stenosis) = less RBC = lower amplitude/weak

I’m not suggesting you calculate AS this way, just FYI you’ll see it
Near field artifact/clutter can be challenging.
2D adjustments include: zoom/depth, focus at the apex, different window, 2 planes.
May use image enhancing agents.

Case

Apical thrombus?
Move focus
Colorize
Depth and Higher Frequency
Near field Artifact

Definity contrast
Beam width/slice thickness artifact
The elevation plane picks up echoes from adjacent area and displays them within the scan plane
2D techniques include: different window, 2 planes, scan through in real-time

LAA Thrombus?
Beam Width Artifact

PSAX, apparent turbulence in left pulmonary artery is actually turbulent MR in LA picked up via elevation plane and beam width.

The matrix transducers have a thinner beam (better elevation resolution) which decreased the beam width artifacts.

Bertrand et al, JASE, May 2016
Beam Width artifact in aorta

Beam Width artifact in LA
Case

Subcostal SAX at Base

Refraction anteriorly (liver or abdominal wall) causes refraction of the beam

Duplicate echoes are placed in the wrong location horizontally

“Mirror image” of the aorta, but this time horizontally

Bertrand et al, JASE, May 2016
The beam changes direction when it intersects a specular reflector at an angle (not perpendicular)

This redirection will cause shadows or duplicate echoes in the wrong location horizontally
Edge Shadows (Refraction Artifact)

The redirection will cause shadows

Often seen in SAX at pap muscle
Summary

1. Identify how the 2D image is created, potential imaging pitfalls and artifacts, and changes required for image optimization
   - Shadow
   - Grating/side lobes
   - Reverberation (mirror image, comet tail)
   - Drop out
   - Near field clutter
   - Beam width
   - Refraction

2. Identify ways the color image is created, potential imaging pitfalls and artifacts, and changes required for image optimization
   - Shadow
   - Angle
   - Aliasing

3. Identify how the PW Doppler is used, advantages, disadvantages, pitfalls and artifacts
   - Angle - Velocity calculation
   - Aliasing

4. Identify when CW Doppler is used, advantages, disadvantages, pitfalls and artifacts
   - Angle – velocity calculation
   - Contamination
References

