Primer and Clinical Significance of Artifacts in Ultrasound

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Disclosures

- I am not a physicist
- I never wanted to be a physicist
- I am not capable of being a physicist
- I should not be presenting to physicists
- I do not believe in the supposed “theory” of gravity
- I will have no time for questions
artifact also artefact (är t -f kt ) n.

- 1. An object produced or shaped by human craft, especially a tool, weapon, or ornament of archaeological or historical interest.
- 2. Something viewed as a product of human conception or agency rather than an inherent element.
- 3. A structure or feature not normally present but visible as a result of an external agent or action, such as one seen in a microscopic specimen after fixation, or in an image produced by radiology or electrocardiography.
- 4. An inaccurate observation, effect, or result, especially one resulting from the technology used in scientific investigation or from experimental error.
IMPRESSION:
1. Discrete anechoic lesion with greatest dimension of 2.1 cm in the superior aspect of the right kidney may represent dilatation of a duplicated collecting system.
2. Increased echogenicity of the superior aspect of the right kidney may be secondary to infection.

Artifacts can change management of patients!
Artifacts: Things to know

- Artifacts are often present in multiples.
- Occur due to:
  - Equipment malfunction or design
  - Operator error
  - Violation of assumptions
  - Physical principles
Assumptions

- The transmitted wave travels along a straight line path from the transducer to the object and back to the transducer.
- The attenuation of sound in tissue does not vary.
- Beam dimensions are small in both section thickness (elevational) and lateral directions.
- All detected echoes originate from the axis of the main beam only.
- All received echoes are derived from the most recently transmitted pulse.
More Assumptions

• The ultrasound wave travels in soft tissue at a constant rate of 1540 m/s in tissue

• Each reflector contributes a single echo when interrogated along a single scan line

• The amplitude of the echo is related to the characteristics of the object scanned and is directly related to the reflective properties of the object
Categories of Artifacts

- Image detail resolution related
- Locational artifacts
- Attenuation artifacts
- Doppler artifacts
Resolution

(Depth, Range)

Axial

(Lateral)

(Beam Width)

Elevational

(Beam Thickness)

Transducer
Axial Resolution

- The ability to display two reflectors along the axis of the beam as distinct
- SPL (mm) = # of cycles in the pulse x the wavelength
- If two reflectors are closer than the SPL/2, they appear as one reflector
- Higher frequency sound → better axial resolution
Axial Resolution

Increased transducer frequency = improved axial resolution
Lateral Resolution

- The ability to display two adjacent reflectors as distinct when lying perpendicular to the axis of the beam.
- Related to the width of the sound beam which can be altered with focusing.
- If two reflectors lying side-by-side are insonated at the same time, due to the width of the sound beam, they will appear as one reflector.
Lateral Resolution

Focal Zone

Image

=
Elevational Resolution

- Determined by the thickness of the imaging plane
- Measured in a direction perpendicular to the imaging plane
- True reflector lies above or below the imaging plane.
- May “fill in” anechoic structures
Slice Thickness Artifact

![Diagram of Slice Thickness Artifact]

False  True
Artifactual Echoes Urinary Bladder
Mass in the Bladder?

No! Bowel which is outside the main beam
Locational Artifacts

- Refraction
- Reverberation
- Comet tail
- Ringdown
- Multipath

- Lobes: Side, Grating
- Speed error
- Range ambiguity
- Mirror image
Refraction

- Predicted by Snell’s Law
  \[ \frac{C_i}{C_t} = \frac{\sin(\theta_i)}{\sin(\theta_t)} \]

- Requires
  - Oblique incidence
  - Different propagation speeds in the two media
Refraction: Types

- **Misregistration**
  - Improper placement
  - Distortion of size or shape

- **Defocusing**
  - Loss of beam coherence
    - Shadowing at the edge of large curved structures

- **Ghost image**
  - Duplication of a structure related to significant acoustic impedance mismatch
Refraction: Misregistration

Object outside of primary beam appears to reside within the beam due to return of refracted sound to the transducer.
Refraction/Misregistration

Apparent discontinuity of the diaphragm due to irregular fatty liver
Refraction: Ghost Image Triplets?

Fake object

Real object

Fake object

Refraction
Apparent aortic duplication due to refraction associated with rectus musculature
Refraction/Defocusing

- Hypo- or anechoic bands at the edge of a curved object
- Extends downward from the curved reflector’s edge parallel to the beam
- Prevents visualization of true anatomy
- Typically seen with fluid-filled structures
Refractile Shadow
Refraction Due to Rectus Musculature?

No! Duplication of the Inferior Vena Cava
Reverberation

- Additional echoes from an interface which are recorded on the image due to repeated reflections prior to reception. Only the first reflection is spatially correct
  - Series of bright bands
  - Parallel to sound beam’s main axis
  - Decreasing in intensity
  - Equidistant from each other
- Echoes can appear between the transducer and a strong reflector or between two strong reflectors
- Echoes may also be the result of defective equipment or improper technique
Reverberation

Echoes are separated equally in time ("step ladder") with decreasing echo amplitude.
Reverberation
Comet Tail

• A series of echoes created by multiple reflections within a small but highly reflective object or close reflective interfaces with acoustic impedance mismatch

• Characteristics
  • Single long hyperechoic echo
  • Parallel to the sound beam’s main axis
  • “Trails off” distally. Decreased amplitude = decreased width
Comet Tail

- May arise from the near wall of the gallbladder when crystalline deposits are present in adenomyosis.
- Thought to be produced by “inspisated” colloid in thyroid nodules.
- Surgical clips, staples, sutures and mechanical heart valves are common sources for comet tail artifact.
- May occur with gas.
Comet Tail

Internal reflections give rise to multiple echoes from an object.
Comet Tail Artifact

Cholesterol crystals in gallbladder
Comet Tail Artifact

Colloid cyst in the thyroid
Ringdown (Resonance)

- Similar to comet tail artifact
- Typically occurs due to the resonance (vibration) of fluid trapped among gas bubbles after being bombarded with ultrasound
- Vibrations produce a continuous sound wave that is transmitted to transducer
Ring-down Artifact

Gas
Multipath

- Results from insonating a specular reflector at an oblique angle
- Reflection angle equals the incident angle.
- The sound wave encounters a second reflector which then redirects the sound wave back to the transducer
- Based on a longer time of flight, a second copy of the reflector is placed artifactually deeper in the image.
Multipath

Real object

Artifact
Side Lobes & Grating Lobes

- Side lobes — weak, off axis lobes associated with a single piezoelectric element
- Grating lobes — weak off axis lobes associated with an array transducer
- When these weak off-axis lobes encounter a strong specular reflector, energy can enhance the beam
- This can produce clutter
- Lobe artifacts can be reduced by transducer design (varying voltage strength, smaller element size), varying transducer angle
Lobe Artifacts

[Diagram showing Lobe Artifacts with labels GL and SL]
Speed Error

- Traditional sonographic equipment presumes a sound propagation velocity of 1540 m/s
- Reflectors will be inappropriately positioned if the propagation velocity is different
- Propagation velocity >1540 m/s
  - Go-return time short ➞ reflector appears shallow
- Propagation velocity <1540 m/s
  - Go-return time long ➞ reflector appears deep
- Hence the development of speed of sound correction
Range Ambiguity

- Shallow depth settings have short go-return times (high PRF’s)
- For shallow reflectors some of the sound energy is reflected and some is transmitted
- Superficial reflected sound energy arrives at the transducer before a second sound pulse is generated
- Deeper (delayed) arrive at the transducer after the transmit of the new pulse
- The system interprets the echoes returning from depth as being associated with the second pulse
- **The system places these echoes in the image near field**, assuming these are early returning pulses from the second pulse
- Alter depth or PRF/utilize lower frequency transducer
Mirror Image

- Created as sound reflects off of a strong reflector and is redirected toward an object
- **Appears as a second copy of the object which is placed deeper on the image**
- Mirror is always present along a straight line between the transducer and the artifact
- True reflector and the artifact are equal distances from the mirror
Mirror Image

Object

Strong reflector

False Image
Hepatic hemangioma is mirrored on the opposite side of the diaphragm.
Attenuation Artifacts

- Acoustic shadowing
- Enhancement
- Reverberation
- Comet tail
- Ring down
- Refraction
- Speckle
Acoustic Shadowing

- Anechoic or hypoechoic region seen deep to a highly attenuating medium
- Prevents visualization of true anatomy
- May be classified as:
  - **Clean**: Posterior to calcification or bone due to high percentage of absorption & reflection with no transmission
  - **Dirty**: Posterior to air filled structures due to high percentage of reflection & small percentage of transmission with secondary reflections
Acoustic Shadowing

“Clean” Shadow
If the reflector is small, shadow may not be visible, since the beam width may exceed the stone diameter. Adjust the focal zone to the level of the reflector and/or increase the frequency to improve visualization of shadow.
Acoustic Shadowing

“Dirty” shadow due to bowel gas
“Dirty” Shadow

Emphysematous Pyelonephritis

Non-dependency suggests gas
All That Shadows is Not Calcium or Gas!

Angiomyolipoma of the kidney
All That Shadows is not Gas or Ca++

Embolization coils producing shadow
Tissue Characterization: Complexity: A Clue to Diagnosis
Fluid + Fat + Soft Tissue + Ca++ = Dermoid
No! Typically produces increased through transmission, not shadowing
Bladder Echoes: Real or Not?
Turn the Patient!

Supine
Shifting Debris

LLD
Acoustic Enhancement/Increased Through Transmission

- Due to lesser sound attenuation of structure compared with surrounding tissues
- Typically seen with fluid filled structures, but may occur with homogeneous solids to a lesser degree
- Hyperechoic region extending beneath an abnormally low attenuating structure
- Considered a beneficial artifact
Posterior Enhancement

Enhancement seen posterior to the gallbladder

Edge shadow
Acoustic Enhancement:
Hepatic Lymphoma

Increased through transmission with homogeneous solid
Focal Enhancement

- Aka – Focal Banding
- Side-to-side region of increased intensity at the focus of an image
- Most notable with linear array transducers
- Decrease the artifact by altering focal zone, increasing # of focal zones
Speckle

- Due to scattering: constructive and destructive
- Associated with normal appearance of:
  - Liver parenchyma
  - Spleen
  - Heart muscle
  - Skeletal muscle
  - Thyroid
  - Kidney
- Coarseness of speckle pattern decreases with increasing transducer frequency
Speckle: It’s What Makes a Liver a Liver

Extra credit: Name the artifact
Pancreatic Mass?

Nope!
Duplex Sonography: Pitfalls in Abdominal Imaging
Whenever there is relative motion between a sound source and a reflector, there will be a change in the frequency of the reflected sound.
Duplex Sonography

• Combines imaging and pulsed Doppler
• System oscillates between two functions
• Image updated for accurate sample volume and Doppler angle
• There is “competition” between system components. Each is strongest with other off
  • Freeze image for Doppler
  • Freeze Doppler for imaging
  • Update sparingly
Color Flow Doppler

- Requires multiple, shorter pulses to produce image
- Utilizes autocorrelation
- Approximates multiple gates
- Mean velocity only
- No angle correction, but angle dependent
- Color saturation, hue proportional to velocity
- Less sensitive to flow than pulsed Doppler
  - Use smallest color box possible to increase frame rate

Answers the age old color Doppler question on flow direction: How does it know?
Power Doppler

• Conventional
  • The flow information is based on echo amplitude
  • No velocity or directional information
  • Very sensitive to slow flow and small vessels (higher S/N), detects flow perpendicular to beam
  • Very susceptible to motion (flash artifact), poor temporal resolution

• Directional
  • Combines power (amplitude) of Doppler signal with directional (phase) information
The Doppler Equation

\[ \frac{2 f_v \nu \cos \theta}{c} \]

- Larger angle
  - Smaller cosine \( \theta \)
  - Smaller Doppler shift
  - Decrease apparent \( V \)
  - At 90° no Doppler signal
- Smaller angle \( \theta \)
  - Larger cosine
  - Larger Doppler shift
**Effect of Incorrect Doppler Angle on Measured Velocity**

Doppler shifted frequency and therefore calculated velocity varies with \( \cos \theta \).

If the Doppler angle is not parallel to the vessel walls/flow stream, the calculated velocity will be in error.

**Appropriate Doppler Angle: Angle Correction Parallel to Vessel Wall**

**Angle Correction Not Parallel to Vessel Walls**
Other Doppler Parameters

- **Power**: transmitted power into tissue (ALARA)
- **Gain**: overall sensitivity to flow signals
- **Pulse repetition frequency** (scale)
  - low pulse repetition frequency to look at low velocities
  - high pulse repetition frequency reduces aliasing
- **Gate size** adjustable (spectral) and should be minimized for sampling, enlarged for “searching”
- **Beam steering** can allow improved Doppler angle
- **Presets** by organ/body habitus and Post-processing
Doppler and Imaging: The “Must Knows”

- Doppler only recognizes flow vector that is parallel to beam (less than “true” flow)
- Larger Doppler angles = smaller Doppler shifts
- Higher reflector (RBC) velocity = greater Doppler shift
- Higher operating frequency = greater Doppler shift
- Duplex requires short pulses for imaging, long for Doppler
  - The system alternates, and produces “competition”
  - Imaging best with Doppler frozen
  - Doppler best with imaging frozen
Doppler and Imaging: The “Must Knows”

Color Doppler

- For each location in window scanner determines
  - Flow direction
  - Mean value
  - Variance
- Window size affects frame rate
  - larger window = slower scanning (↓PRF)
  - more Doppler pulses required

and.... for Power Doppler

- Very sensitive to slow flow and small vessels (higher S/N), detects flow perpendicular to beam
- Very susceptible to motion (flash artifact), poor temporal resolution
Duplex Sonography: Potential Pitfalls

- For all Doppler studies
  - Inappropriate Doppler gain
  - Inappropriate Doppler scale
  - Inappropriate Doppler angle
  - Aliasing/Range Ambiguity
  - Mirroring
  - Wall filter

- AND for color Doppler
  - Perivascular color: tissue vibration
  - Color assignment in moving, anechoic spaces
  - Color bleeding: Doppler gain too high
  - Specular reflector: highly reflective interfaces
  - Twinkle artifact
Wall Filter: Effect on Spectral Display

- Filters out low frequency high amplitude shifts (high pass) due to soft tissue (wall) motion that would overwhelm flow
- Adjustable, but still may cause erroneous estimation of End Diastolic Velocity (EDV)
Resistive Index Erroneously Measured as 1.00 Due to Wall Filter
“Auto-trace” Limitations

Auto-trace is a machine-generated, time saving tool that may improve accuracy when spectral tracing is strong and technically good.

Weak spectral signal, high wall filter and auto-trace = Disaster
Spectral Doppler Scale

- Scale should allow visualization of entire waveform with size suitable for measurement
- High scale reduces visibility of waveform morphology and predisposes to inaccurate measurement
- Low scale may produce aliasing
Color Doppler Scale

- Color scale should produce gentle shading of color due to change in blood flow velocity or Doppler angle
- Wide scale may simulate thrombus
- Narrow scale may produce aliasing and be mistaken for flow acceleration
Doppler Sample Volume

• Spectral Doppler
  • Sample volume can be increased when searching for stenosis, but should be decreased when sampling
  • Too large a sample volume may incorporate more than one flow stream or vessel and average velocities
  • Too small may result in missing a stenotic jet

• Color Doppler
  • Color box should be as small as possible to allow adequate frame rate for increased Doppler sensitivity
Sample Volume Incorporates Arterial and Venous Flow
Aliasing

- Nyquist limit = 2x PRF (pulse repetition frequency)
- Aliasing occurs when frequency exceeds the Nyquist limit
  - Increasing the PRF or decreasing baseline will diminish aliasing
  - Reducing the depth of the sample volume (gate) will allow an increase in the PRF.
  - Reducing the frequency of the transmitted pulse \( (f_t) \) will reduce the Doppler shifted frequency.
  - Decreasing the angle between the beam axis and the vessel axis will reduce the Doppler shifted frequency.
- Aliasing may be a useful indicator of high-velocity flow, stenosis detection
Aliasing

- **Spectral aliasing produces a wrap-around effect** on the Doppler display with the peaks of the waveforms “cut off” and displayed on the opposite side of the baseline.

- **Color Doppler aliasing projects the color of reversed flow within central areas of highest velocity**

- True color changes from red to blue shades are etched in black and involve the deepest shades on the color scale. This occurs due to:
  - Changes in the Doppler angle
  - Reversal of blood flow direction

- **Color changes caused by aliasing are not etched in black and involve the brightest colors on the color scale**
Aliasing: Peak Systole “Cut Off” and Displayed Below Baseline

Aliasing Corrected by Widening the Spectral Scale
Aliasing may be a useful indicator of higher velocity flow

- Mild Portal Vein Anastamotic Stenosis
- Focal area of aliasing
- Color Doppler localization for spectral sampling
Perivascular Tissue Artifact = Visible Bruit

Tissue vibration artifact is produced by turbulence and may provide clue to disease

• severe stenosis
• arteriovenous fistulas
• shunts
Soft Tissue Motion = Enemy of Doppler

“Take a deep breath”
Assignment of Color to (Moving) Anechoic Spaces: Flash Artifact Will NOT Produce a Spectral Tracing

LONG LT KIDNEY
Increase gain until small amount of “noise” in tissues, then back it down
“Bleeding” = Overwriting

- Gray scale images a must!
- May obscure pathology
- Decrease gain
- Adjust scale to allow visualization of vessel walls
Twinkle Artifact

- At a highly reflective interface, the US beam undergoes a phase shift, resulting in an increase in pulse duration.
- Multiple incidental beams generate various Doppler shifts.
- **Produces rapidly changing mixture of red and blue colors.**
- Focal zones placed distal to the stone increase the artifactual color signal.
- Not specific: Occurs with close to 90% of stones, but other bright reflectors can produce twinkling, e.g. gas.
- Spectral Doppler demonstrates no flow.
Mirror Image

- Created as sound reflects off of a strong reflector and is redirected toward an object
- Appears as a second copy of the object which is placed deeper on the image
- Mirror is always present along a straight line between the transducer and the artifact
- True reflector and the artifact are equal distances from the mirror
- Doppler data also duplicated
Mirror Image: Imaging and Doppler

Rt Sub Long

Subclav Rt

Pleura

Rt Sub Long

Rt Sub Long
Spectral Duplication: Mirror Image Appears on Opposite Side of Baseline

- Electronic duplication: gain set too high
- True sensing: too large of a Doppler gate: beam covers flow in both directions from same vessel
- Decrease gain
- Decrease gate size
High PRF and Range Ambiguity

High PRF systems emit multiple pulses without waiting for the original one to be received. This results in an increase in PRF and a spectral display that is not aliased.

This produces ambiguity in signal origin, with multiple potential sites displayed (arrows).

Range Ambiguity can also occur with color Doppler with superficial display of a deep vessel.
“Take Home Points”
“Take Home Points”

- Smaller Doppler angles are preferred
- The Doppler angle should reflect the actual flow vector
- Sample volume/color box should be minimized for interrogation
- Doppler and imaging “compete” when used together
- Spectral and color scales must be optimized to avoid errors
- Doppler gain should be adjusted to avoid excessive signal
- Artifacts related to aliasing, motion and echogenic interfaces are common
Conclusions

Doppler artifacts are generally easily recognizable and may provide a clue to diagnosis if interpreted correctly.

Questions or Suggestions?
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Something Fishy? Consider Artifact

http://radiology.uchicago.edu/page/faculty-lectures