



## Module 4: Display Modes, Image Formation & Temporal Resolution

Carlos Jimenez PhD(c), DPT, RMSK, CPSS

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## Display Modes, Image Formation & Temporal Resolution

- Display modes (A, B, M)
- Scan conversion
- Digital storage
- Frame rate
- Real-time image behavior

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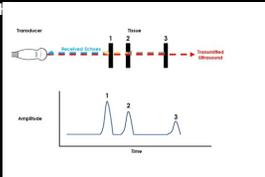
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## A-Mode

- Amplitude Mode (Rarely Used in MSK)
- Represents echo amplitude vs depth
- Used in ophthalmology, not MSK



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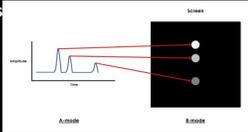
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**B-Mode**



- **Brightness Mode — Core of MSK Ultrasound**
- Echo amplitude → grayscale brightness
- Most common imaging mode in MSK
- 2D anatomical representation



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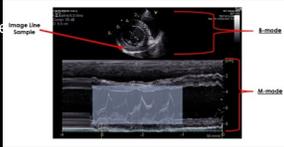
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**M-Mode**



- **Motion Mode - Useful for Dynamic Structures**
- Shows motion along a single line
- Useful for:
  - Snap phenomena
  - Muscle fasciculations
  - Tendon subluxation



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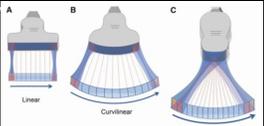
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**SECTION B - Real-Time Imaging Overview**



- Machine Reconstructs Image Line-by-Line
- One pulse creates one scan line
- Many lines = one frame
- Frame rate depends on line number



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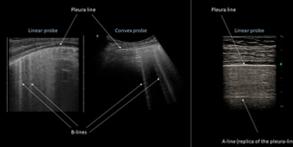
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### Scan Line Density

- More Lines = Higher Detail but Lower Frame Rate
- High density = smoother edges
- Low density = higher frame rate



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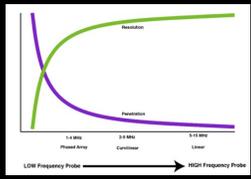
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### SECTION C — FRAME RATE & TEMPORAL RESOLUTION

- Depth, Line Density, Field Width, PRF
- Frame rate when:
  - Depth ↓
  - Sector width ↓
  - Line density ↓
  - PRF ↑



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### Temporal Resolution

#### Accuracy of Motion Representation

- Higher frame rate = better temporal resolution
- Essential for scanning:
  - Snapping hip
  - Dynamic tendons
  - Joint instability

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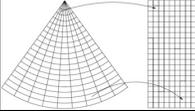
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 **SECTION D - SCAN CONVERTER & MEMORY**  
**Scan Converter Function**

- Analog Echo → Digital Pixel Matrix
- Converts beam data into stored image
- Determines pixel resolution
- Coordinates image spatial mapping



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 **Analog vs Digital Storage**

- Digital Storage Dominates Modern MSK Ultrasound
- Digital storage: higher fidelity
- Easier archiving
- Better post-processing

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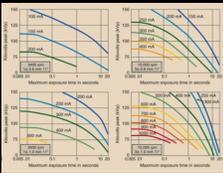
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 **Preprocessing**

- Adjustments Made Before Data Is Stored
- Affects raw data
- Includes:
  - TGC
  - Dynamic range
  - Write zoom
  - Edge enhancement



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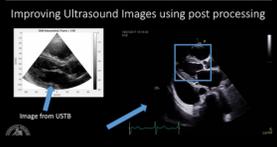
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**Postprocessing**

- Adjustments Made After Data Is Stored
- Includes:
  - Gray-scale curves
  - Read zoom
  - Map changes

Improving Ultrasound Images using post processing



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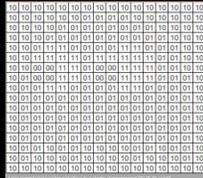
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**SECTION E — DISPLAY & IMAGE STORAGE**  
**Binary System**

- How Ultrasound Assigns Digital Values
- Each pixel = numerical value
- Stored as binary (0/1 sequences)



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**Steps in Processing Echo to Image**

- From Raw Echoes to Diagnostic Display
- Receive echo
- Process via receiver functions
- Convert to digital
- Store
- Display image

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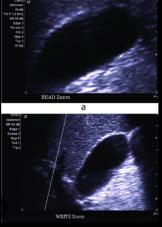
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 **Read vs Write Zoom**

- True Resolution Zoom vs Pixel Enlargement
- Write zoom = higher resolution
- Read zoom = magnification only



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 **SECTION F — PRACTICAL MSK IMPLICATIONS**  
**How These Concepts Improve MSK Scanning**

- Theory → Image Quality → Diagnosis
- Frame rate for dynamic tests
- Write zoom for tendon pathology
- Compression & DR for nerves

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 **RMSK Exam Focus Areas**

- High-Yield Content for RMSK
- Temporal resolution
- Pre vs postprocessing
- Frame rate determinants
- Display modes
- Scan conversion



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 **References Module 4**

- Kremkau FW. *Diagnostic Ultrasound: Principles & Instruments*.
- Hedrick WR et al. *Ultrasound Physics & Instrumentation*.
- Hoskins PR et al. *Diagnostic Ultrasound: Physics & Equipment*.
- Szabo TL. *Ultrasound Imaging: Inside Out*.
- Rumack CM et al. *Diagnostic Ultrasound*.
- AIUM Technical Standards.
- Athanasiou & Tardivon. *Eur J Radiol*. 2012.

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 **MODULE 5 — Doppler Physics, Color Flow, and Clinical MSK Application**

Carlos Jimenez PhD (c), DPT, RMSK, CPSS

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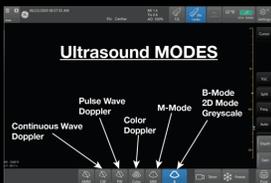
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 **Module 5: Doppler Physics, Color Flow, and MSK Applications**

- Doppler effect
- Aliasing
- PW vs CW
- Color flow + Power Doppler
- MSK-specific clinical relevance



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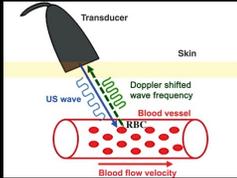
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### What Is the Doppler Effect?

**Change in Frequency Due to Motion**

- Moving RBCs → frequency shift
- Positive shift = flow toward transducer
- Negative shift = flow away



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### Doppler Equation (RMSK Core)

**" $f_D = (2 \times f_o \times v \times \cos\theta) / c$ "**

- Doppler shift proportional to:
- Transmit frequency ( $f_o$ )
- Blood velocity ( $v$ )
- Cosine of angle ( $\theta$ )

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### SECTION B — ANGLE CORRECTION (Critical Concept)

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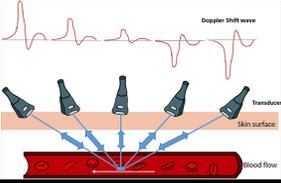
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**Doppler Angle ( $\theta$ )**

**Cos $\theta$  Determines Accuracy of Velocity**

- Best angle: 30–60°
- 0° = maximum signal
- 90° = no Doppler shift



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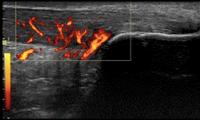
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**Why Angle Does NOT Apply to MSK Neovascularity**

**Tendon Neovessels Are Random — Do Not Angle Correct**

- Tendon neovessels = multidirectional
- Angle correction unnecessary
- Look for presence, not velocity



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**SECTION C — TYPES OF DOPPLER**

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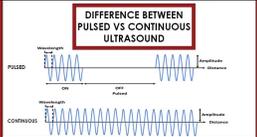
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 **Continuous Wave Doppler**

Infinite PRF → No Aliasing

- Pros: measures high velocities
- Cons: no depth specificity
- Rare in MSK



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 **Pulsed Wave Doppler**

Depth-Specific but Prone to Aliasing

- Sample volume
- Measures velocities at selected depth
- Aliasing possible



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 **SECTION D — ALIASING**

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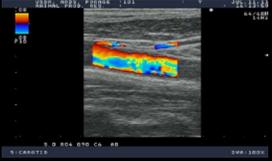
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**What Is Aliasing?**



“When Doppler Shift Exceeds Nyquist Limit”



**On Slide:**

- Nyquist limit =  $PRF / 2$
- Appears as wrap-around on spectrum

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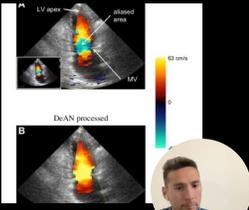
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**How to Fix Aliasing (RMSK Exam Focus)**

Increase PRF, Lower Frequency, Change Angle, Use CW



**Solutions:**

- Increase scale (PRF)
- Lower Doppler frequency
- Reduce depth
- Change angle
- Switch to CW (non-MSK)

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**SECTION E — COLOR FLOW DOPPLER**

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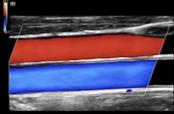
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 **How Color Doppler Works**

**Encodes Flow Direction and Mean Velocity**

- Red = toward
- Blue = away
- Color maps are arbitrary



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 **Limitations of Color Doppler**

**Angle-Dependent, Aliasing-Prone, Low Frame Rate**

- Fails with perpendicular flow
- Sensitive to motion artifact
- Lower frame rate

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 **SECTION F — POWER DOPPLER  
(IMPORTANT FOR MSK)**

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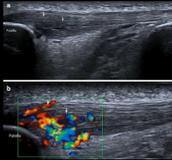
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 **What Is Power Doppler?**

**Displays Signal Amplitude Instead of Velocity**

- More sensitive to low flow
- No direction info
- Less angle-dependent



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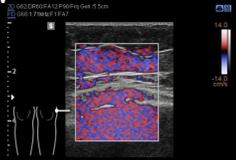
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 **Limitations of Power Doppler**

**Motion Sensitive but Best for Slow Flow**

- Very sensitive to transducer motion
- No velocity measurement
- No direction information



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 **SECTION G — SPECTRAL DOPPLER PARAMETERS**

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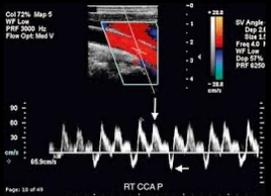
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 **Spectral Analysis**

Displays Full Range of Velocities Over Time

- Peak systolic velocity
- End-diastolic velocity
- Waveform shape



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 **SECTION H — MSK CLINICAL APPLICATIONS**

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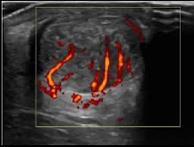
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 **Doppler for Tendinopathy**

Detecting Neovascularity & Hyperemia

- Achilles
- Patellar tendon
- Elbow extensors



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 **Doppler for Muscle Injuries**

**Detecting Hemorrhage or Active Bleeding**

- High-flow jet in acute rupture
- Absence of flow in organized hematoma



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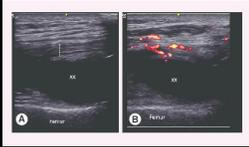
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 **Doppler for Synovitis & Bursitis**

**Detecting Inflammatory Hyperemia**

- Mild synovitis
- Moderate/severe synovitis



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 **Summary**

**Doppler Enhances MSK Evaluation When Used Correctly**

- Doppler effect fundamentals
- Aliasing principles
- PW vs CW
- Color vs Power Doppler
- MSK clinical indications

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### References — Module 5 (Doppler Physics & MSK Applications)

- Hoskins PR, Martin K, Thrush A. *Diagnostic Ultrasound: Physics and Equipment*. 3rd ed. CRC Press; 2019.
- Kremkau FM. *Diagnostic Ultrasound: Principles and Instruments*. 10th ed. Elsevier; 2020.
- Hedrick WR, Hylkes DL, Starchman DE. *Ultrasound Physics and Instrumentation*. 5th ed. Mosby/Elsevier; 2013.
- Evans DH, McDicken WN. *Doppler Ultrasound: Physics, Instrumentation and Clinical Applications*. 2nd ed. Wiley; 2000.
- Rubin JM, Adler RS. "Doppler Ultrasound: Clinical and Technical Principles." *Radiologic Clinics of North America*. 2001;39(3):587-630.
- American Institute of Ultrasound in Medicine (AIUM). *Practice Parameter for the Performance of Doppler Ultrasound Examinations*. Latest revision 2020.
- Bianchi S, Martinoli C. *Ultrasound of the Musculoskeletal System*. Springer; 2007.
- Galletti S, Oliva F, et al. "The Role of Doppler Ultrasound in Tendinopathy." *British Journal of Sports Medicine (BJSM)*. 2012;46(9):555-556.

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### MODULE 6 — Advanced Artifacts & Error Sources

Carlos Jimenez PhD (c), DPT, RMSK, CPSS

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### Advanced Artifacts and Error Sources in MSK Ultrasound

- Propagation errors
- Velocity errors
- Mirror image
- Reverberations
- Side lobes & grating lobes
- Slice-thickness artifact
- Range ambiguity
- Beam aberration

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## SECTION A — PROPAGATION & VELOCITY ARTIFACTS

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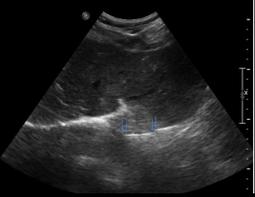


### Speed Error Artifact

When Tissue Speed ≠ 1540 m/s  
(Machine Assumption)

On Slide:

- Fast tissues → structure placed too shallow
- Slow tissues → structure placed too deep



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### Propagation Speed Mismatch in MSK

Fat, Muscle, Tendon All Have Different Velocities

- Fat ~1450 m/s
- Muscle ~1580 m/s
- Tendon ~1700 m/s
- Bone extremely high

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**SECTION B — REFRACTION  
ARTIFACT**

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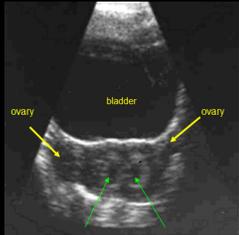
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**Refraction Artifact**

**Bending of the Beam Creates Duplicate or Shifted Structures**

- Occurs at oblique interfaces
- Produces lateral displacement
- Common at muscle-fat or tendon-fat borders



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**SECTION C — REVERBERATION  
ARTIFACT FAMILY**

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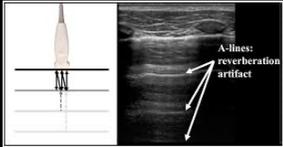
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**Reverberation Artifact**



Sound Bounces Repeatedly Between Two Strong Reflectors

- Multiple equally spaced echoes
- Occurs between probe surface & fascia
- Between tendon & bone



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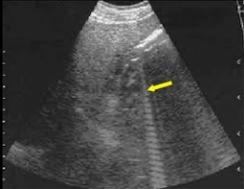
**Comet Tail Artifact**



Short, Dense Reverberation Pattern

On Slide:

- Closely spaced echoes
- Often from small calcifications or metal



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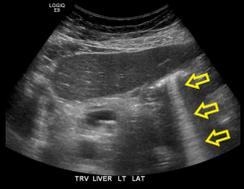
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**Ring-Down Artifact**



Resonance from Gas (Not MSK-Common but RMSK-Tested)

- Bright continuous band
- Caused by gas bubbles



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 **Mirror Image Artifact**

False Duplicate Structure Appears on Opposite Side of Strong Reflector

- Occurs next to curved reflectors
- Appears as mirrored copy



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 **SECTION E — SIDE LOBES & GRATING LOBES**

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 **Side Lobe Artifact**

Off-Axis Energy Returning as False Echoes

- Creates spurious internal echoes
- Seen in cysts or bursae
- Higher risk in fluid-filled structures



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**Grating Lobes**



Array-Related Version of Side Lobes

- Caused by element spacing issues
- Mitigated by subdicing & apodization



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**SECTION F — SLICE THICKNESS ARTIFACT**



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**Slice-Thickness Artifact**



Structures Outside the Imaging Plane Appear Inside It

- Mimics debris in fluid
- Important in bursa, joint recesses



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## SECTION G — BEAM WIDENING & ABERRATION

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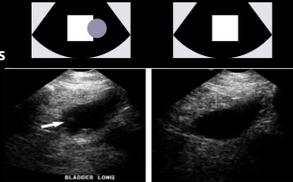
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### Beam Width Artifact

Wider Beam at Depth Blurs Edges

- Degrades lateral resolution
- Affects small tendons & nerves



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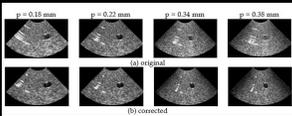
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### Beam Aberration

Heterogeneous Tissue Causes Beam Distortion

- Fat layers distort beam
- Irregular refraction
- Blurry or shifted structures



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### SECTION H — RANGE AMBIGUITY

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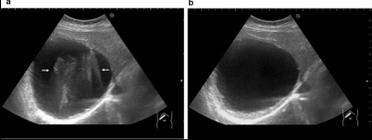


### Range Ambiguity

Echo Returns After Next Pulse — Misplaced Structure

On Slide:

- High PRF = risk
- Appears too shallow



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### Edge Shadowing

Refraction Around Curved Boundaries Creates Shadow Bands

- Seen at tendons, nerves, vessels
- Benign artifact



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## SECTION J — CLINICAL MSK CORRECTIONS

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## How to Correct Artifacts

**Adjust, Re-Angle, Reposition**

- Change angle
- Change frequency
- Adjust TGC
- Narrow field of view
- Use stand-off for superficial structures

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## Summary

**Artifacts Are Diagnostic Clues, Not Errors**

- Some indicate pathology
- Some are operator-induced
- Recognizing them prevents misdiagnosis

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**References — Module 6**

- Hedrick WR et al. *Ultrasound Physics and Instrumentation*. 5th ed. 2013.
- Kremkau FW. *Diagnostic Ultrasound*. 10th ed. 2020.
- Hoskins PR et al. *Diagnostic Ultrasound: Physics & Equipment*. 3rd ed. 2019.
- Szabo TL. *Diagnostic Ultrasound Imaging: Inside Out*. 2nd ed. 2014.
- Fessell DP, van Holsbeeck M. *Ultrasound Clinics*. 2007;2(4):629–653.
- Thomas RH. *Semin Musculoskelet Radiol*. 2013;17(4):461–469.
- Bianchi S, Martinoli C. *Ultrasound of the Musculoskeletal System*. 2007.
- AIUM Practice Parameters & Technical Standards (2019–2022).

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**MODULE 7 — QUALITY ASSURANCE (QA), EQUIPMENT PERFORMANCE, & ERROR SOURCES**

Carlos Jimenez PhD (c), DPT, RMSK, CPSS

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**Module 7: Quality Assurance, System Performance & Error Sources**

- QA basics
- System testing
- Image uniformity
- Resolution tests
- Dead zone
- Axial & lateral resolution
- Equipment care

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## SECTION A — WHAT IS QUALITY ASSURANCE?

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## What is Ultrasound QA?

Routine evaluation to ensure consistent, safe, and accurate imaging.

Frequency	Frequency/Interval	Performed by whom?	Action
Daily	Before use	Operator or expert	See action required
Quarterly	Before use	Physician or physicist or other qualified person	See action required
Annual	Before use	Physician or physicist or other qualified person	See action required

- Detects equipment malfunction
- Ensures consistent performance
- Required by AIUM and accrediting bodies

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## Who Performs QA?

Sonographers, MSK clinicians, physicists, and biomedical engineers.

- Daily: clinician/sonographer
- Quarterly/semiannual: physics or biomedical
- Annual: full system audit

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## SECTION B — PHANTOMS & TEST OBJECTS

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## Types of Phantoms

Tools to measure system performance objectively.

- Tissue-mimicking phantoms
- String Doppler phantoms
- Beam-profile phantoms



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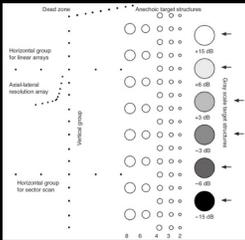
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## Tissue-Mimicking Phantom

Used for grayscale, depth, resolution, and uniformity evaluation.

- Dead zone
- Axial/lateral resolution
- Depth accuracy
- Uniformity



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## SECTION C — SYSTEM PERFORMANCE TESTS

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### Dead Zone

Region close to the transducer where accurate imaging is not possible.

- Caused by transducer ring-down
- Measured with superficial targets



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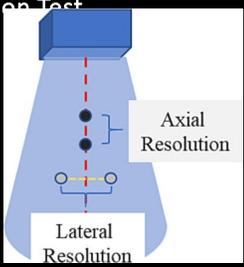
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### Axial Resolution Test

Ability to distinguish structures along the beam path.

- Measured with vertically aligned targets
- Depends on SPL



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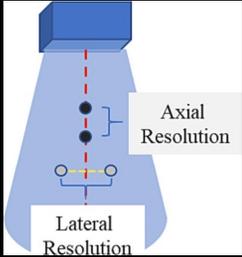
**Lateral Resolution Test**



Ability to distinguish structures side-by-side.

**On Slide:**

- Measured with horizontal targets
- Depends on beam width



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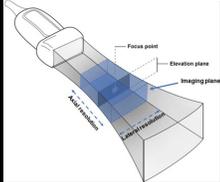
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**Elevational (Slice-Thickness) Resolution**



Accuracy in the third dimension — beam height.

- Causes slice-thickness artifact
- Evaluated with thin structures



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**Depth Accuracy**



How well the machine places structures at correct depth.

- Depends on sound speed assumption
- Checked with known-depth objects



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## SECTION D — DOPPLER QA

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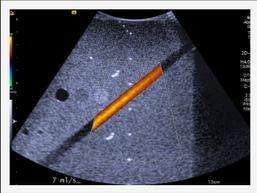
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### Doppler Sensitivity

Ability to detect low flow signals.

- Power Doppler sensitivity
- Low-velocity testing



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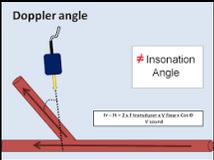
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### Doppler Angle Accuracy

Ensuring correct velocity measurement.

- Alignment of flow simulator
- PRF and scale calibration



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## SECTION E — IMAGE UNIFORMITY & NOISE

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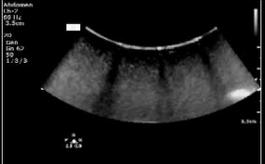
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### Image Uniformity

Brightness should be consistent across the entire field.

- No dark/bright bands
- No drop-out zones



Indication: 12.7  
2.4cm  
100  
17.8/8

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### Noise & Clutter

Random or patterned echoes that do not represent anatomy.

- Electrical noise
- Electronic failure
- Inadequate shielding

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## SECTION F — EQUIPMENT CARE & ERROR SOURCES

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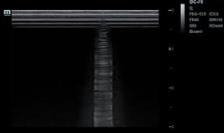
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## Transducer Integrity

Most QA issues originate from the probe.

- Cracked lens
- Damaged cable
- Dead elements



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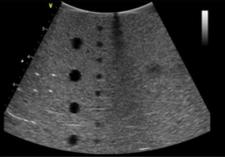
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## Artifacts Caused by Equipment Failure

Not all artifacts are physics — some are hardware failures.

- Horizontal banding
- Vertical streaks
- Element dropout



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### MSK-Specific QA Considerations

Resolution, uniformity, linearity matter the most.

- Tendon fiber clarity
- Nerve fascicle visibility
- Cartilage interface smoothness

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### Diagnostic Accuracy Measures

Sensitivity, Specificity, PPV, and NPV

- Sensitivity = True Positive Rate
- Specificity = True Negative Rate
- PPV = Probability injury is present when US is positive
- NPV = Probability injury is absent when US is negative

		Disease		
		Yes	No	
Test result	Positive	True positive A	False positive B	Positive predictive value = A / (A+B)
	Negative	False negative C	True negative D	Negative predictive value = D / (C+D)
		Sensitivity = A / (A+C)	Specificity = D / (B+D)	

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### Why This Matters in MSK Ultrasound

Ultrasound Accuracy Depends on Context

Examples:

- Achilles rupture = high sensitivity
- Rotator cuff partial tears = lower specificity
- Hamstring MTJ injuries = high PPV
- Plantar fascia tears = high NPV

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### Pre-Test Probability (Practical Explanation)

**Your Clinical Exam Influences Ultrasound Value**

- High suspicion → PPV increases
- Low suspicion → NPV increases
- Ultrasound should be interpreted with clinical reasoning

		Disease		
		Yes	No	
Test result	Positive	True positive A	False positive B	Positive predictive value = A / (A+B)
	Negative	False negative C	True negative D	Negative predictive value = D / (C+D)
		Sensitivity = A / (A+C)	Specificity = D / (B+D)	

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### References — Module 7 (Quality Assurance + Diagnostic Accuracy)

Kremkau FW. *Diagnostic Ultrasound: Principles and Instruments*. 10th ed. Elsevier; 2020.  
 Hadrick WR, Wiley DL, Sarachman DE. *Ultrasound Physics and Instrumentation*. 5th ed. Mosby; 2013.  
 Hoskins PR, Martin K, Thrush A. *Diagnostic Ultrasound: Physics & Equipment*. 3rd ed. CRC Press; 2019.  
 Szabo TL. *Diagnostic Ultrasound Imaging: Inside Out*. 2nd ed. Academic Press; 2014.  
 Goodlett MM et al. Real-time B-mode ultrasound QC test procedures. *Ultrasound Med Biol*. 1998;24:1353–1363.  
 Fornage BD. Hardware and image quality problems. *Radial Clin North Am*. 2001;39:499–515.  
 AIUM. *Routine Quality Assurance for Diagnostic Ultrasound Equipment*. 2020–2022.  
 AIUM. *MSK Ultrasound Practice Parameter*. 2022.  
 De Jesus JO et al. Accuracy of MRI, ultrasound & clinical exam for rotator cuff tears. *AJR*. 2009;192:1701–1707.  
 Smith TO et al. Diagnostic accuracy of ultrasound for Achilles tendon tears. *KSTA*. 2011;19:1255–1263.  
 Whittaker JL et al. Imaging with ultrasound in rehabilitation. *JOSPT*. 2019;49:327–349.  
 Bianchi S, Martignoli C. *Ultrasound of the Musculoskeletal System*. Springer; 2007.

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