# ACR Requirements and the Annual Survey

Sandra Larson, PhD

University of Michigan Medical Center, Ann Arbor, MI

# ACR Program Requirements

- http://www.acr.org/~/media/ACR/Documents/Accreditation/US/Requirements.pdf
- **Effective June 1, 2014.**
- Requirements:

  - Acceptance Testing

  - Annual Survey

  - Routine QC

  - Preventive Maintenance

# ACR Program Requirements

- The accreditation application will include:

  - A report from the most recent annual survey
  - Documentation of corrective action

- “Strongly recommended” that QC is done under the supervision of a qualified medical physicist.

# ACR Program Requirements

- All clinically used probes must be tested.
- A phantom (or test object) is required, but no model or type is specified.
- No Ultrasound QC manual exists.
- No Pass/Fail criteria are provided for any of the tests.
- Note: the Quality Control sections of the program requirements for Ultrasound Accreditation and Breast Ultrasound Accreditation are identical.

# Acceptance Testing

- Must be done for new equipment and after major repairs or upgrades.
- Should be comprehensive.
- Should include all tests done for the annual survey to provide performance baselines.
- Beyond the above, the physicist or QC designee must decide what constitutes a comprehensive test of the system.

# Ultrasound QC Resources

- AAPM Ultrasound Task Group No. 1, "Real-time B-mode ultrasound quality control test procedures", By MM Goodsitt et al, Med Phys 25(8):1385-1406, 1998.
- AIUM, "Quality Assurance Manual for Gray Scale Ultrasound Scanners (Stage 2)", edited by E. Madsen, AIUM, Laurel, MD, 1995.
- The Institute of Physical Sciences in Medicine (IPSM) Report No. 71, "Routine Quality Assurance of Ultrasound Imaging Systems", edited by R Price, York: ISPM, 1995.

# Annual Survey

- Required Tasks

  - Physical and Mechanical Inspection
  - Image Uniformity and Artifact Survey
  - Geometric Accuracy
  - System Sensitivity
  - Scanner Image Display Performance
  - Primary Interpretation Display Performance
  - Evaluation of QC Program

- Optional Tests: Contrast Resolution and Spatial Resolution.

# Physical and Mechanical Survey

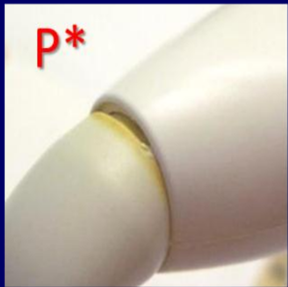
- Check the transducers carefully.

  - Active surface integrity
  - Cable condition
  - Connector (damaged pins, dirt or dust)

- Check the scanner (include electrical hazards, pinch hazards, infection control concerns).

  - Main console
  - Keyboard
  - Power cables
  - Integrity of probe ports
  - Motions and locks
  - Ancillary equipment

# Examples



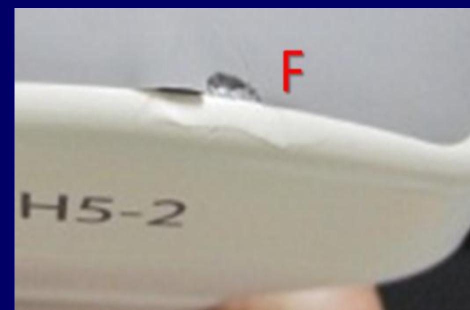


Grommet/Housing Separation


Lens Delamination


Lens Pitting

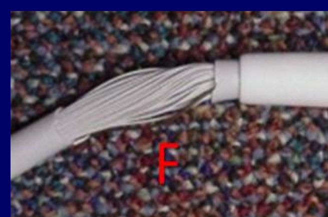

Lens Peeling / Delamination



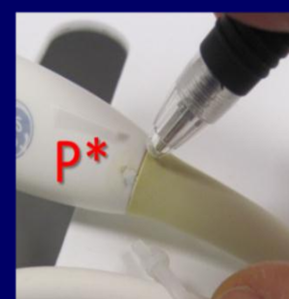

Cracked Housing/ Lens Damage


Loose Scan Head


Partial Cable Tear




Complete Cable Tear




Peeling of Housing Layer


Separation of Handle


Bent Connector Pins


Connector Damage

*Pass / Fail decisions are often subjective*

Slide provided by N. Hangiandreou

# Phantom Considerations

- Commercial ultrasound phantoms are usually designed with a tissue mimicking gel-based or rubber-based material.
- Gel-based material characteristics:

  - Speed of sound: 1540 m/s

  - Attenuation coefficient: 0.5 or 0.7 dB/cm-MHz

  - Usable lifetime: 2-3 years

- Rubber-based material characteristics:

  - Speed of sound: ~1430 m/s

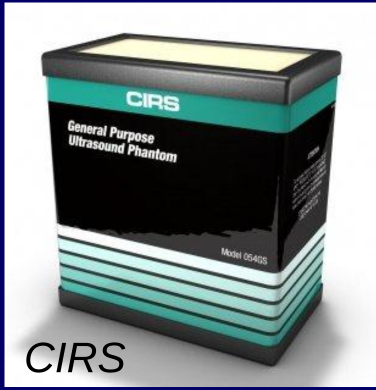
  - Attenuation coefficient: 0.5 or 0.7 dB/cm-MHz

  - Usable lifetime: 10 years or more.

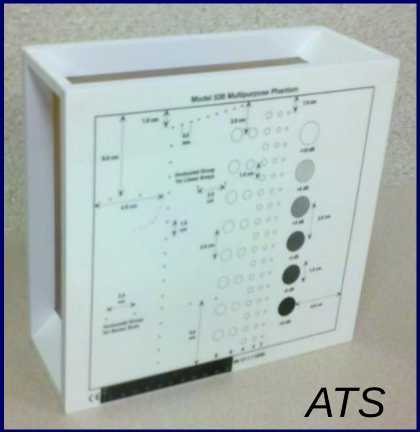
# Phantom Considerations

- No single phantom can be used for all tests.
- Tissue-mimicking phantoms are expensive. This cost cannot be ignored as you design the QC program for your facilities.
- Rather than discuss the available types of phantoms now, common available phantom options will be mentioned for each of the annual tests covered in this session.

*Gammex*



*CIRS*



*ATS*

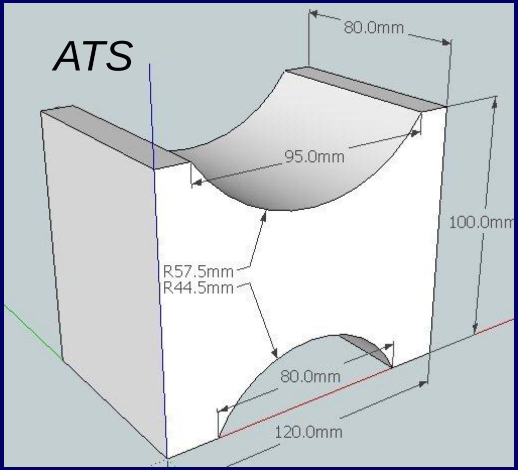

*DM King PhD, et al*

# Image Uniformity and Artifact Survey

- This is one of the most effective tests you will perform, but requires experience to interpret the results.
- You will need a phantom with a uniform (or mostly uniform) section.


ATS


EL Madsen, PhD

ATS

Gammex


DM King PhD, et al

# Image Uniformity and Artifact Survey
## (The Quick Way)

- Perform on all clinically used transducers.
- Use a fairly short image depth that allows good visibility of the transducer-phantom interface.
- Adjust the system settings for a moderately bright and uniform image.  Use the same settings that were used at acceptance.
- Evaluate uniformity in live images.  Troubleshoot when needed.
- Document what you see or don’t see.  Report anything of concern to the users.

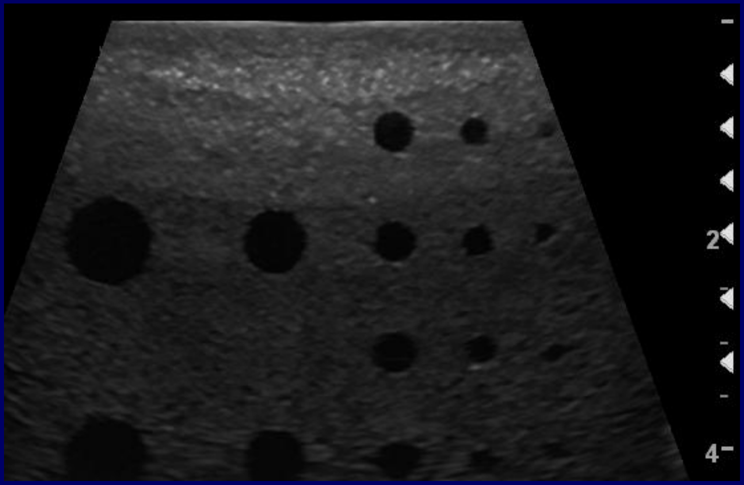
# Evaluating Uniformity/Artifacts

- Our eyes are very good at identifying artifacts in uniform images.  How do you know which artifacts are important?

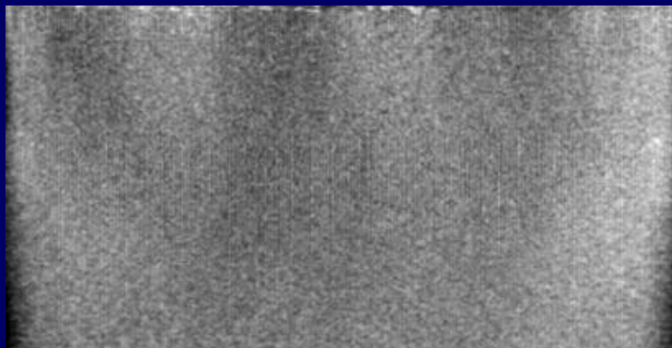
  - Some artifacts are inherent to the system design.
  - Some artifacts are too subtle to negatively affect patient images.
  - Some artifacts are visible, but easily worked around during patient imaging.
  - Some artifacts should be repaired.

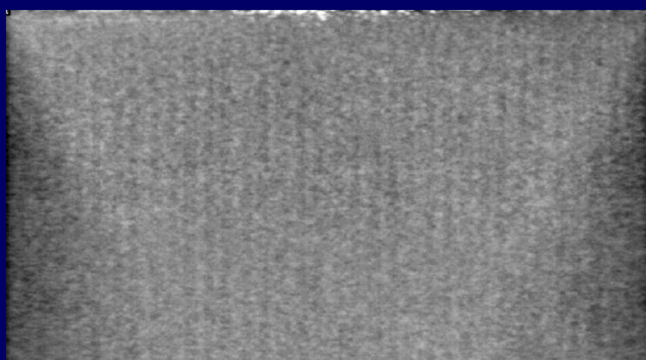
# Inherent Nonuniformities

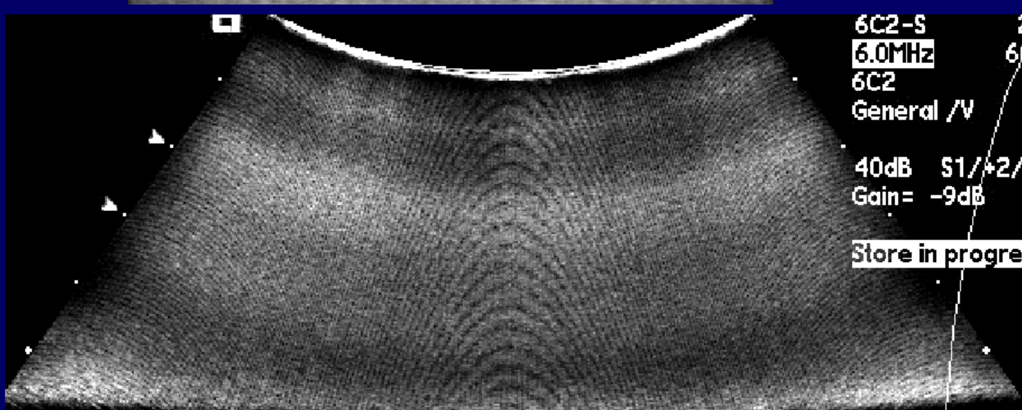
- Those artifacts inherent to the system design should be established during acceptance.
- Having multiple transducers of the same model makes this much easier. Otherwise, you must rely on the manufacturer’s reply.

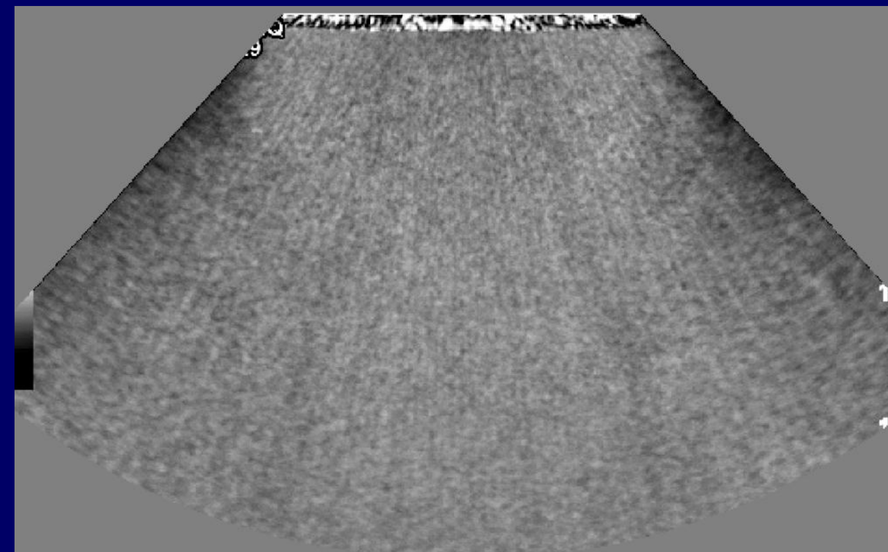


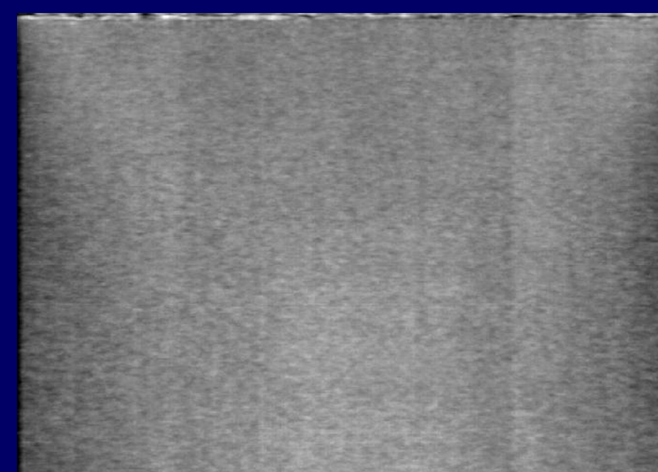
# Inherent Nonuniformities







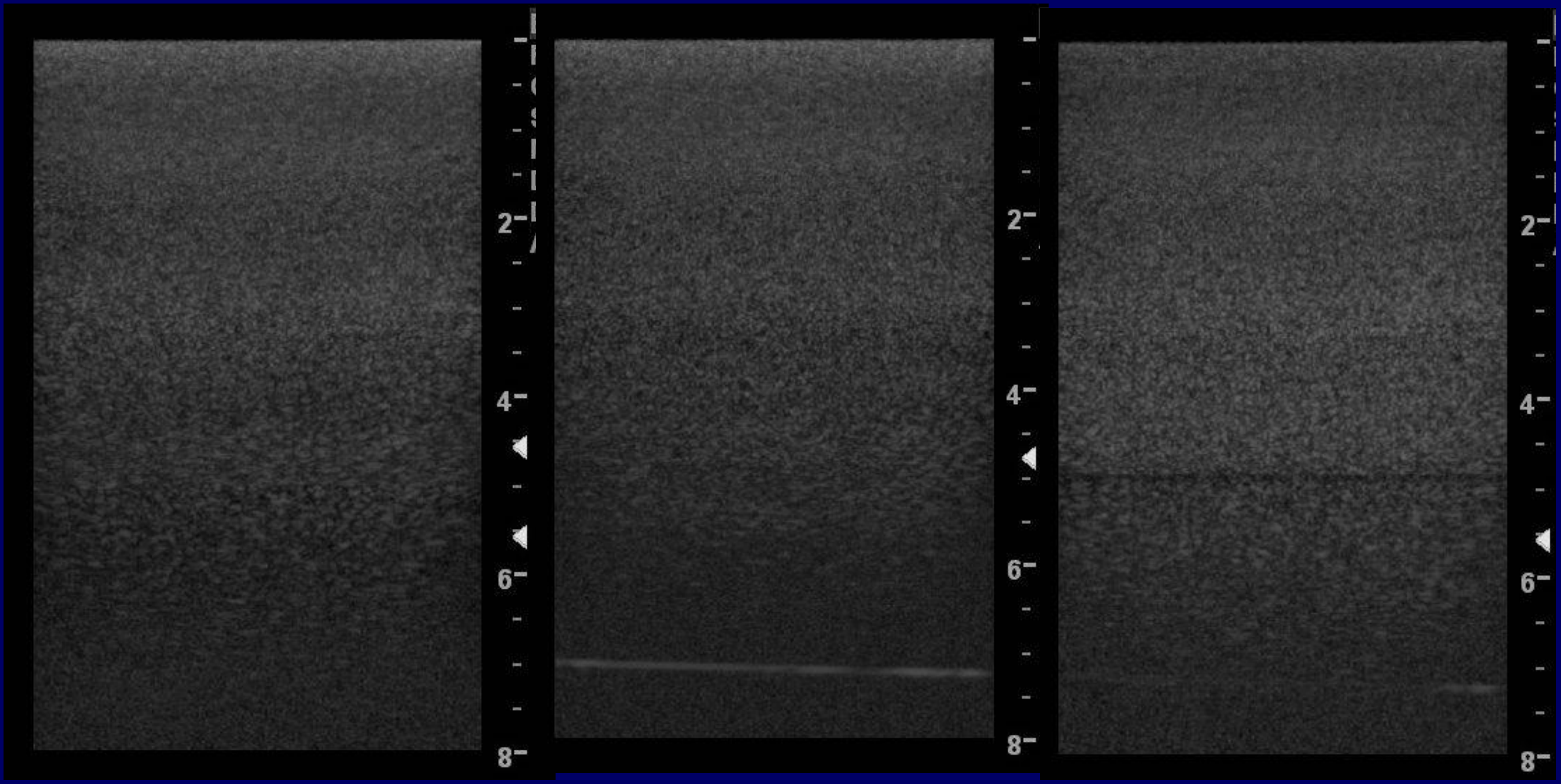





Images provided by N. Hangiandreou

# Inherent Nonuniformities

- The location and number of focal zones can significantly affect these inherent artifacts.

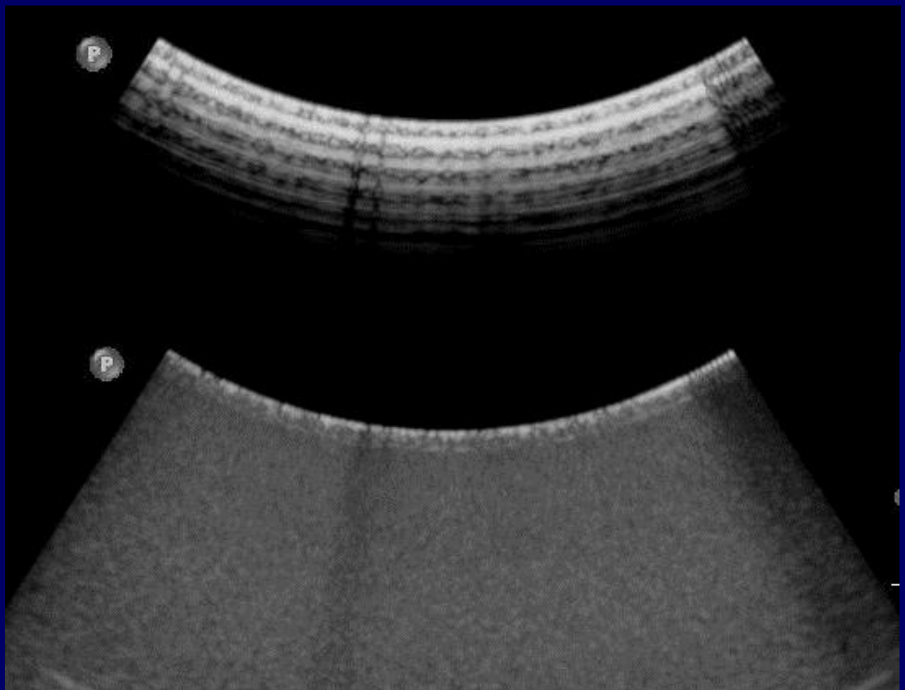


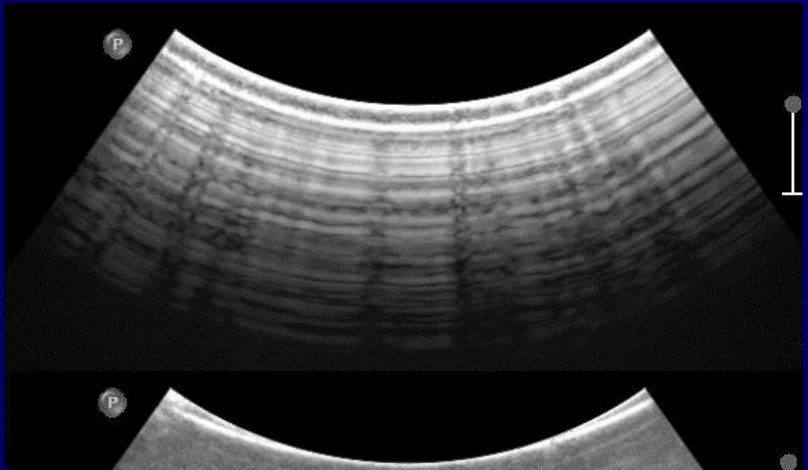
# Troubleshooting Nonuniformities

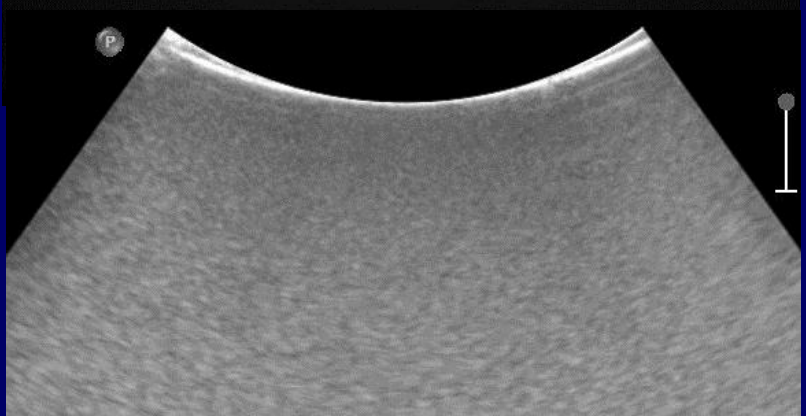
- Make sure the problem is reproducible.
  - Make sure there is good coupling between the transducer and the phantom.
  - Disconnect the probe from the scanner, check for debris in the connector and reconnect.
  - Try connecting to a different port.
  - Try rebooting the scanner.
  - Flex the transducer cable to see if it affects the artifact.

# Viewing Artifacts

- A uniform phantom is the most thorough way to view artifacts quickly, but it's not the only way.
- Many damaged-element artifacts can be seen in air scans, but be careful.

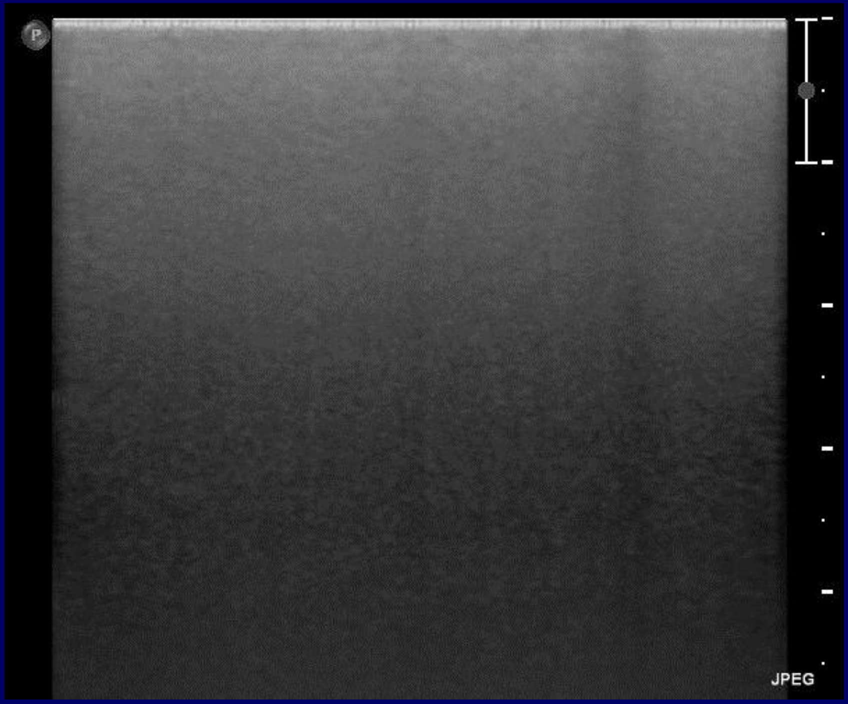






# Viewing Artifacts

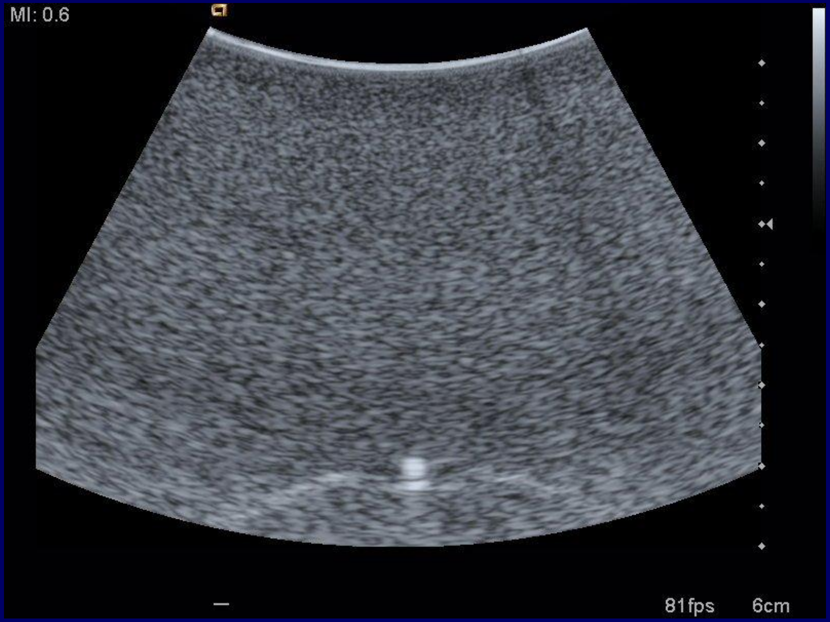
- We can better visualize artifacts by averaging a cine loop.



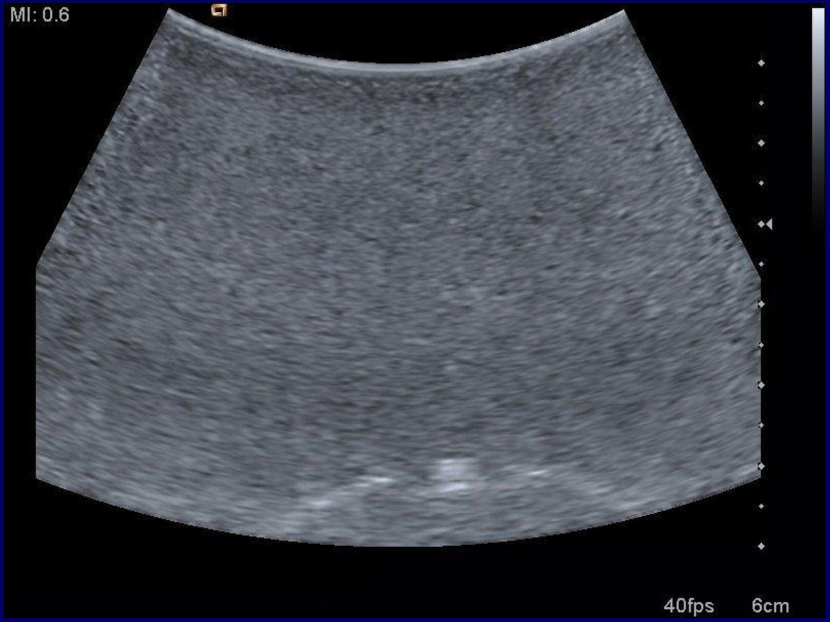
# Viewing Artifacts

- Sometimes image processing, like spatial compounding and harmonic imaging, can obscure image artifacts.

**Without Spatial Compounding**

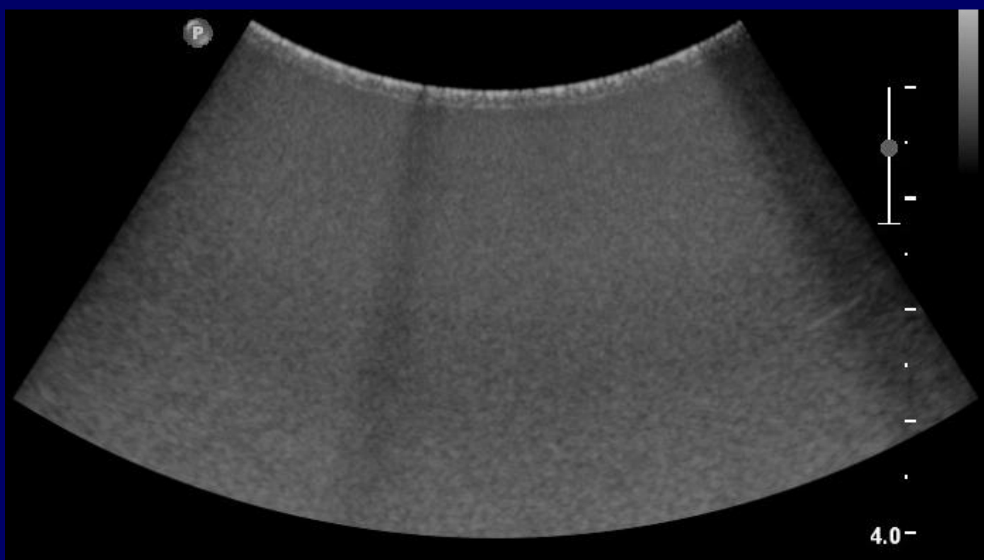


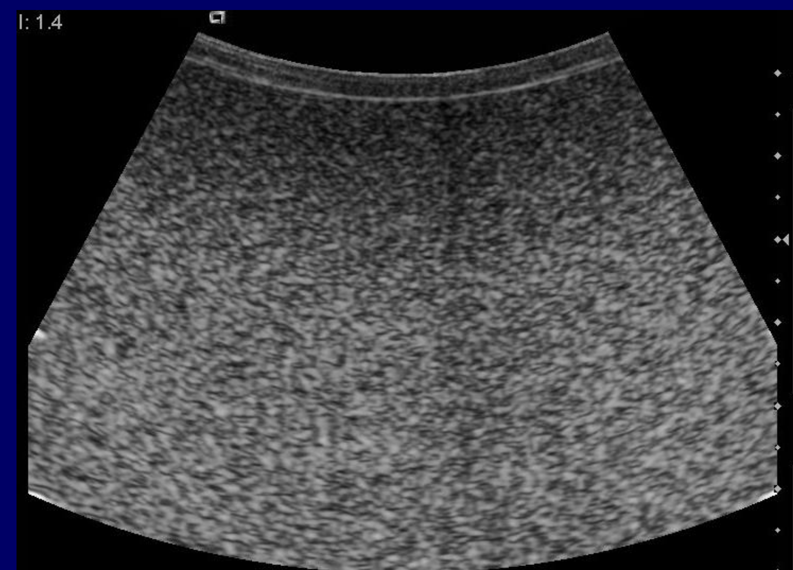

**With Spatial Compounding**



# Evaluating Uniformity/Artifacts

- How do we decide what artifacts are actionable?
- Is the medical physicist qualified to make this decision?



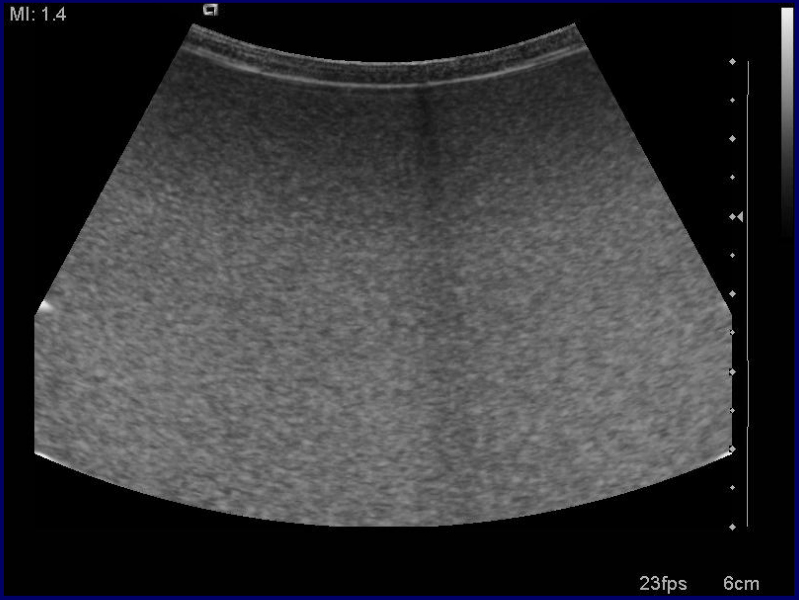



# Quantitative Uniformity Assessment?

- The AAPM Ultrasound Subcommittee is working on a project to quantitate radial nonuniformities.
- The goal is to provide some guidance on when these artifacts can be ignored and when they cannot.

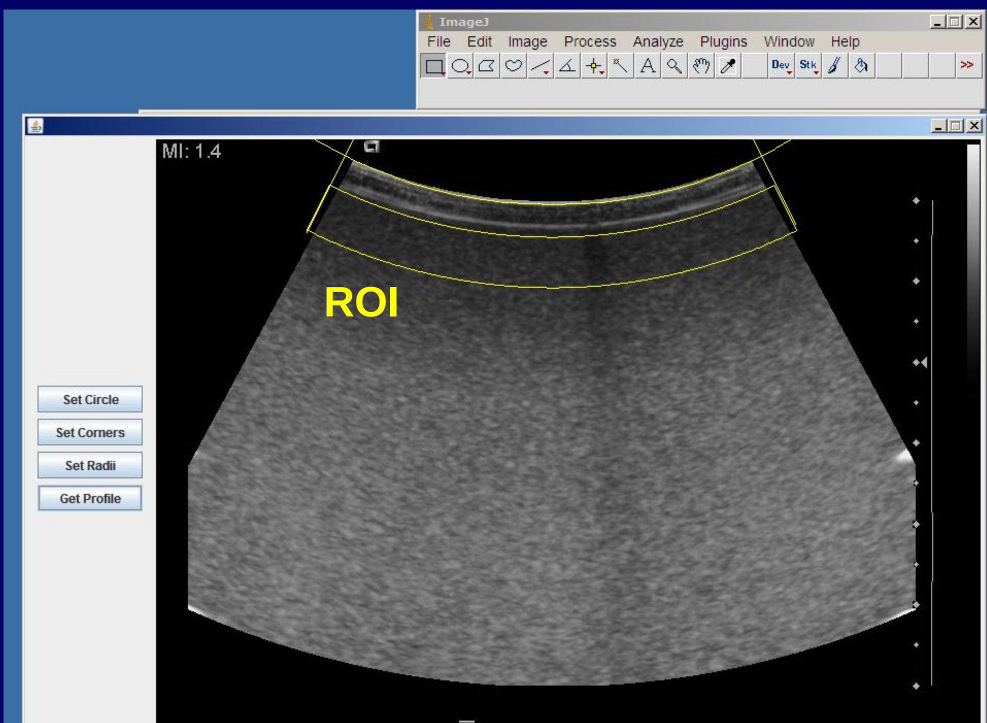
Cine Loop

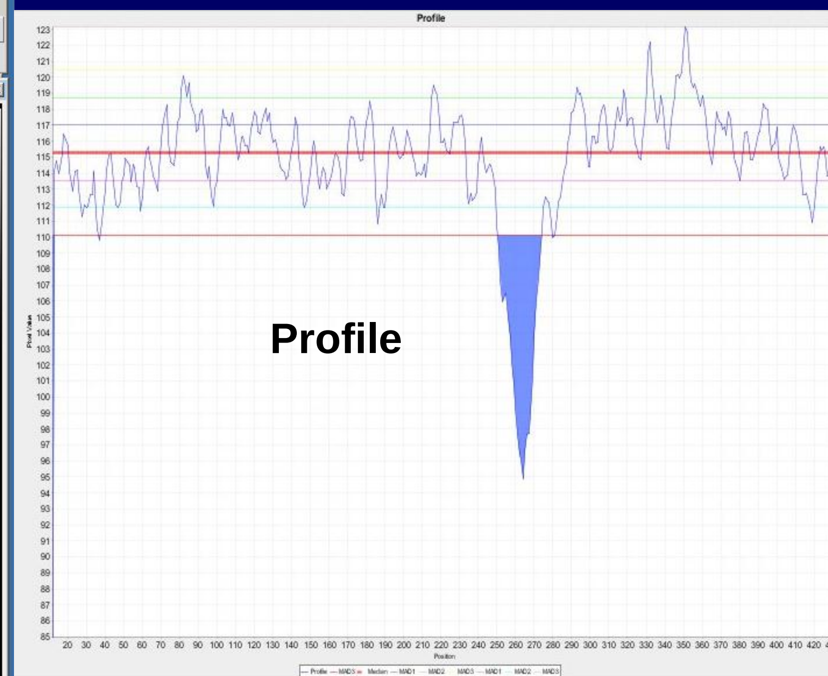

Median Image



# Quantitative Uniformity Assessment?

- Our software (a plugin to the open source software ImageJ) creates a median image from a cine loop.  It allows the user to create an ROI and plot the results.



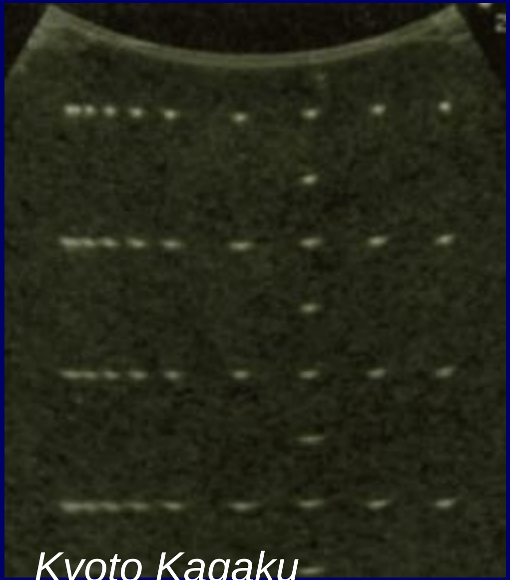
# Quantitative Uniformity Assessment?

- The working group is currently trying to find an appropriate metric from this data that can meet our goal.
- We ultimately hope to make the software available to AAPM members free of charge.
- A second working group within the Ultrasound Subcommittee is working to assess the effect of radial nonuniformities on the accuracy of Doppler measurements.
- This is an important question for the uniformity evaluation, and it cannot be assessed visually!

# Geometric Accuracy

- Can use a phantom with filament targets or other discrete objects at known distances in vertical and horizontal planes.
- Most manufacturers offer these objects in a general or multi-purpose QC phantom.

*Gammex*



*Kyoto Kagaku*

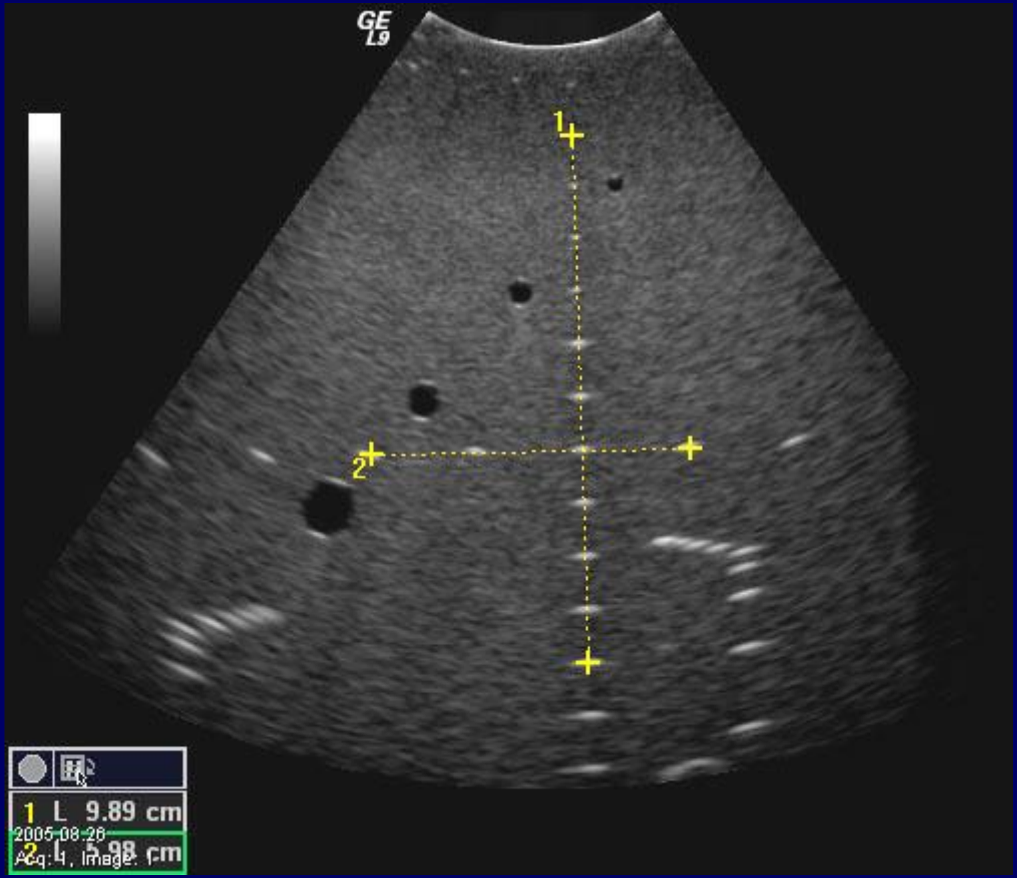
Can alternatively use other objects of known size in a phantom or test object.

# Geometric Accuracy

**Suggested Action Levels:**

from Ultrasound TG 1 (Goodsitt et al)

- **Vertical Limit: 1.5% of the actual distance or 1.5 mm, whichever is greater**
- **Horizontal Limit: 2% of the actual distance or 2 mm, whichever is greater**

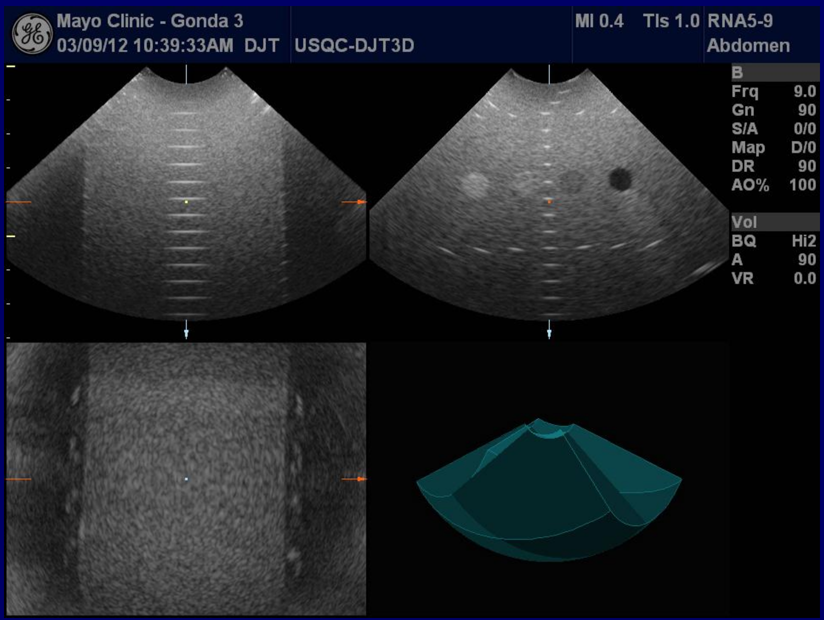



Scanner settings:

Any setting that makes the measurement easier (keep the filaments small and easily viewed).

# Geometric Accuracy
## (for 3D and 4D transducers)

- Scan the phantom parallel to the filament targets.
- Measure distance in the orthogonal view.





Images provided by N. Hangiandreou

# **Geometric Accuracy** (caveats)

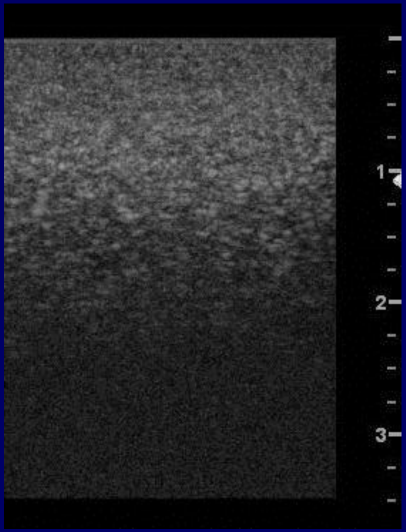
- If you are using a soft phantom (typically a gel-based phantom), take great care not to apply pressure to the phantom surface.  This could deform the phantom and displace the objects inside.  Also, make sure the phantom is not dehydrated.
- Make sure your scan plane is perpendicular to the filaments.  Rotation of the transducer can cause horizontal distance errors.
- Make sure the phantom is at the appropriate temperature for imaging.

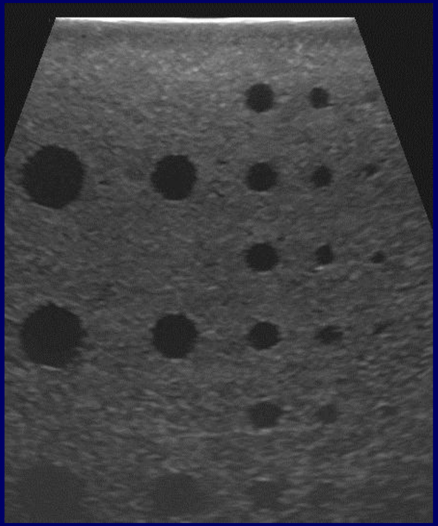
# System Sensitivity

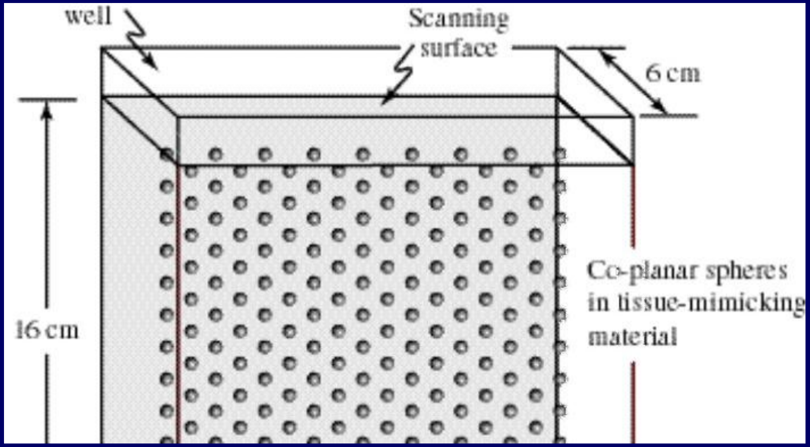
- Sensitivity is typically monitored by measuring the Depth of Penetration (DOP).
- The DOP can be defined as the greatest depth at which echo signals can be distinguished from the noise.

# System Sensitivity - DOP

- Need a tissue-mimicking phantom section that is several cm wider than the transducer and extends to a depth of about 18 cm.
- The target phantom section could be uniform, contain anechoic cylindrical or spherical objects, or cylindrical/spherical objects at a set dB below the background.





# System Sensitivity

System Settings:

- Depth of field must be larger than DOP (if possible).
- Place a focal zone as close as possible to the DOP.
- Use maximum output/power.
- TGC high enough to see the electronic noise, but no saturation of the pixels.
- Consistency of the system settings from one year to the next is critical for reproducibility of this measurement.

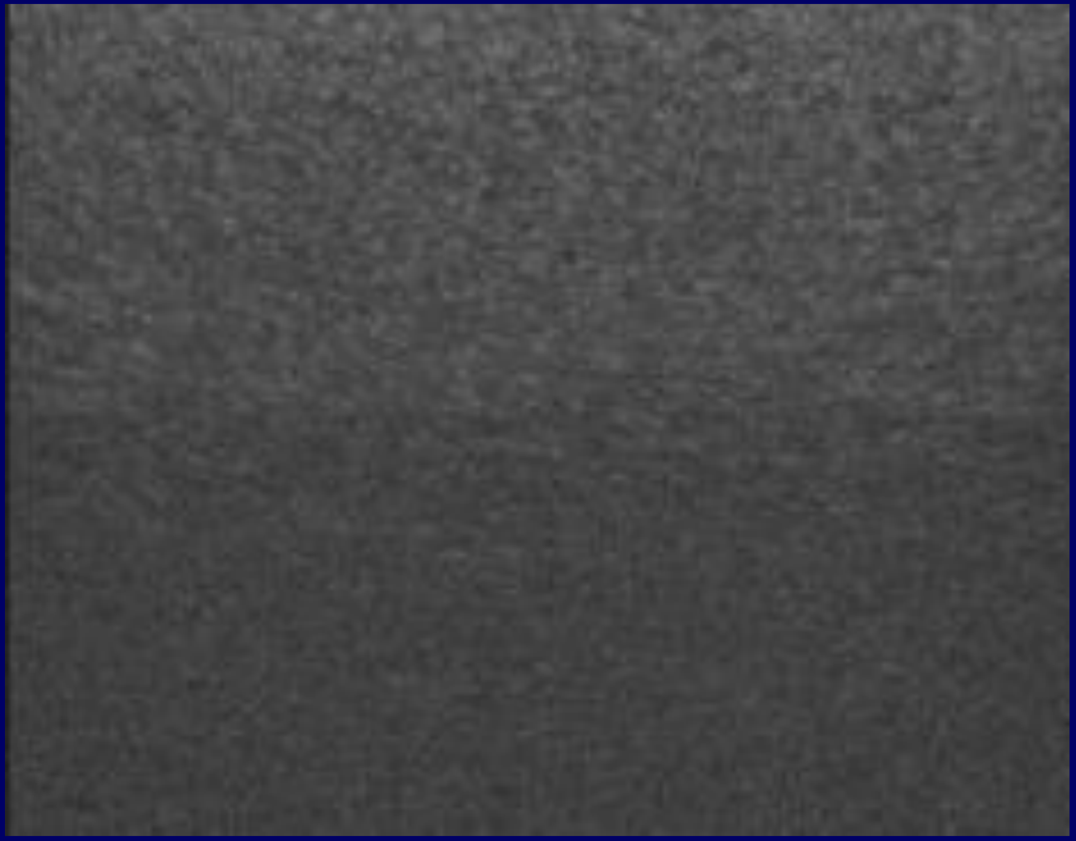
# System Sensitivity
## (The Quick and Subjective Way)

- DOP can be estimated with a quick visual assessment of a uniform image or an image with objects.

Action Limit:
(from Ultrasound TG 1)

- difference from baseline > 0.6 cm

If you’re unsure, try rocking the transducer left-right.



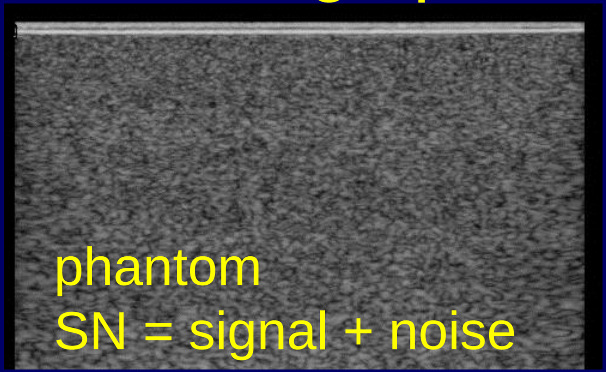
# System Sensitivity
## (The Objective Way)

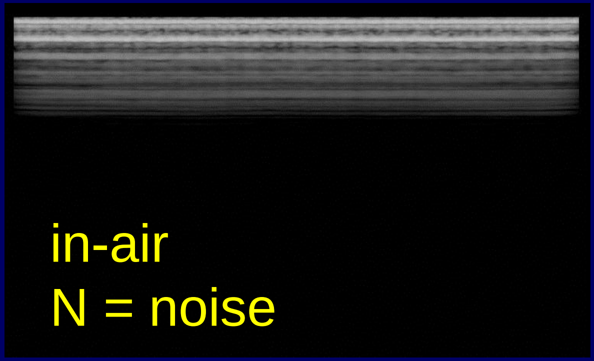
- Can calculate DOP from a plot of SNR vs depth (as described in IEC 61391-2).
- The IEC algorithm:
  - Need a uniform phantom and in-air image pair.

$$SNR_{IEC}(d) = \sqrt{\frac{SN(d)^2}{N(d)^2} - 1}$$

$d$ = distance from transducer face
$SN$ = mean pixel values from phantom image
$N$ = mean pixel values from in-air image

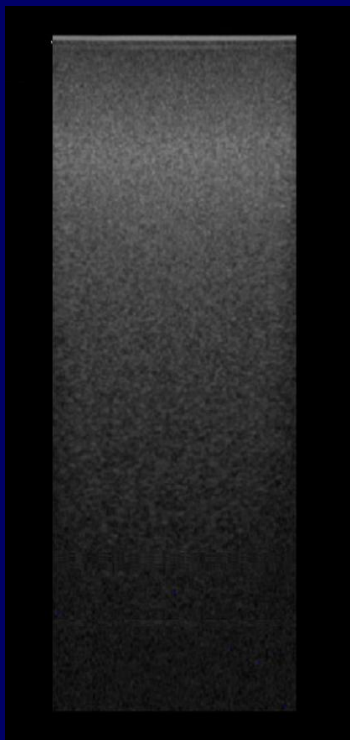
$$SNR_{IEC}(DOP) = 1$$



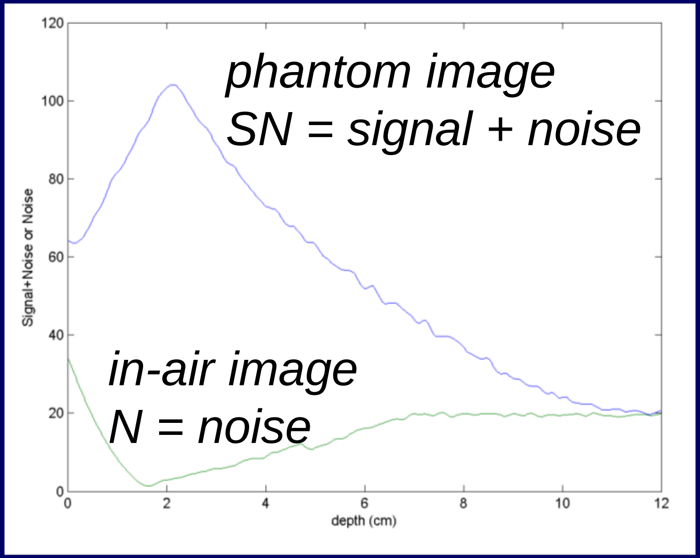



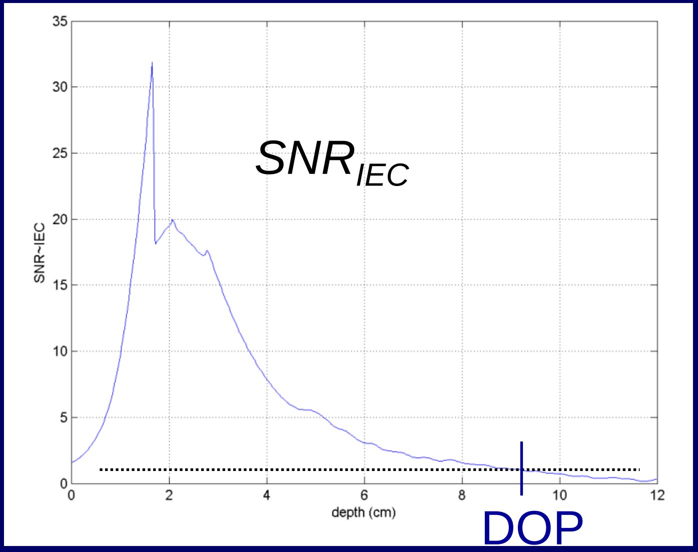
# System Sensitivity
## (The Objective Way)

phantom
SN = signal + noise



Plots provided by N. Hangiandreou




*> Gorny et al. Implementation and validation of three automated methods for measuring ultrasound maximum depth of penetration: application to ultrasound quality control. Med Phys. 2005 Aug;32(8):2615-28*

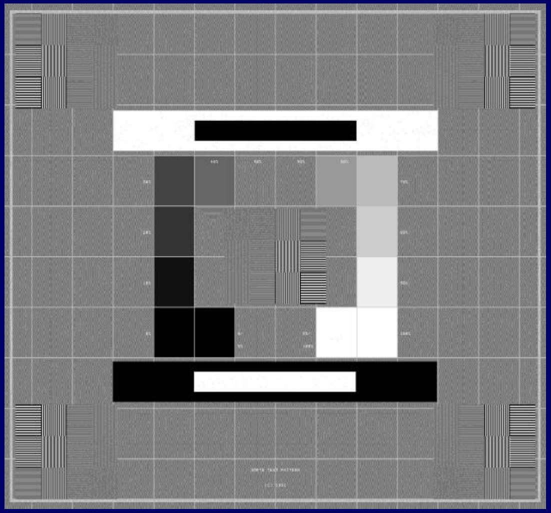
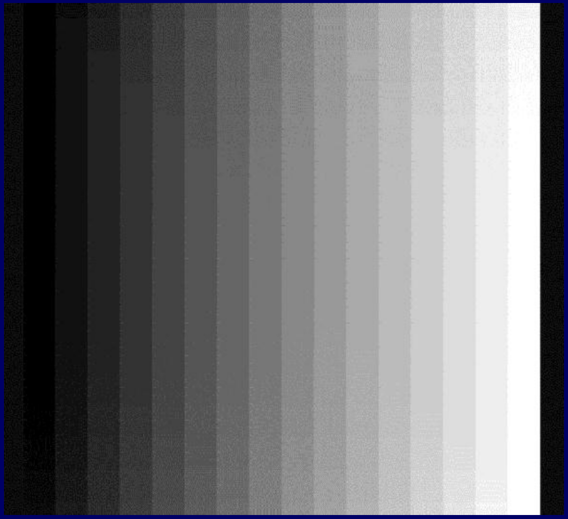
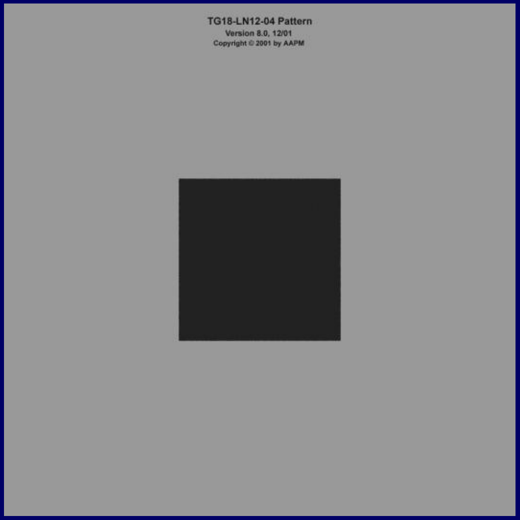
*> Stekel et al. Evaluation of the International Electrotechnical Commission Standard Technique for Measuring the Ultrasound Depth of Penetration. Presented at AIUM 2012.*

# System Sensitivity (Caveats)

- A single profile line down the phantom will be too noisy, so we should average multiple pixels (but how many?) at the same depth - complicated for curved and sector arrays.
- May need additional noise reduction - filters, multiple images.
- If your phantom has targets, what will this do to the data?
- For some transducers, the DOP is deeper than the maximum displayed depth. How do you define the sensitivity in this case? One option: use a different reference point, such as $SNR_{IEC} = 2$.

# Ultrasound Scanner Electronic Image Display Performance

- The scanner display must be of diagnostic quality.  It is just as important to patient diagnosis as reading room displays.
- It must be tested, but we are limited by the tools provided by the manufacturer.

# Scanner Display Performance

- The standard for testing image displays is the report of AAPM TG18.
- ACR does not give specific recommendations for this test.
- The tests may be different for each type of scanner, depending on the available tools.
- The tests should include:

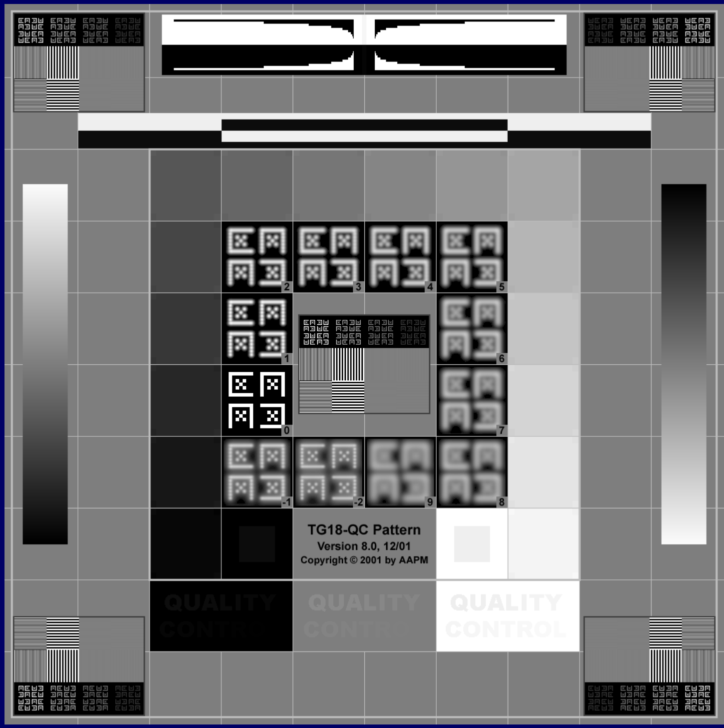
  - General image quality

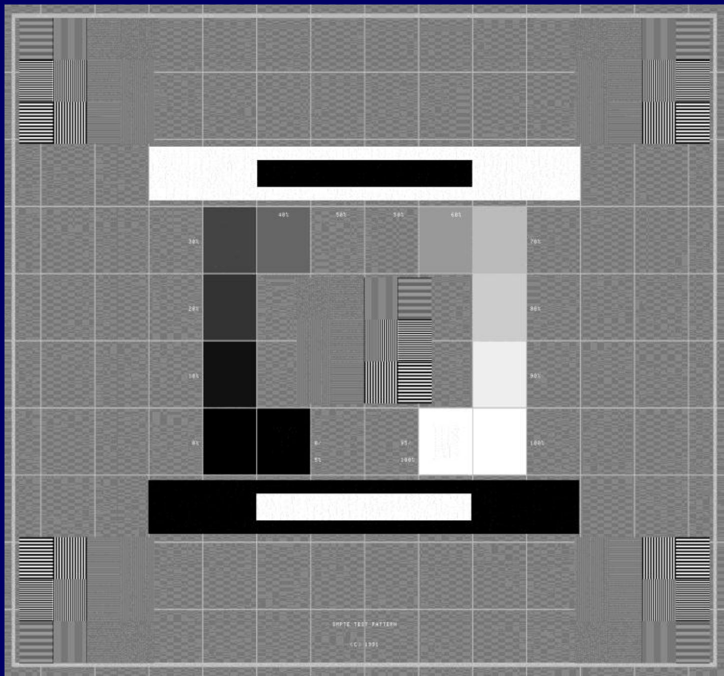
  - Artifact survey

  - Luminance calibration and uniformity

# General Display Quality

- Use a pattern like the SMPTE or TG18-QC, if possible.
- Look for:
  - Distinguishable grayscale levels and low contrast patterns
  - Image blur
  - Geometric distortion
  - Other artifacts



# Display Artifact Survey

- Best with uniform test patterns (preferably one dark and one light).
- Look for:
  - Dead (black) pixels
  - Stuck (white) pixels
- Scratches and other surface damage are usually relevant only if they can be seen in patient images.


# Luminance Measurement

- Use a photometer to measure the luminance at several grayscale levels.
- Try to include measurements near maximum and minimum brightness.

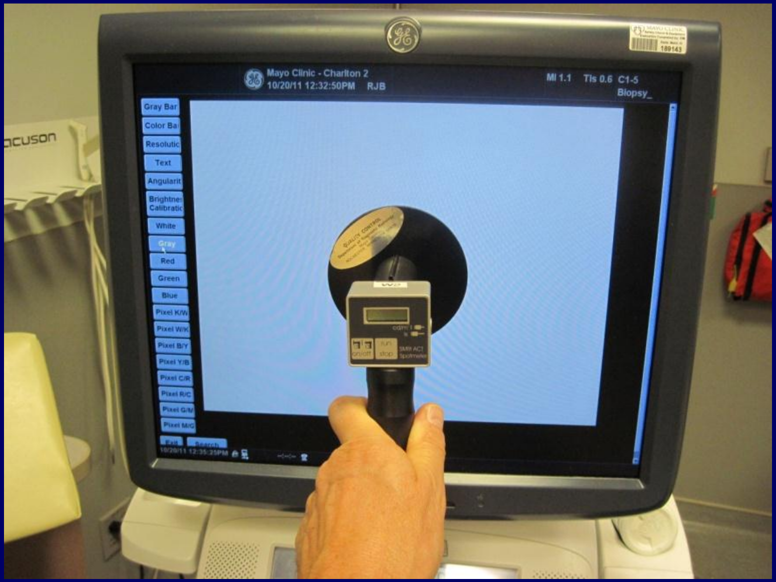


Image provided by N. Hangiandreou

- If a uniform image is available, check luminance uniformity by making multiple measurements across the image.

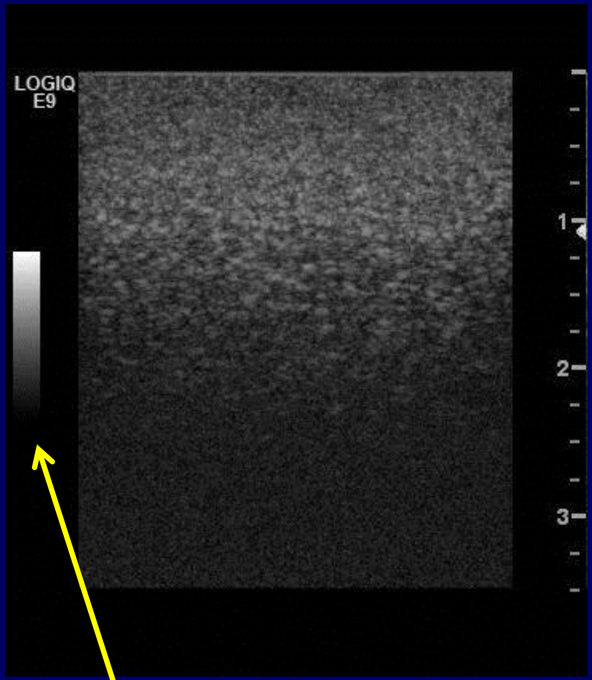
# No Test Patterns?

- If test patterns are not available:

  - Use the grayscale bar as a quick check of consistency of display dynamic range.

  - Look for image blur in text.
  - Use an in-air ultrasound image to check a low luminance level.

  - You may be able to check a high luminance level by maximizing the gain, output power and TGC for a uniform image.



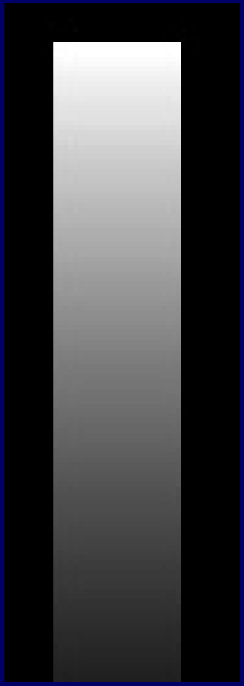
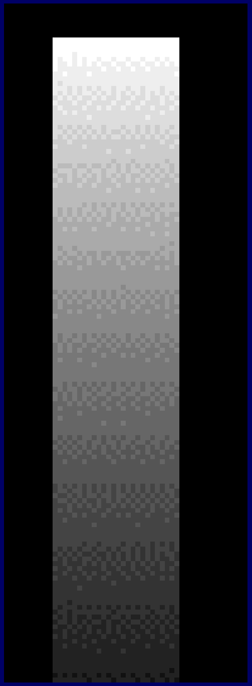
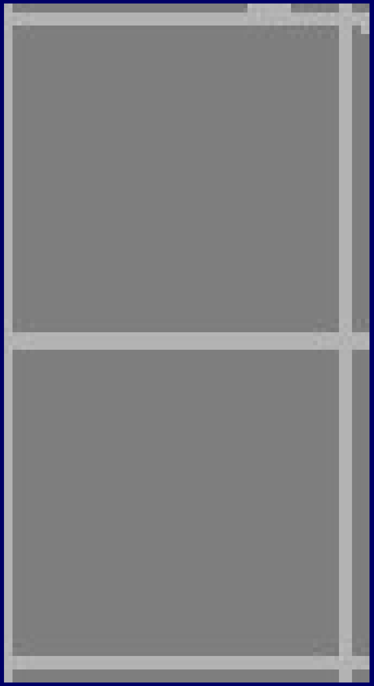
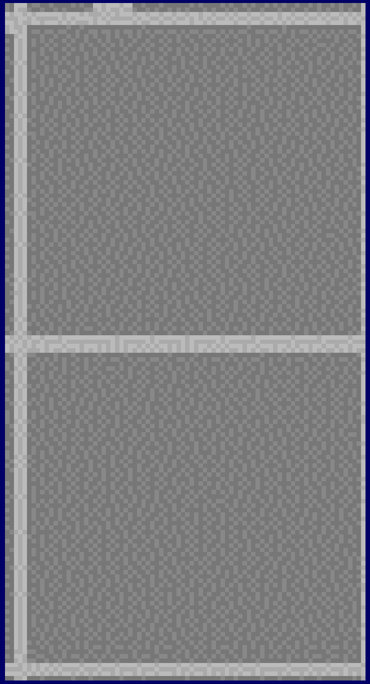

Length of graysclale bar should not vary significantly from baseline (within 10%).

# Primary Interpretation Display Performance

- ACR only requires testing of these displays if they are located at the same facility as the ultrasound scanner.
- The TG18 test patterns can be installed on most of these displays, so we are not limited by the ultrasound manufacturer's tools.
- These will often be PACS workstations, the testing of which may be handled by the PACS group. A reference to their test results should be sufficient to satisfy the ACR.

# Primary Interpretation Display Performance

- Keep in mind that software upgrades can inadvertently cause changes in LUT or bit depth in the images being sent to these displays.

# Evaluation of QC Program

- Review the routine QC records

  - Were the tests performed on time?

  - If a problem was found, is there a record of corrective action?

  - Note any unusual trends in the routine and annual data – are additional tests warranted?

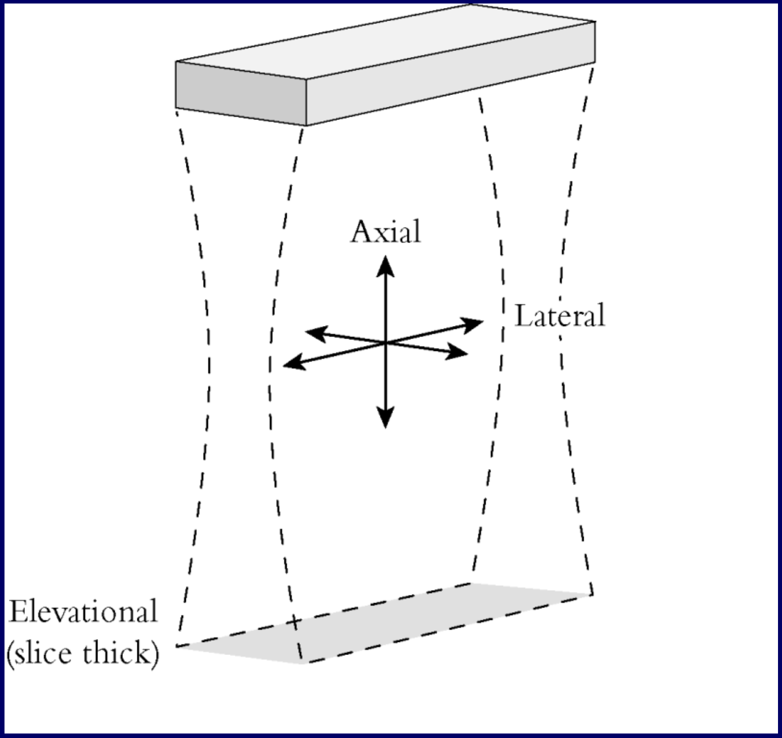
- Review the service logs

  - If certain issues were not identified in the routine QC, would altering the QC program help identify them?

# Spatial Resolution

- Optional for the annual test, but may be a good idea to include for acceptance testing and potential troubleshooting.

- Spatial resolution can be measured in 3 dimensions: axial, lateral and elevational (slice thickness).



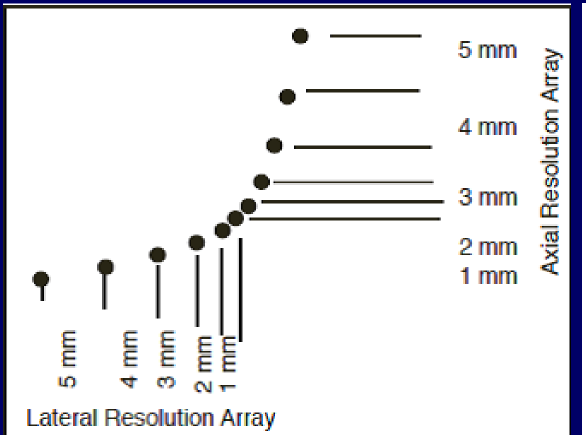
# Spatial Resolution

System Settings:

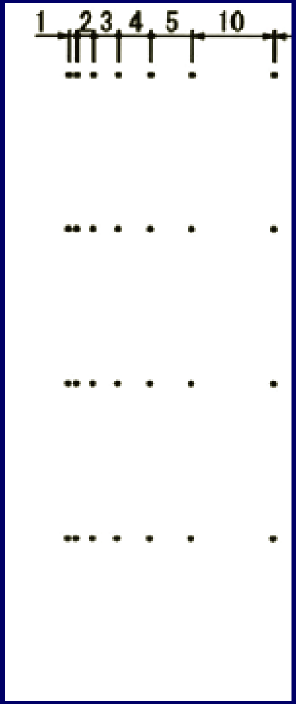
- Place a focal zone at the depth of the resolution target of interest.
- For nylon filaments, adjust gain and TGC such that background texture of the phantom is barely visible.
- For other objects, adjust gain and TGC to maximize visibility of the targets and minimize electronic noise.
- Consistency of all system settings from one year to the next is critical for reproducibility of this measurement.

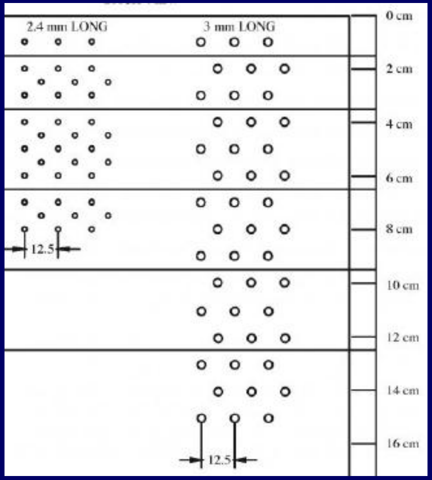
# Spatial Resolution
## (The Quick Way)

- Can use a phantom with resolution targets for both axial and lateral measurements.
- Can use a spherical lesion or cylindrical plug phantom to test all 3 dimensions at once.



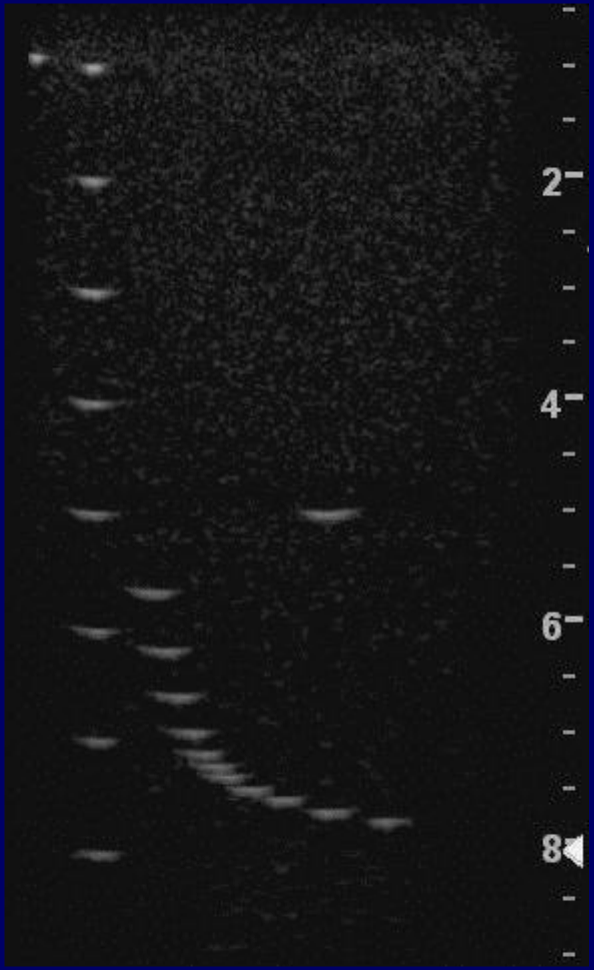




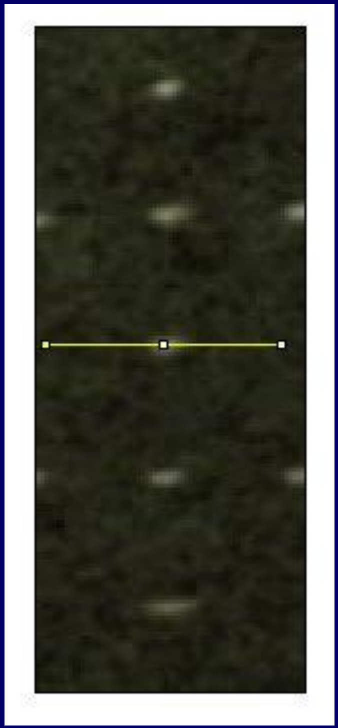
# Spatial Resolution
## (The Quick Way)

**Suggested Criteria:**
from Ultrasound TG 1



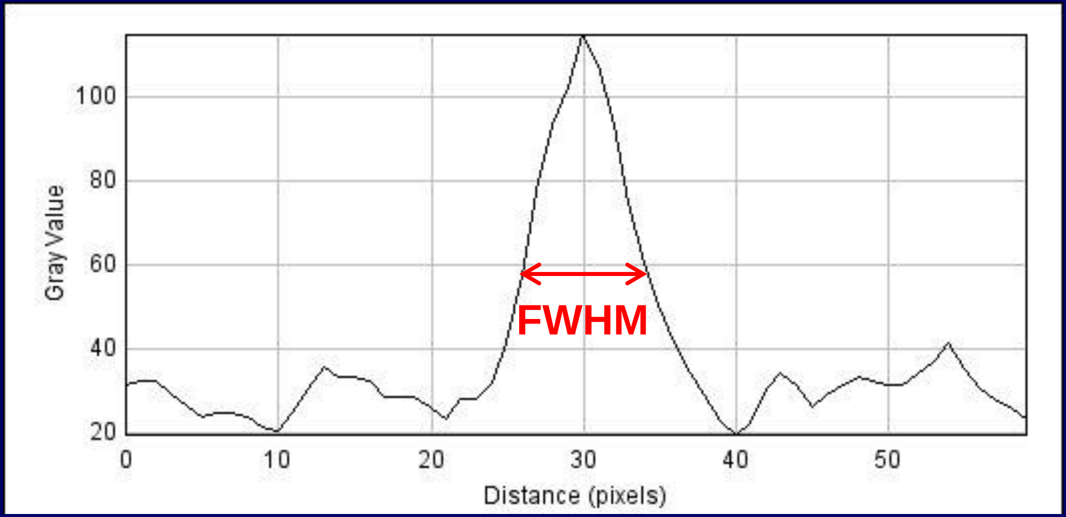

- Axial resolution:
  1 mm or less for $f_c$ > 4 MHz
  2 mm or less for $f_c$ < 4 MHz
  or
  measurable change from baseline
- Lateral resolution:
  2.5 x focal length / (frequency in MHz x aperture in mm)
  or
  change > 1 mm from baseline

# Spatial Resolution



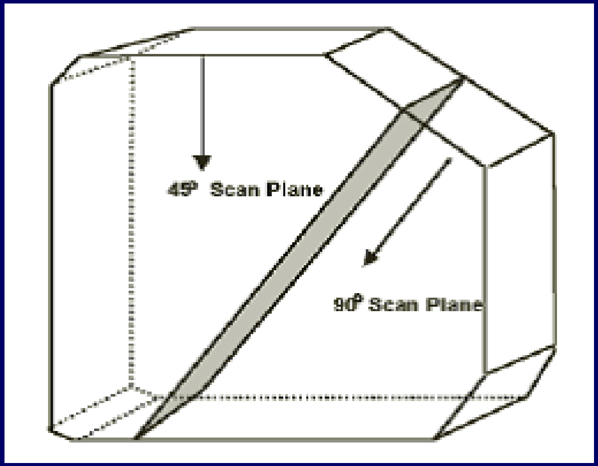
- Axial and lateral resolution can most quantitatively be described by the FWHM or FWTM of a profile through a filament target.
- Software to do this is not generally available on ultrasound scanners.

Would have to transfer images to a secondary system.

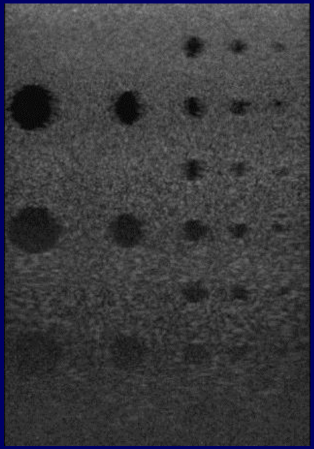


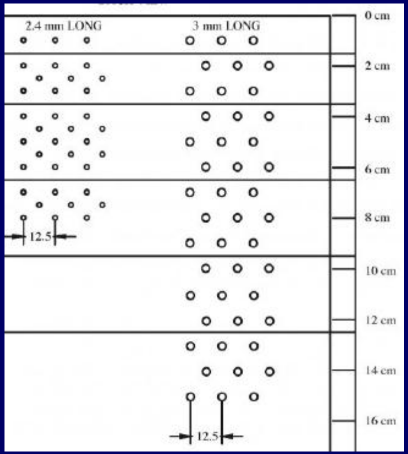
# Spatial Resolution
## (Elevational)

- Resolution in the elevational dimension can be measured directly with an inclined plane phantom.



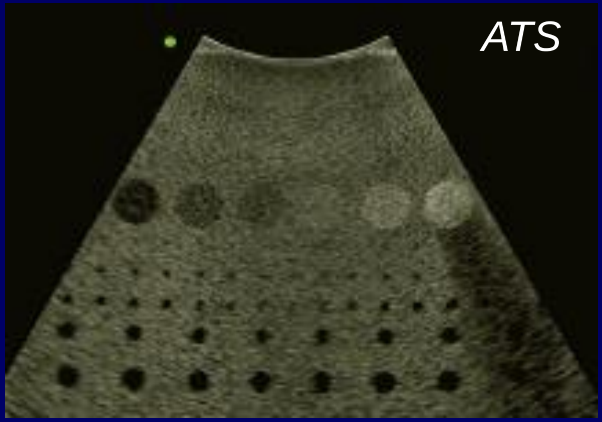

- It can be measured indirectly by assessing overall resolution (all 3 dimensions) of low echogenic targets of different sizes at different depths.

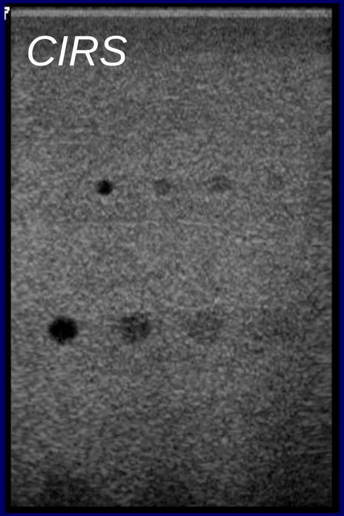





# Contrast Resolution

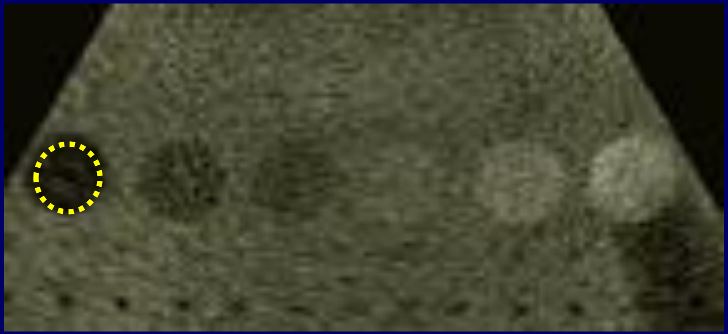
- Optional for the annual, but may be a good idea for acceptance testing.
- Could use anechoic objects, low contrast echogenic objects, 2D cylindrical objects or 3D spherical objects.
- The quick way: report what you see.

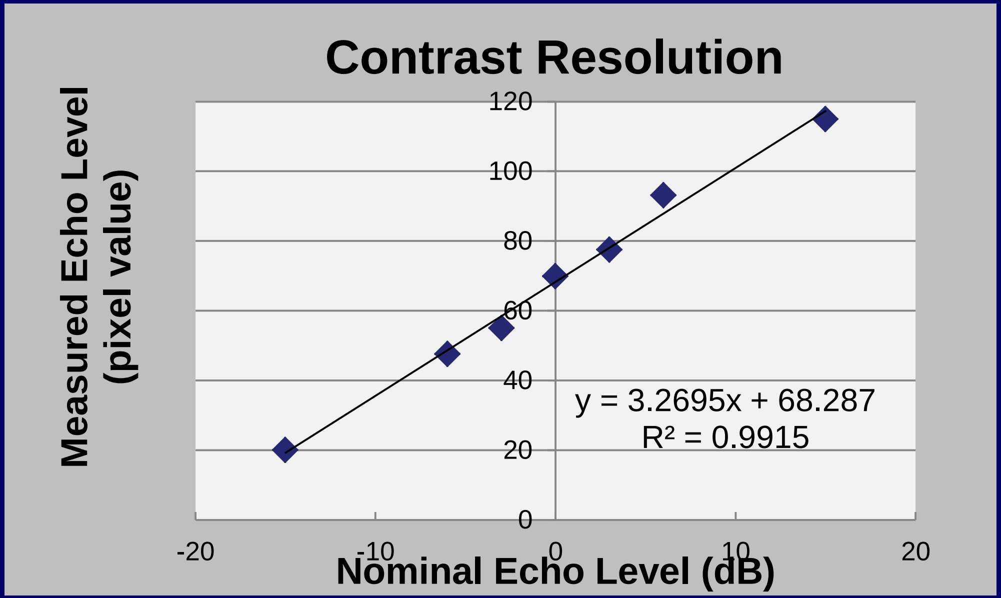




# Contrast Resolution

- Contrast Resolution can be defined as the slope of the regression line through a plot of the image gray levels vs. the nominal echo level [dB].
- Uses multiple linearized images and backgrounds.

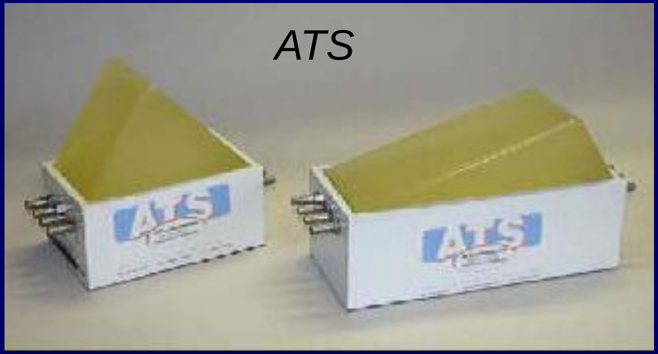





**Ref:** JM Thijssen et al, *Ultrasound in Med and Biol.* 33: 460-471.

# Doppler Testing

- The ACR currently does not have any requirements for Doppler testing.  Doppler testing requires physical measurements of hemodynamic values, not a subjective judgment of image quality.
- Such tests require specialized phantoms (string phantom or flow phantom).


# Primary Doppler Tests

- **Doppler signal sensitivity**
- **Doppler angle accuracy**
- **Color display and gray-scale image congruency**
- **Range-gate accuracy**
- **Flow readout accuracy**



**Refs: 1)** The Institute of Physical Sciences in Medicine. (1995). Routine Checking of Ultrasound Doppler Devices.

**2)** American Institute of Ultrasound in Medicine. (2007). Performance Criteria and Measurements for Doppler Ultrasound Devices: Technical Discussion-Second Edition

# Acceptance Tests?

- Acceptance is a good time to establish some baseline digital data (DOP from IEC definition, FWHM for spatial resolution), even if you don’t plan to use such tests annually. This data could be useful in troubleshooting image quality concerns later.
- During acceptance, it may be useful to perform some tests with and without the special processing modes (spatial compounding and harmonic imaging).

# Documentation

A summary page is recommended.

## MEDICAL PHYSICIST'S ULTRASOUND QC TEST SUMMARY

| | | | |
|---|---|---|---|
| Site Name | | Report Date | |
| Address | | Survey Date | |
| US Unit Manufacturer | | Model/Year | |
| System Location | | UMHS Tag # | |
| Medical Physicist Name | | Signature | |

Survey Type: ☐ Eqpt Evaluation of new unit ☐ Annual Survey

### Medical Physicist's QC Tests

*("Pass" means all components of the test passes; indicate "Fail" if any component fails)*

Transducer #1: ______ Transducer #2: ______
Transducer #3: ______

| | PASS/FAIL | | |
|---|---|---|---|
| Transducer | #1 | #2 | #3 |
| 1. **Uniformity and Artifacts** | | | |
| 2. **System Sensitivity,** Maximum Depth of Visualization | | | |
| Current Value (mm): | | | |
| 3. **Dead Zone (Ring Down)** [≤ 2 mm Pass] | | | |
| 4. **Anechoic Target Resolution** | | | |
| 5. **Contrast Resolution** | | | |
| 6. **Spatial Resolution** [at 40 mm depth] **Axial** | | | |
| Current Value (mm): | | | |
| **Lateral** | | | |
| Current Value (mm): | | | |
| 7. **Geometric Accuracy** | | | |

| | PASS/FAIL |
|---|---|
| 8. **Scanner Display Quality** | |
| 9. **Physical and Mechanical Inspection** | |
| 10. **Evaluation of QC Program** | |

### Medical Physicist's Recommendations for Quality Improvement

# Sample Data Form

## Ultrasound QC

| | | | | | |
|---|---|---|---|---|---|
| Facility | | System ID | | Operator | |
| US Make/ Model | | UMHS Tag # | | Date | |
| | | Phantom ID | | | |

**Transducer Inspection (for each probe):**

Check transducer condition for frayed or cracked cords, cracked or damage housing, cracked or delaminated face.
Check uniformity with the TGC at mid-range, then adjust as necessary to get a good image.
Check penetration with maximum power and (single) transmit focal setting; measure the maximum distance for which you can view texture echoes in the phantom. DOP should not vary by more than 0.6 cm from baseline value.

| Transducer ID/ Tag # | Exam Setting | Depth of Focal Zone (in cm) | FOV (in cm) | Freq (MHz) | Image Uniformity OK / Not OK | Depth of Penetration (in cm) | DOP at Acceptance (in cm) | $DOP_{IEC}$ (in cm) | Cables/Cracks Delaminations OK / Not OK | Service Needed Yes / No |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | |
| | | | | | | | | | | |
| | | | | | | | | | | |
| | | | | | | | | | | |
| | | | | | | | | | | |
| | | | | | | | | | | |

Setup:

Comments:

# Sample Data Form

## Scanner Display and Harcopy Quality

The grayscale length should not change by more than 10% from baseline.

| | Display Focus | Display Artifacts? | Image Quality, SMPTE (OK/ not OK) | Grayscale length (in mm) | Scale length at acceptance (in mm) | Service Needed Yes / No |
|---|---|---|---|---|---|---|
| Scanner | | | | | | |
| Hardcopy | | | | | | |
| Read Station | | | | | | |

**Display Luminance (cd/m$^2$)**

| 0% | 5% | 10% | 20% | 40% | 60% | 80% | 90% | 100% |
|---|---|---|---|---|---|---|---|---|
| | | | | | | | | |

**Display Uniformity (cd/m$^2$)**

| UL | UR | Center | LL | LR |
|---|---|---|---|---|
| | | | | |

| %Difference |
|---|
| |

## Geometric Accuracy:

Vertical error should be within 1.5% of actual (or 0.15 cm); horizontal error should be within 2% of actual (or 0.2 cm).

| Transducer ID/Serial No. | Exam Setting | Actual Vertical Distance (in cm) | Measured Vertical Distance (in cm) | Vertical Error (cm) | Actual Horizontal Distance (in cm) | Measured Horizontal Distance (in cm) | Horizontal Error (cm) |
|---|---|---|---|---|---|---|---|
| | | | | | | | |
| | | | | | | | |
| | | | | | | | |

Comments:

# Quantitative Ultrasound QC

- Software is becoming more readily available for a quantitative approach to US QC.
- UltraiQ, available from CIRS http://www.cirsinc.com/file/Products/078/078_DS_112713.pdf.
- QA4US, from Radboud university medical ctr http://www.qa4us.eu.

# Quantitative Ultrasound QC

- Additional software under development:
  - Uniformity software from the AAPM ultrasound subcommittee.
  - Software for DOP and Geometric Accuracy measurements (EL Madsen, et al).
  - for details, see presentations from AAPM 2013 annual meeting at http://www.aapm.org/meetings/2013AM/PRAbs.asp?mid=77&aid=22645

# Quantitative Ultrasound QC

## References


- Thijssen, J.M., Weijers, G., and De Korte, C.L. (2007) “Objective Performance Testing and Quality Assurance of Medical Ultrasound Equipment”, *Ultrasound in Med and Biol.* 33: 460-471.
- Gibson, N.M., Dudley, N.J., and Griffith, K. (2001) “A Computerized Quality Control Testing System for B-mode Ultrasound”, *Ultrasound in Med and Biol.* 27: 1697-1711.
- Kofler, J.M., and Madsen, E.L. (2001) “Improved Method for Determining Resolution Zones in Ultrasound Phantoms with Spherical Lesions”, *Ultrasound in Med and Biol.* 27: 1667-1676.

# Ultrasound QC Resources

- AAPM Ultrasound Task Group No. 1, “Real-time B-mode ultrasound quality control test procedures”, By MM Goodsitt et al, Med Phys 25(8):1385-1406, 1998.
- AIUM, “Quality Assurance Manual for Gray Scale Ultrasound Scanners (Stage 2)”, edited by E. Madsen, AIUM, Laurel, MD, 1995.
- The Institute of Physical Sciences in Medicine (IPSM) Report No. 71, “Routine Quality Assurance of Ultrasound Imaging Systems”, edited by R Price, York: ISPM, 1995.

# Ultrasound QC Resources

- EFSUMB Technical Quality Assurance Group US-TQA/B, “Guideline for Technical Quality Assurance (TQA) of Ultrasound devices (B-Mode)”, By C Kollmann et al,
  https://www.thieme-connect.de/ejournals/html/10.1055/s-0032-1325347?update=true.
- IEC documents 62791, 62736, 61391-2 http://www.iec.ch/dyn/www/f?p=103:23:0::::FSP_ORG_ID,FSP_LANG_ID:1281,25
- “Ultrasound Equipment Quality Assurance” by J Zagzebski and J Kofler, in “Quality Management in the Imaging Sciences”, J Papp ed, 2002.