Ultrasound Quality Control: A Practical Overview of Tests, Methods, and ACR Accreditation Requirements

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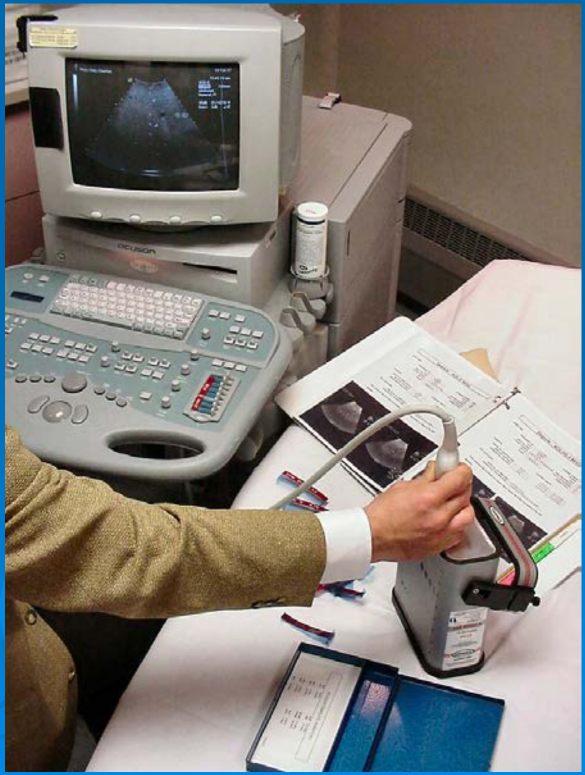

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Outline of topics

- Overview of new QC requirements in the ACR Ultrasound and Breast Ultrasound accreditation programs
- Annual survey test methods
- Routine QC test methods
- Does QC testing add value in ultrasound?
- Conclusions

New QC requirements in the ACR Ultrasound and Breast Ultrasound accreditation programs

- Effective June 1, 2014
- Includes acceptance testing, annual performance survey, routine QC, and preventive maintenance
  - *Maximize the value of QC investment*
- Application & renewal submissions require annual survey reports
- Physicist involvement is "strongly recommended"

Ultrasound Accreditation

Program Requirements

ACR
AMERICAN COLLEGE OF RADIOLOGY

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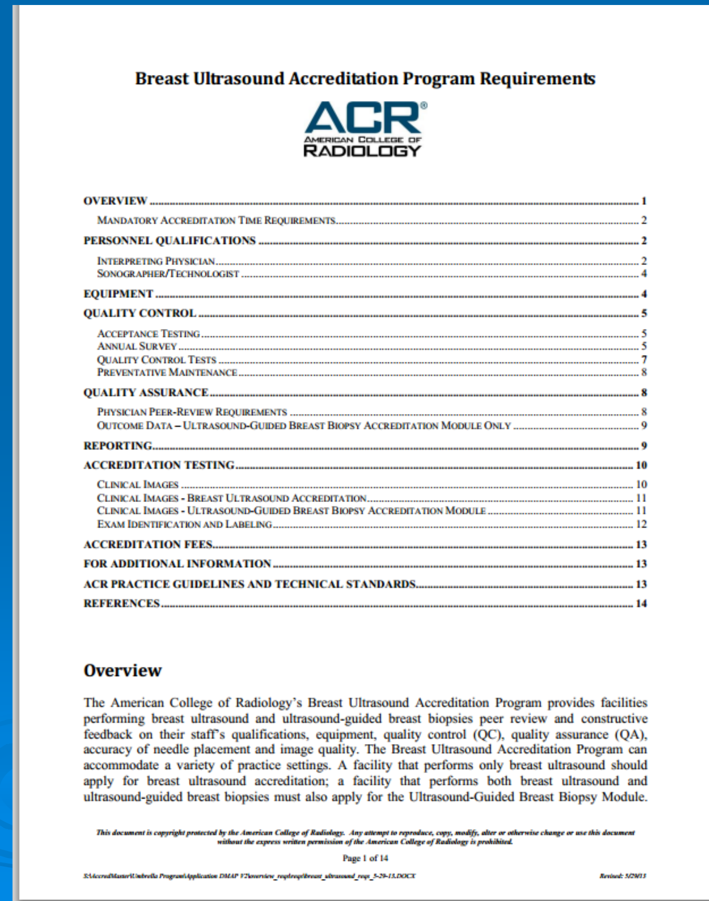
- Specific tests are required for annual survey and routine QC
  - All probes must be tested
  - Acceptance test ~ annual survey tests
- An Ultrasound QC Manual does *not* yet exist
  - Specific testing methods are not prescribed (subjective and objective methods are acceptable)
  - Use of phantom(s) or test object(s) is required, but no specific vendor or model is given, and custom test objects are acceptable
  - *No specific pass/fail performance criteria are prescribed*



Breast Ultrasound Accreditation Program Requirements

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Overview

The American College of Radiology's Breast Ultrasound Accreditation Program provides facilities performing breast ultrasound and ultrasound-guided breast biopsies peer review and constructive feedback on their staff's qualifications, equipment, quality control (QC), quality assurance (QA), accuracy of needle placement and image quality. The Breast Ultrasound Accreditation Program can accommodate a variety of practice settings. A facility that performs only breast ultrasound should apply for breast ultrasound accreditation; a facility that performs both breast ultrasound and ultrasound-guided breast biopsies must also apply for the Ultrasound-Guided Breast Biopsy Module.

Annual survey tests

Annual System Performance Evaluation	
QC Test	**Description**
1. Physical and Mechanical Inspection	Assures the mechanical integrity of the equipment, and the safety of patient and operator.
2. Image Uniformity and Artifact Survey	Identifies the presence of artifacts, often axial or lateral streaks in scans of uniform sections of a phantom. The use of "in-air" images (i.e., images acquired without the use of gel or phantom) may also be useful in detecting superficial artifacts.
3. Geometric Accuracy	Commonly involves use of the scanner calipers to measure known distances between phantom test targets in the axial and lateral directions. Other tests of geometric accuracy are acceptable, e.g. verifying accuracy of the pixel size calibration in the image header.
4. System Sensitivity	Methods relying on visual determination of the maximum depth of visualization of speckle patterns or phantom targets, and quantitative measurements of signal-to-noise ratio (SNR), have been reported.
5. Ultrasound Scanner Electronic Image Display Performance	Maintaining the performance of the image display is critical for providing the greatest diagnostic benefit of the scanner. Display characteristics that are evaluated may include gray scale response and luminance calibration, presence of pixel defects, and overall image quality. These evaluations are typically performed using specialized test pattern images, and may also require photometric equipment. See ACR Technical Standard for Electronic Practice of Medical Imaging.
6. Primary Interpretation Display Performance*	Primary diagnostic displays may be electronic soft-copy displays on a PACS workstation or hard-copy films. They should also include worklist monitors only if used for primary interpretation (other than color analysis). Display characteristics that are evaluated may include gray scale response and luminance calibration, presence of pixel defects, and overall image quality. These evaluations are typically performed using specialized test pattern images, and may also require photometric equipment. See ACR Technical Standard for Electronic Practice of Medical Imaging. (* Only required if located at the facility where ultrasound is performed.)
7. Contrast Resolution (Optional)	The use of both anechoic and low contrast echogenic targets has been suggested, as has the use of 2D cylindrical targets and 3D spherical targets.
8. Spatial Resolution (Optional)	Should be measured in the axial, lateral, and elevational directions. Various approaches have been described for these measurements via visual interpretation of groups of phantom pin/fiber targets and using computer-based algorithms to measure pin dimensions[1-4].
9. Evaluation of QC Program	Provides an independent assessment of the QC program, checks that appropriate actions are taken to correct problems, identifies areas where quality and QC testing may be improved, and enables a comparison of QC practices with those of other ultrasound sites.

Annual survey test methods

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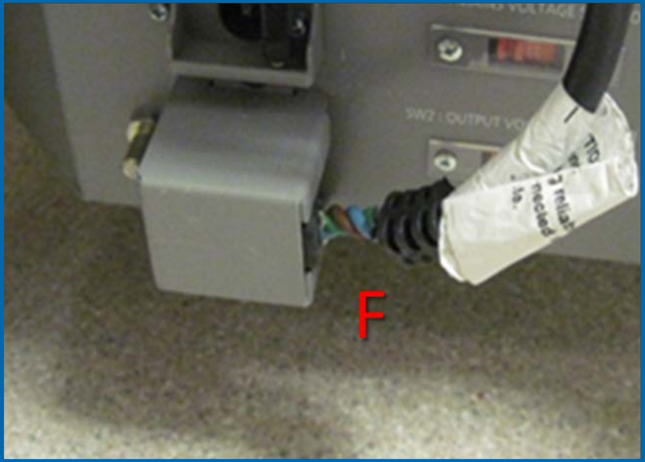
Physical and mechanical inspection

- Scanner
  - Wheel locks
  - Monitor bezel
  - Keyboard
  - Power cable
  - Probe ports
  - Ancillary equipment (auxiliary display, probe tracking system, etc)
  - etc
- Probes
  - Face
  - Handle / housing
  - Cable connection to handle, strain relief
  - Cable
  - Connector
  - etc

Examples

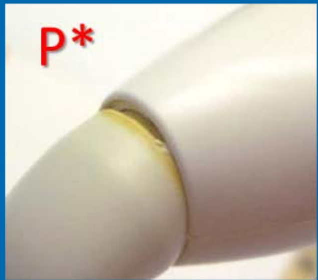
Control Panel Cracked



Power Cord Pulled

Inoperable wheel locks

Examples



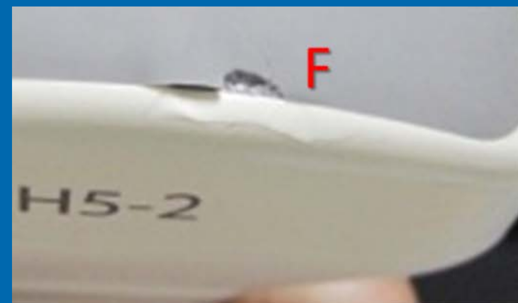
Grommet/Housing Separation

Grommet/Housing Separation

Lens Delamination

Lens Pitting

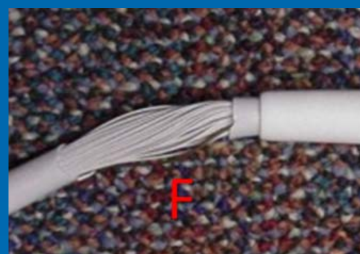
Lens Peeling / Delamination



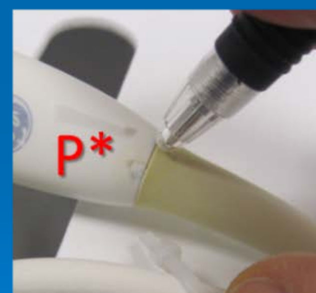
Cracked Housing/ Lens Damage

Loose Scan Head

Partial Cable Tear



Complete Cable Tear



Peeling of Housing Layer

Separation of Handle

Bent Connector Pins

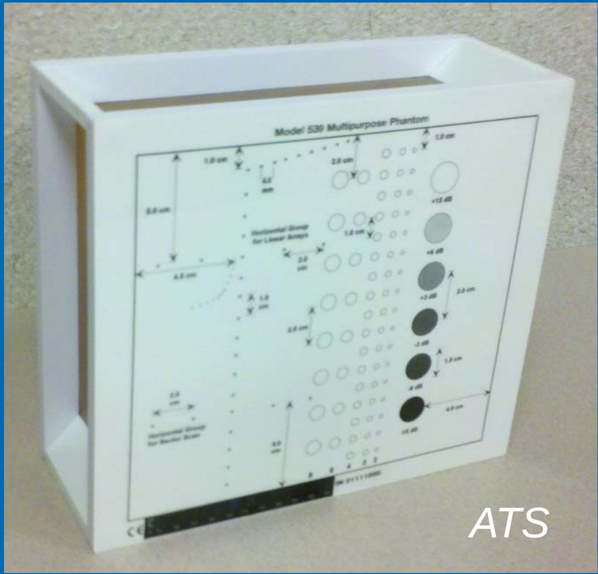
Connector Damage

Pass / fail decisions are often subjective

Image uniformity & artifact survey

- *Most effective test for identifying problems*
- Scan a test object/phantom
  - Optimize scan parameters for greatest sensitivity
  - Time-varying phantom speckle signal
- View live scan images
  - Debug any artifacts observed
- Export phantom & in-air clips
  - Retrospectively cine review
  - Process → median or mean image
- Assess severity of detected artifacts, and determine needed action

Phantoms

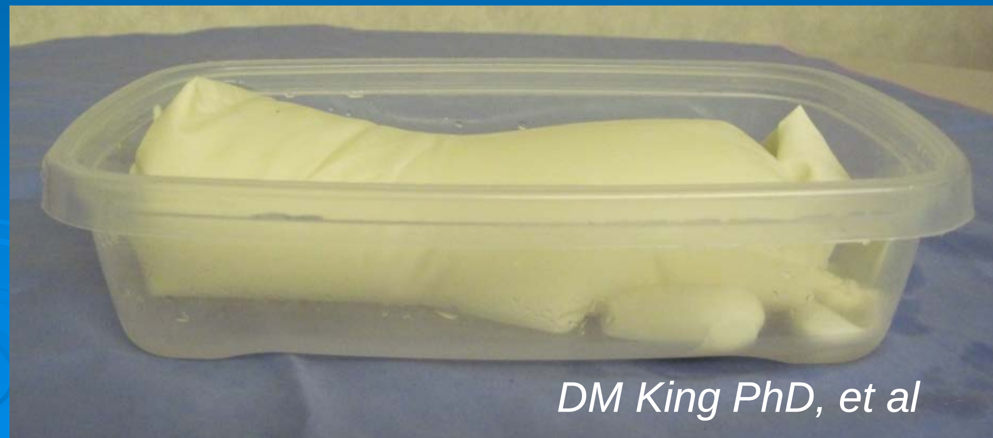


ATS

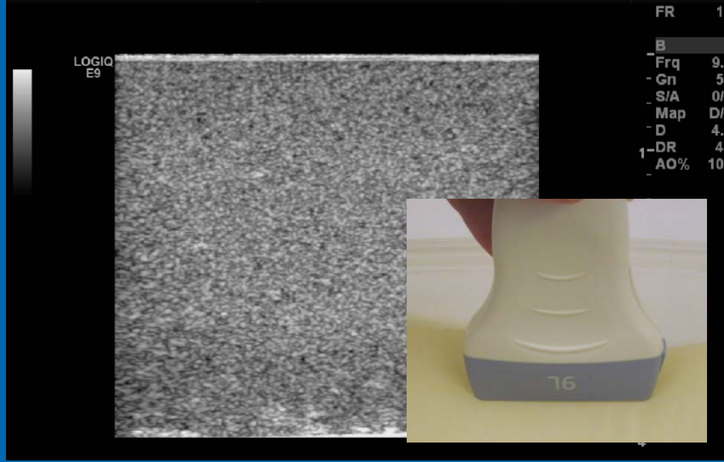
Gammex

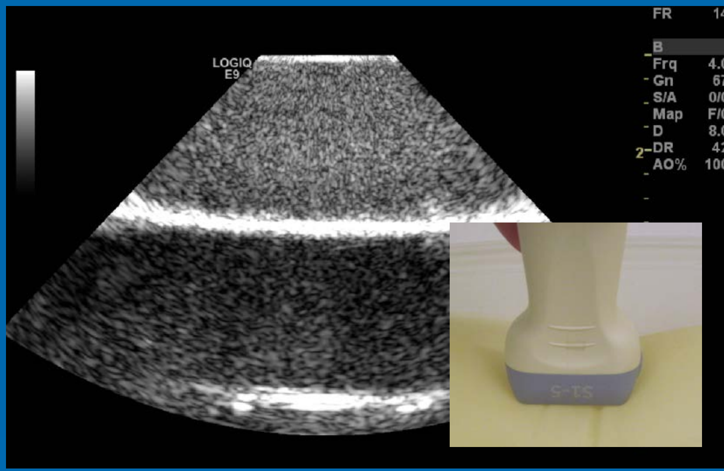
EL Madsen, PhD

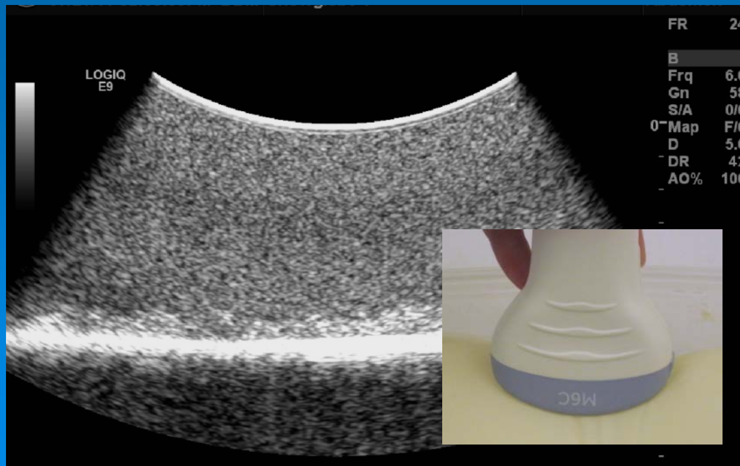
Cristel Biau, Gammex

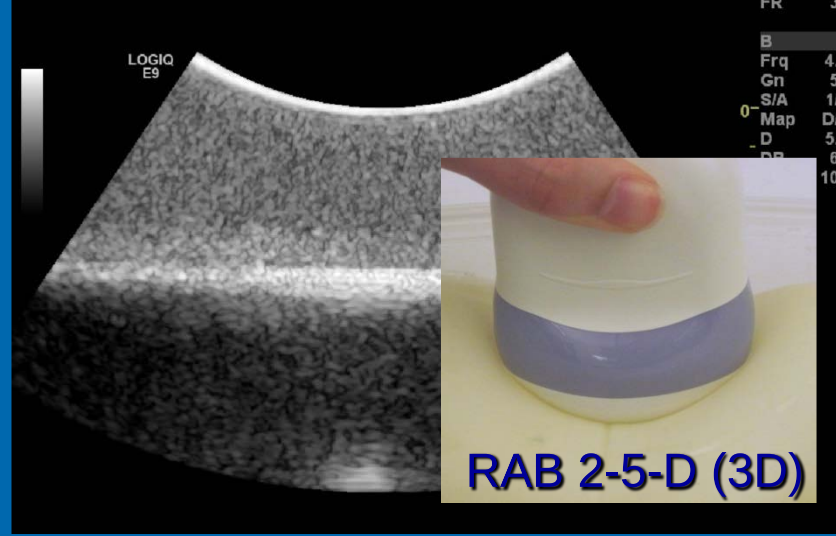


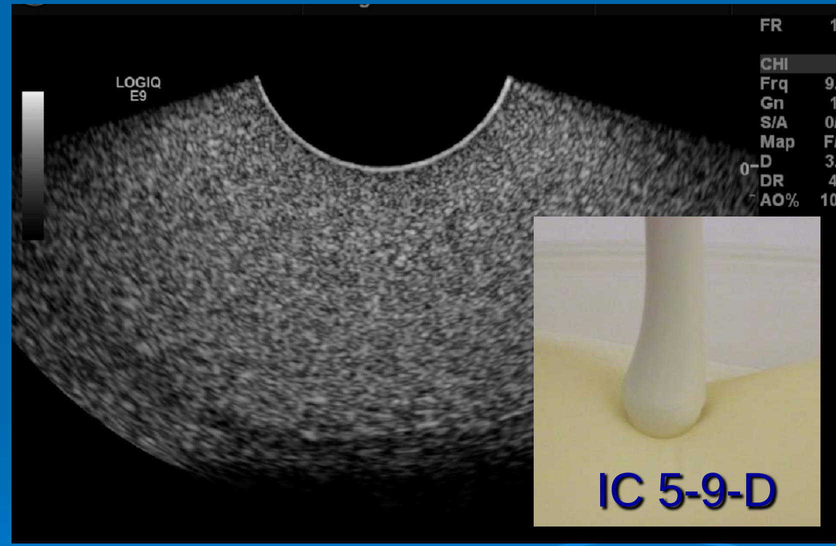
DM King PhD, et al









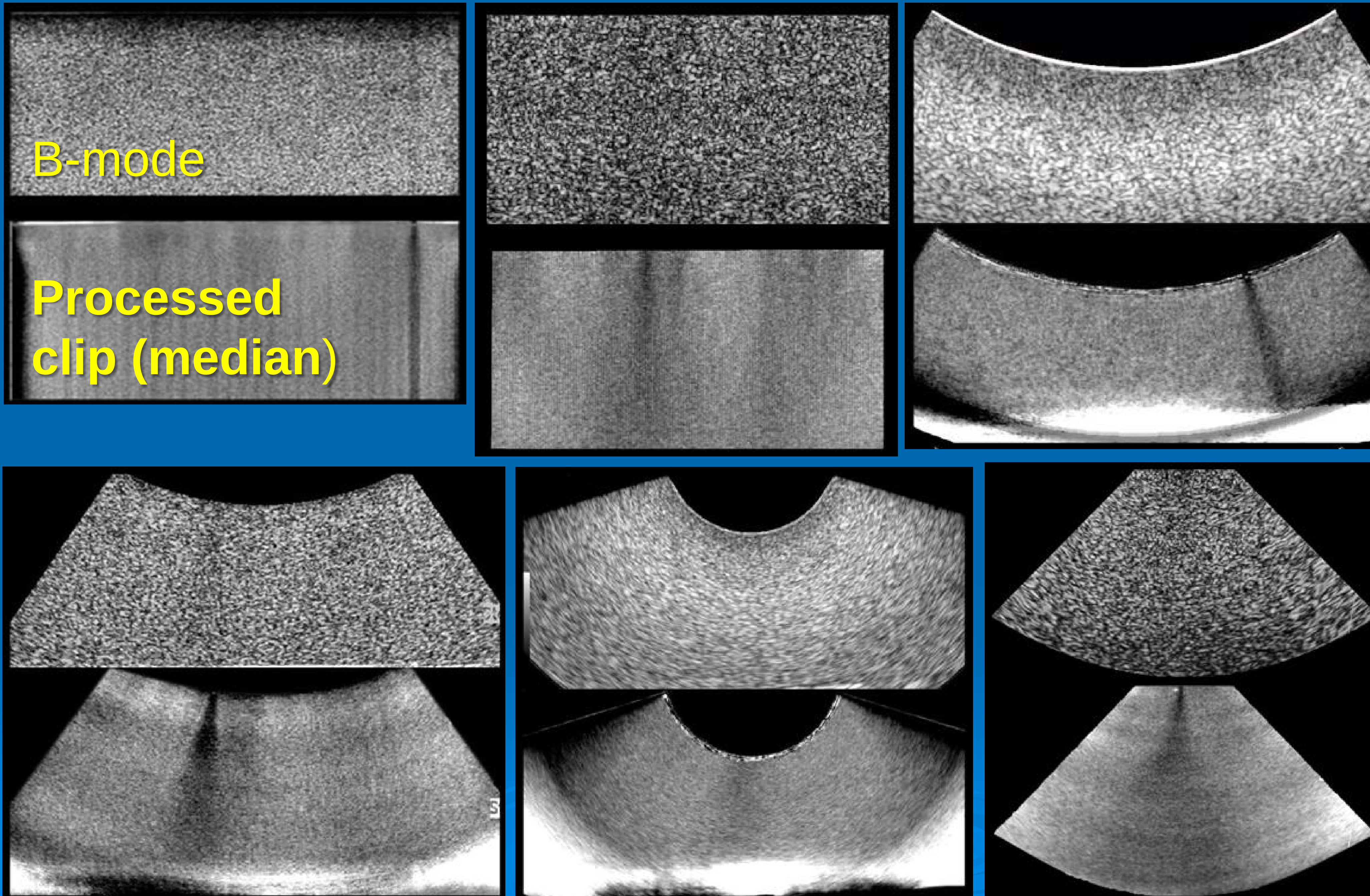


Also…

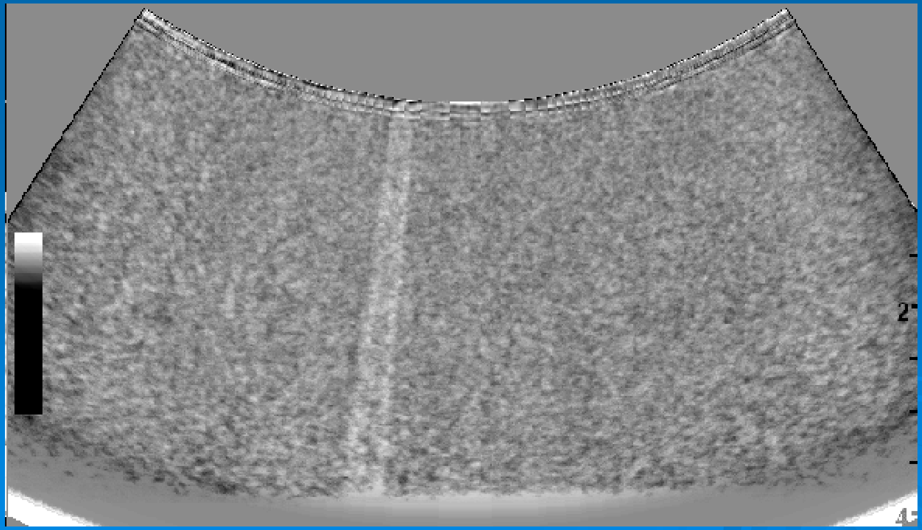
- *Bi-plane prostate probe*
- *Automated breast volume scanner*
- *Endoscopic US probe*

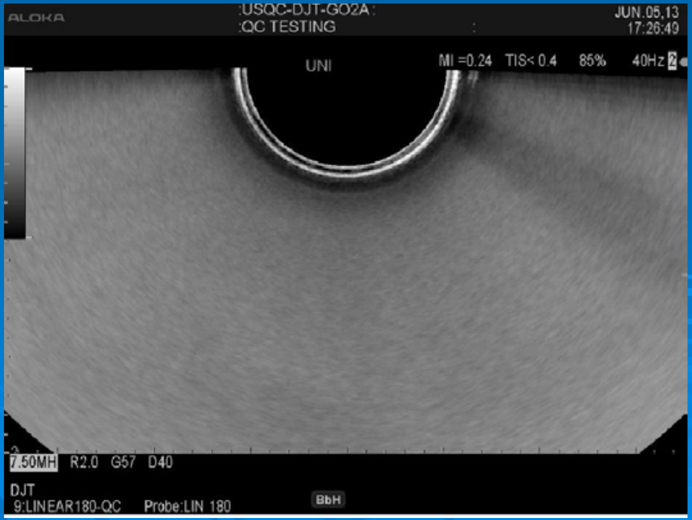
Scan parameters for high sensitivity uniformity assessment

- Maximize acoustic output
- Highest fundamental frequency
- Minimum depth that utilizes full array
- Single, superficial transmit focal zone
- Dynamic range at/near minimum
- Gain and TGC adjusted to provide ~uniform field with good signal at probe face
- Disable spatial compounding


B-mode
Processed clip (median)

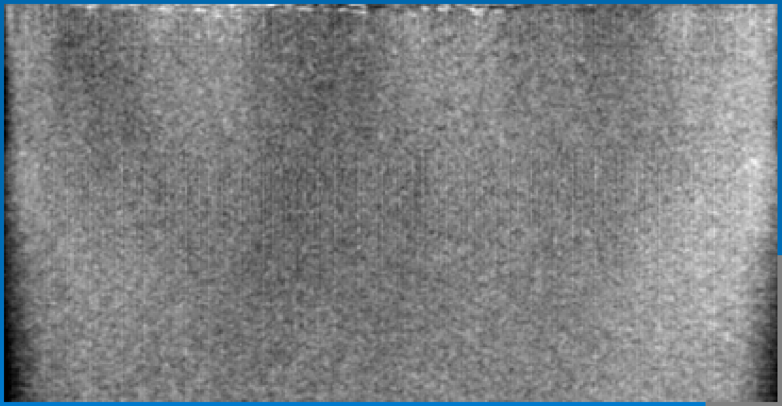
- Median/mean image > live scanning >> still image in terms of artifact detection sensitivity
- Artifacts of concern are typically superficial and oriented along axial direction
- Hypoechoic artifacts more common than hyperechoic artifacts

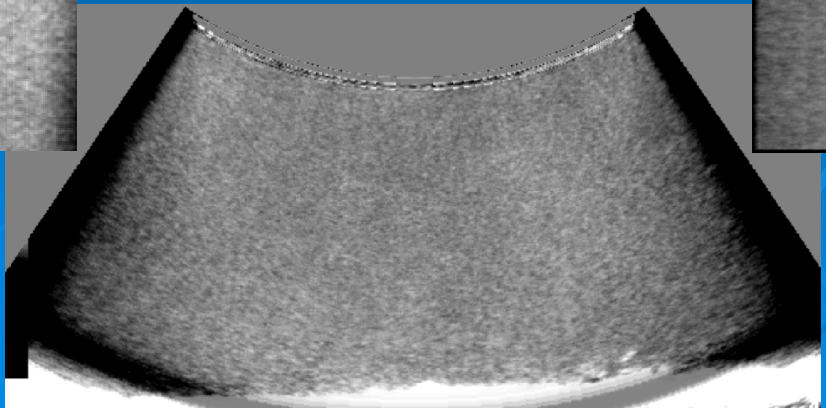


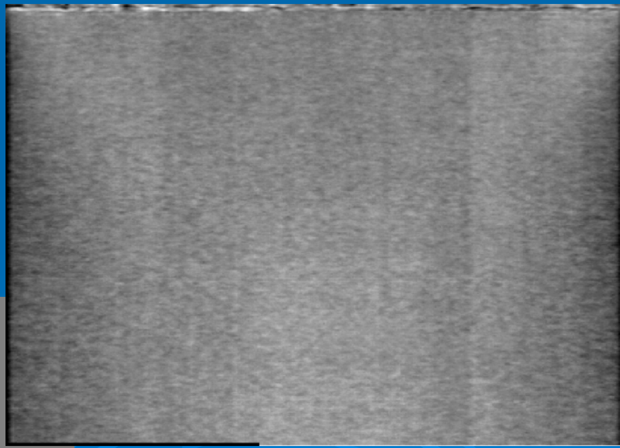


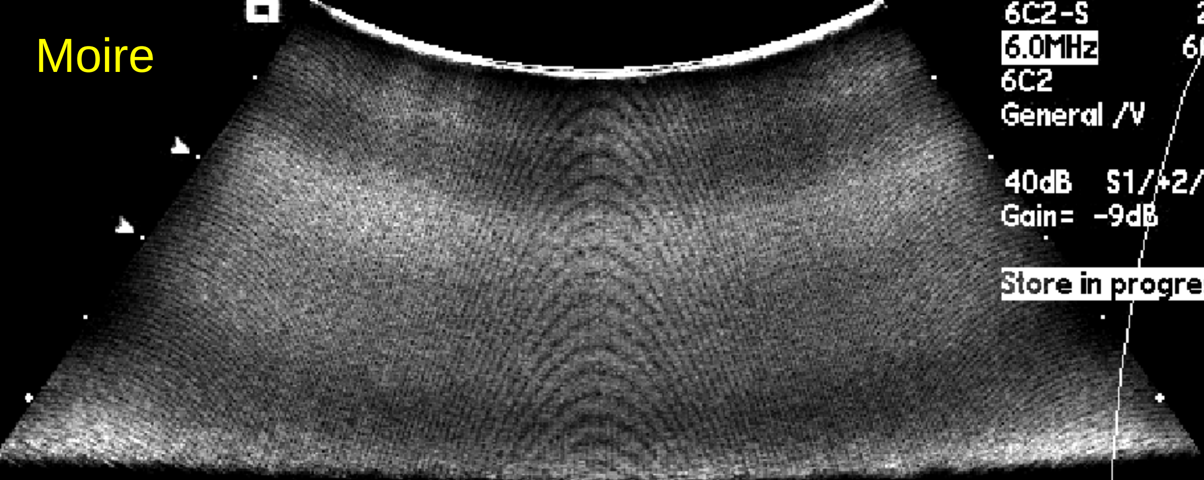
Intrinsic uniformity artifacts

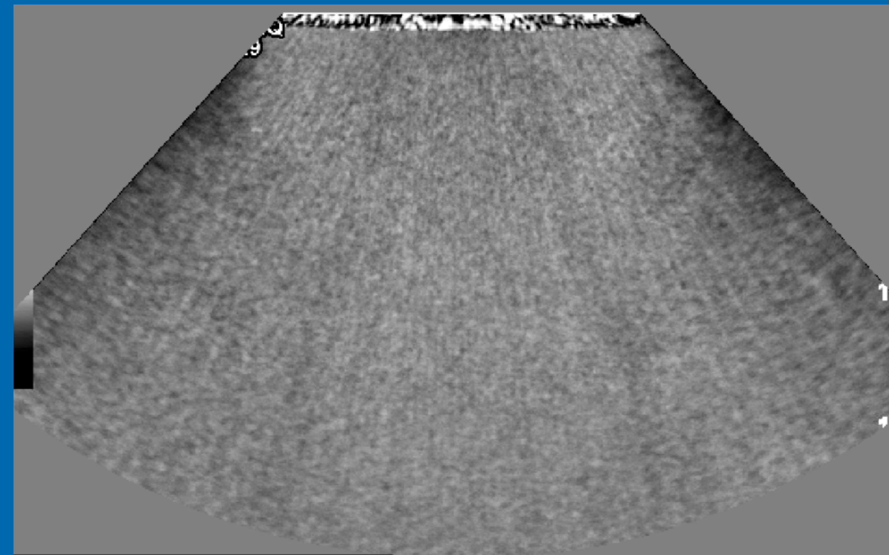
- Patterns of signal non-uniformity seen in multiple instances of the same probe model
  - Large scale non-uniformities
  - Corduroy, moire, cross-hatch, etc, patterns
- *These are not QC (or acceptance test) failures*





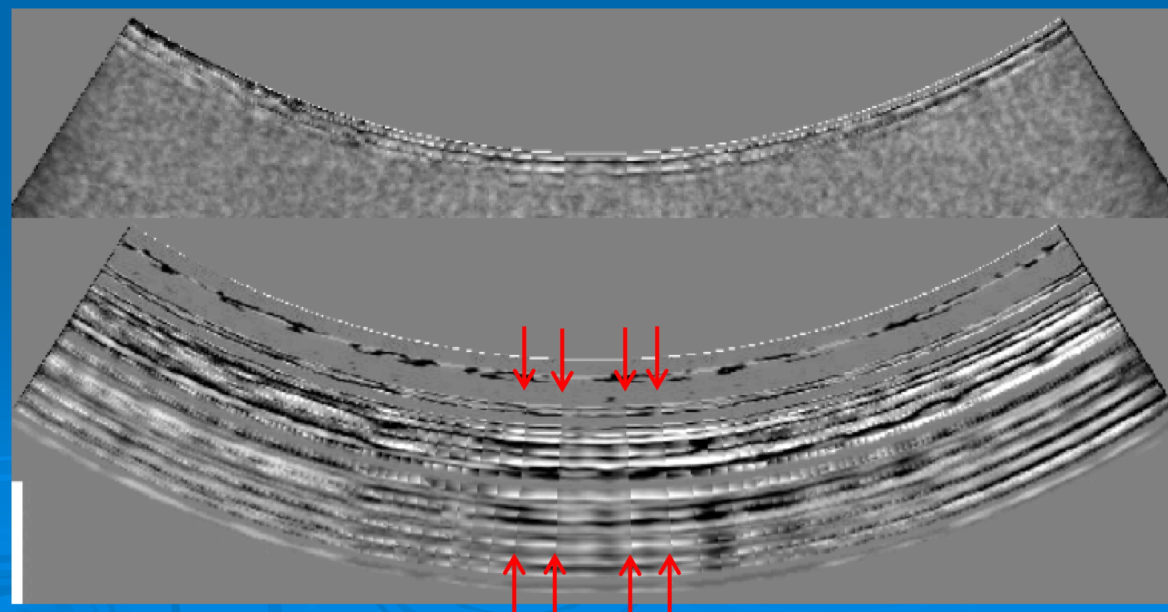



Moire
6C2-S
6.0MHz
6C2
General /V
40dB
Gain= -9dB




Cross hatch


Corduroy



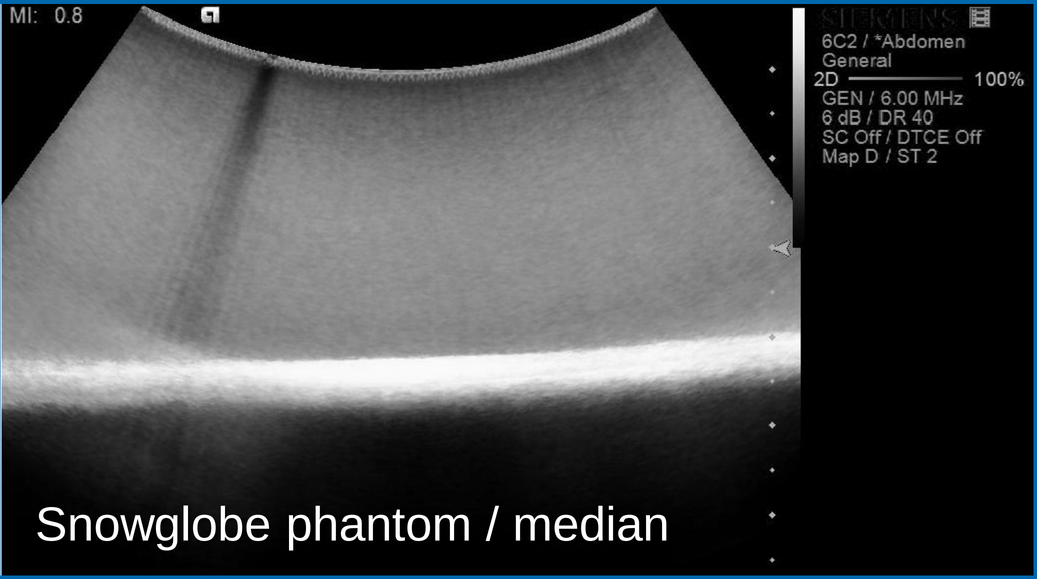
Debugging uniformity artifacts

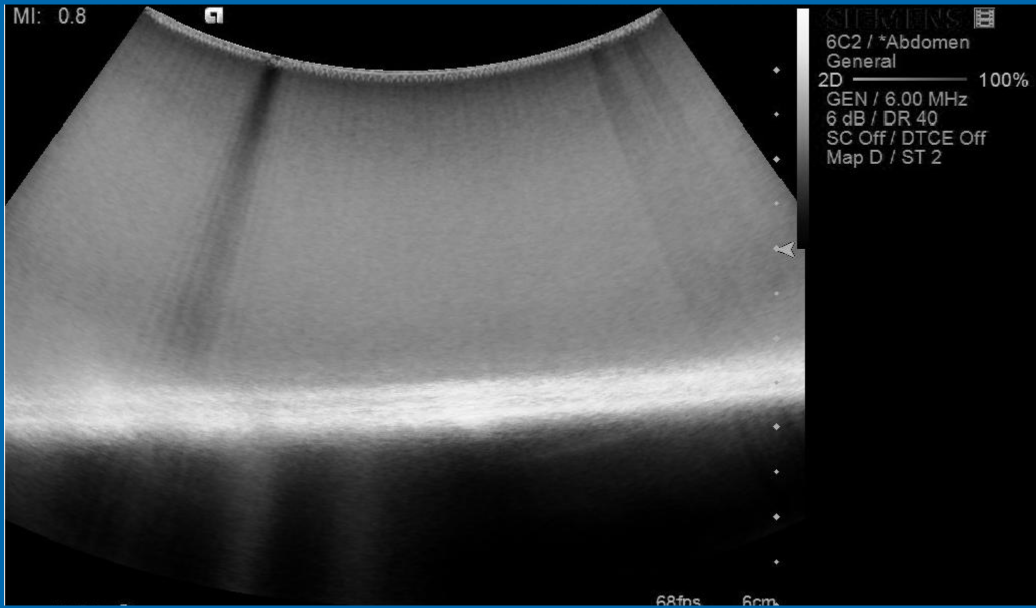
- *Many artifacts seen are not reproducible* (e.g. due to dirty contacts in connector)
- Artifacts may be due to problems with the probe (elements, conductors, connector) or scanner (port, components of data channel)
- *Want to be sure we're dealing with a real equipment problem, and ordering repair or replacement of the right component*

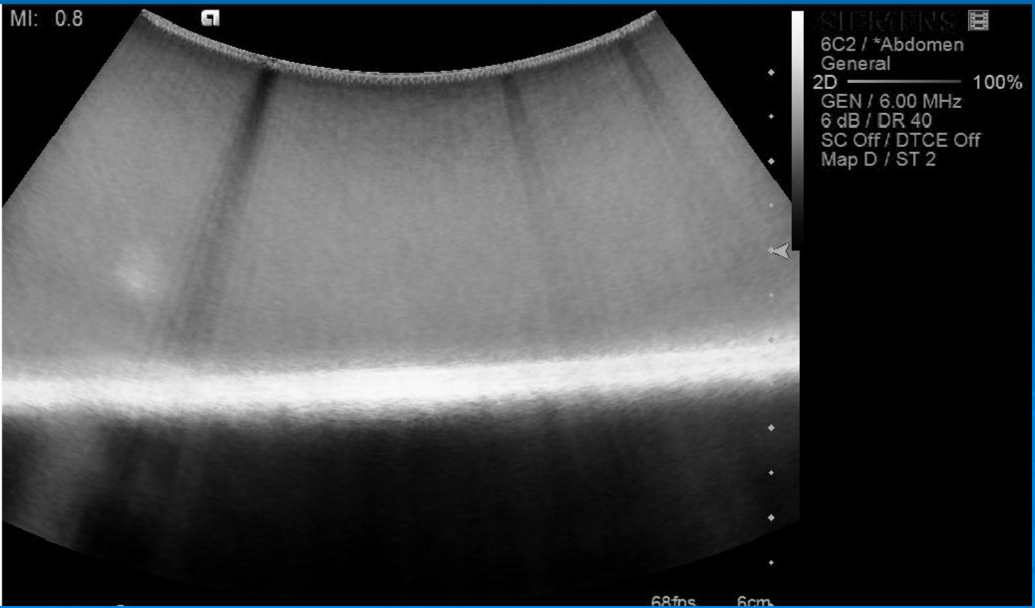
Debugging uniformity artifacts

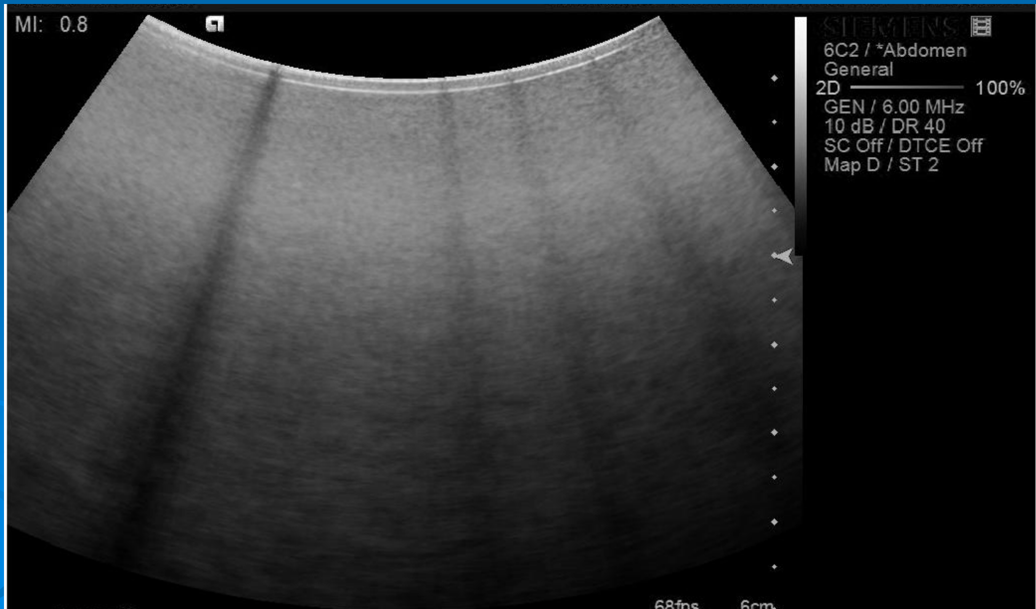
- When an artifact is initially noted, try…
  - Assuring good coupling to the phantom
  - Checking for dirt/debris on probe face, probe connector or scanner port
    - Inspect equipment for dirt, etc
    - Remove and re-seat probe in same scanner port
    - Blow out probe connector & scanner port with canned air
  - Checking different combinations of probes and ports (and scanners if possible)
  - Rebooting the scanner, and retesting
  - Flexing the probe cable to assess artifact stability…

Cable flex artifact - Example

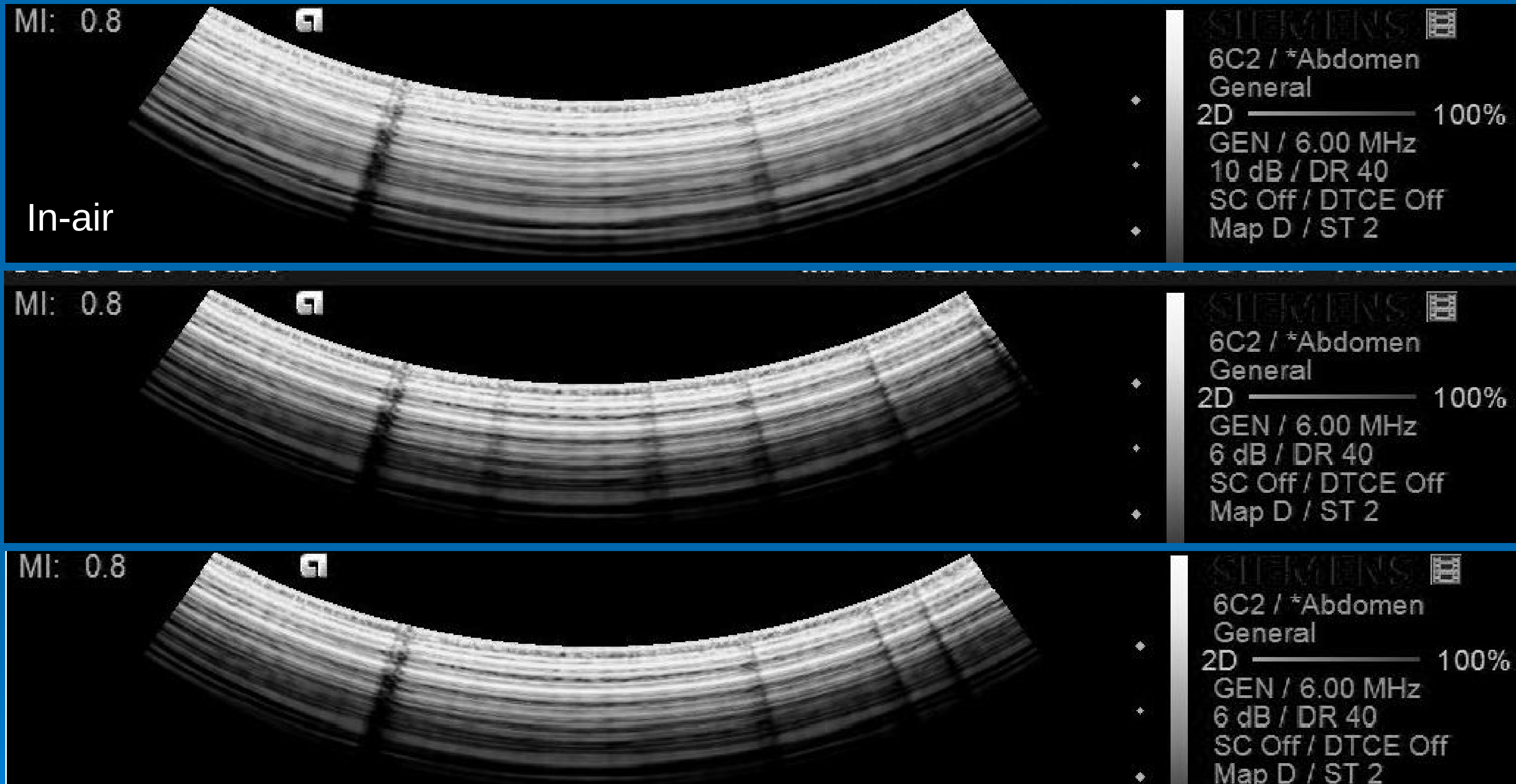








Cable flex artifact - Example



All in-air and phantom clips acquired in a span of 3 minutes
Are these problems prone to ~rapid decline?

Typical behavior of uniformity artifacts over time

- Analyzed uniformity QC findings for 210 probes over a period of 2.5 years
  - Visual artifact detection from median images
  - Subjective, visual assessment of artifact severity
    - Scale: P, P1, P2, P3, F -- considering artifact visibility (air, phantom, & clinical images), location, size, number
- Primary question:

  How does artifact severity change over time?

Reference: Stekel S, Hangiandreou N, Tradup D. Analysis of Uniformity Artifacts Detected During Clinical Ultrasound Quality Control. J Ultrasound Med 32(suppl):S109, 2013.

- Results
  - **58** probes with artifacts were detected
    - **22** probes failed at initial artifact detection, ~spontaneous
    - **36** probes initially detected with "subcritical" artifacts
      - **9** probes with "subcritical" initial severity scores (P1, P2, or P3) failed during the 2.5 yr study period
        - Time to failure ranged from 3-14 months (mean = 9.1 mo)
        - *A pattern of progressive worsening was not seen, ~spontaneous*
      - **27** probes with "subcritical" initial severity scores did not fail during the study
        - Observation time ranged from 0.5-16 mo (mean = 10.5 mo)
        - During 6 months after study period, 4 of these did fail
        - *A pattern of progressive worsening was not seen*

- Conclusions
  - Most failures were “spontaneous” (i.e. occurred after a previous “perfect” uniformity evaluation)
  - Once detected, “subcritical” artifact severity remains stable
    - 25% failed within 3-14 months, but without gradual increases in severity (i.e. “spontaneously”)
  - *No reliable trend of gradual progressive worsening of detected transducer artifacts was seen*
    → Implications for QC frequency?
- Limitation of the study
  - Subjective severity assessment

Performance criteria for uniformity artifacts (and other tests): When to fix or replace?

- *Risk versus cost equation can be very subjective & can potentially vary over time*

- These factors should be considered:
  - Patient and operator safety
    - Abrasion or pinching, electrical, infection/cleaning
  - Risk of incorrect diagnosis

    (Mårtensson M, Olsson M, Segall B, et al. High incidence of defective ultrasound transducers in use in routine clinical practice. Eur J Echocardiogr 2009, 10:389-94.)

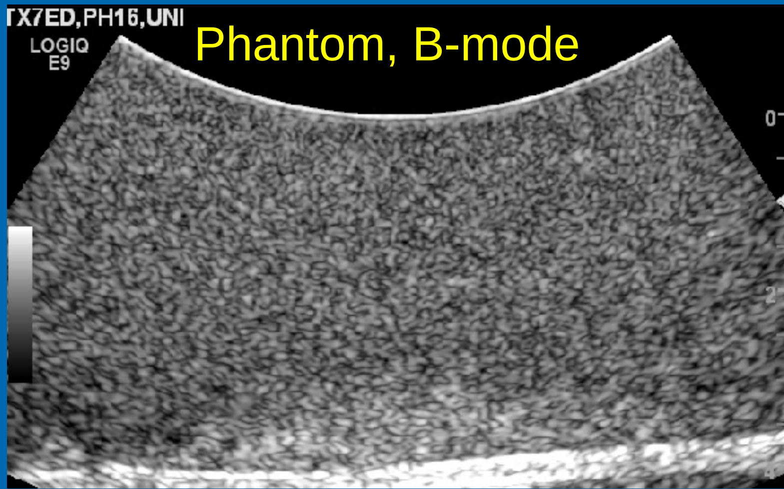
When to fix or replace?

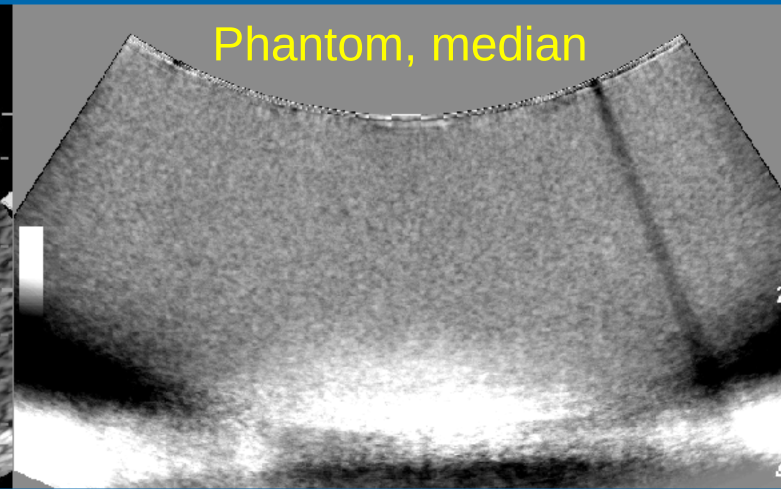
- These factors should be considered *(cont.)*:
  - Use for procedures
    - Impact on consistent visibility of needle/device
  - Visibility in clinical exams
    - Artifact contrast, size, position, number
    - Quality indicator of practice (patient, outside MD)
  - Reduced functionality and effectiveness
    - Limited useful FOV
    - Spectral Doppler (?)
  - Likelihood of rapid performance decline
  - Service contract / financials

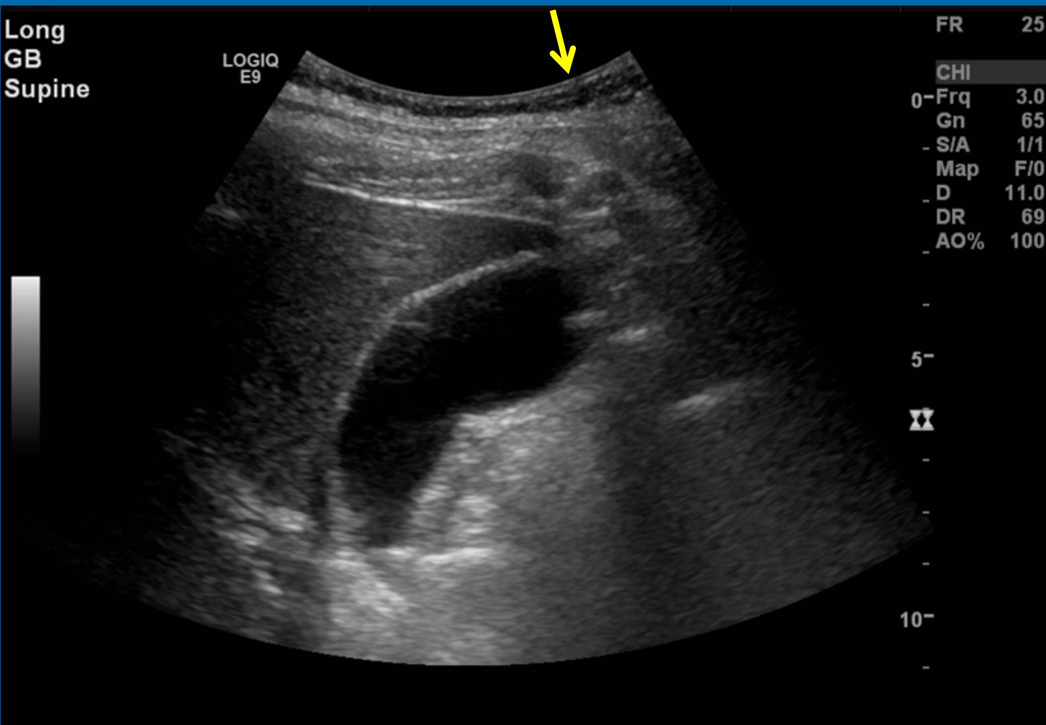
When to fix or replace?

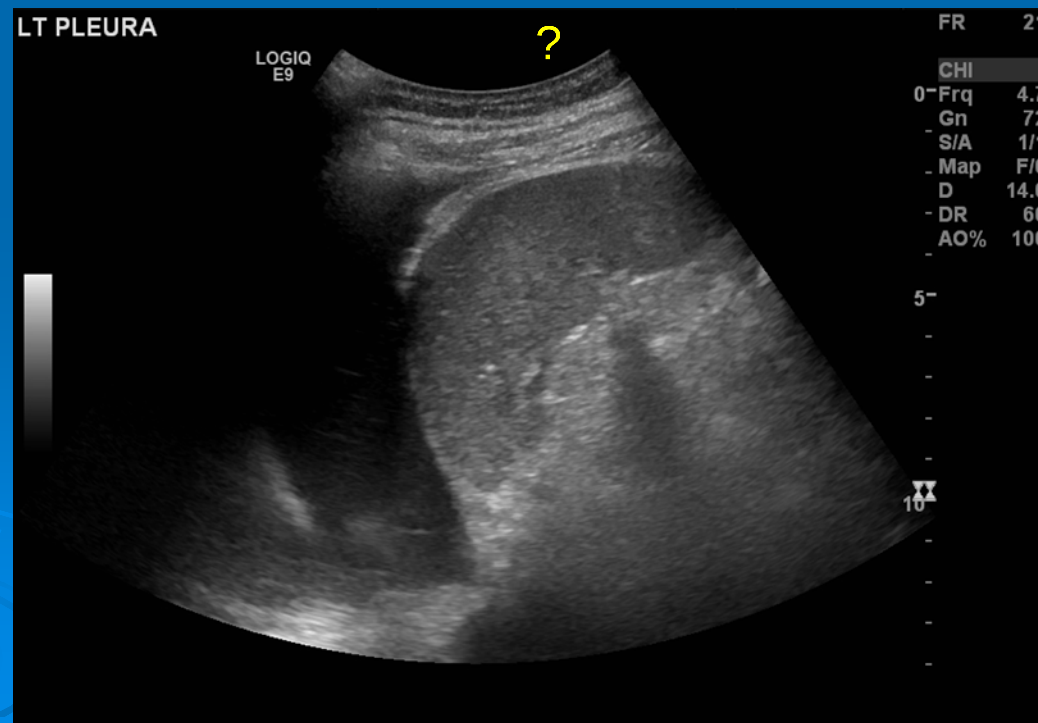
- Practical impact to clinical ultrasound practice can be lessened by notifying users of the issue
  - Greater care when cleaning or disinfection
  - Avoid use of probe for procedures
  - Avoidance of problem regions of array
- Sonographers/MDs are used to recognizing and effectively dealing with many artifacts in every exam
- *Discuss potential equipment failures with the practice*

Example 1


TX7ED,PH16,UNI
LOGIQ
E9
Phantom, B-mode
0


Phantom, median


Long
GB
Supine
LOGIQ
E9
FR 25
CHI
Frq 3.0
Gn 65
S/A 1/1
Map F/0
D 11.0
DR 69
AO% 100
0
5
10


LT PLEURA
LOGIQ
E9
?
FR 21
CHI
Frq 4.7
Gn 72
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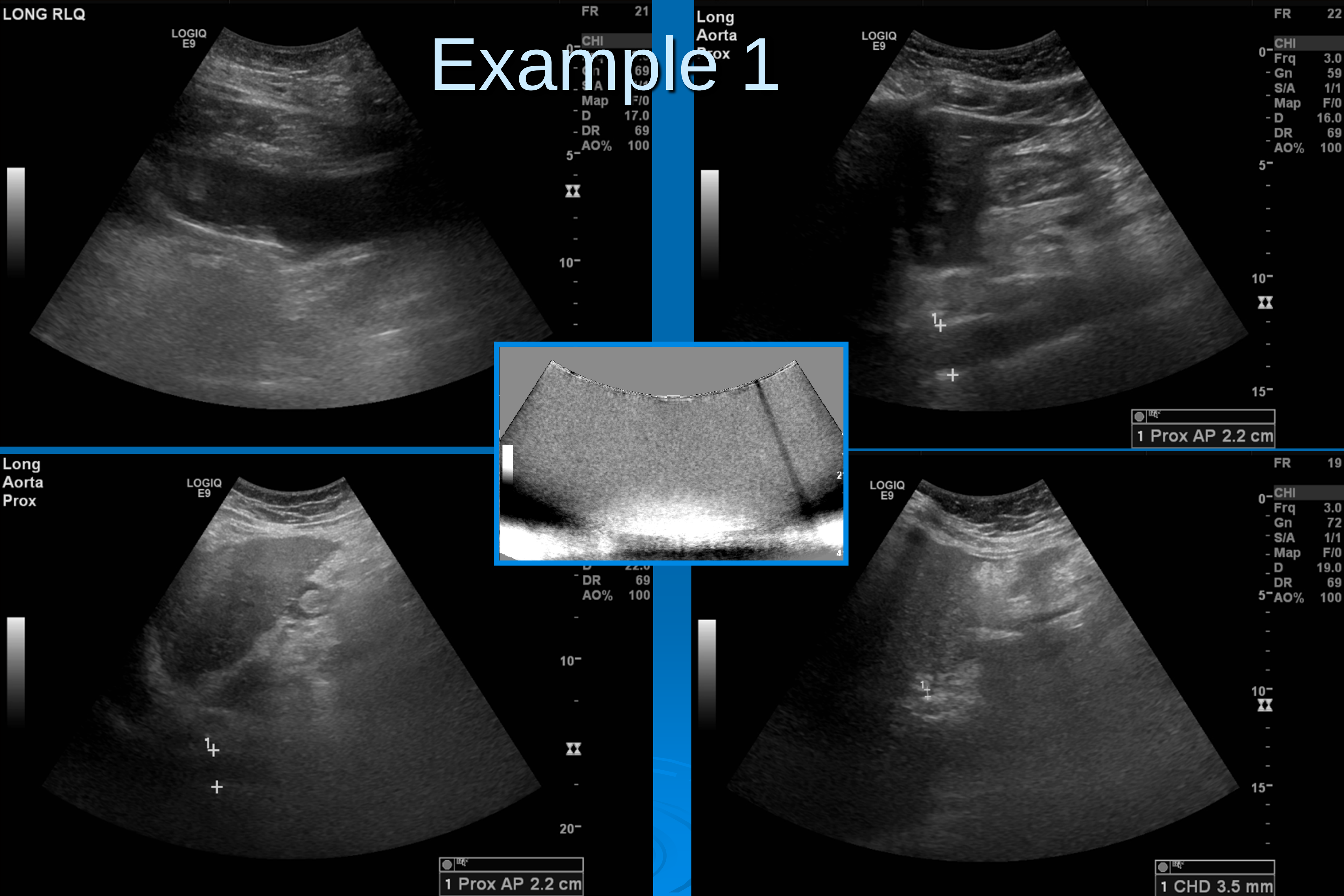
Map F/0
D 14.0
DR 66
AO% 100
0
5
10

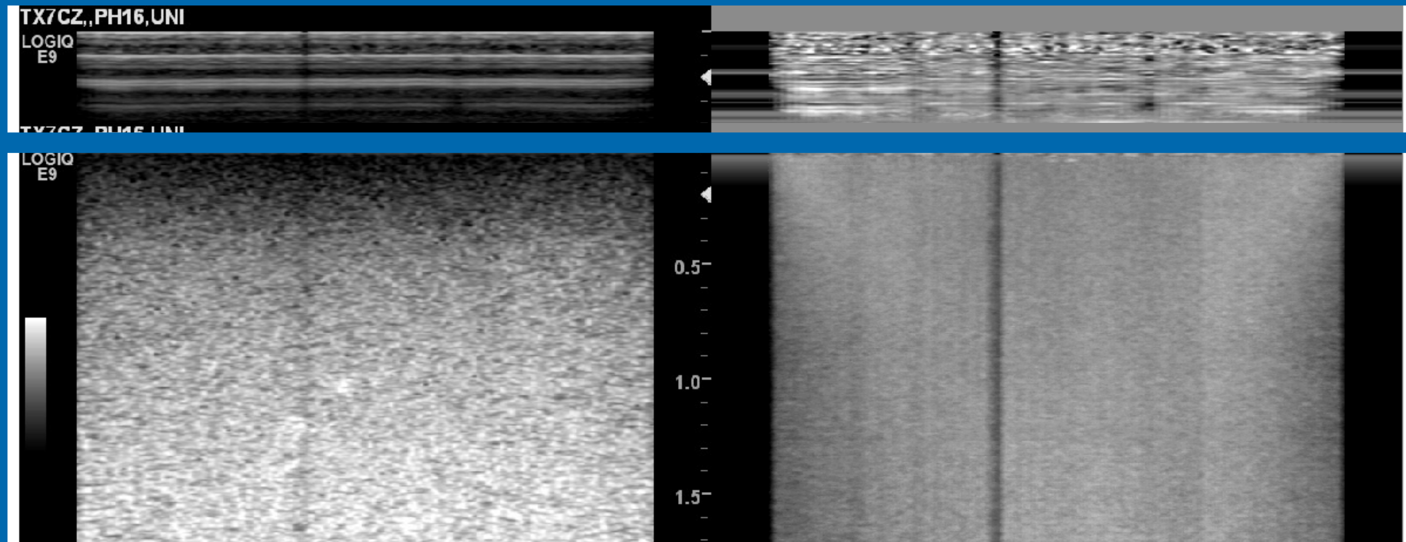
Example 1

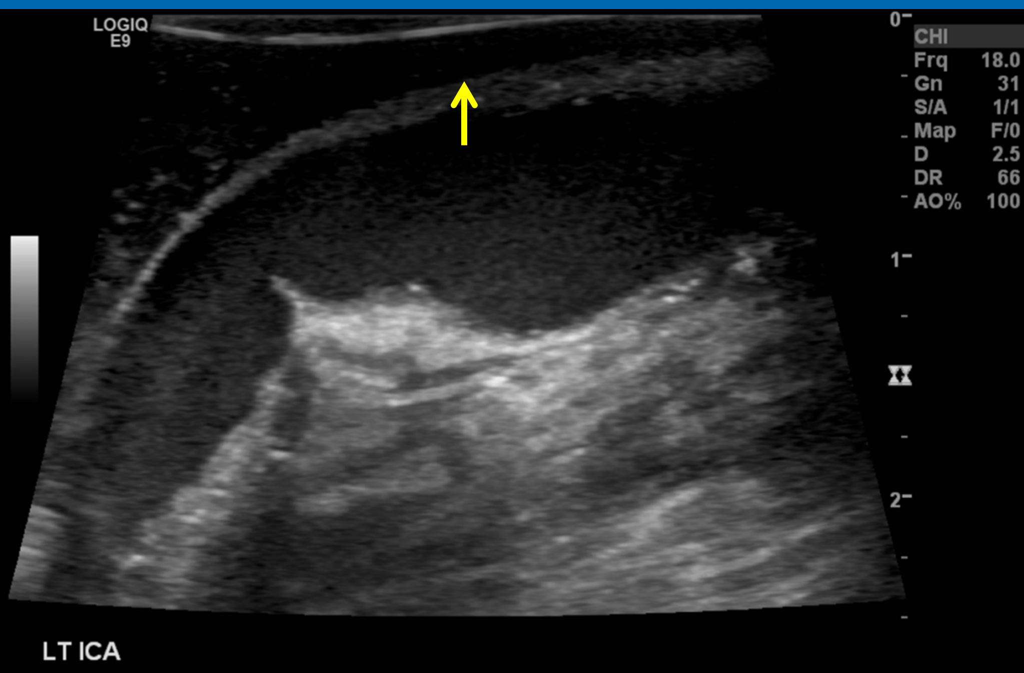

LONG RLQ
LOGIQ E9
FR 21
CHI
Map F/0
D 17.0
DR 69
AO% 100
Long Aorta Prox
LOGIQ E9
FR 22
CHI
Frq 3.0
Gn 59
S/A 1/1
Map F/0
D 16.0
DR 69
AO% 100
1 Prox AP 2.2 cm
Long Aorta Prox
LOGIQ E9
DR 69
AO% 100
1 Prox AP 2.2 cm
LOGIQ E9
FR 19
CHI
Frq 3.0
Gn 72
S/A 1/1
Map F/0
D 19.0
DR 69
AO% 100
1 CHD 3.5 mm

Example 2

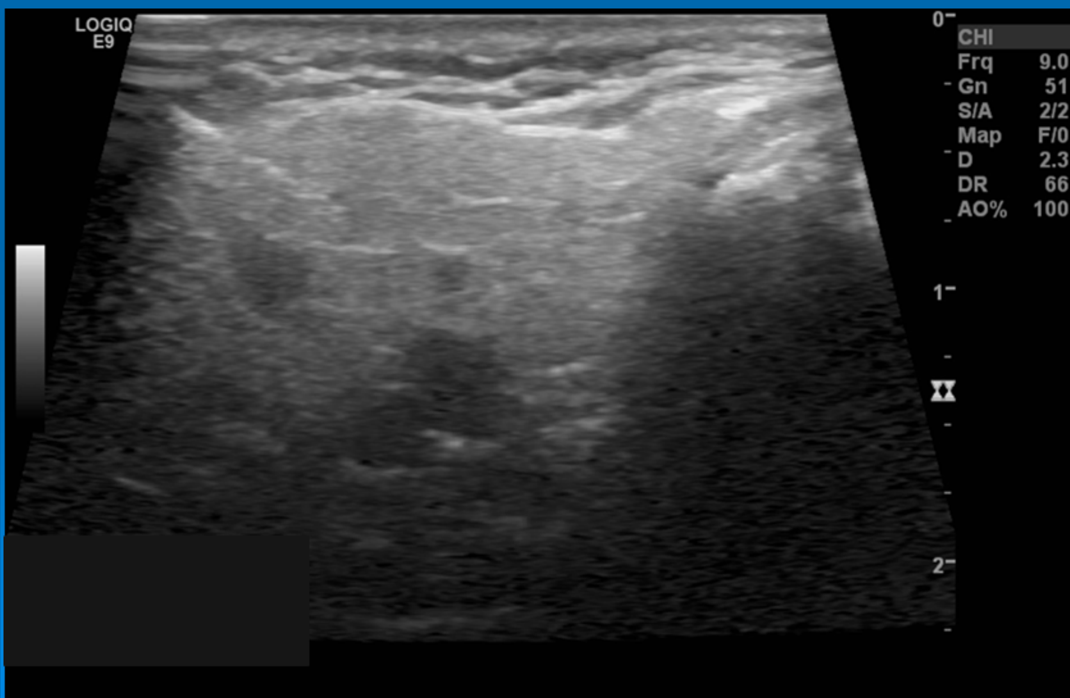
In-air

Phantom





Example 2


LOGIQ
E9
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2
CHI
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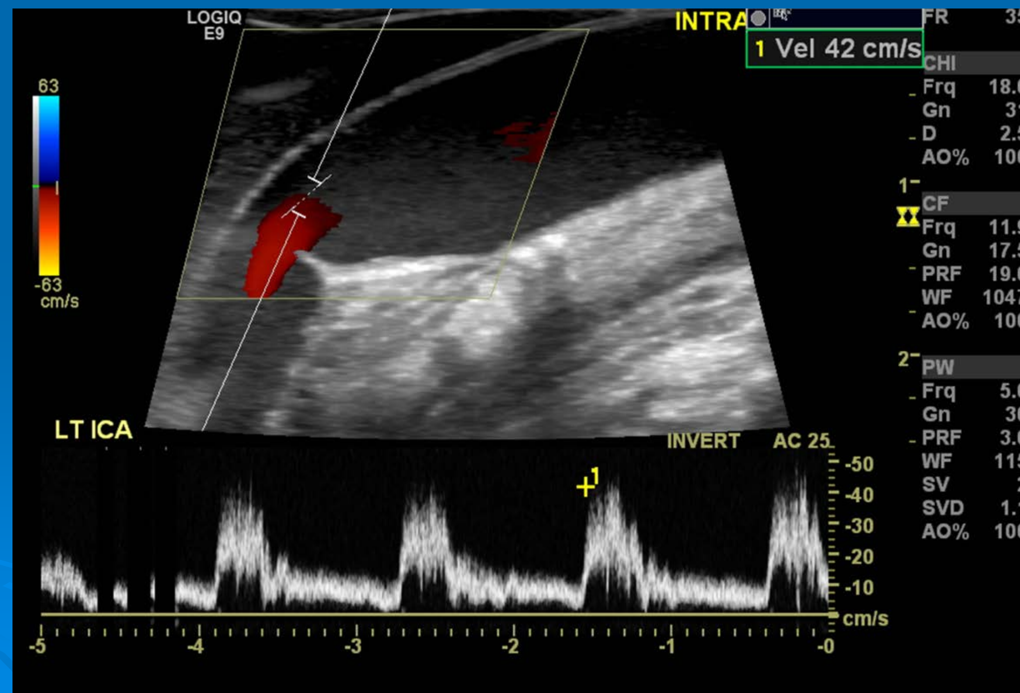
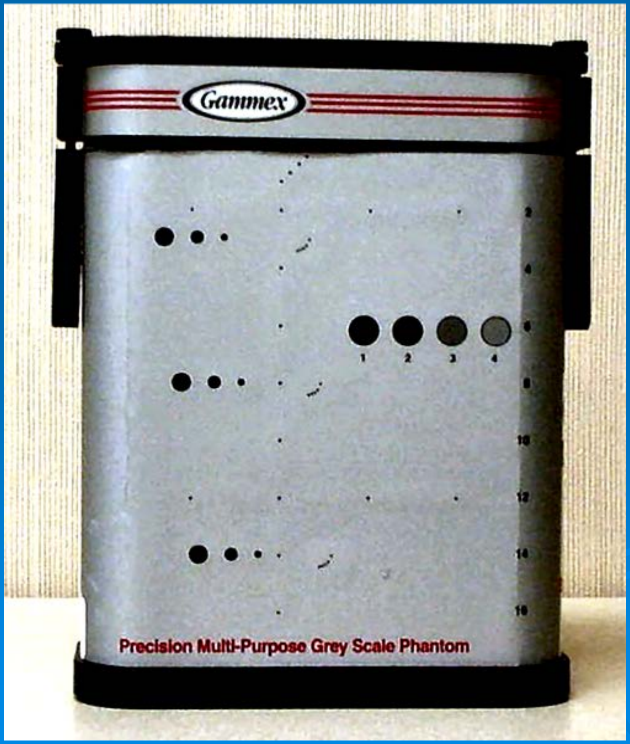
S/A 2/2
Map F/0
D 2.3
DR 66
AO% 100

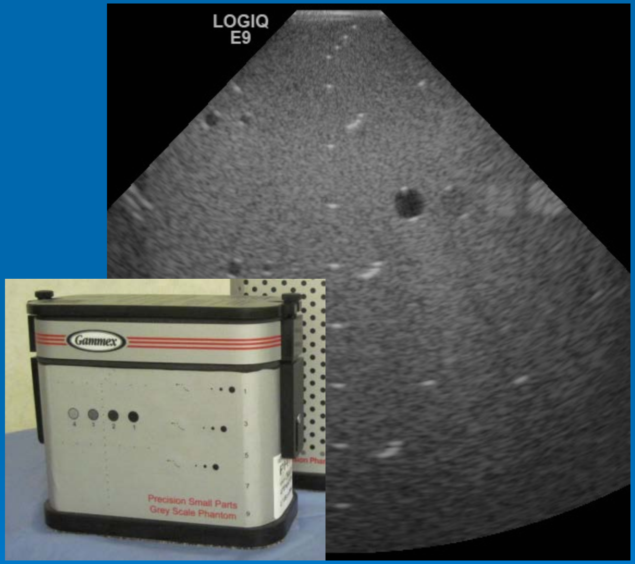

LOGIQ
E9
INTRA
1 Vel 42 cm/s
FR 35
CHI
Frq 18.0
Gn 31
D 2.5
AO% 100
CF
Frq 11.9
Gn 17.5
PRF 19.6
WF 1047
AO% 100
PW
Frq 5.0
Gn 36
PRF 3.6
WF 115
SV 2
SVD 1.1
AO% 100
63
-63
cm/s
LT ICA
INVERT
AC 25
-50
-40
-30
-20
-10
cm/s
-5
-4
-3
-2
-1
-0

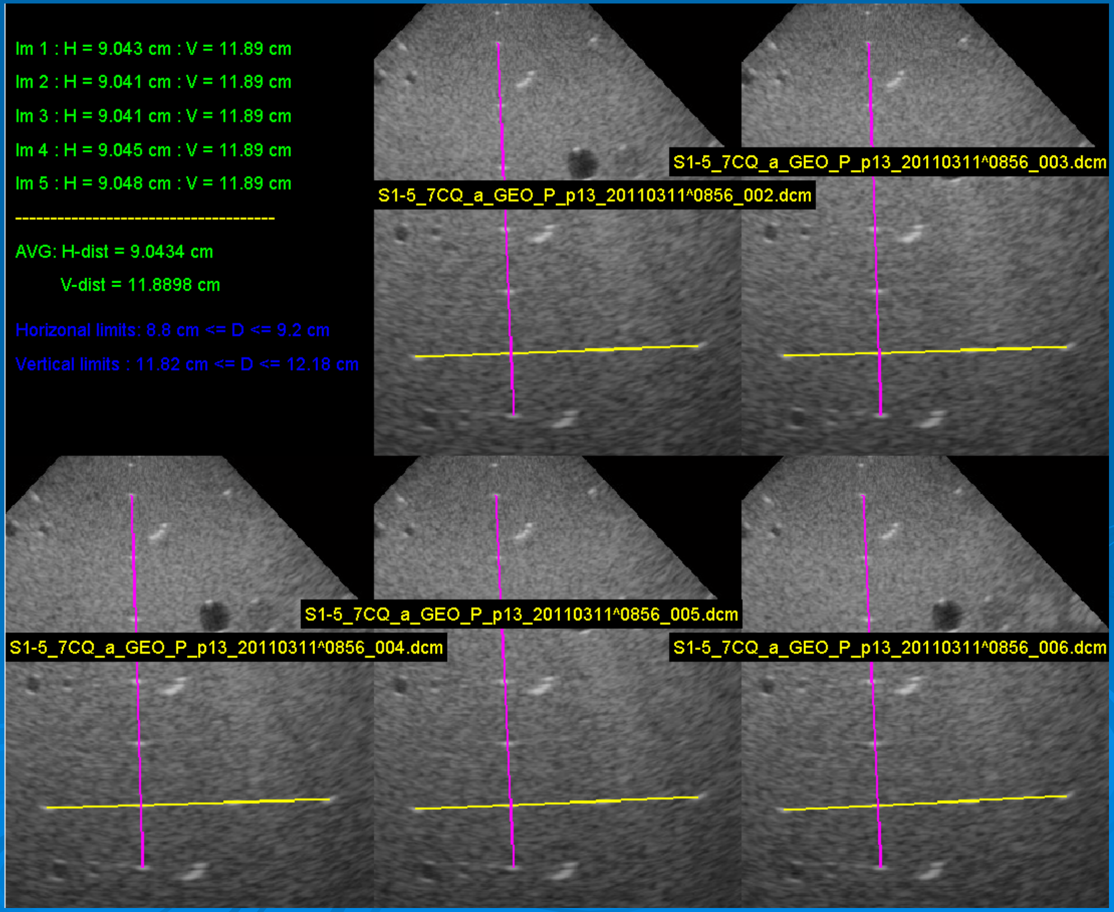
Geometric accuracy:
Axial and lateral directions

- Measure known axial (vertical) and lateral (horizontal) distances with scanner calipers
  - Verify image geometry & proper operation of scanner caliper tool



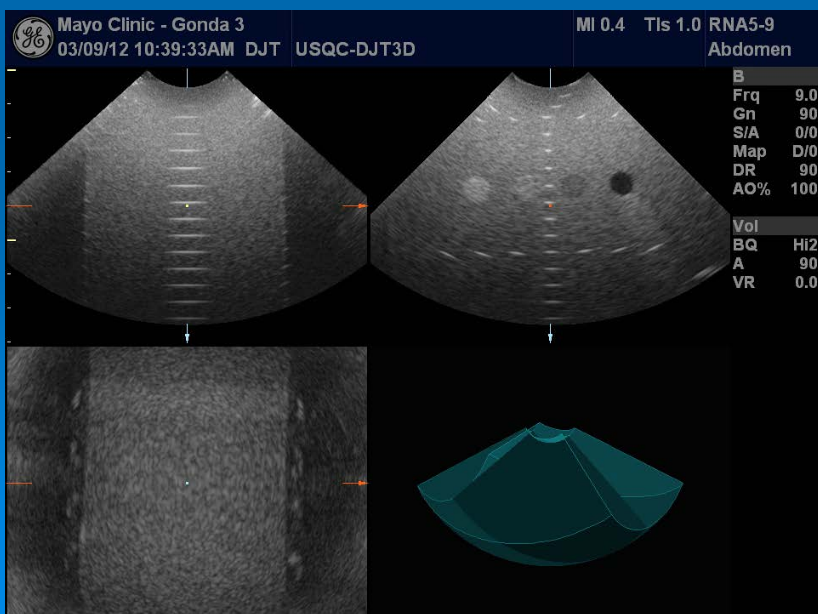
- Automated "distance" measurements
  - Verification of image geometry/pixel size calibration
  - Performance limits
    (Goodsitt et al, Medical Physics
    1998; 25:1385-406)

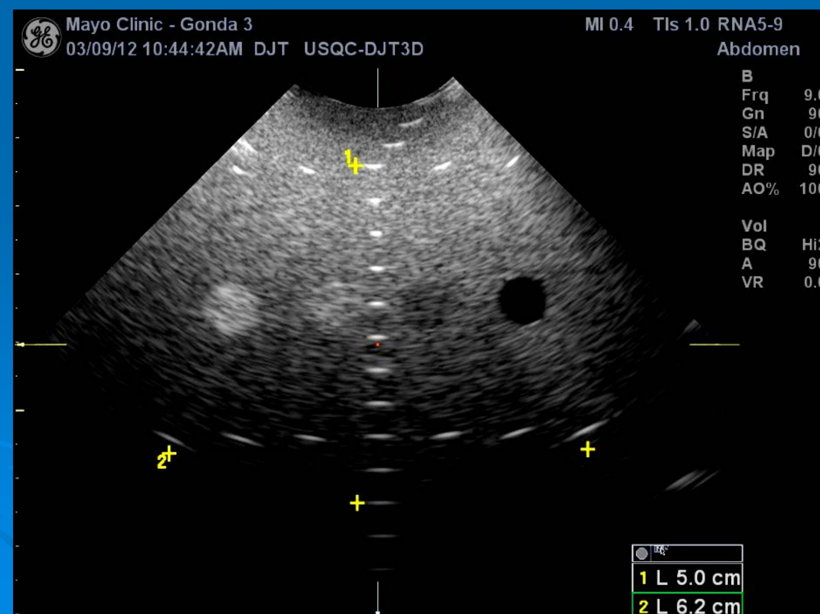




Geometric accuracy:
Elevational direction, for 3D or 4D probes

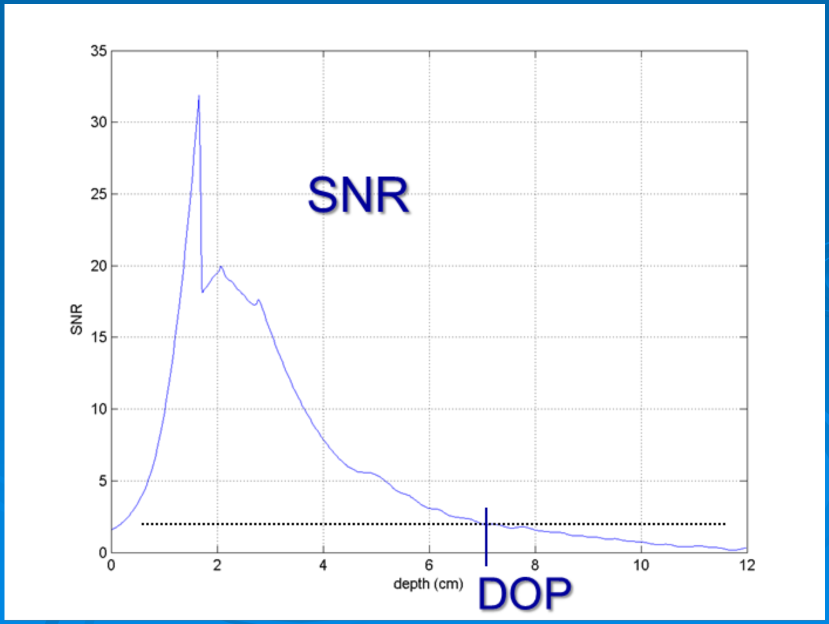
- Performance limits
  - Goodsitt et al, 1998, ≥lateral (potential acquisition errors)
  - Scanner vendor specification





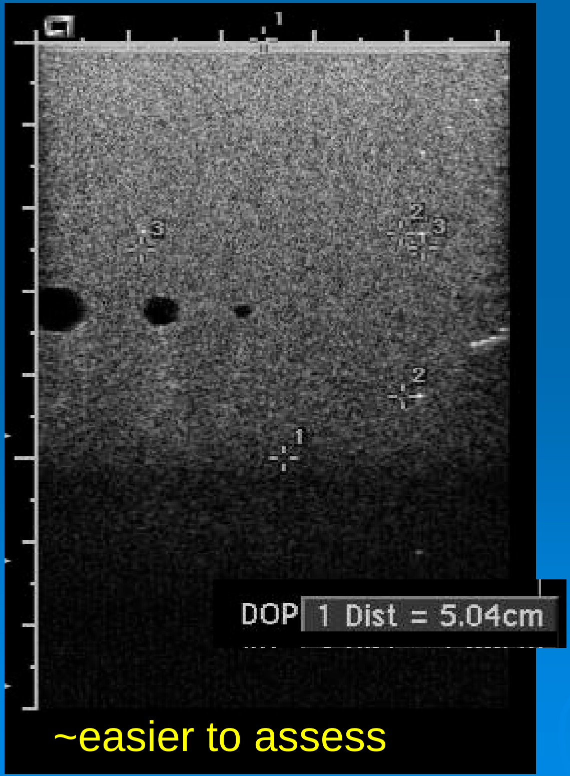
System sensitivity

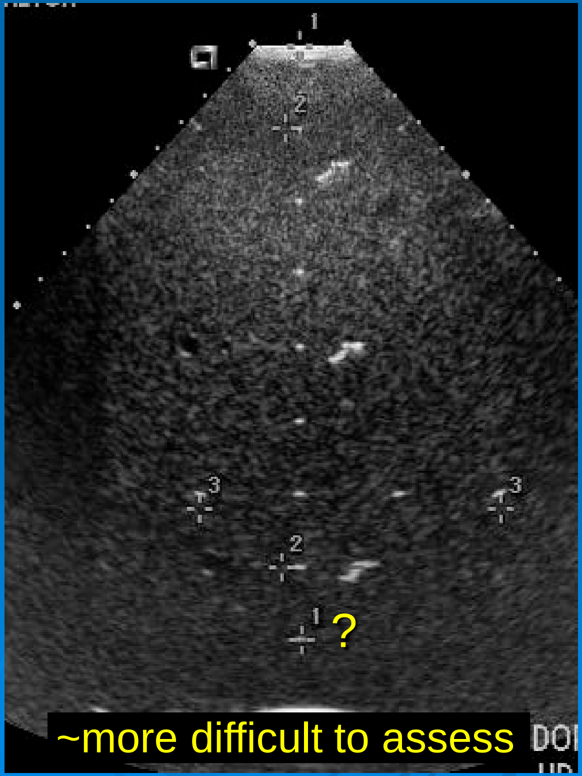
- Common approaches
  - Visual DOP estimation
  - Calculation of DOP from SNR vs depth curve falling to a specified threshold value
    - Variety of proprietary algorithms have been reported
    - IEC 61391-2
- Goodsitt et al provide recommended action & defect levels
  - Independent of target DOP value

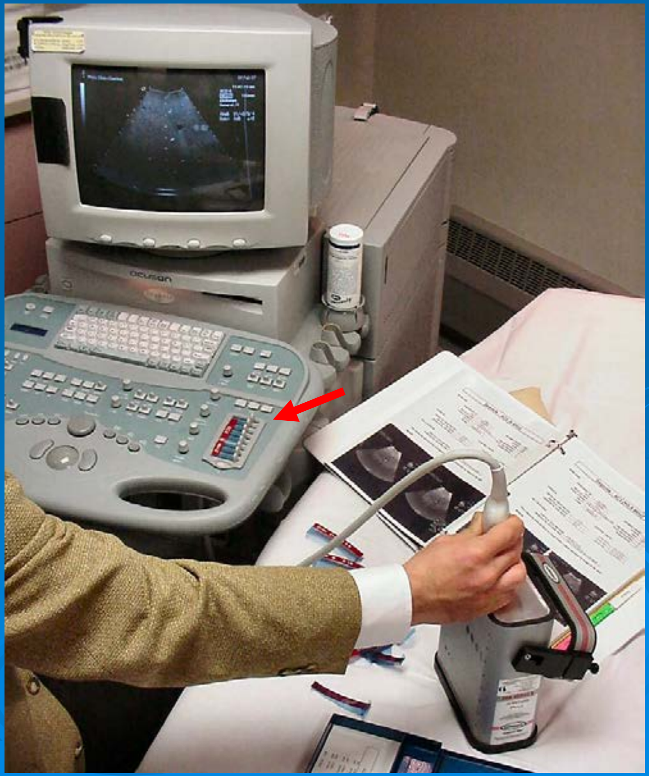


➢ Visual DOP estimation

- Visually estimate greatest depth of reliable visualization of speckle → *subjective, ~biased*
- Maintaining highly-consistent control settings is critical, and can be challenging (e.g. TGC)







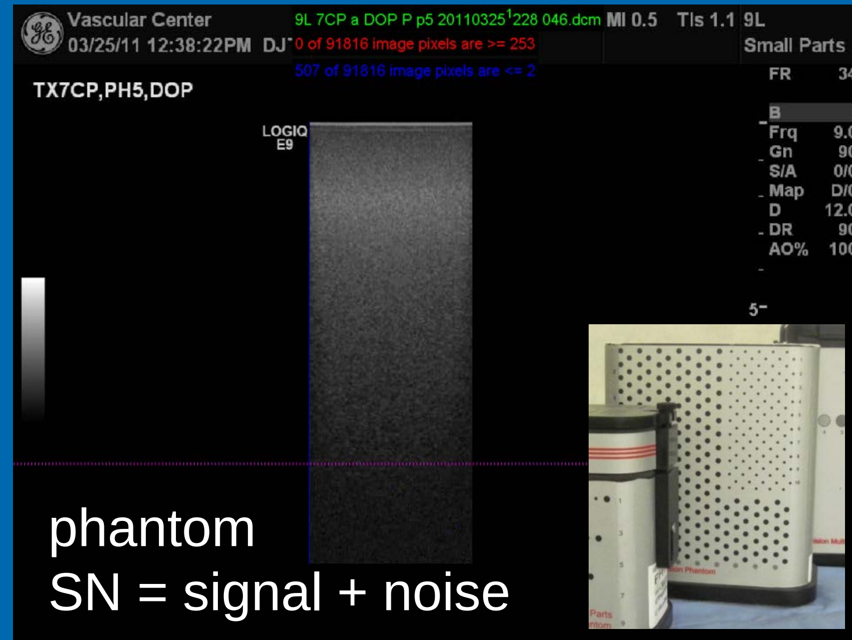
IEC DOP algorithm

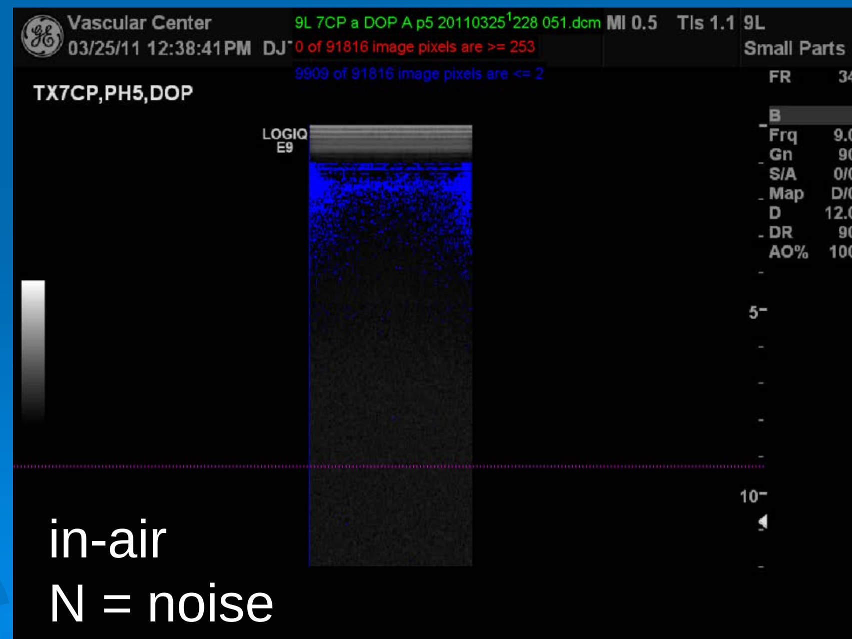
- Obtain uniform phantom and in-air image pair
- SNR & DOP are calculated as follows:

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

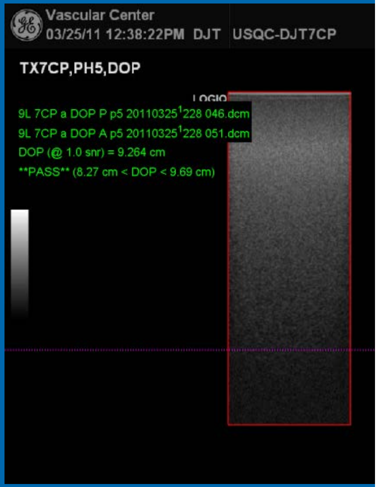
d = distance from transducer face
SN = mean pixel values from phantom image
N = mean pixel values from in-air image

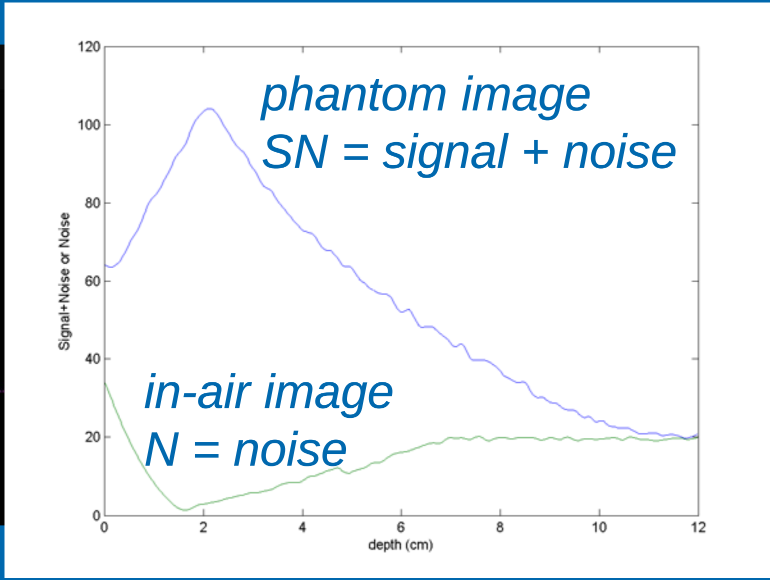
$$SNR_{IEC}(DOP) = 1$$

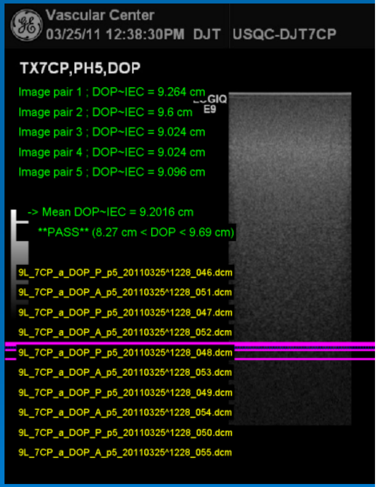


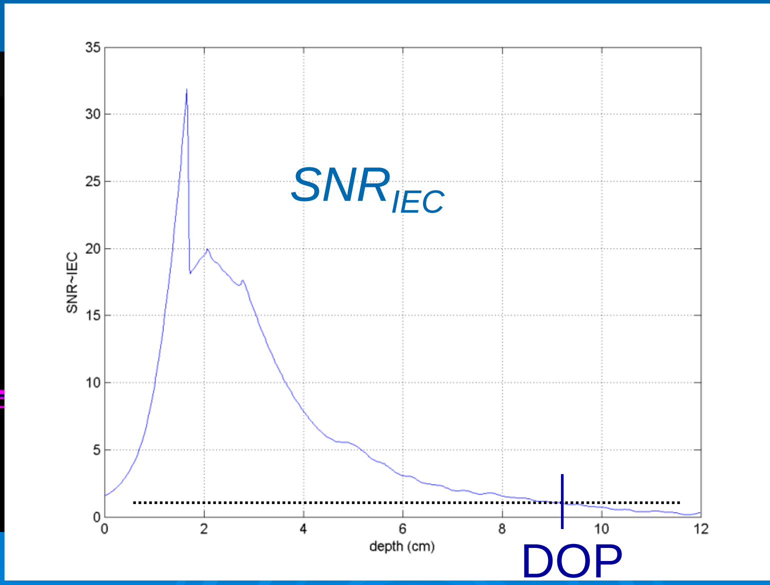


- Nuances
  - Using phantoms with targets
  - Curved and sector/ vector images
  - Number of pixels at each depth
  - Filtering the SNR vs depth function
  - Averaging DOP from multiple image pairs









> 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

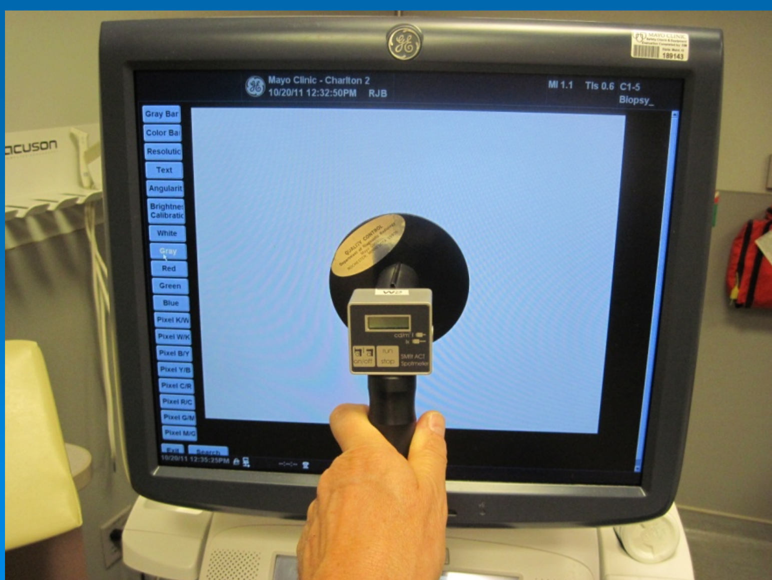
> Stekel et al. Evaluation of the International Electrotechnical Commission Standard Technique for Measuring the Ultrasound Depth of Penetration. Presented at AIUM 2012.

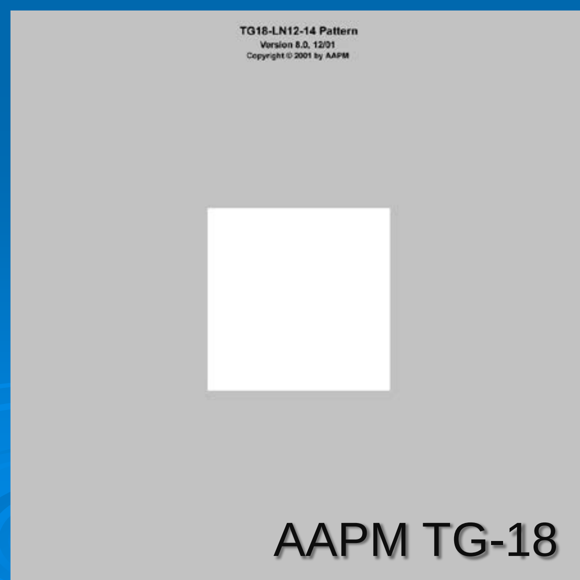
Ultrasound scanner electronic image display performance

- Critical component of performance assessment: *Ultrasound scanner monitor is effectively a primary diagnostic display device*
- No requirements of specific tests
  - Reference to “ACR-AAPM-SIIM Technical Standard for Electronic Practice of Medical Imaging”
- Three main components of eval:
  - Verify luminance calibration
  - Visual assessment of general display quality
  - Artifact survey

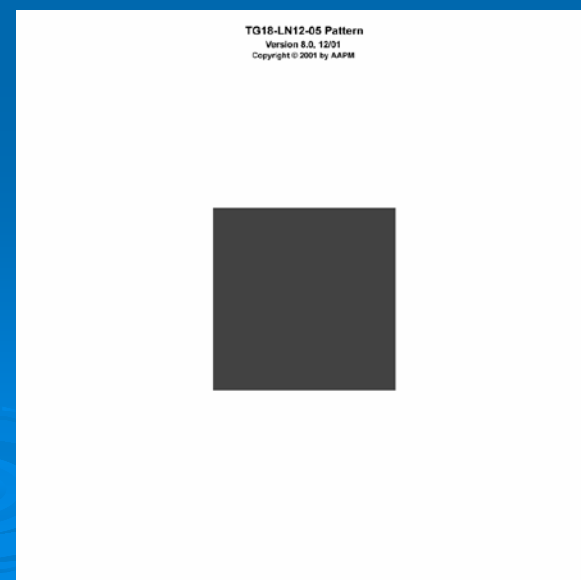
Calibration and luminance measurement

- Measure luminance with photometer at ~3-5 grayscale levels
  - But may be limited in number of grayscale test patterns available on the scanner, especially older units
- Should be performed at a frequency appropriate to the specific display technology in use (auto calibration, stabilization), and previous QC data

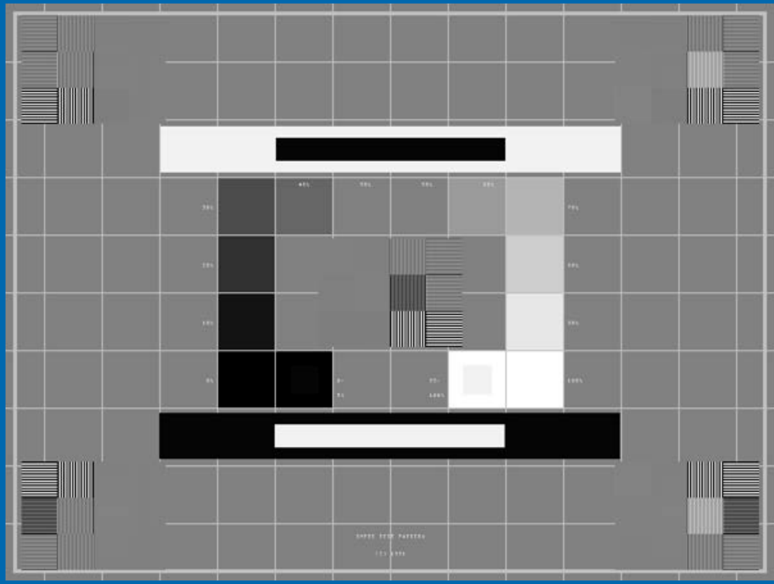


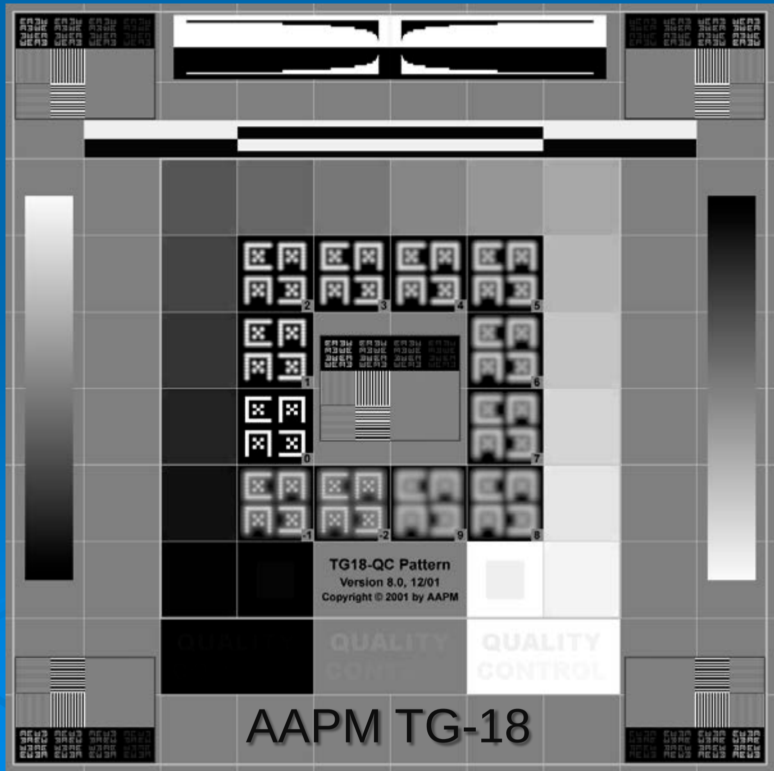


AAPM TG-18



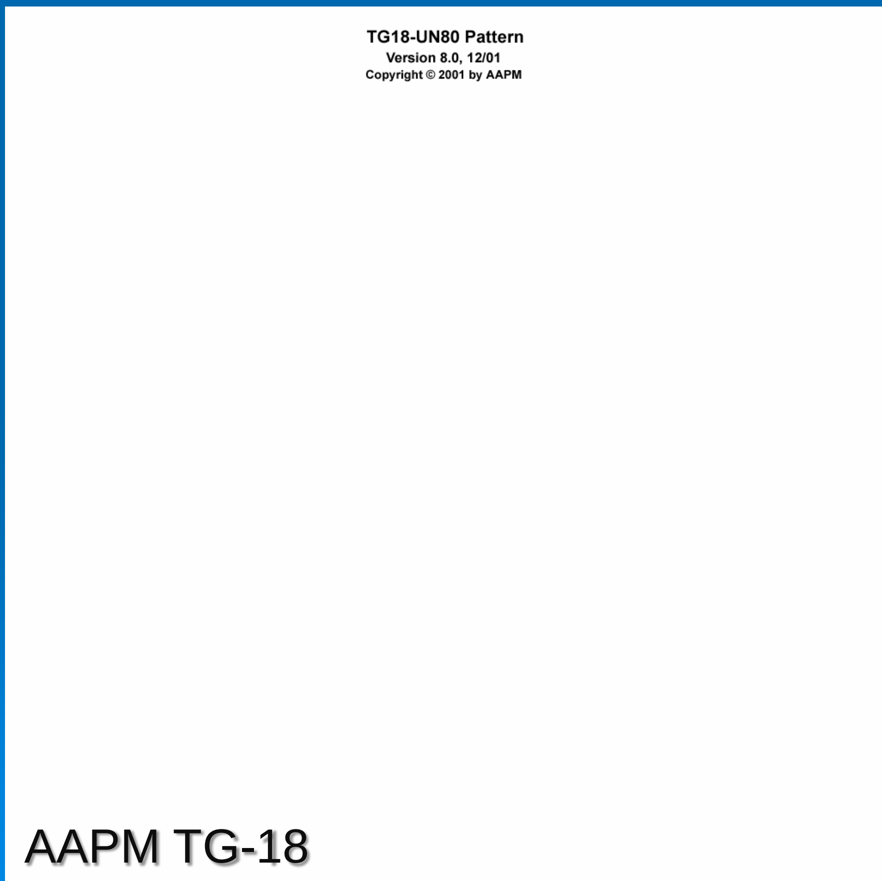
- Visual assessment of general display quality using a SMPTE or similar test pattern
  - Visibility of contrast patches
  - Image blur
  - Geometric distortion
  - Other display artifacts (e.g. banding, “tearing”, etc)
  - *Many of these artifacts are more relevant to CRTs (which are becoming more and more uncommon)*

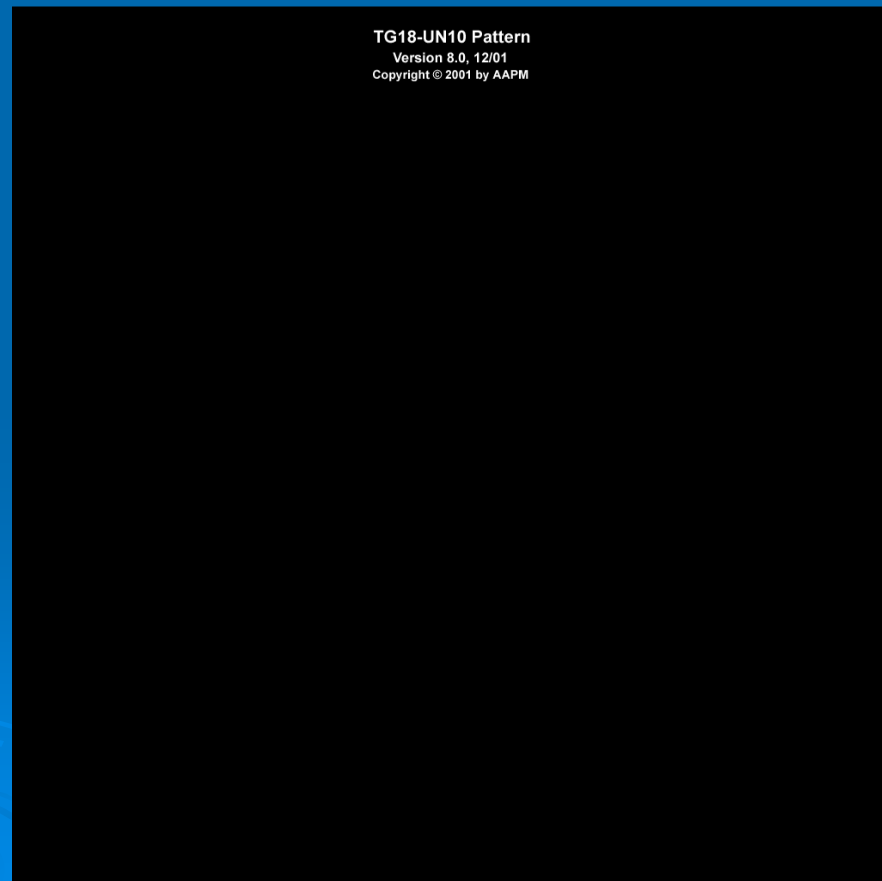




Artifact survey – Flat panel display pixel defects

- Dead (black) pixels
- Stuck (bright) pixels





Primary interpretation display performance

- This most likely means PACS workstations, or dedicated US workstation (e.g. Siemens ABVS workstation)
- Testing only required for diagnostic workstations used for US exam primary interpretation, *and located at same facility as the US scanner*
- No requirements of specific tests
  - Reference to “ACR-AAPM-SIIM Technical Standard for Electronic Practice of Medical Imaging”
- *Inclusion of display testing results obtained by PACS team or service group would be acceptable*

Evaluation of (routine) QC program

- Review of routine QC tests performed by sonographer (or service engineer)
  - Recorded on a logbook form (provided by the physicist)
  - Are tests being done on the desired schedule?
  - Are tests being performed and interpreted correctly?
- *Provides an opportunity for education and practice quality improvement*

Routine US QC: Transducer Evaluation (v1.0)

Date: ______________ **Initials:** ______________

P=Pass F=Fail NA=Not Applicable

Transducer Inventory				Physical & Mechanical Inspection	Image Uniformity and Artifact Survey (Air & Phantom)				
Xducer Model (special location info)	Xducer ID	Xducer Serial Number	Xducer Located P/F	P/F	Artifact Noted:			P/F	P/F
S1-5					Air		Ph		
S4-10					Air		Ph		
C1-5					Air		Ph		
M6C					Air		Ph		
9L					Air		Ph		
11L					Air		Ph		
ML6-15					Air		Ph		
L8-18i					Air		Ph		
IC5-9					Air		Ph		
RIC5-9					Air		Ph		

Transducer Inventory: The purpose of documenting the Transducer Inventory is to maintain an accurate count of an ultrasound scanner's assigned transducers (Xducer). The location of each assigned Xducer listed under the Transducer Inventory should be verified. Xducers that are shared between scanners and not stored with the assigned scanner should have a special location noted and it's presence verified. Xducer ID and serial numbers should be verified during the inventory check.

Physical & Mechanical Inspection: Assure the mechanical integrity of the equipment, and the safety of patient and operator, including assessments of: (1) cables are free of kinks and other damage; (2) connectors and contacts are free of damage; (3) connector lock is functional; (4) lens is free from damage and delamination.

Image Uniformity and Artifact Survey: Identifies the presence of artifacts, often axial or lateral streaks in scans of uniform sections of a phantom. The use of "in-air" images (i.e., images acquired without the use of gel or phantom) may also be useful in detecting superficial artifacts. All transducer ports on each scanner should be tested using at least 1 transducer.

Geometric Accuracy: Elevational *(3D transducers only)*

Scanner ID:	Xducer Model:	Xducer ID:	Reconstructed Horiz. Distance (cm)			P/F
			Measured	L.C.L.	U.C.L.	
	RIC5-9					

L.C.L.= lower control limit U.C.L= upper control

***See Notes Page for any failed (F) items,or resuts marked with an asterisk (*).**

Mayo Clinic | Department of Radiology | Division of Medical Physics

Routine QC tests

Likely performed by sonographer(s) in the clinical practice twice per year (quarterly testing is recommended)

Specific methods prescribed by medical physicist

Routine QC		
QC Test	**Description**	**Minimum Frequency**
1. Physical and Mechanical Inspection	Assures the mechanical integrity of the equipment, and the safety of patient and operator.	Semiannually
2. Image Uniformity and Artifact Survey	Identifies the presence of artifacts, often axial or lateral streaks in scans of uniform sections of a phantom. The use of "in-air" images (i.e., images acquired without the use of gel or phantom) may also be useful in detecting superficial artifacts. All transducer ports on each scanner should be tested using at least 1 transducer.	Semiannually
3. Geometric Accuracy (mechanically scanned transducers only)	Commonly involves use of the scanner calipers to measure known distances between test targets. Measurement is required only in the mechanically scanned directions.	Semiannually
4. Ultrasound Scanner Electronic Image Display Performance	Maintaining the performance of the image display is critical for providing the greatest diagnostic benefit of the scanner. They should also include worklist monitors only if used for primary interpretation (other than color analysis). Display characteristics that are evaluated may include gray scale response, presence of pixel defects, and overall image quality. These evaluations are typically performed using specialized test pattern images. See ACR Technical Standard for Electronic Practice of Medical Imaging.	Semiannually
5. Primary Interpretation Display Performance*	Primary diagnostic displays may be electronic soft-copy displays on a PACS workstation or hard-copy films. Display characteristics that are evaluated may include gray scale response and luminance calibration, presence of pixel defects, and overall image quality. These evaluations are typically performed using specialized test pattern images, and may also require photometric equipment. See ACR Technical Standard for Electronic Practice of Medical Imaging. (* Only required if located at the facility where ultrasound is performed.)	Semiannually, or as judged appropriate based on the specific display technology, or prior QC testing data

Same as Annual Survey

Sample findings provided by physicist will be helpful

Routine QC test methods

Routine QC		
QC Test	Description	Minimum Frequency
1. Physical and Mechanical Inspection	Assures the mechanical integrity of the equipment, and the safety of patient and operator.	Semiannually
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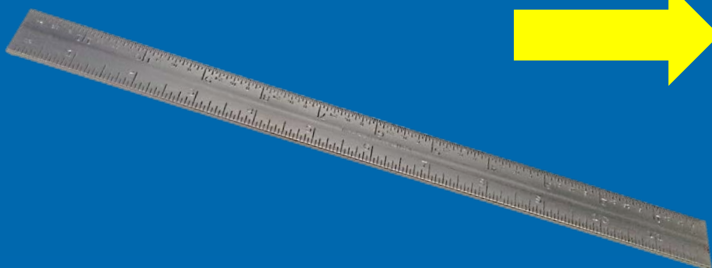
Routine QC test methods

Only needed for mechanically scanned probes (mechanical 3D4D probes; 360-deg probe?)

Testing only needed for the mechanically scanned direction (e.g. elevational/slice)

Dedicated, inexpensive test object and methods



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No requirements of specific tests

Visual inspection of test patterns (no photometer measurements)

Guidance from physicist regarding specifics of this evaluation will be helpful

Routine QC test methods

Routine QC		
QC Test	**Description**	**Minimum Frequency**
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Routine QC test methods

Only required for PACS displays in same facility as scanner

No requirements of specific tests

Visual inspection of test patterns, as for scanner monitor evaluation

Physicist could recommend that no testing by the sonographers is needed, if adequate QC is being done by another group, e.g. PACS team

Routine QC		
QC Test	**Description**	**Minimum Frequency**
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Routine QC test methods

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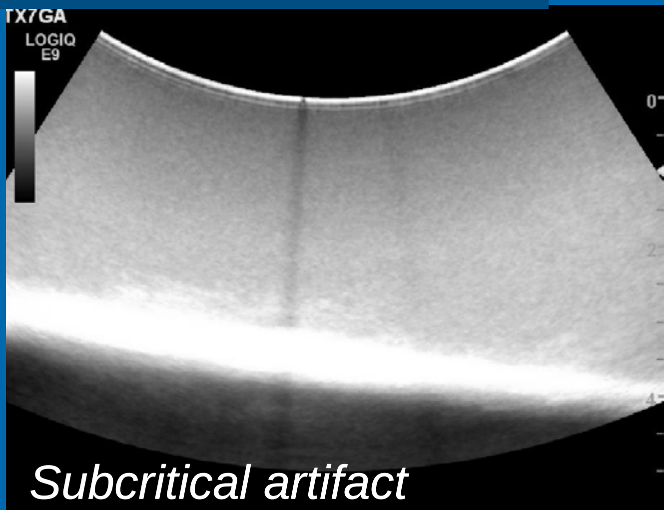
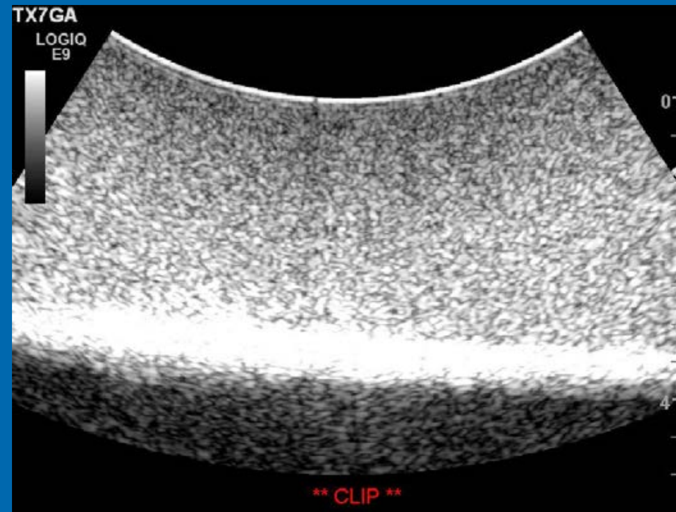
Image uniformity & artifacts survey

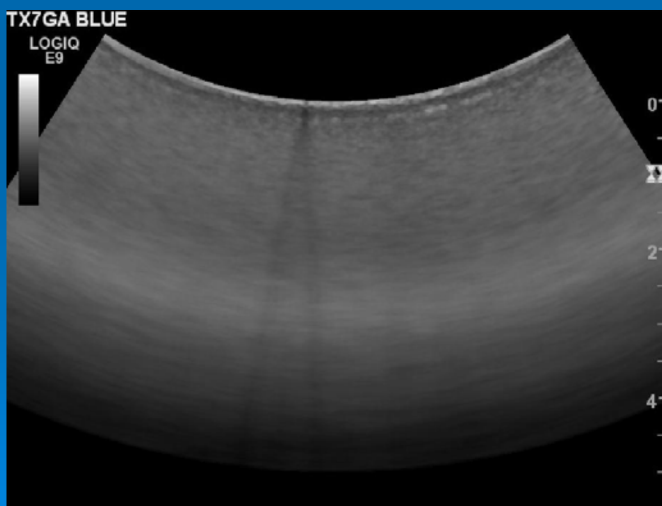
- *Complexity of uniformity evaluation as done by physicist poses potential problems for sonographers (avoiding false-positives)*
- Methods with *reduced sensitivity and increased efficiency* compared with those used for annual survey may be advantageous
  - Phantom
  - Scan parameters
  - Visual inspection during live scanning (versus processed images)
  - Examples of significant and insignificant findings

Annual survey testing





QC preset
Snowglobe



Clinical preset
Rubber phantom

Median **B-mode**

Routine QC testing

Physicist will be essential to success of routine US QC program

- Provide straightforward, well-documented testing methods and results forms
  - Emphasize low-cost, easy-to-use phantoms & test objects
  - Provide good, hands-on training
- Document clear criteria for passing and failing test results, with examples
  - Also supply guidance for the types of results for which a physics consult is appropriate
- Enable the ability to easily forward US images from the practice to the physicist for consultation

Does QC testing add value in ultrasound?

- Experience at Mayo Rochester → "Yes"
  - Acceptance testing
    - 45 scanners, 249 transducers and 1 US workstation
    - 3 vendors, 3 system models
    - *Issues found with 6.7% of scanners, 12% of probes, and one 3D US workstation*
  - Quality control testing
    - 45 scanners, 265 transducers
    - 4 vendors, 9 system models
    - *Average annual failure rates of 10.5% (scanners) and 13.9% (probes) were observed over 4 year period*

Conclusions

- New QC requirements in the ACR ultrasound and breast ultrasound accreditation programs
  - Effective June 1, 2014
  - Goal: Maximize the value of QC investment
- These requirements can be met without great investments of time or money
  - *Physicist involvement will be critical*
- Should have a positive impact on the quality of ultrasound practices

Conclusions

- Opportunities
  - Continued development of objective, validated, testing methods
    - Improved availability of effective, efficient image processing and analysis software
    - Development of clinically-correlated performance benchmarks and failure thresholds
  - Analysis of testing needs for additional scanner modes
    - Spectral and color Doppler
    - Elastography

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