Diagnostic Ultrasound Imaging Quality Assurance

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Purpose

- Outline a QA program that is
  - Responsive to clinical US lab accrediting bodies, ACR and AIUM
  - Effective at detecting some important system flaws
  - Can be carried out effectively by medical physicists
- Briefly introduce advanced tools that may enhance or even serve as an alternative to methods that will be discussed
  - UltraIQ analysis software for phantom images
  - Aureon transducer tester

Information on US QA

- Goodsitt M M *et al* 1998 Real-time B-mode ultrasound quality control test procedures. Report of AAPM Ultrasound Task Group No. 1 *Med. Phys.* **25** 1385
- IEC 61391-1 (2006) Ultrasonics – Pulse-echo scanners – Part 1: Techniques for calibrating spatial measurement systems and measurement system psf response
- IEC 61391-2 (2010) Ultrasonics– Pulse-echo scanners – Part 2: Measurement of maximum depth of penetration and local dynamic range (1996)
- **IEC 62736 Ultrasonics (2016) – Pulse-echo scanners – Simple methods for periodic testing to verify stability of an imaging system's elementary performance**
- **AIUM 2014, AIUM Quality Assurance Manual for Gray Scale US Scanners.**
- King et al, Evaluation of a low cost liquid ultrasound test object for detection of transducer artefacts. Phys. Med. Biol. 55 (2010) N557-570.
- Hangiandreou NJ et al, Four-year experience with a clinical ultrasound quality control program. Ultrasound in Med. & Biol. 37: 1350-57, 2011.

Information From US Accreditation Bodies

- Ultrasound Accreditation Program Requirements, Am College of Radiology, http://www.acraccreditation.org/~/media/ACRAccreditation/Documents/Ultrasound
- ACR-AAPM Technical Standard for Diagnostic Medical Physics Performance Monitoring of Real Time Ultrasound Equipment. http://www.acr.org/~/media/ACR/Documents/PGTS/standards/MonitorUSEquipment.pdf
- AIUM 1998, American Institute of Ultrasound in Medicine, Routine Quality Assurance for Diagnostic Ultrasound Equipment. http://aium.s3.amazonaws.com/resourceLibrary/rqa.pdf

Annual Surveys, Routine QA (ACR)

- Physical and and mechanical inspection; sterility
- Image display performance
- Image Uniformity
  - Element "dropout" and other sources on non-uniformity
- System sensitivity and/or penetration capability
- Geometric measurement accuracy during program initiation
- Annual surveys: required
- 6-month Routine QC: optional
- Contrast resolution, spatial resolution: optional items for annual survey.

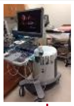
http://www.acraccreditation.org/Modalities/Ultrasound

American Institute of Ultrasound in Medicine:

- General US QC, 2008
- Original: "QA in the Clinic"
  - Sonographers helped draft
- Outlines what to do
  - Sonographers
  - Physicists/engineers
  - Good agreement with ACR
- Limited information on methodology
  - Requires a phantom
  - Phantom left to users

Physical and Mechanical Inspection, ACR

- Console



  - Air filters
  - Lights, indicators
  - Wheels, wheel locks
  - Proper cleaning (are procedures in place?)
  - Viewing monitor, keyboard clean

Before

Air filters

(Record holder)

After

Routine QA: Cleanliness, safety

"Physical and Mechanical Inspection" (ACR)

- Console
  - Air filter reminder, www.ultrasonix.com

(Like a "check engine light")

Image Display (Scanner and PACS)

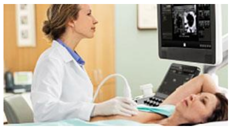
- Important for monitor on machine to be set up properly to view all echo levels available and entire gray bar pattern.
  - Set up during acceptance testing
  - Take steps to avoid casual adjustments (mark or inscribe contrast and brightness controls)
- Most machines provide one or more gray scale test patterns for setup and for routine QC.
  - are all gray bars visible? (System, PACS)

www.philips.com

Gray bar on GE Logiq 9

Image Display (Scanner and PACS)

- Gain and sensitivity adjustments done using system monitor
- Intrepretation most often done on a PACS workstation.
- Important that there is agreement between image features viewable on PACS and the features seen on the system monitor.
- We were finding that the 15 gray bar pattern built into the machine was not sensitive enough to subtle, but important faults in monitor agreement.



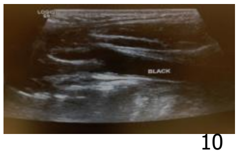


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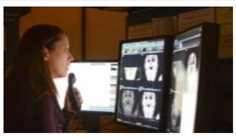
Image Display (Scanner and PACS)

- Gain and sensitivity adjustments done using system monitor
- Intrepretation most often done on a PACS workstation.
- Some data sent by machine to PACS, and easily viewable on PACS, not seen on system monitor



i-phone photo of US system monitor

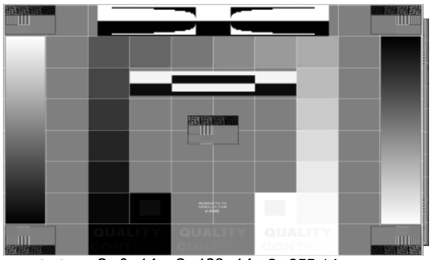
PACS

Monitor agreement (cont.)

- " …. the images displayed on the PACS monitors are the ones we rely upon for the diagnosis. Many of us …. check our images on PACS stations in the work area prior to reviewing them with the radiologist because we realize the images may appear slightly different between the two [system and PACS] monitors." (UW sonographer)

SMPTE, TG18 or Other Gray Scale Test Pattern

- Available on most scanners
- 0% to 100% gray bar pattern
- Squares for detecting geometric distortion
- Are all gray transitions visible?
- Is the 0-5% transition visible?
- Is the 95-100% transition visible?



TG18: Q=0+14 I=1 | Q=128+14 I=129 | Q=255-14 I=254

System Worksheet, page 2 of Report for each scanner

General Machine Cleanliness:

Keyboard and knobs clean?	☒Yes	☐No
Monitors Clean?	☒Yes	☐No
Air Filters clean?	☐Yes	☒No

Mechanical and Electrical:

Wheels fastened securely and rotate easily?	☒Yes	☐No
Wheel locks work well?	☒Yes	☐No
Accessories fixed securely?	☒Yes	☐No
Cords attached securely?	☒Yes	☐No

PACS Workstation-System Monitor

Contrast and Brightness between scanner and workstation:
☐1 poor ☐2 ☐3 average ☒4 ☐5 excellent

Assessment made from Both 1 & 2 below:
Generate a gray bar pattern. Save it to PACS.
Number of gray levels seen on the system monitor 15+
Number of gray levels seen on the PACS 15+
*Gray bar visualization:
With "patient" registered, push "exam utilities;" push "test pattern."
Record an image and compare to the workstation
Count the number of gray levels seen in the room and on the PACS monitor.
SMPTE Pattern: 0-5% transition: seen on system monitor: NO seen on PACS: YES
95-100% transition: seen on system monitor: YES seen on PACS: YES

For low level echo detectability, do probes 'Depth of Penetration' results judged on the system monitor agree what you would have chosen if judging on PACS?
☒Yes

Assessment made from Both 1 & 2 below:
Generate a gray bar pattern.
Save it to PACS.

Number of gray levels seen on the system monitor 15+

Number of gray levels seen on the PACS 15+

SMPTE Pattern: 0-5% transition:
system monitor: NO
PACS monitor: YES

SMPTE Pattern: 95-100% transition:
system monitor: YES
PACS monitor: YES

Routine QA: Transducers

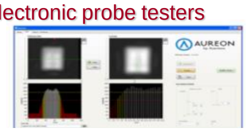
- Check all transducers on the system
- Transducer Inspection
  - Delaminations
  - Frayed cables
  - Proper cleaning

www.providian.com

Transcducer Tests

- Most facilities use phantoms for transducer imaging tests and further system evaluation

- Some have access to electronic probe testers

Tests using phantoms. Current materials:

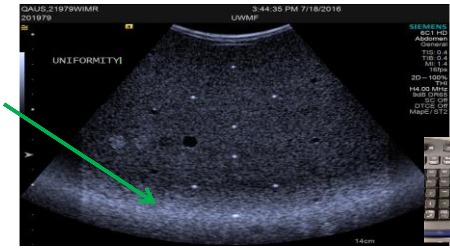
- Water-based gels
  - Advantages:
    - Speed of sound = 1540 m/s
    - Attenuation ~ proportional to frequency (specific attenuation expressed as 0.5 or 0.7 dB/cm-MHz
    - Backscatter
  - Disadvantages:
    - Subject to desiccation (?)
    - Must be kept in containers
    - Requires scanning window

Tests using phantoms. Current materials:

- Solid, non-water-based materials (urethane)
- Advantages:
    - Not subject to desiccation
    - No need for scanning window; possibility for soft, deformable scanning window
    - Produce tissue-like backscatter
  - Disadvantages:
    - C= 1430-1450 m/s
    - Attenuation ~ proportional to $f^{1.6}$
    - Surface easily damaged if not cleaned regularly to remove gels

Phantom test 1: Image Uniformity

- Done with each transducer
- This example is not a transducer fault, but a TGC problem



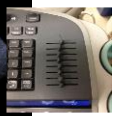


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Image Uniformity

- Considered to be the most impor-tant and useful test!
- Ideally:
  - No loss of sensitivity near edges of the image
  - No evidence of element dropout
  - No vertical 'shadows'

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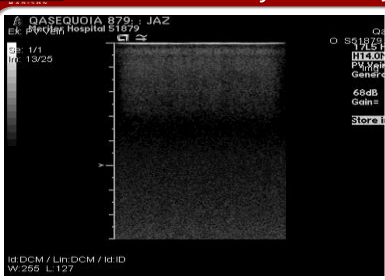
Non-Uniformity caused by element dropout



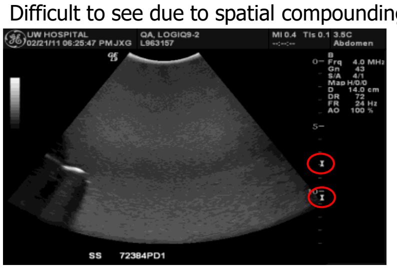
- Most frequent fault seen in QA testing
- Image a phantom using good coupling
- Search for "shadows" emanating from the transducer
- Common in new and old probes!

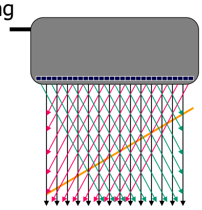
Need Proper Technique to Detect Element Dropout

Transducer with severe element dropout
Difficult to see due to spatial compounding

Need Proper Technique to Detect Element Dropout

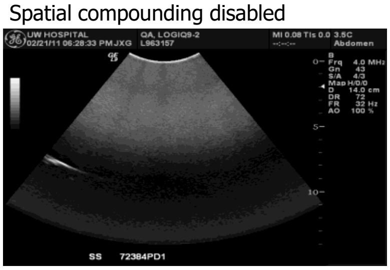
Transducer with severe element dropout
Difficult to see due to spatial compounding





Need Proper Technique to Detect Element Dropout

Transducer with severe element dropout
Spatial compounding disabled

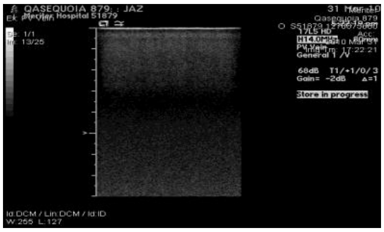


Disable spatial compounding
- cross-beam
- Sono-CT
- Sea Clear

Use single, shallow transmit focus

Difficulties with Uniformity

- Visualizing 1-2 element dropouts
- Use persistence; translate transducer.



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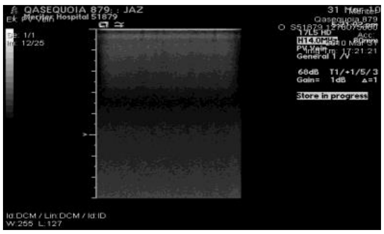
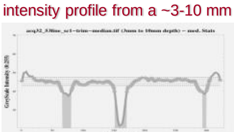


Objective Criteria being developed

- IEC 62736 Ultrasonics (2016) – Pulse-echo scanners – Simple methods for periodic testing to verify stability of an imaging system's elementary performance
- AAPM Ultrasound Subcommittee Task Group
- Record a cine loop while translating the transducer ⊥ to the image plane.
- Compute the **'median'** image for this (~100) image loop
- Plot a lateral intensity profile from a ~3-10 mm axial range

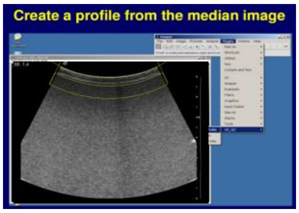


Median image

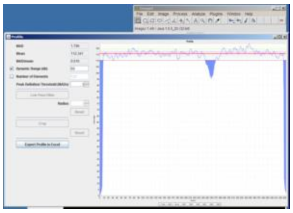
- A dip >3dB and more than 2 elements wide is worth counting as a defect of possible concern.

Image Uniformity(Automated QC Software)

S Larson et al, AAPM Ultrasound Task Group



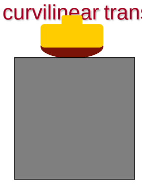
Median Image
Lateral profile from the median image



Dip magnitude and width analyzed in uniformity assessment

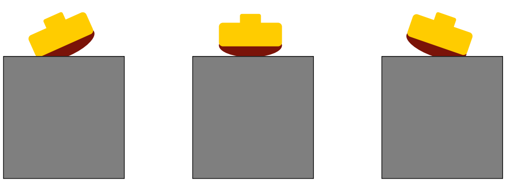
Difficulties with Uniformity

- Coupling to a flat surface phantom scanning window with curvilinear transducers



Difficulties with Uniformity (coupling)

- Solution 1: rock transducer from side to side



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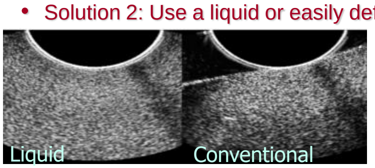
Difficulties with Uniformity (coupling)

- 

Difficulties with Uniformity (coupling)

- Solution 2: Use a liquid or easily deformable TM material



King et al, Evaluation of a low-cost liquid ultrasound test object for detection of transducer artifacts. Phys. Med. Biol. 55 (2010) N557-570.

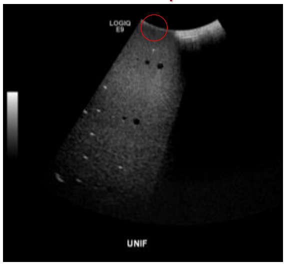
Difficulties with Uniformity (coupling)

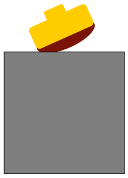
- Solution 3: Use a phantom having concave windows (Goodsitt et al, AAPM Ultrasound Task Group work)

(AIUM 2014, AIUM Quality Assurance Manual for Gray Scale Ultrasound Scanners, manufactured by Ernest Madsen, Univ. of Wisc.)

Difficulties with Uniformity (coupling)

- Solution 3: Use a phantom having concave windows

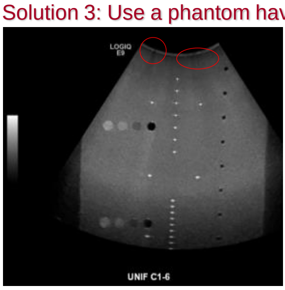


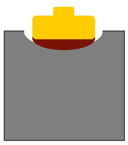


General Purpose

Difficulties with Uniformity (coupling)

- Solution 3: Use a phantom having concave windows





Gammex 410

Transducer worksheet part of UW Report

Instructions, uniformity ratings (UW-Madison, not other groups, such as AAPM):
1=uniform
2=minor inhomogeneity (no more than 2 minor dips)
3=Significant inhomogeneities; transducer is functional, but consider replacing
4=Immediate repair or replacement recommended
Data table (1 line for each transducer)

Transducer ID/Serial Number	Cables/ cracks/ delaminate		Uniformity, dropout		Sensitivity (Depth of Penetration) (MHz/cm)	Geometric Accuracy H: cm/actual cm V: cm/actual cm	Conclusions and recommendations
	OK	No	OK	No			
C1-5 79635YP9	☒	☐	☒	☐	5MHz/13.71cm H5MHz/10.6 cm	H: 5.81/6 V: 8.01/8	Uniformity Rating 1 DOP ≈ to previous results ☒ Yes ☐ No Click here to enter comments.

Firstcall Probe Tester by ACETARA

Refurbished (Sonora) Firstcall to test transducers

- Transducer contact surface immersed in water with beam directed towards a specular reflecting surface
- Each element driven by special pulser-receiver; echo signal detected and analyzed for element sensitivity, other measures.
- Need special adapter for each sys.

http://www.acertaralabs.com

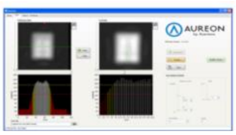
Test console with probe adapter

Aureon by ACETARA

Device to test ultrasound transducers

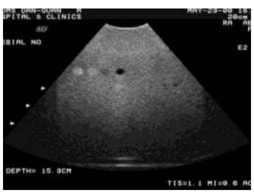
- 2D matrix receiver captures energy profile of transducer while running on the scanner system
- All 1-D and 2-D transducers from any manufacturer
- All operating modes, including ARFI and shear wave imaging
- Assesses lens stability over time
- Potential to calculate acoustic dose

http://www.acertaralabs.com



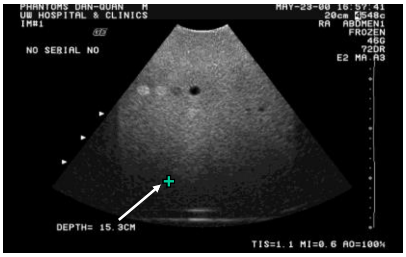
Sensitivity, Maximum Depth of Penetration

- Considered by many as a good overall check of the integrity of the system
- FOV at 18 cm (or set to match the phantom)
- Output power (MI) at max
- Transmit focus at deepest settings
- Gains, TGC for visualization to the maximum distance possible



Maximum "Relative" Depth of Penetration

How far can you see the speckle pattern in the material?



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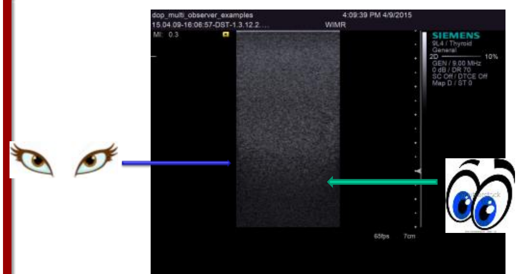
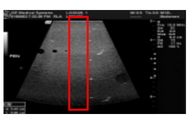
Problem: Subjective assessment



Objective Maximum Depth of Visualization

- Shi, Al-Sadah, Mackie, Zagzebski, Signal to Noise Ratio Estimates on Ultrasound Depth of Penetration (abstract only), *Medical Physics 30*: 11367, 2003.
- Gorny, Tradup, Bernatz, Stekel, and Hangiandreou, "Evaluation of an Automated Depth of Penetration Measurement for the Purpose of Ultrasonic Scanner Comparison", (abstract only), J. Ultrasound Med 23: S76, 2004.
- Rubert, et al, Automated Depth of Penetration Measurements for Quality Assurance in Ultrasound (Abstract only), Medical Physics 342, 11367, 2015.
- Specified in IEC International Standards 61391-2 (2010) and 62736 ("Maximum Relative Depth of Penetration" in 62736)
- Compute mean pixel value vs. depth for phantom (signal+noise) and for noise only (noise)
- Depth where (signal+noise)/noise = 1.4 =DOP

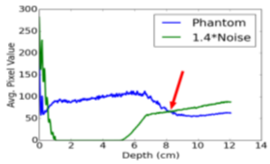


IEC Standard 61391-2: Automated Method

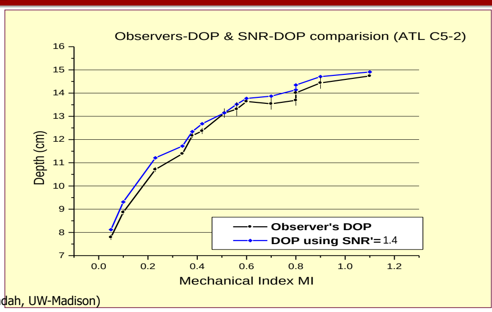
1. Record a phantom image

2. Record an in-air "noise" image

3. Average Both Images Horizontally



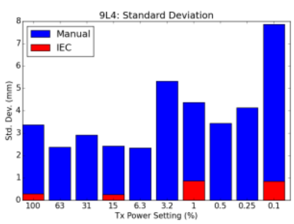
SNR'-DOP tracks well Observer-DOP



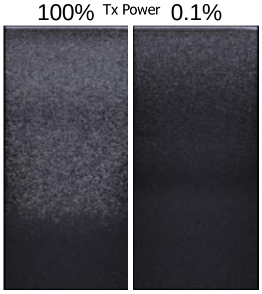
(Al-Sadah, UW-Madison)

Comparison of Standard Deviations: 9L4

Blue: 7 students trained to assess DOP visually
Red: Repeat measurements using S+N/N=1.4



100% Tx Power 0.1%



UW Report Transducer worksheet (page 3)

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Distance Measurement Accuracy: Vertical

- Actual 8.0 cm
- Measure 7.94 cm
- error 0.75%
- Acceptable
  - *Action: >1.5mm or 1.5%
  - *Defect: >2mm 0r 2%

*Goodsitt M M *et al* 1998 Real-time B-mode ultrasound quality control test procedures. Report of AAPM Ultrasound Task Group No. 1 *Med. Phys.* **25** 1385

Distance Measurement Accuracy: Horizontal

- Actual 6.0 cm
- Measure 6.05 cm
- error < .8%
- Acceptable
  - *Action: >2mm or 2%
  - *Defect: >3mm 0r 3%

*Goodsitt M M *et al* 1998 Real-time B-mode ultrasound quality control test procedures. Report of AAPM Ultrasound Task Group No. 1 *Med. Phys.* **25** 1385

Routine QA (ACR General US Program)

- Distance Measurement Accuracy tests
  - Necessary? ("Scanner is a transducer tied to a computer.")
  - May be important for specific uses
    - Images registered from 3-D data sets
    - Workstation measurements
    - Radiation seed implants

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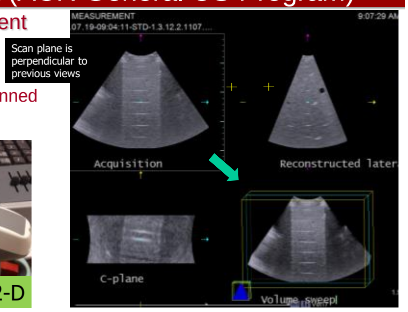
Routine QA (ACR General US Program)

- Distance Measurement Accuracy tests
  - Required in the mechanically scanned direction



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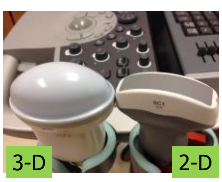
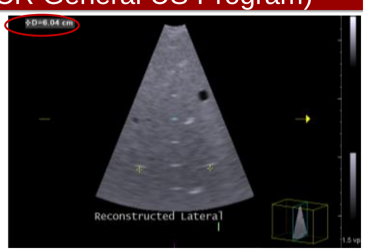
  - Required in the mechanically scanned direction





Actual: 6.0 cm
Measured: 6.04 cm
Error: <0.7%

UW Report Transducer worksheet (page 3)

Instructions, uniformity ratings (UW-Madison, not other groups, such as AAPM):
1=uniform
2=minor inhomogeneity (no more than 2 minor dips)
3=Significant inhomogeneities; transducer is functional, but consider replacing
4=Immediate repair or replacement recommended
Data table (1 line for each transducer)

Transducer ID/Serial Number	Cables/ cracks/ delaminate		Uniformity, dropout		Sensitivity (Depth of Penetration) (MHz/cm)	Geometric Accuracy H: cm/actual cm V: cm/actual cm	Conclusions and recommendations
	OK	No	OK	No			
C1-5 79635YP9	☒	☐	☒	☐	5MHz/13.71cm H5MHz/10.6 cm	H: 5.91/6 V: 8.01/8	Uniformity Rating 1 DOP ≈ to previous results ☒ Yes ☐ No Click here to enter comments.

Spatial Resolution?

- Not done routinely
  - 2 image sets, each taken with a different speed of sound assumption in the beam former
  - Targets not agreed on universally
    - Anechoic objects get fuzzy with poorer resolution
    - Line targets get wider
  - Requires standardized gain settings to make meaningful
  - Enhance using computational methods to measure point spread function width?

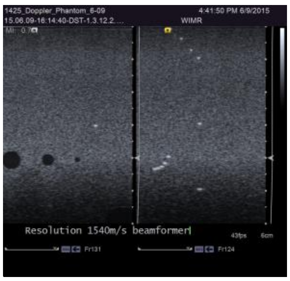
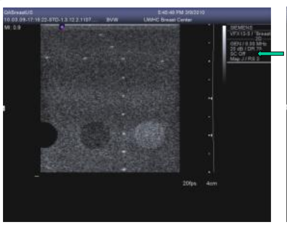


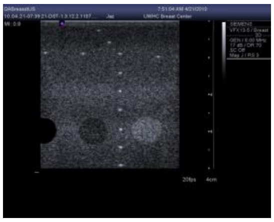
Image of a phantom is useful for qualitative comparisons!



Conventional — Spatial Compounding

Images obtained during routine Breast QC testing, 3/2010

Image of a phantom is useful for qualitative comparisons!



Conventional

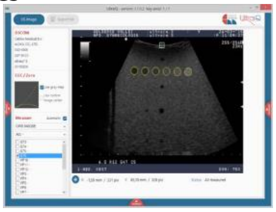
Spatial Compounding

Images obtained 1 month later, after a software change;

UltraiQ

Software to analyze QC images

- Element drop-out (New)
- Sensitivity (SNR) (New)
- Post processing (New)
- Dynamic range
- Axial resolution
- Lateral resolution
- Caliper accuracy
- Penetration depth



www.cablon.nl/UltraiQ

Measurement results provided in trend graphs

UW Report (page 1, Summary)

Site, Location, Facility
UAP, Date, Physicist

Machine ID, PACS ID

Equipment Evaluation

Tests	Pass/Fail	Comments
1. Physical and Mechanical Inspection	Pass	
2. Image Uniformity and Artifact Survey	6 Probes Pass 0 Probes Fail	There is an obvious (small) region of element dropout in the C1-6 transducer. Other transducers exhibit no apparent dead elements.
3. Geometric Accuracy	6 Probes Pass 0 Probes Fail	
4. System Sensitivity	6 Probes Pass 0 Probes Fail	
5. Scanner Electronic Image Display Performance	Pass	The SMPTE test pattern 0%-5% transition is not seen on the display, but is seen on PACS images.
6. Primary Interpretation Display Performance*	Select one.	All gray level transitions in video test pattern seen; all transitions on SMPTE pattern also seen.
7. Contrast Resolution (Optional)	Enter #. Probes Pass Enter #. Probes Fail ☒ Not Tested	
8. Spatial Resolution (Optional)	6 Probes Pass 0 Probes Fail ☐ Not Tested	Images of resolution test zones of the phantom are obtained for reference.

Medical Physicist's (or designee's) Recommendations for Quality Improvement:

The purpose of this program is to: inspect mechanical features and cleanliness of the imaging system; evaluate adequacies of image monitor settings; inspect transducers and check for flaws, dead elements, loss of sensitivity; and assess geometric accuracy (calipers); and record an image for use in assessing consistency of resolution for each probe. During acceptance tests, Doppler also is assessed.

The system is operating well with all probes. The SMPTE test pattern offers an additional, challenging low level gray transition (0% - 5 %) which often is not easily visualized on the system monitors, and this is the case for this machine.

Generally, the system is operating well.

4-year Experience with a clinical ultrasound quality control program,

(Hangiandreou et al., Ultrasound Med Biol 37, 1350-1357, 2011)

Evaluation Method	# of detected "failures"	% of detected "failures"	Recommendation
Mechanical Integrity	47	25.1	Quarterly
Image uniformity	124	66.3	Quarterly
Distance Accuracy	0	0.0	Annually
DOP (penetration)	3	1.6	Annually, (if done with software)
Clinical Problems	13	7.0	Sonographer's daily inspections
TOTAL	**187**	**100.**	

Future

- Incorporate computational methods for more objective tests
- Expand to other operating modes
  - Pulsed Doppler
    - Sensitivity (signal to noise at a given depth, for both fast and slow flow conditions)
    - Velocity accuracy
    - Etc
    - QIBA volume flow project (just starting)
  - Color flow
  - Elasticity, shear wave (SW) imaging
    - QIBA work on SW velocity in liver (advanced stages)

Summary

- Setting up, maintaining an equipment QA program is straight forward
- The ACR listed procedures form a useful, basic QA program
  - Directed by physicist or lab personnel
  - Integrated effort including lab and technical staff
  - Requires a Phantom
  - Closely correlates with AIUM list of factors needing to be tested
- Transducer uniformity problems, element dropout, a frequent fault in today's scanning machines
- Computational methods can be developed for objective tests