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

• IEC 62736 Ultrasonics (2016) – Pulse-echo scanners – Simple methods for periodic testing to verify stability of an imaging system’s elementary performance
Information From US Accreditation Bodies


Annual Surveys, Routine QA (ACR)

- Physical 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.

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

Routine Quality Assurance for Diagnostic Ultrasound Equipment

www.aium.org
Physical and Mechanical Inspection, ACR

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

Air filters
(Record holder)

Before

After

Routine QA: Cleanliness, safety

“Physical and Mechanical Inspection” (ACR)

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

(“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)
Image Display (Scanner and PACS)

- Gain and sensitivity adjustments done using system monitor.
- Interpretation 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.

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: $Q = 0 + 14$
l = 1

$Q = 128 + 14$
l = 129

$Q = 255 - 14$
l = 254

Monitor agreement (cont.)

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+

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
Transducer 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

**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

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

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

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.

Objective Criteria being developed

- 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
- A dip >3dB and more than 2 elements wide is worth counting as a defect of possible concern.
Dip magnitude and width analyzed in uniformity assessment.

Difficulties with Uniformity

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

Solution 1: rock transducer from side to side.
Difficulties with Uniformity (coupling)

- **Solution 1:** Rock transducer from side to side

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

- **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 Kalbert, 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)

<table>
<thead>
<tr>
<th>Transducer ID/Serial Number</th>
<th>Cables/ cracks/delamination</th>
<th>Uniformity dropout</th>
<th>Sensitivity Depth of Penetration (MHz/cm)</th>
<th>Geometric Accuracy H:cm/actual H cm</th>
<th>Geometric Accuracy V:cm/actual V cm</th>
<th>Conclusions and recommendations</th>
<th>Uniformity Rating 1</th>
<th>DOP = to previous results</th>
<th>OK</th>
<th>No</th>
<th>Click here to enter comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>C1-5 78635YP9</td>
<td>☒</td>
<td>☐</td>
<td>☒</td>
<td>5MHz/13.71cm</td>
<td>H: 5.81/6 V: 8.01/6</td>
<td>☒</td>
<td>Yes</td>
<td>Yes</td>
<td>☒</td>
<td>☐</td>
<td>☒</td>
</tr>
</tbody>
</table>
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.

Firstcall Probe Tester by ACETARA
http://www.acertaralabs.com

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

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

Test console with probe ‘adapter’

http://www.acertaralabs.com
Maximum "Relative" Depth of Penetration

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

Problem: Subjective assessment

Objective Maximum Depth of Visualization

- 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

Comparison of Standard Deviations: 9L4

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

<table>
<thead>
<tr>
<th>Transducer ID/Serial Number</th>
<th>Character</th>
<th>Signal return</th>
<th>Uniformity, dropout</th>
<th>Sensitivity (Depth of Penetration) MHz/cm</th>
<th>Geometric Accuracy H: cm/actual cm</th>
<th>V: cm/actual cm</th>
<th>Conclusions and recommendations</th>
</tr>
</thead>
<tbody>
<tr>
<td>C1-5</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>5MHz/13.71 cm</td>
<td>8.01/8.01B</td>
<td>OK</td>
</tr>
</tbody>
</table>

Uniformity Rating 1
DOP = to previous results
☐ Yes ☐ No
Click here to enter comments.

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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 or 2%


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Distance Measurement Accuracy: Horizontal

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

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

- Required in the mechanically scanned direction

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

<table>
<thead>
<tr>
<th>Transducer ID/Serial Number</th>
<th>Cables/裂缝</th>
<th>Uniformity, Dropout</th>
<th>Sensitivity: Depth of Penetration (MHz/cm)</th>
<th>Geometric Accuracy H: cm/actual cm</th>
<th>V: cm/actual cm</th>
<th>Conclusions and recommendations</th>
</tr>
</thead>
<tbody>
<tr>
<td>C1-5 79639YP9</td>
<td>☒</td>
<td>☐</td>
<td>5MHz/13.71 cm</td>
<td>H: 5.91/6</td>
<td>V: 8.01/8</td>
<td>Uniformity Rating 1</td>
</tr>
</tbody>
</table>

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
Images obtained 1 month later, after a software change;

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

Measurement results provided in trend graphs

Ultra iQ
www.cablon.nl/UltraiQ

Equipment Evaluation

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

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)

<table>
<thead>
<tr>
<th>Evaluation Method</th>
<th># of detected <em>failures</em></th>
<th>% of detected <em>failures</em></th>
<th>Recommendation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mechanical Integrity</td>
<td>47</td>
<td>25.1</td>
<td>Quarterly</td>
</tr>
<tr>
<td>Image uniformity</td>
<td>124</td>
<td>66.3</td>
<td>Quarterly</td>
</tr>
<tr>
<td>Distance Accuracy</td>
<td>0</td>
<td>0.0</td>
<td>Annually</td>
</tr>
<tr>
<td>DOP (penetration)</td>
<td>3</td>
<td>1.6</td>
<td>Annually, if done with software</td>
</tr>
<tr>
<td>Clinical Problems</td>
<td>13</td>
<td>7.0</td>
<td>Sonographer's daily inspections</td>
</tr>
<tr>
<td>TOTAL</td>
<td>187</td>
<td>100.0</td>
<td></td>
</tr>
</tbody>
</table>

**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 straightforward
- 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