Quality Assurance of Ultrasound Imagers in Diagnostics

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• Overview of ultrasound image formation
• Features that affect the performance
• QC testing procedures
• Discussion: efficacy of ultrasound QC tests
Ultrasound Image Formation

A-mode amplitude display

B-mode or M-mode Brightness display (Gray-scale)

**Range Equation:** \( D = \frac{c \times t}{2} \) where \( c = 1.54 \text{ mm/\textmu s} \)

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Single Element Transducer

**Near Field** (Fresnel zone)

**Far Field** (Fraunhofer zone)

**AAPM, Pittsburgh, July 27, 2004**
Lateral Resolution

the minimum distance between two objects positioned perpendicular to the axis of the beam where both are displayed as separate structures.

Lateral Resolution is determined by the beam profile.

Ultrasound Transducers

- Linear Array
- Curve Linear Array
- Phased Array
- Endocavity Array

AAPM, Pittsburgh, July 27, 2004

www.acuson.com/transducers
Beam Forming

\[ p(\mathbf{r} - \mathbf{r}_j, \omega) \]

Single-zone transmit-receive focus
Frame Rate Limitation

The frame rate is ultimately limited by the sound propagation speed ($c$).

The maximum frame rate is determined by the following relationship, where $D$ is the maximum depth of the field of view, and $N$ is the total number of acoustic lines per frame.

$$Frame - Rate_{max} = \frac{c}{2ND}$$
Dynamic-receive Focusing

Parallel Beam Forming
Spatial Resolution

• Axial
• Lateral
• Elevational (slice thickness)

Axial Resolution

the minimum distance between two objects positioned along the axis of the beam where both are displayed as separate structures.

Axial - Resolution ≈ \( \frac{SPL}{2} \)
Spherical Lesion Phantom

- 2 and 4 mm diameter spherical targets;
- Low scatter level;
- Target centers are co-planar.

1 ½ D (Matrix) Transducer

Conventional Linear Array Transducer

Courtesy of Dr. J. A. Zagzebski, UW-Madison
AAPM, Pittsburgh, July 27, 2004
Goal of Ultrasound QC Program

• To make sure a system is set up correctly and performs to specified standards.
• To maintain the consistency of the performance.
• To reveal problems at its earliest stage before it severely interferes with the clinical practices.

ACR Accreditation

www.acr.org

• Breast Ultrasound Accreditation Program (including Ultrasound-guided Breast Biopsy)
• General Ultrasound Accreditation Program
  • Obstetrical
  • Gynecological
  • General
  • Vascular
  • Combination of the above
AIUM Accreditation
www.aium.org

• Ultrasound practices in various fields:
  • Breast
  • Obstetrical and Trimester-Specific Obstetrical
  • Gynecological
  • Abdominal/General

ACR Accreditation QC Requirements

• A QA program should be in place;
• The QA program must be directed by a medical physicist or by the supervising physician;
• Routine QC testing must be done at least semi-annually;
• Do the same tests, monitor changes over time and take corrective actions when necessary;
• Testing results, corrective action, and the effects of corrective action must be documented and maintained on site.
• There is currently no ACR-preferred single phantom.
Distance Accuracy

- Scan the phantom with a vertical column and a horizontal row of reflectors;
- The digital caliper readout on screen is checked against the known distance between reflectors;

Criteria:
- Vertical: 1.5% of the actual distance or 2 mm, whichever is greater.
- Horizontal: 3% of the actual distance or 3 mm, whichever is greater.

System Sensitivity/Penetration

This test should be done with following settings:
- maximum transmit power,
- proper receiver gain and TGC that allows echo texture to be visible in the deep region,
- transmit focus at the deepest depth.
Image Uniformity

Array Transducer Failure

www.4sonora.com
Courtesy of GW Moore
Soft and/or Hard Copy Recording I

The shades of gray, weak, and strong echo texture should be optimized and consistent between the image display on the ultrasound scanner and the photographic hard copies or soft copy displays on the workstation in the reading room.

- For quick follow-up testing, the Gray-scale bar pattern on the clinical image display can be used.

Soft and/or Hard Copy Recording II

- Use the SMPTE test pattern and other patterns if they are available on the ultrasound scanner.
- Workstation monitor display should be included in QC tests.
Soft and/or Hard Copy Recording III

– Film processor QC needs to be done daily.
– Darkroom fog test needs to be done at least semi-annually.

Low Contrast Object Detectability

Scans of a low contrast resolution phantom can reveal the low contrast object detectability which is an optional test on the ACR semi-annual QC test list for general ultrasound accreditation.
Dead Zone (Ring Down)

A group of reflectors consisting of fibers are placed at different separations from the top of the phantom (~1-8 mm). As the transducer scans across the top, the distance from the transducer to the first reflector completely imaged is equal to the dead zone (ring down) distance.

Axial and Lateral Resolution

Spatial resolution may be evaluated by either of the following ways:
- **Count** the number of the pins distinguished without overlap in lateral and axial direction; thus the minimum target spacing is documented;
- **Measure** the size of the pin in lateral and axial direction.
Ultrasound Doppler QC Testing

- Doppler QC tests include
  - Doppler signal sensitivity;
  - Doppler angle accuracy;
  - Color display and Gray-scale image congruency;
  - Range-gate accuracy;
  - flow readout accuracy.

Doppler Velocity Accuracy:
Variations among 8 clinical units each with transducers of 3.5 MHz, 5 MHz and 7 MHz.

<table>
<thead>
<tr>
<th>Flow Rate (ml/min)</th>
<th>100</th>
<th>237</th>
<th>398</th>
<th>611</th>
<th>800</th>
<th>1093</th>
<th>AVG</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.5MHz</td>
<td>5.7%</td>
<td>10.2%</td>
<td>6.7%</td>
<td>8.0%</td>
<td>10.2%</td>
<td>13.0%</td>
<td>9.0%</td>
</tr>
<tr>
<td>5 MHz</td>
<td>17.4%</td>
<td>7.7%</td>
<td>10.6%</td>
<td>6.9%</td>
<td>13.9%</td>
<td>13.0%</td>
<td>11.6%</td>
</tr>
<tr>
<td>7 MHz</td>
<td>8.2%</td>
<td>8.2%</td>
<td>4.1%</td>
<td>9.2%</td>
<td>7.1%</td>
<td>12.5%</td>
<td>8.2%</td>
</tr>
<tr>
<td>Average</td>
<td>10.4%</td>
<td>8.7%</td>
<td>7.1%</td>
<td>8.0%</td>
<td>10.4%</td>
<td>12.9%</td>
<td>9.6%</td>
</tr>
</tbody>
</table>
Assurance of Electrical and Mechanical Safety

The equipment related physical checks are also worth attention. These include:
– checking for any cracks or delamination in the transducers,
– noting for loose and frayed electric cables, loose handles or control arms,
– checking the working condition of the wheels and the wheel locks,
– making sure all the accessories (such as VCR, printer, etc.) are fastened securely to the system,
– Making sure the image monitors are clean and the air filters are not too dusty.

Efficacy of Ultrasound QC Tests

• NM Donofrio et al, JCU 12: 251-260; 1984
(They found QC tests such as depth of penetration, axial resolution, gray scale efficacious.)
• SC Metcalfe et al, BJR 65: 570-575; 1992
(They found poor correlation between QC measurements and related subjective operator assessment on many QC parameters.)
• NJ Dudley et al, EJU 12: 233-245; 2001
(The results of two ultrasound QA programs were reviewed.)
• NJ Dudley et al, UMB 22:1117-1119; 1996
(They emphasize the importance of rigorous testing of circumference measuring calipers in obstetric ultrasound applications.)
Review of A QA/QC Program
in a period of 7 years

Group I (28 units with age of 5 years or less)
101 reports with 67 deficiencies:

<table>
<thead>
<tr>
<th>Test</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Image uniformity test</td>
<td>30%</td>
</tr>
<tr>
<td>Mechanical checks</td>
<td>27%</td>
</tr>
<tr>
<td>Image display soft / hard copy quality</td>
<td>21%</td>
</tr>
<tr>
<td>Poor spatial and contrast resolution</td>
<td>9%</td>
</tr>
<tr>
<td>Doppler QC tests (sensitivity, color congruency)</td>
<td>6%</td>
</tr>
<tr>
<td>Software problem</td>
<td>4%</td>
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<tr>
<td>Maximum depth of visualization reduction</td>
<td>3%</td>
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</table>

Review of A QA/QC Program (cont.)
in a period of 7 years

Group II (10 units with age of over 5 years)
28 reports with 67 deficiencies:

<table>
<thead>
<tr>
<th>Test</th>
<th>Percentage</th>
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</thead>
<tbody>
<tr>
<td>Poor spatial and contrast resolution, dead zone</td>
<td>31%</td>
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<tr>
<td>Mechanical checks</td>
<td>25%</td>
</tr>
<tr>
<td>Maximum depth of visualization reduction</td>
<td>18%</td>
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<tr>
<td>Image display soft / hard copy quality</td>
<td>15%</td>
</tr>
<tr>
<td>Software problem</td>
<td>6%</td>
</tr>
<tr>
<td>Image uniformity test</td>
<td>3%</td>
</tr>
<tr>
<td>Doppler QC tests (sensitivity, color congruency)</td>
<td>2%</td>
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</table>
Summary

• The guidelines for diagnostic ultrasound QA/QC programs are descriptive. Maintaining an ultrasound QA/QC program is straightforward and useful in identifying deficiencies.

• Assessment of the efficacy and relevance of ultrasound QA procedures is rare.

• As ultrasound technology advances rapidly, the guidelines need to be updated periodically.