

QA/QC of Ultrasound Imagers: Basic Physics, Procedures and Experiences

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Outline

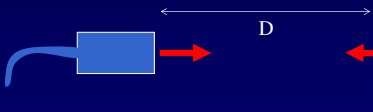
- General overview of basic ultrasound physics
- QA/QC guidelines provided by professional bodies
- Accreditation programs
- QC testing procedures and phantoms
- Discussion: efficacy of ultrasound QA/QC program
- References

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US Imaging Range Equation

$$D = ct/2$$

D is the depth where the echoes are generated;
 c is sound propagation speed in the media;
 t is the time delay between the pulse emission and echo reception.



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Frame Rate Limitation

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

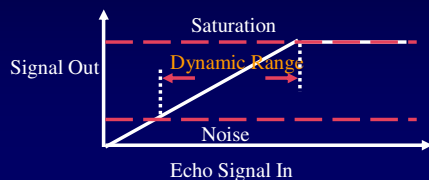
The maximum frame rate is determined by the following relationship, where D is the maximum depth of the field of view, and N is the total number of acoustic lines per frame.

$$\text{Frame - Rate}_{\max} = \frac{c}{2ND}$$

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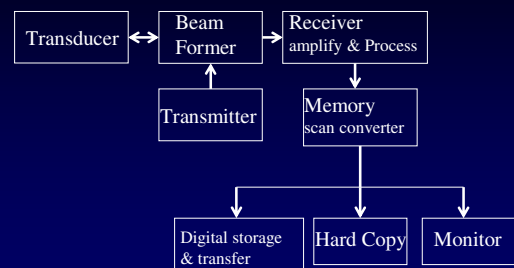
Dynamic Range

Dynamic range is the ratio of the largest to smallest signals that an instrument or a component of an instrument can respond to without distortion.



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Block Diagram of an Ultrasound Imager



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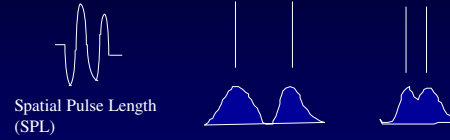
Gain Vs Power

- Increasing either gain or power increases signal amplitude and image brightness throughout the field
- Increasing output power also increases the signal to noise ratio; increasing gain increases the signal level as well as the noise level. Therefore, increasing the power will improve penetration but increasing the gain will not.
- Increasing output power also increases exposure to the patient; increasing gain does not.

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Axial Resolution

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



$$\text{Axial - Resolution} \approx \frac{\text{SPL}}{2}$$

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Lateral Resolution

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



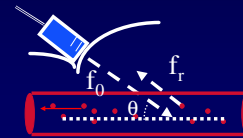
Lateral Resolution is determined by the beam profile.

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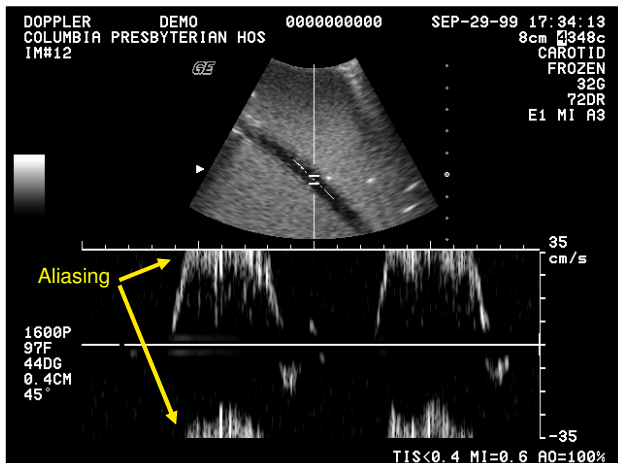
DOPPLER SHIFT f_D

Considering the Doppler angle θ :

$$f_D \approx \frac{2v \cos(\theta) f_0}{c}$$



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Goal of Ultrasound QA/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.

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Three Levels of Ultrasound QC Testing

- Level 1 – Frequent QC testing:
Operator's QC
- Level 2 – Semi-annual or annual QC
testing: Physicist's QC
- Level 3 – Acceptance testing / baseline
set-up

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Guideline By

American Association of Physicists in Medicine
(AAPM)
Ultrasound Task Group No. 1

“Real-time B-mode ultrasound quality control
test procedures”

By MM Goodsitt *et al*

Medical Physics. 25(8):1385-406, 1998 Aug.

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Guideline By

American Institute of Ultrasound in Medicine
(AIUM)

“Quality Assurance Manual for Gray Scale
Ultrasound Scanners (Stage 2)”
edited by E. Madsen

AIUM, Laurel, MD, 1995

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Guideline By

The Institute of Physical Sciences in Medicine
(IPSM)
Report No. 71

“Routine Quality Assurance of Ultrasound
Imaging Systems”
edited by R. Price

York: ISPM, 1995

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Guideline By

American Institute of Ultrasound in Medicine
(AIUM)

“Performance Criteria and Measurements for
Doppler Ultrasound Devices: Technical
Discussion – 2nd Edition”

AIUM, Laurel, MD, 2002

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Guideline By

The Institute of Physical Sciences in Medicine
(IPSM)
Report No. 70

“Testing of Doppler Ultrasound Equipment”
edited by PR Hoskins, SB Sherriff and JA Evans

York: ISPM, 1994

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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

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AIUM Accreditation

www.aium.org

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

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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.

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ACR Recommended Semi-Annual QC Tests for Breast Ultrasound Accreditation

- Maximum depth of visualization
- Distance accuracy (vertical and horizontal)
- Uniformity
- Electrical-mechanical cleanliness condition
- Anechoic void perception
- Ring down
- Lateral resolution
- Quality Control Checklist

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ACR Recommended Technologist's QC Tests for Breast Ultrasound Accreditation

- Adherence to universal infection control procedures for each biopsy
- All transducers should be cleaned between patients
- Distance calibration - **quarterly**
- Gray scale photography - **quarterly**

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ACR Required Semi-Annual QC Tests for General Ultrasound Accreditation

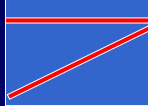
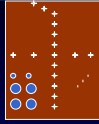
- System sensitivity and/or penetration capability
- Image uniformity
- Photography and other hard copy recording
- Low contrast object detectability (**optional**)
- Assurance of electrical and mechanical safety
- Vertical and horizontal distance accuracy (**recommended only when the program is initiated for a scanner**)

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Ultrasound QC Phantoms

B-mode:

1. Multi-purpose or general purpose tissue/cyst phantom
2. Low contrast resolution phantom
3. Spherical lesion phantom
4. Beam profile and slice thickness phantom
5. Prostate QC phantom



Doppler-mode:

1. Flow phantom
2. String phantom

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Ultrasound Phantom Suppliers

- ATS Labs, Bridgeport, CT
– www.atslabs.com
- CIRS, Norfolk VA
– www.cirsinc.com
- Gammex RMI, Madison WI
– www.gammex.com
- Nuclear Associates, Hicksville NY
– www.inovision.com/Nuclear_Associates
- Research Laboratories

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Desiccation: Water-based Phantom Material

- Monitoring Desiccation (moisture loss)
 - Monitor phantom weight loss regularly
 - Rejuvenation requirements provided by manufacturer
 - Rejuvenation recommended usually after a 10 - 15 gram weight loss
 - Rejuvenation accomplished by injecting a water-alcohol fluid through the polyurethane scanning surface

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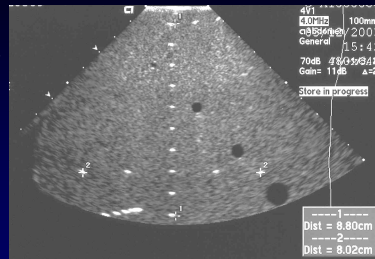
Rejuvenation: Water-based Phantom Materials

- Rejuvenation Procedures and Hints
 - Follow manufacture's recommended rejuvenation procedures
 - Remember: 1 gram = 1 cc = 1 ml
 - Remove air bubbles from syringe prior to injection
 - Pick a remote location for injection - seal with super glue

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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.

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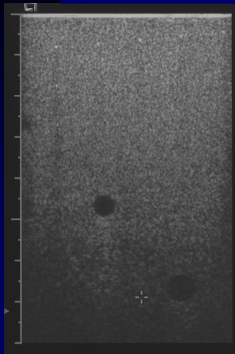
System Sensitivity/Penetration

The maximum depth of visualization is determined by comparing the gradually weakening echo texture to electronic noises near the bottom of the image.

Do this test with the same settings and monitor the changes over time.

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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.

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Image Uniformity

Adjust the TGC controls and other sensitivity controls to obtain an image as uniform as possible

Inspect the image to detect any kinds of

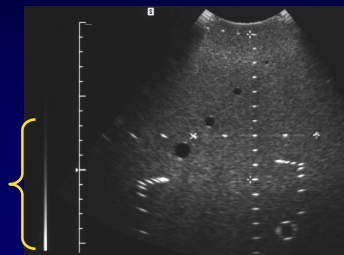
- vertical or radially oriented streaks
- dropouts
- reduction of brightness near edges of the scan
- brightness transitions between focal zones

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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.

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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.

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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.

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Assurance of Electrical and Mechanical Safety

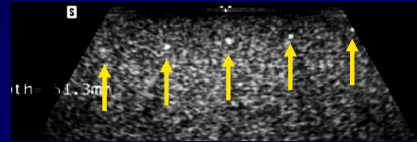
The equipment related physical checks are also worth attention. These include:

- 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.

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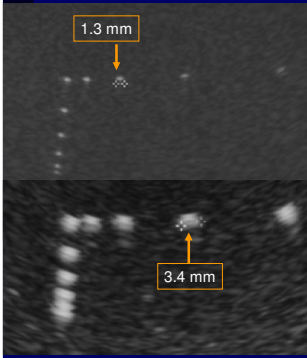
Dead Zone (Ring Down)

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.



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Axial and Lateral Resolution



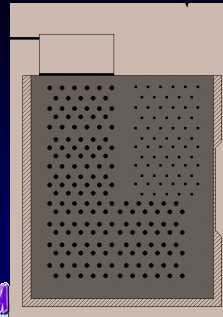
Spatial resolution may be evaluated by either of the following ways:

- 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.

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Spherical Lesion Phantom

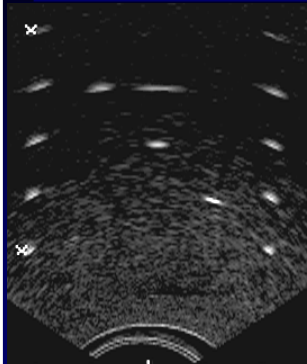
- 2 and 4 mm diameter spherical targets;
- Low scatter level;
- Target centers are co-planar.



Courtesy of Dr. J. A. Zagzebski, UW-Madison

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Prostate Ultrasound QC Methods



- Distance Accuracy
- Template overlay

Courtesy of Dr. J. Kofler, Mayo Clinic

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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.

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

Flow Rate (ml/min)	100	237	398	611	800	1093	AVG
3.5MHz	5.7%	10.2%	6.7%	8.0%	10.2%	13.0%	9.0%
5 MHz	17.4%	7.7%	10.6%	6.9%	13.9%	13.0%	11.6%
7 MHz	8.2%	8.2%	4.1%	9.2%	7.1%	12.5%	8.2%
Average	10.4%	8.7%	7.1%	8.0%	10.4%	12.9%	9.6%

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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:

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

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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:

Poor spatial and contrast resolution, dead zone	31%
Mechanical checks	25%
Maximum depth of visualization reduction	18%
Image display soft / hard copy quality	15%
Software problem	6%
Image uniformity test	3%
Doppler QC tests (sensitivity, color congruency)	2%

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Discussion

- The guidelines for ultrasound QA/QC programs are descriptive.
- Maintaining an ultrasound QA/QC program is straightforward and effective in identifying deficiencies.
- Ultrasound phantoms are needed for evaluating performance and testing consistency. However, we need to know that the tissue mimicking material can only mimic some of the properties of tissue in real clinical situations.

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Discussion (cont.)

- Assessment of the efficacy and relevance of ultrasound QA procedures is rare.
- The guidelines need to be updated periodically as ultrasound technology develops.

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References

- J Zagzebski, "US quality assurance with phantoms." In Categorical Course in Diagnostic Radiology Physics: CT and US Cross-Sectional Imaging, Edited by L. Goldman and B. Fowlkes, 2000, Oak Brook, IL: Radiological Society of North America, pp. 159-170.
- J Zagzebski and J Kofler, "Ultrasound Equipment Quality Assurance," in Quality Management in the Imaging Sciences, ed. By J Papp, 2002, St. Louis, Mosby, pp. 207-215.
- SC Metcalfe and JA Evans, "A study of the relationship between routine ultrasound quality assurance parameters and subjective operator image assessment", The British Journal of Radiology, 65: 570-575, 1992.

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- NM Donofrio, JA Hanson, JH Hirsch, WE Moore, "Investigating the efficacy of current quality assurance performance tests in diagnostic ultrasound", Journal of Clinical Ultrasound, 12: 251-260, 1984.
- J. Kofler, R. Kruger, Z. Lu, B. Fowlkes and M. Holland, "Clinical Ultrasound Physics: a workbook for physicists, residents and students", Medical Physics Publishing, 2001.

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END

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