Current Ultrasound Quality Control Recommendations and Techniques

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Thank you for your interest – today I hope to provide some basic recommendations for beginning a program for ultrasound quality control in a hospital setting

Learning Objectives

- Learners should:
  - Understand what the beginning steps are to implement a Quality Control program for ultrasound equipment
  - Know which tests are appropriate to assess clinical image quality
  - Know how to select test objects appropriate for these tests
  - Know how to establish objective criteria
  - have a basic introduction to accreditation bodies and standards for ultrasound QC

These are the learning objectives I have for the presentation today

Why do US QC?

- From AAPM Website - Clinical Service and Consultation
- Many medical physicists are heavily involved with responsibilities in areas of diagnosis and treatment, often with specific patients. These activities take the form of consultations with physician colleagues. In radiation oncology departments, one important example is the planning of radiation treatments for cancer patients, using either external radiation beams or internal radioactive sources. An indispensable service is the accurate measurement of the radiation output from radiation sources employed in cancer therapy. In the specialty of nuclear medicine, physicists collaborate with physicians in procedures utilizing radionuclides for delineating internal organs and determining important physiological variables, such as metabolic rates and blood flow. Other important services are rendered through investigation of equipment perfor-mance, organization of quality control in imaging systems, design of radiation installations, and control of radiation hazards. The medical physicist is called upon to contribute clinical and scientific advice and resources to solve the numerous and diverse physical problems that arise continually in many specialized medical areas.

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Before charging in to test ultrasound equipment, it is good to understand and know the extent of ultrasound equipment present. Ultrasound is a very ubiquitous imaging modality – due to it's low cost and relative ease of use. For this reason, it is not always easy to locate every ultrasound instrument that exists!

First Steps

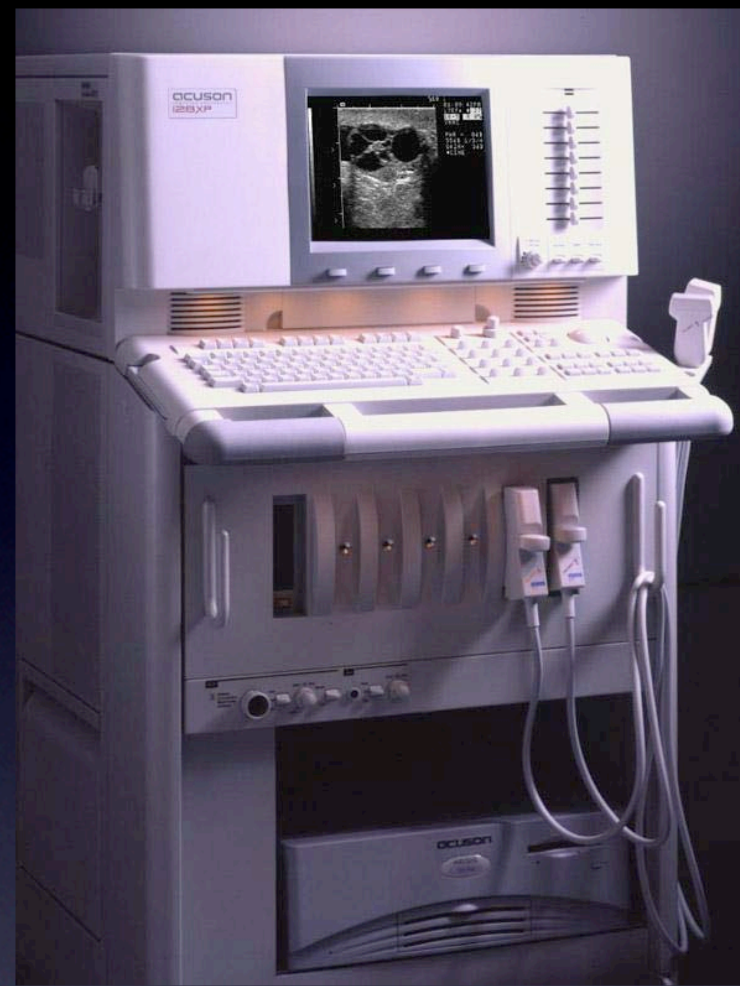
- Inventory of US equipment and probes
  - Radiology, Cardiology, Vascular Surgery, Ob/Gyn
  - Pediatrics, Interventional labs, Emergency Room, Radiotherapy
  - OR suites, Orthopedics
    - (lots of different types of systems - many different probes!)
- Prioritize
  - service contracts?
  - knowledgable users?

First, you need to know where ultrasound is being done in your institution and how open the users are to establishing a QC program. From a quality control standpoint, the most cooperative users of ultrasound will likely be in general radiology imaging. This has to do more with prior experience in dealing with Medical Physics and a more general understanding of quality improvement requiremets. In some institutions, radiology may handle many other specialities. However, as ultrasound has become cheaper and easier, other specialties have incorporated ultrasound into their practice. Accreditation bodies have also recognized this (for example, American Institute of Ultrasound in Medicine). There is perhaps as wide of a variation in types of ultrasound equipment as uses for it.

You will need to determine if there are service contracts in place on each piece of equipment. If you have clinical engineering support, determine if there is regular preventive maintenance. Often there are service programs available on high end equipment that are useful.

You will also need to contact each site and determine who the knowledgable users are (e.g. sonographers). These individuals are of great help when working on the scanners and can provide instruction on which settings are appropriate and most often used.

First Steps



General purpose ultrasound units come in a variety of shapes and sizes. You will likely first be able to locate the US systems in Radiology; others will most likely be found in Cardiology, Ob/Gyn and vascular services. US units are becoming smaller and more ubiquitous and might be found in non-traditional places.

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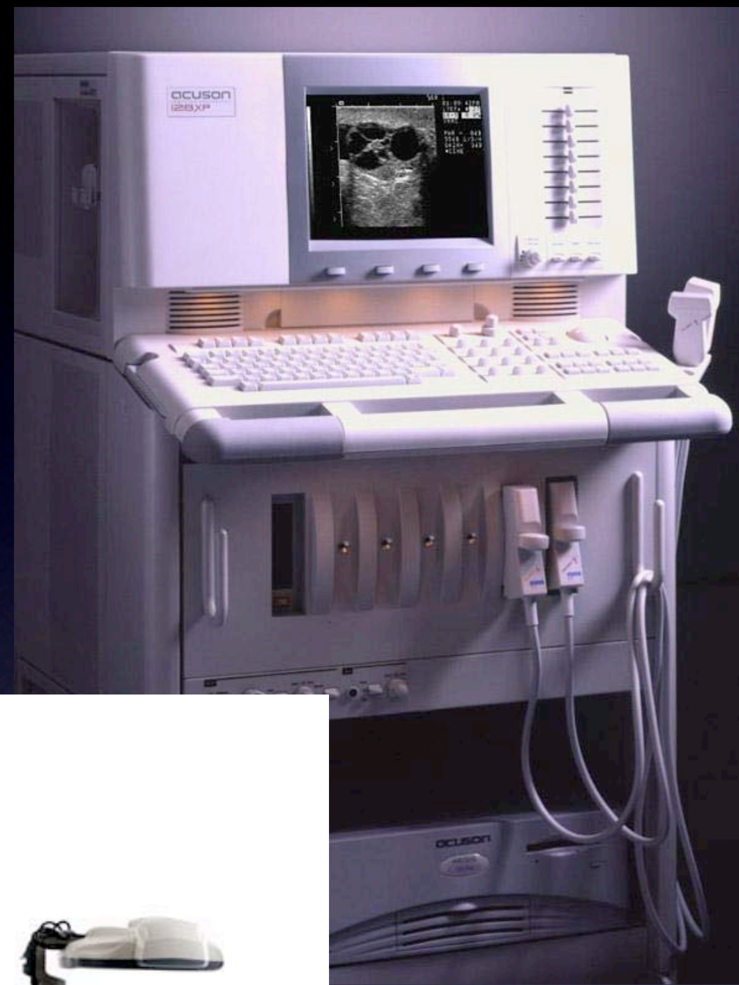

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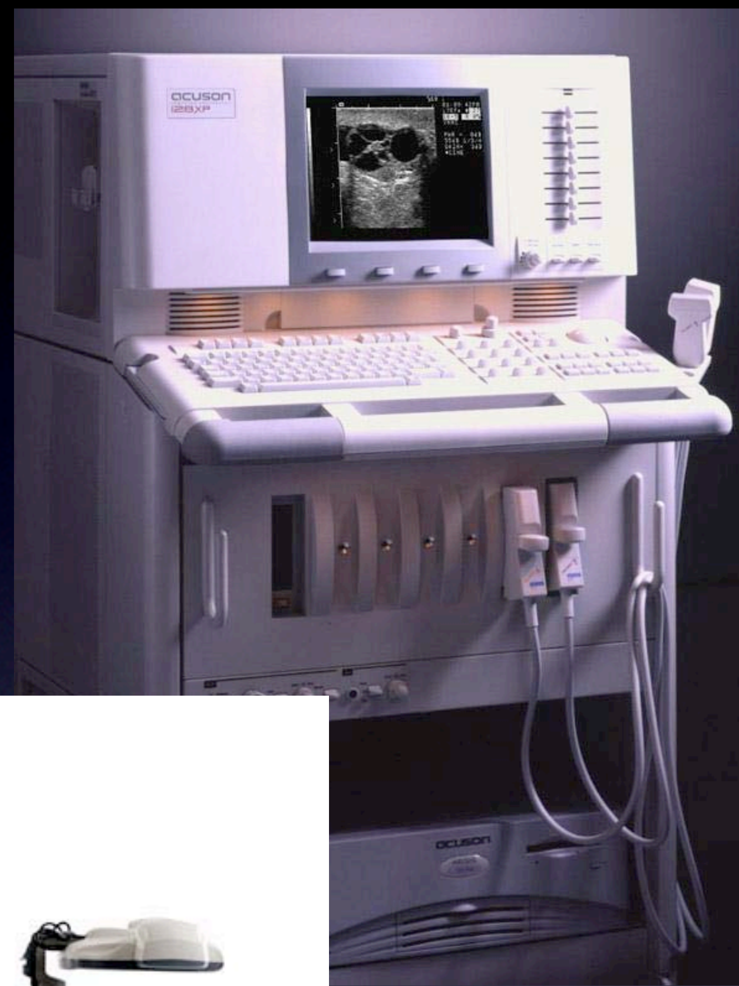
First Steps

- What kind of equipment?



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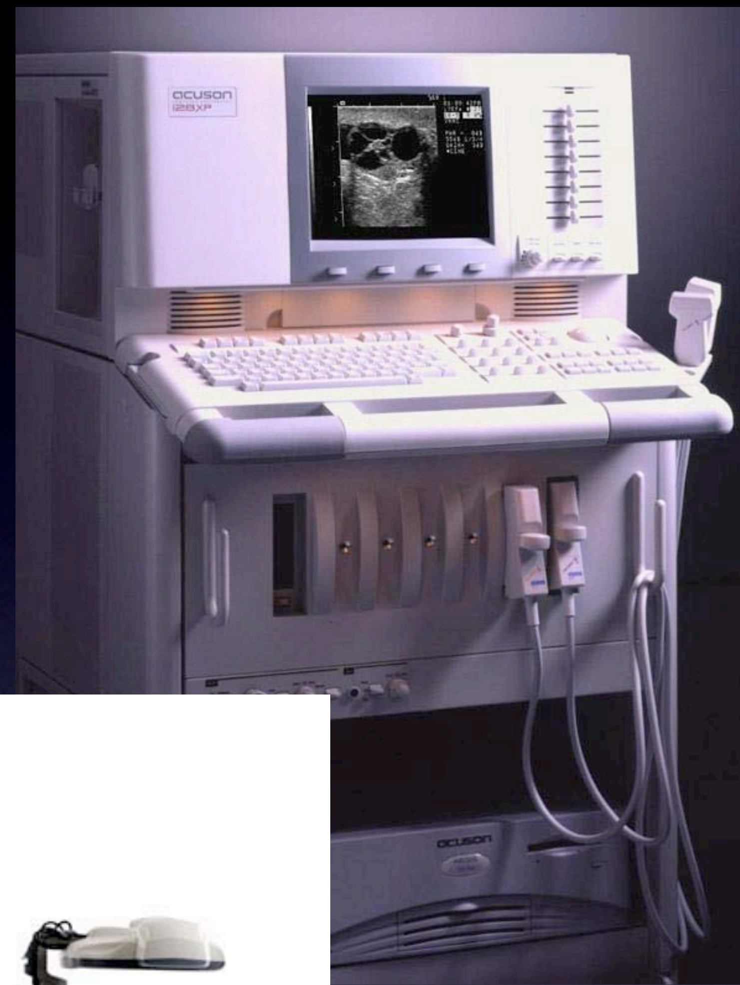
First Steps

- What kind of equipment?
  - General purpose Ultrasound units (Radiology)



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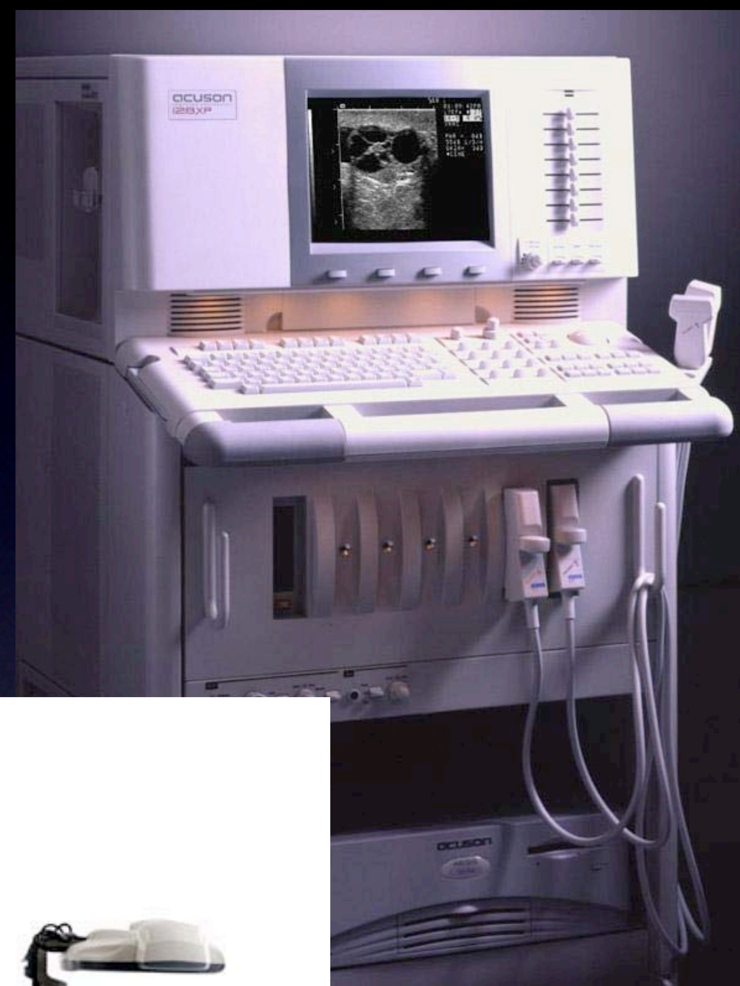
First Steps

- What kind of equipment?
  - General purpose Ultrasound units (Radiology)
  - Echocardiography (Cardiology)



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First Steps

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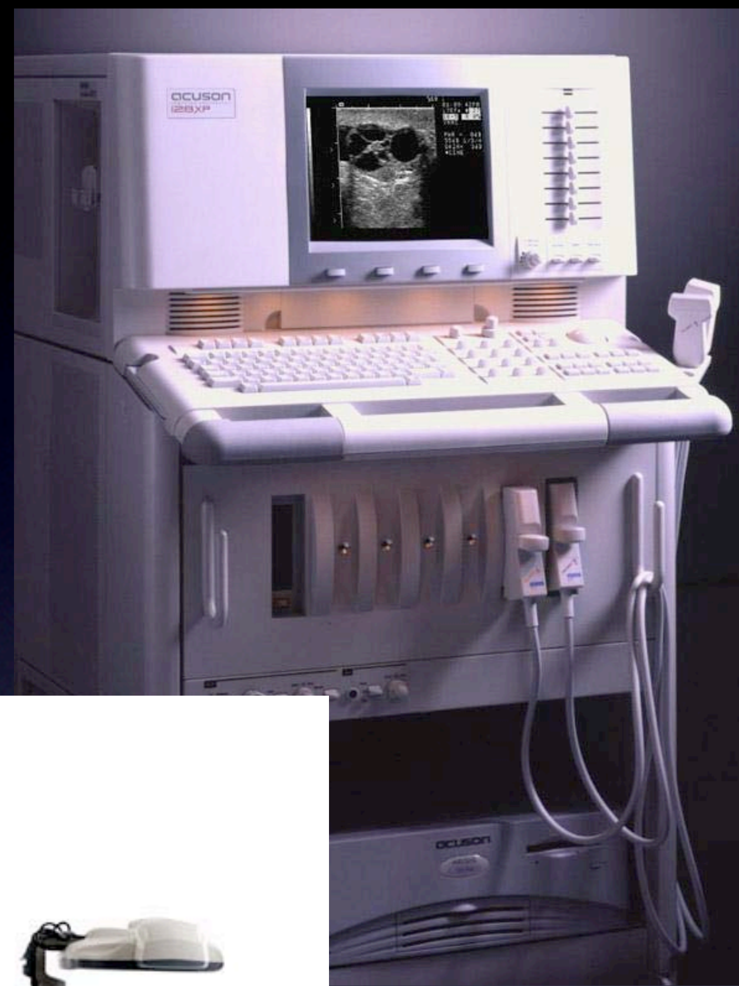
  - Echocardiography (Cardiology)
  - Small or special purpose units (Ob/Gyn, vascular)



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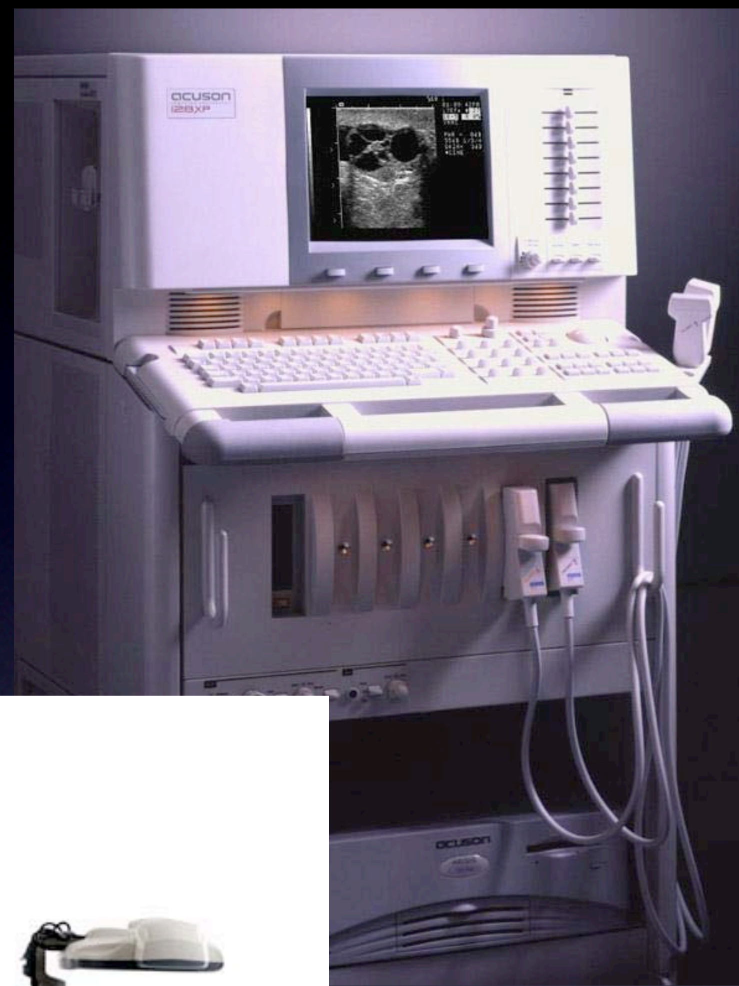

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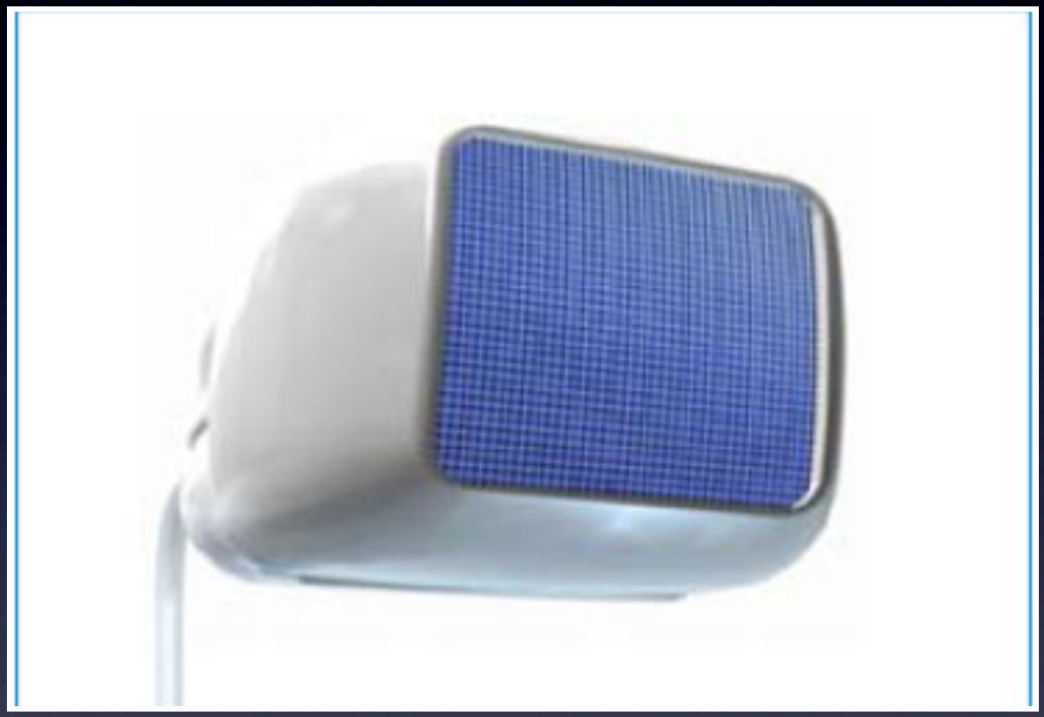
Transducer Types

- Linear arrays
- Phased arrays
- curvlinear arrays
- 1-D, 1.5-D, 2-D arrays

Ultrasound units are usually equipped with two or more transducers. These vary in shape (and imaging method) as well as frequency. Higher frequency transducers are used to shallow imaging applications that demand higher resolution. Lower frequency transducers are typically used to image deeper structures in the body. Access to acoustic windows in the body is another reason for a variety of shapes and sizes. More recently, transducers are evolving from a single row of elements to having multiple rows of elements.

2-D Array Transducers

- 2,500 elements
- 2D imaging
- live bi-plane imaging
- full volume and 3D



These transducers are becoming increasingly complex, but have more and more capability. These are becoming more difficult to evaluate using standard QC phantoms. Because of the number and complexity of transducers, care must be taken to keep ultrasound QC testing simple and effective.

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Basic Imaging Performance Tests

- System Sensitivity
- Uniformity
- Spatial accuracy
- Contrast and Spatial Resolution

These are four basic ultrasound tests, in order of importance – As I will mention later, the first two are required for ACR accreditation.

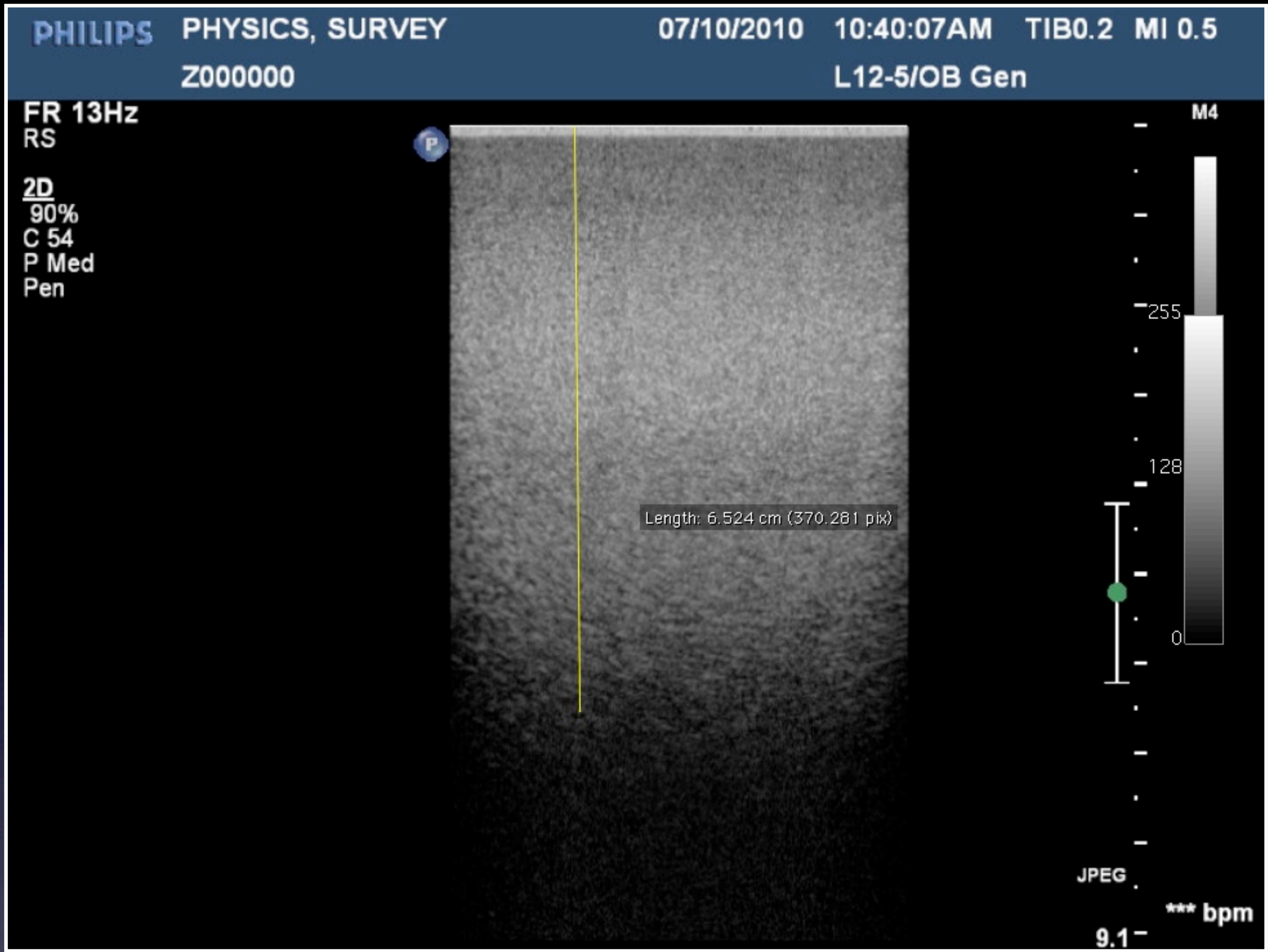
System Sensitivity

- How deep into the phantom can the instrument image? Affected by:
  - Signal to Noise ratio
  - Electronic interference and/or bad cables
  - improper instrument calibration/setup
  - Transducer acoustic coupling
    - piezo-element - matching layer(s) - body
  - Failure of components or boards of internal scanner components

System sensitivity is a measure of the ability of the instrument to detect a small signal (backscattered sound) against a noisy background. It can be affected by a number of issues that might increase noise or decrease the signal. Higher attenuation at high frequencies means that the depth of imaging for these transducers will be less.

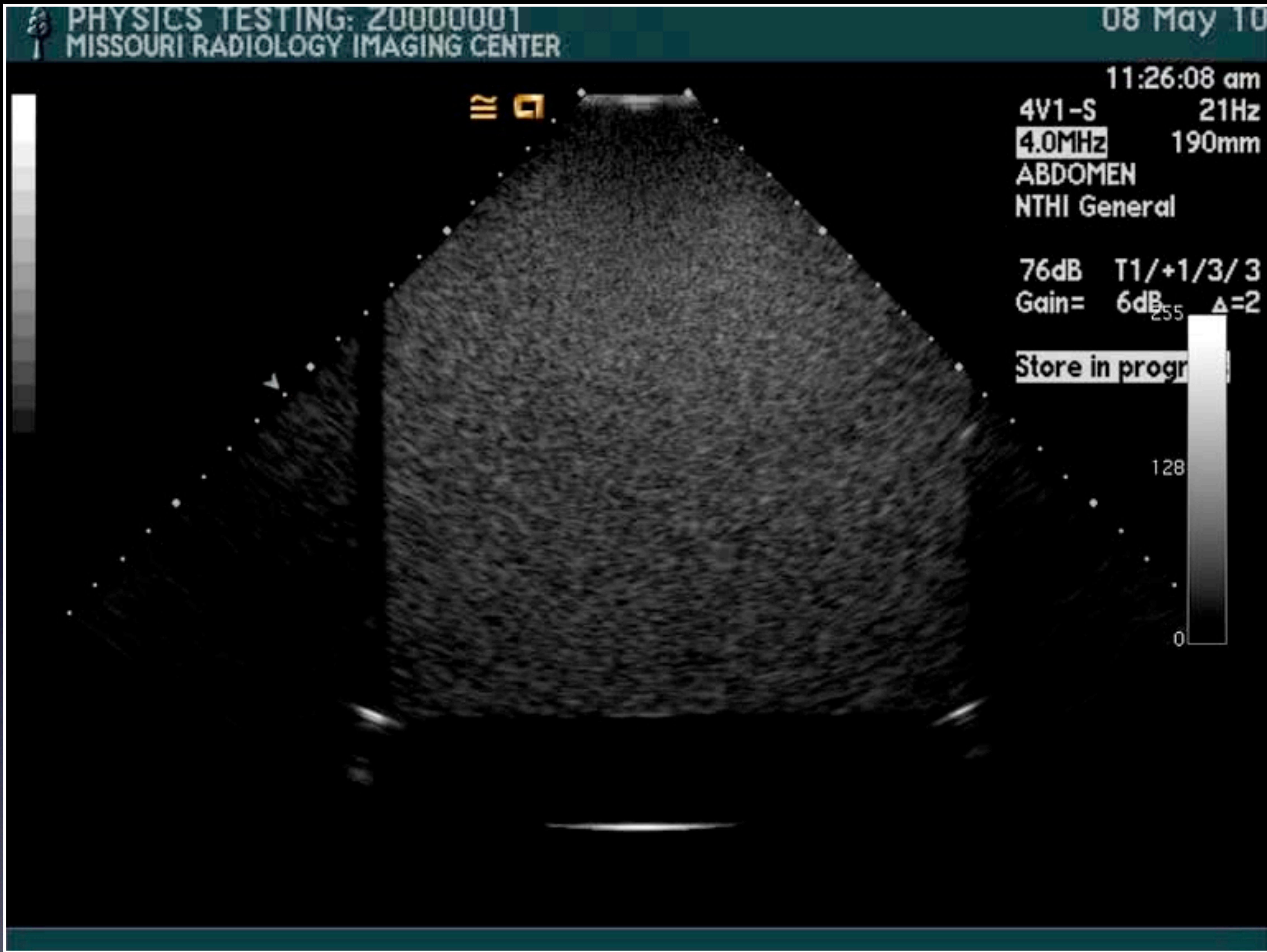
Speckle vs. E-noise

Movie illustrating the concept of speckle (with Tx still) and noise.



Maximum Depth of Penetration

Max Depth of penetration is the point in the image where the signal drops off to the point where it is not visualized against the noise in the image. Remember that in ultrasound the signal is contained within "speckle". This is better appreciated in a real-time image with the transducer held still. The speckle motion correlates with the movement of the transducer - the electronic noise continues to be seen.

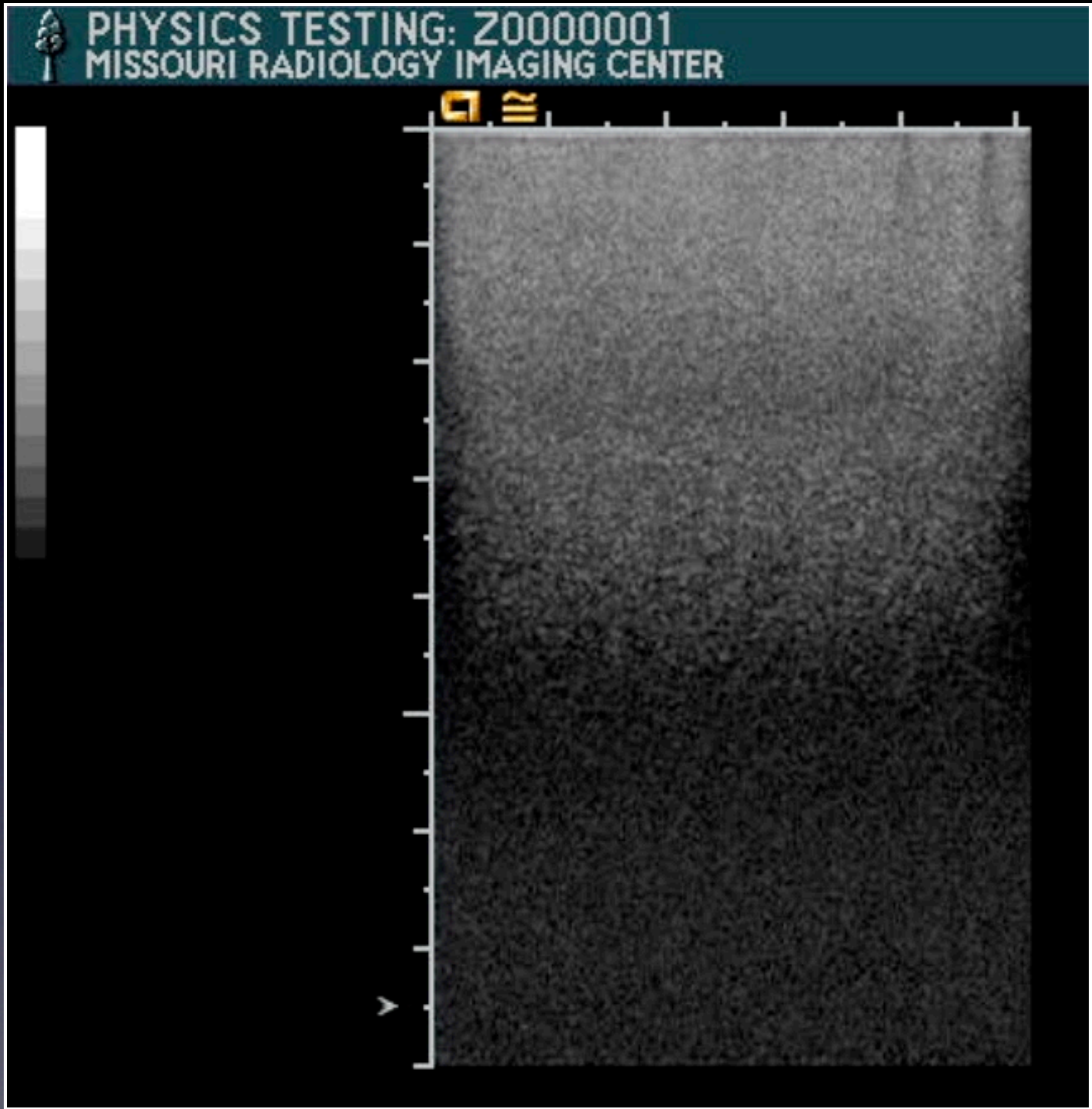


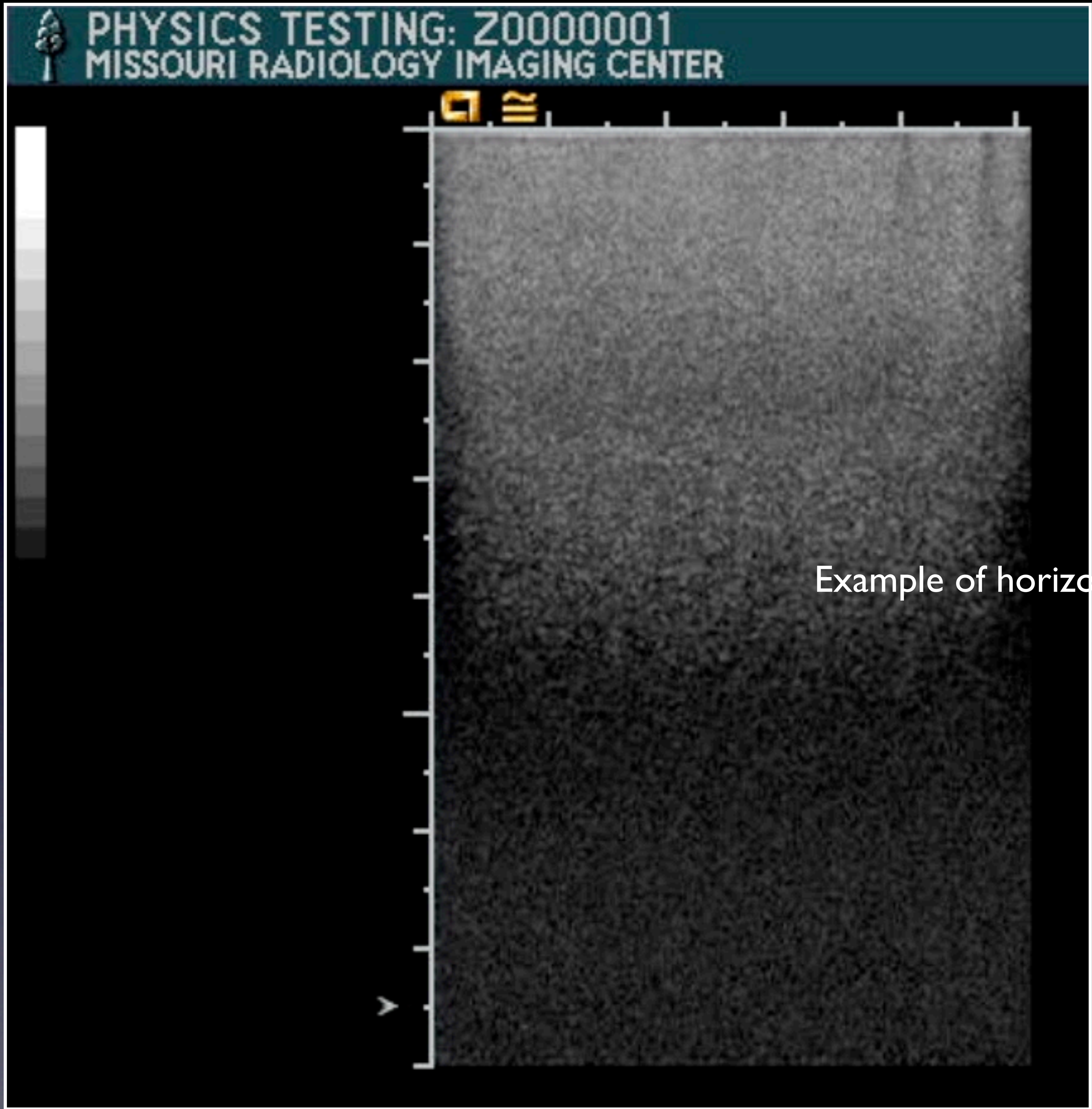
All the way to the bottom!

Uniformity

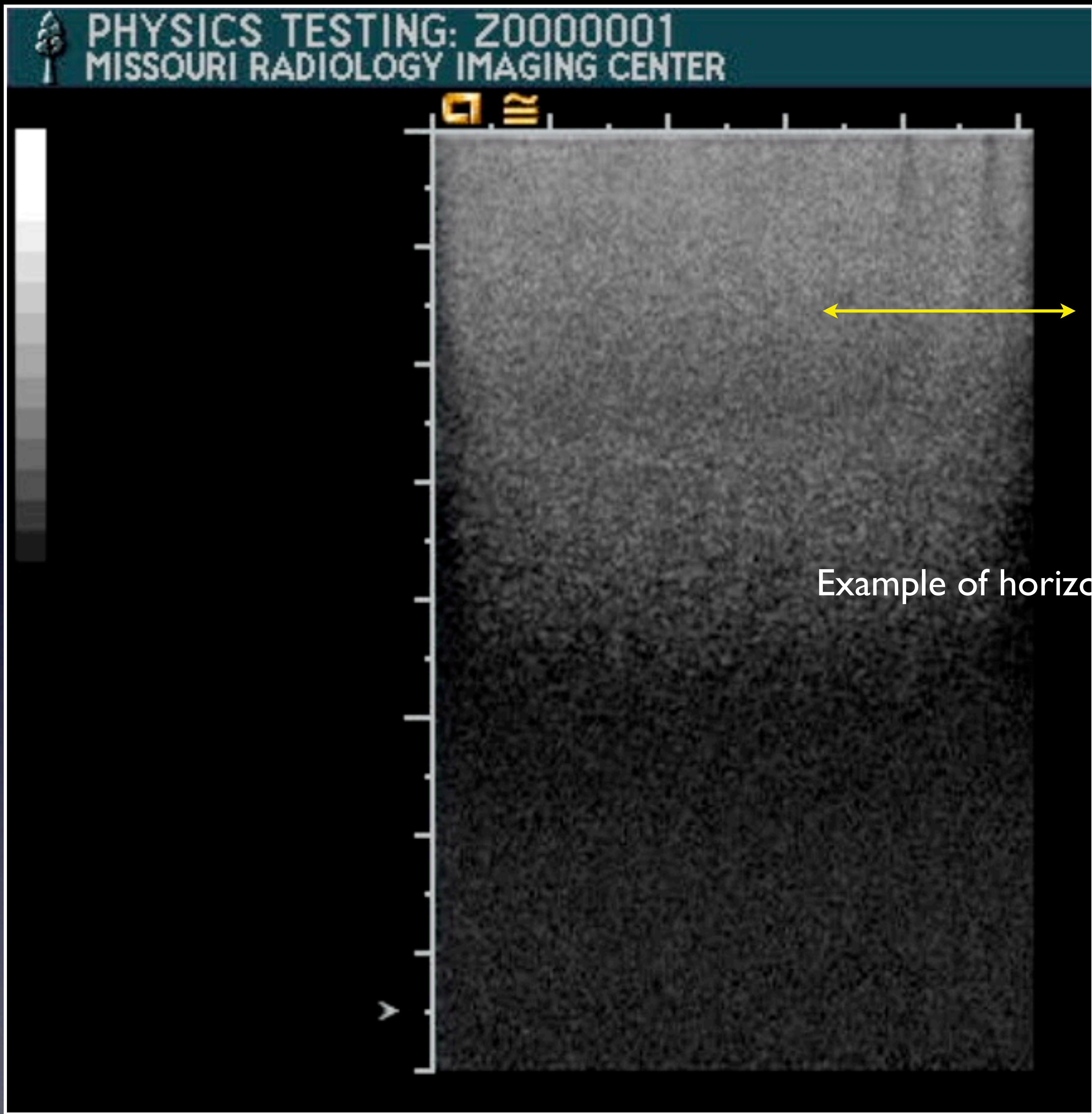
- Horizontal Uniformity
  - Individual element viability
  - decoupling of matching layers and elements
  - a non-uniformity noticeable on phantom may not be noticeable by clinical users
    - seek to replicate with a clinical case and consult image interpreters to ascertain seriousness of the non-uniformity
- Vertical Uniformity
  - Time gain compensation
  - Combining multiple focus depth
  - if it exists, it usually can be resolved by adjustment - if it cannot be resolved, seek service immediately.

Uniformity is judged based on the appearance of the brightness of a plain image. The image can be describe as being uniform across the horizon (parallel to the transducer face). Horizontal uniformity may be affected by a number of issues concerning the ultrasound system. Vertical uniformity is not natural in ultrasound due to attenuation. Time-Gain compensation is used to create a uniform image over a range of depths. A system should be able to create a uniform image vertically using TGC. Most systems use some range of focus depths or multiple focus depths and then “stitch” images together. A nominally operating system should be able to generate a uniform image with depth.


PHYSICS TESTING: Z0000001
MISSOURI RADIOLOGY IMAGING CENTER



Example of horizontal non-Uniformity



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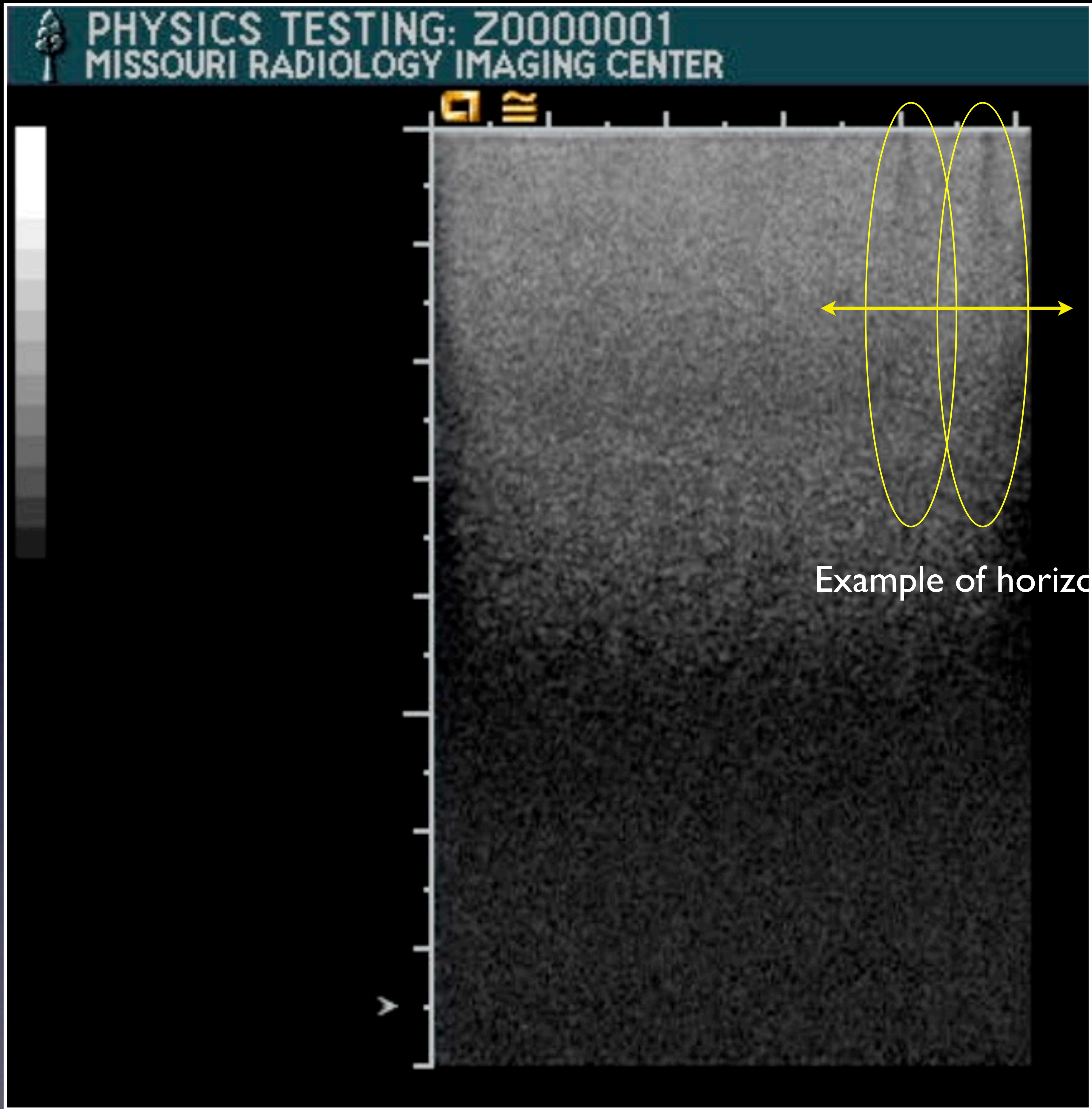

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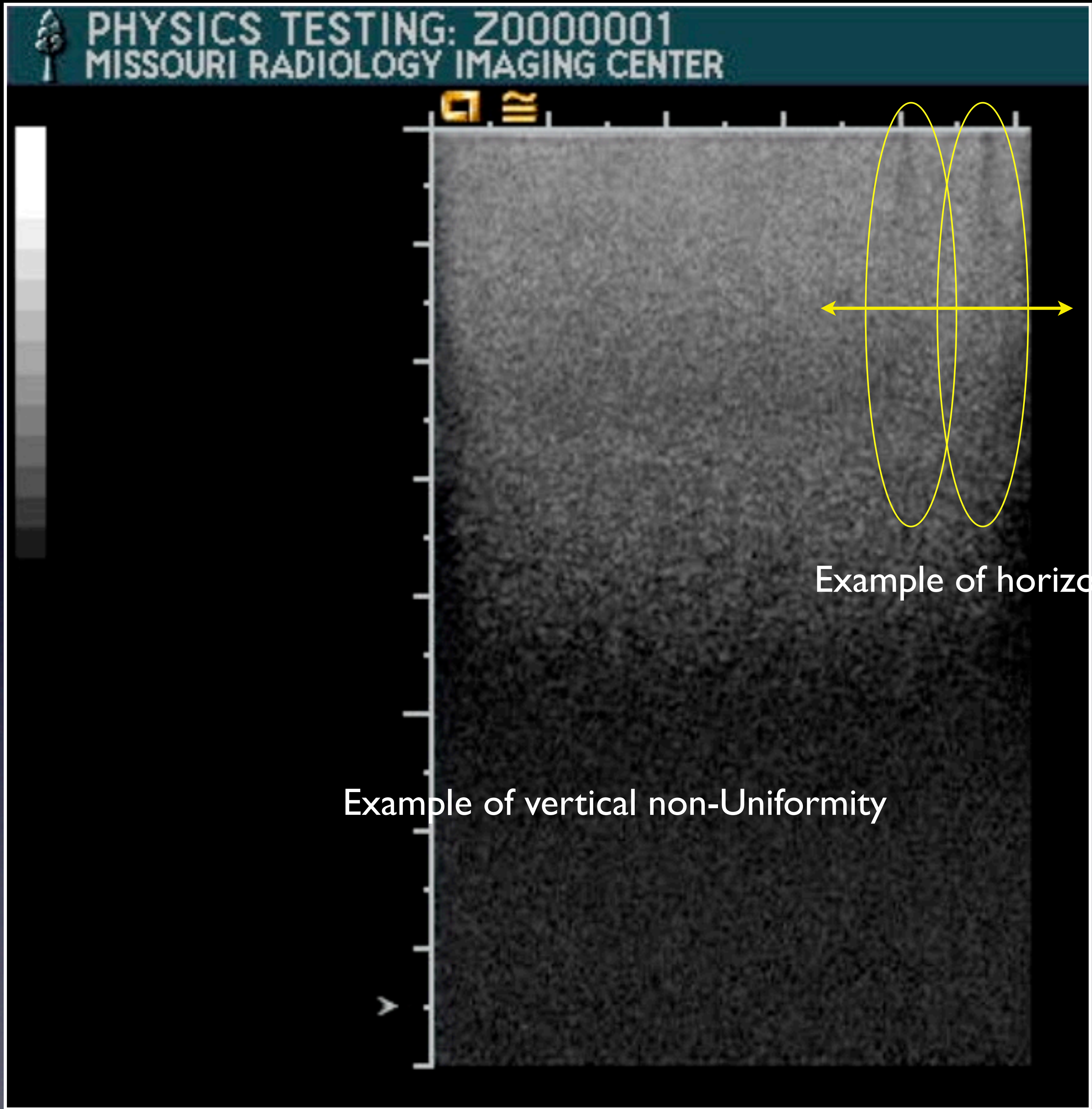
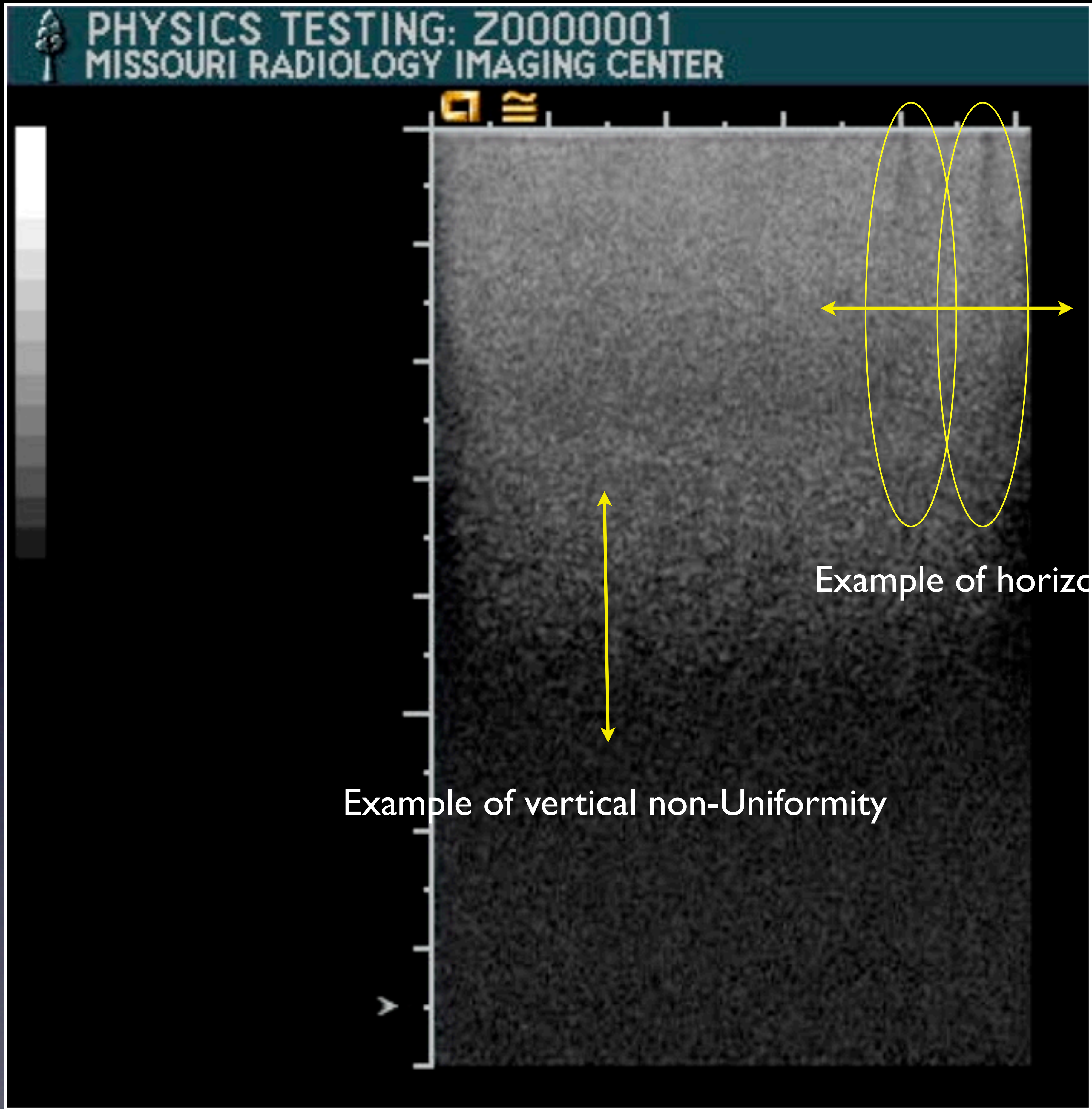


Example of horizontal non-Uniformity

Example of vertical non-Uniformity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Example of horizontal non-Uniformity
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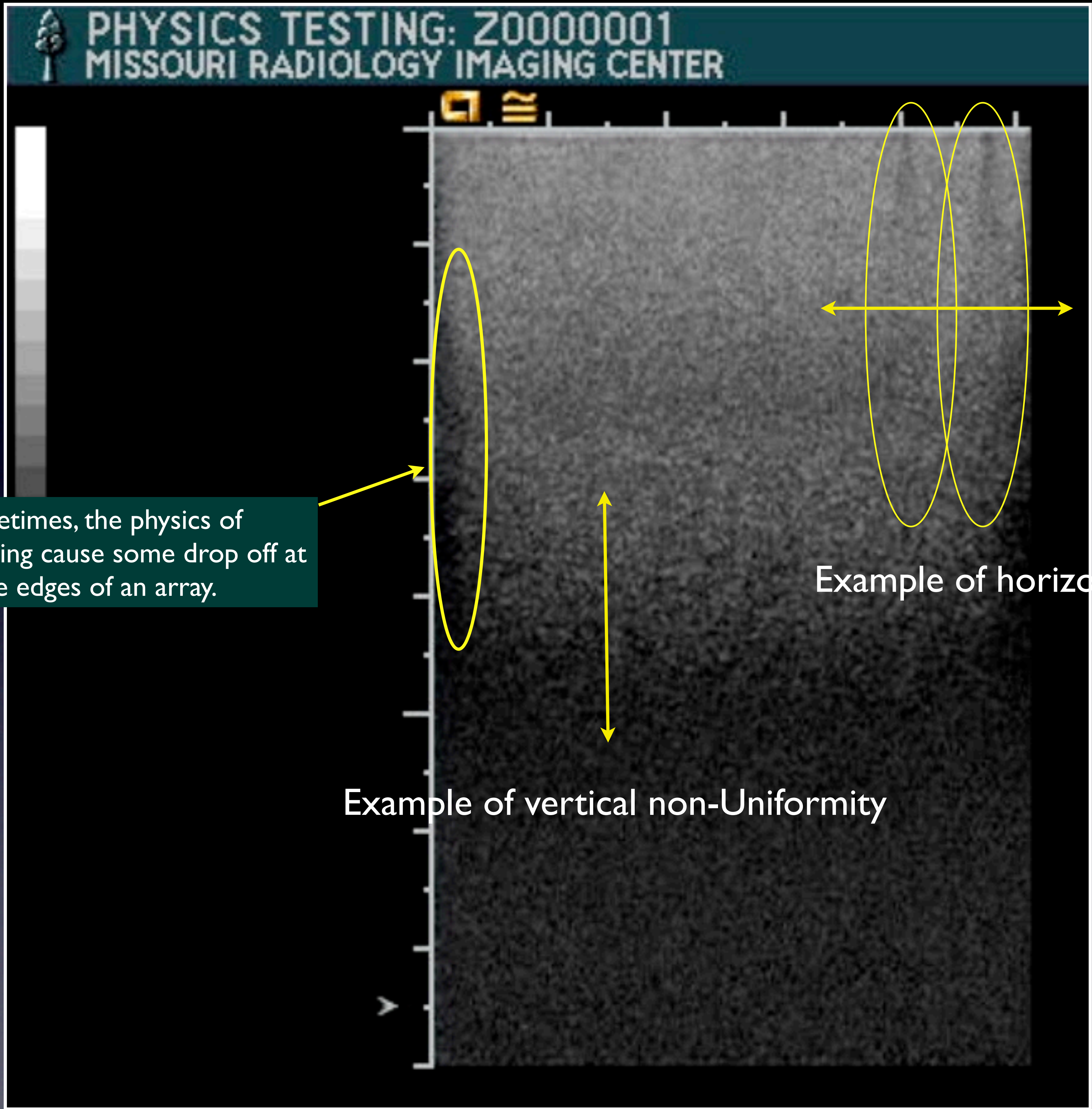
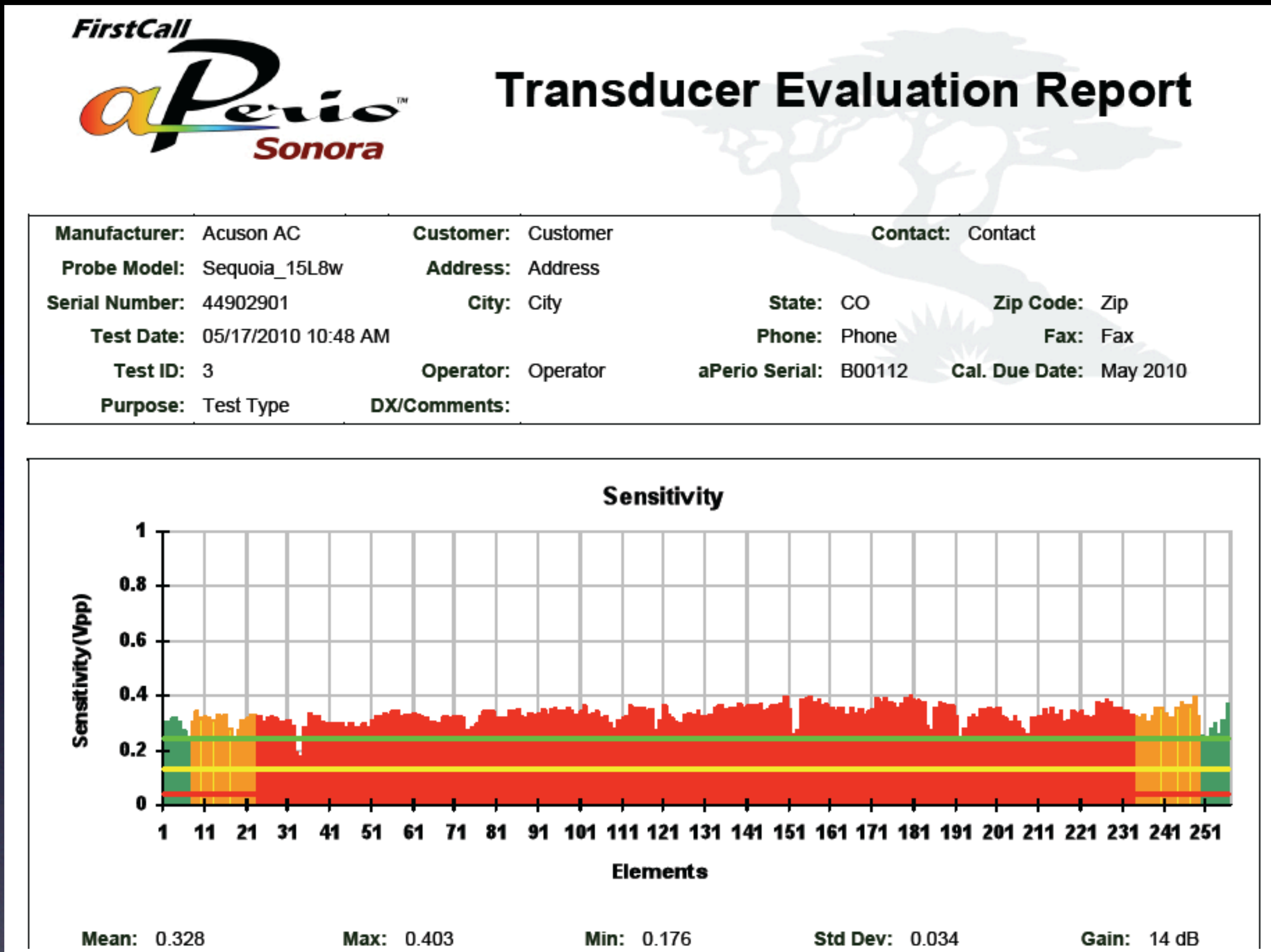


Sometimes, the physics of beamforming cause some drop off at the edges of an array.

Example of horizontal non-Uniformity

Example of vertical non-Uniformity


FirstCall aPerio Sonora

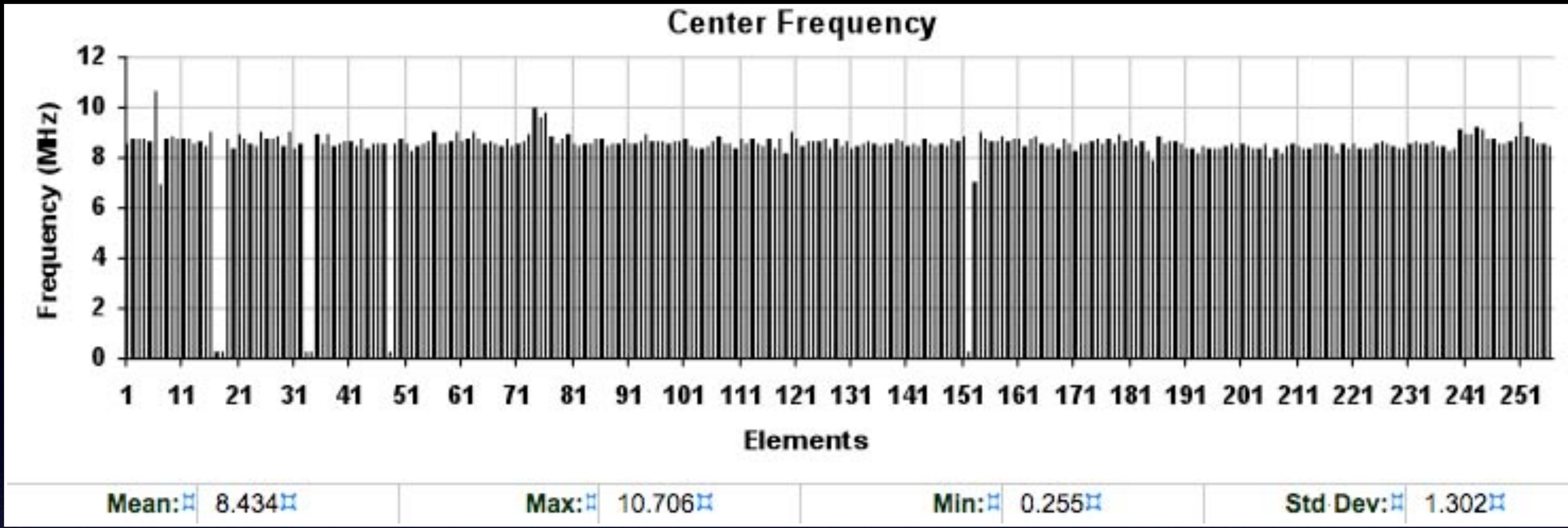
Transducer Evaluation Report

Manufacturer:	Acuson AC	Customer:	Customer	Contact:	Contact
Probe Model:	Sequoia_15L8w	Address:	Address		
Serial Number:	44902901	City:	City	State: CO	Zip Code: Zip
Test Date:	05/17/2010 10:48 AM			Phone: Phone	Fax: Fax
Test ID:	3	Operator:	Operator	aPerio Serial: B00112	Cal. Due Date: May 2010
Purpose:	Test Type	DX/Comments:			

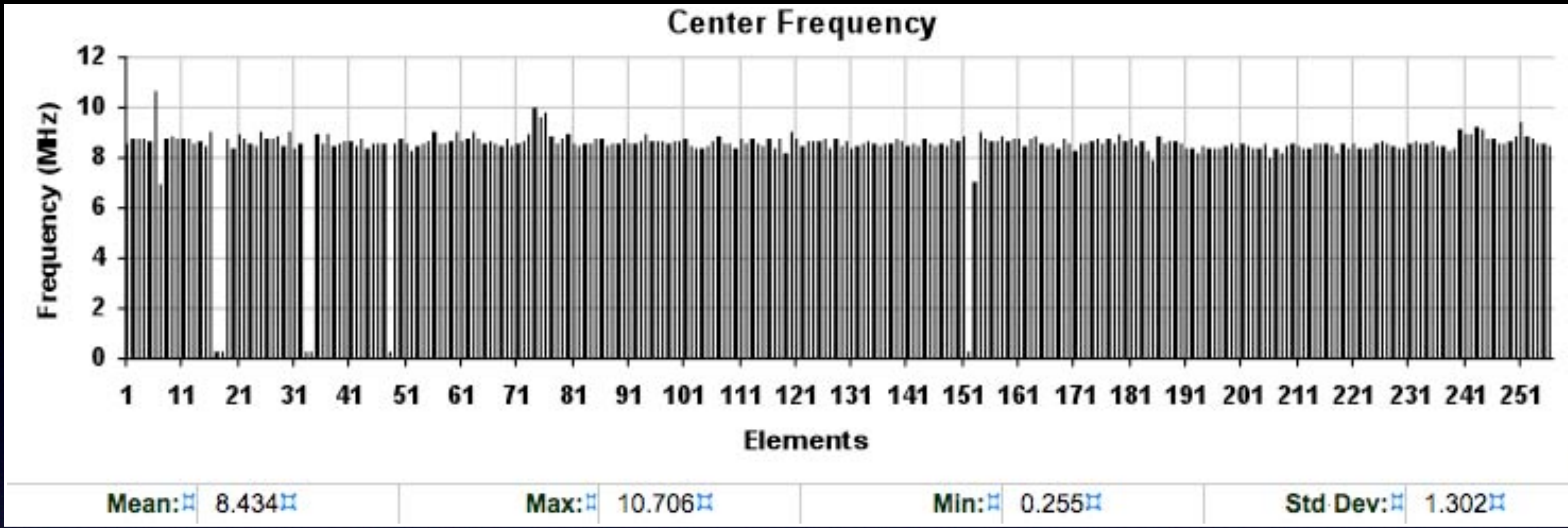
Mean: 0.328 Max: 0.403 Min: 0.176 Std Dev: 0.034 Gain: 14 dB

Probe testing device results

If transducer problems are uncovered, it is possible to investigate each element of the probe. This is the sensitivity test for the probe in the previous slide. It looks as if the sensitivity is uniform.



However, looking at the center frequency of the response from the transducer, we see that there are two groups of elements that are not working properly - center frequency < 1 MHz for elements 15-18 and 33-36.



Signal dropout corresponds to lost elements
(image reversed to show correlation to element dropout)

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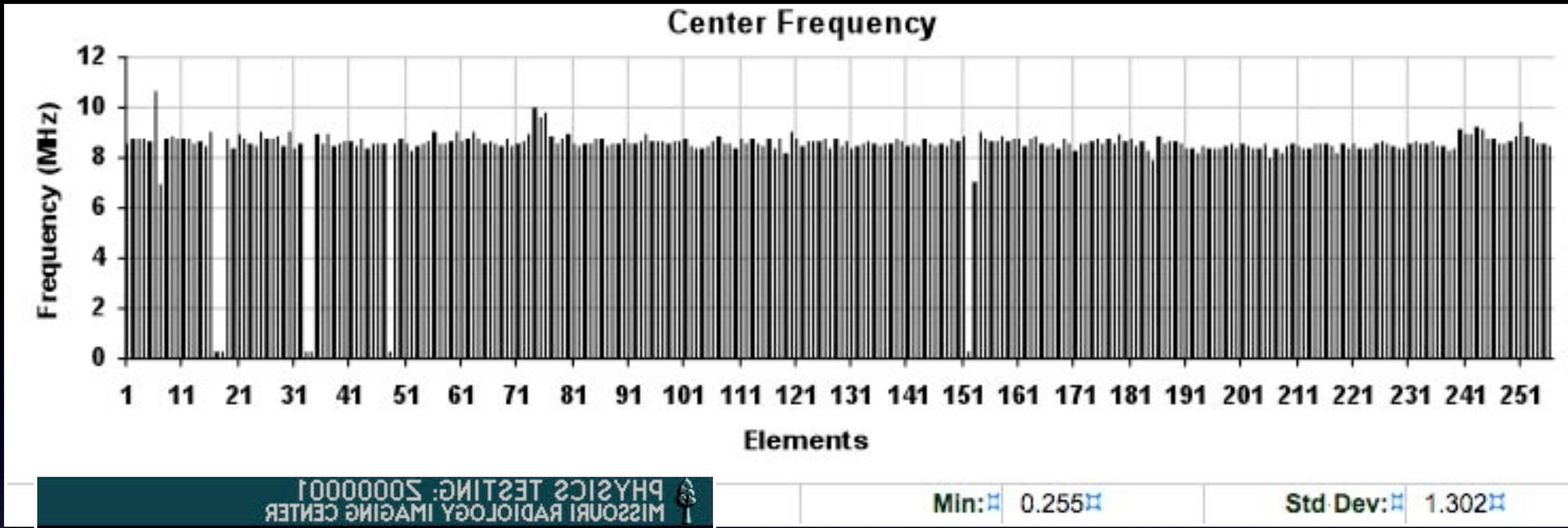

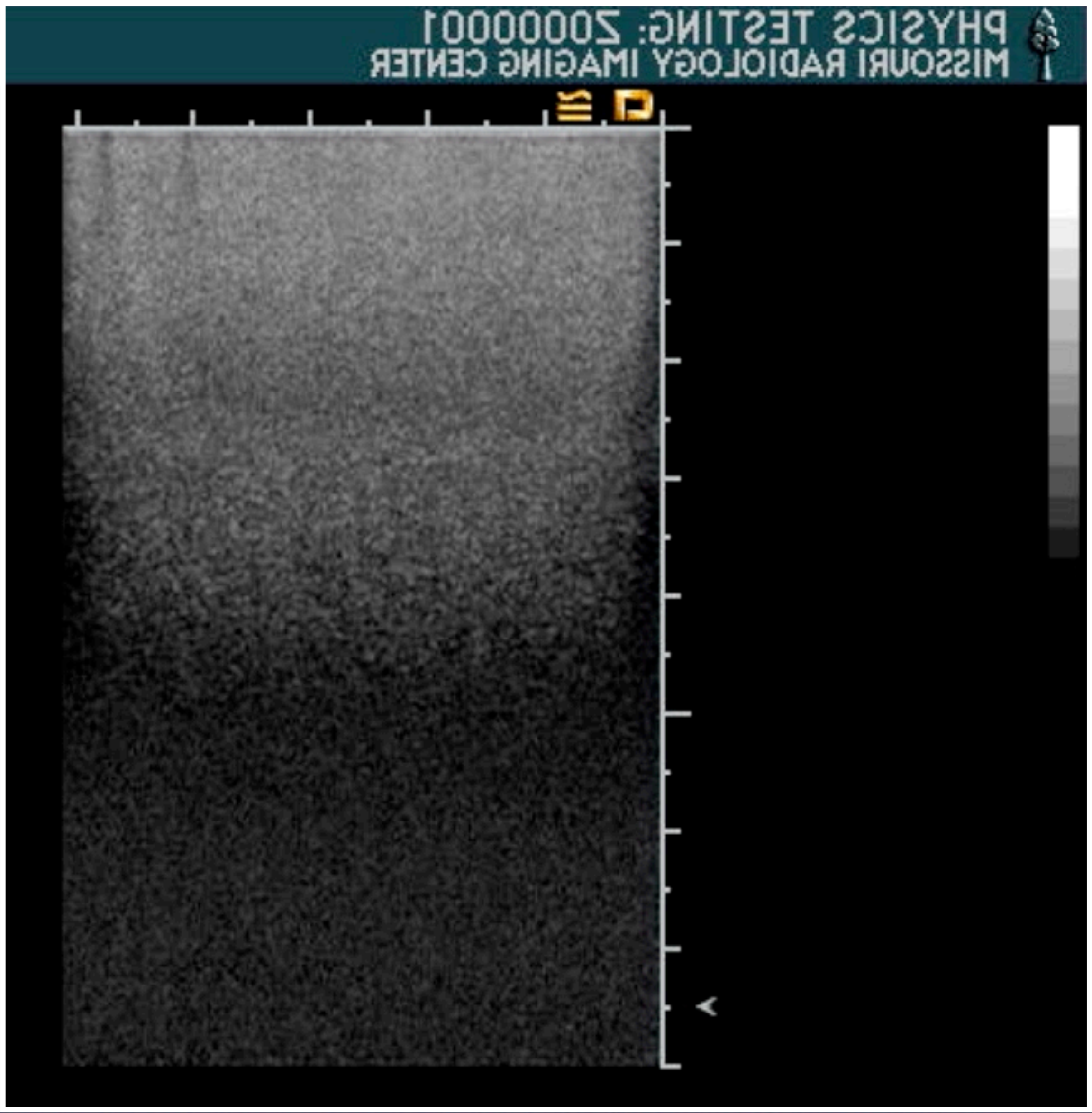

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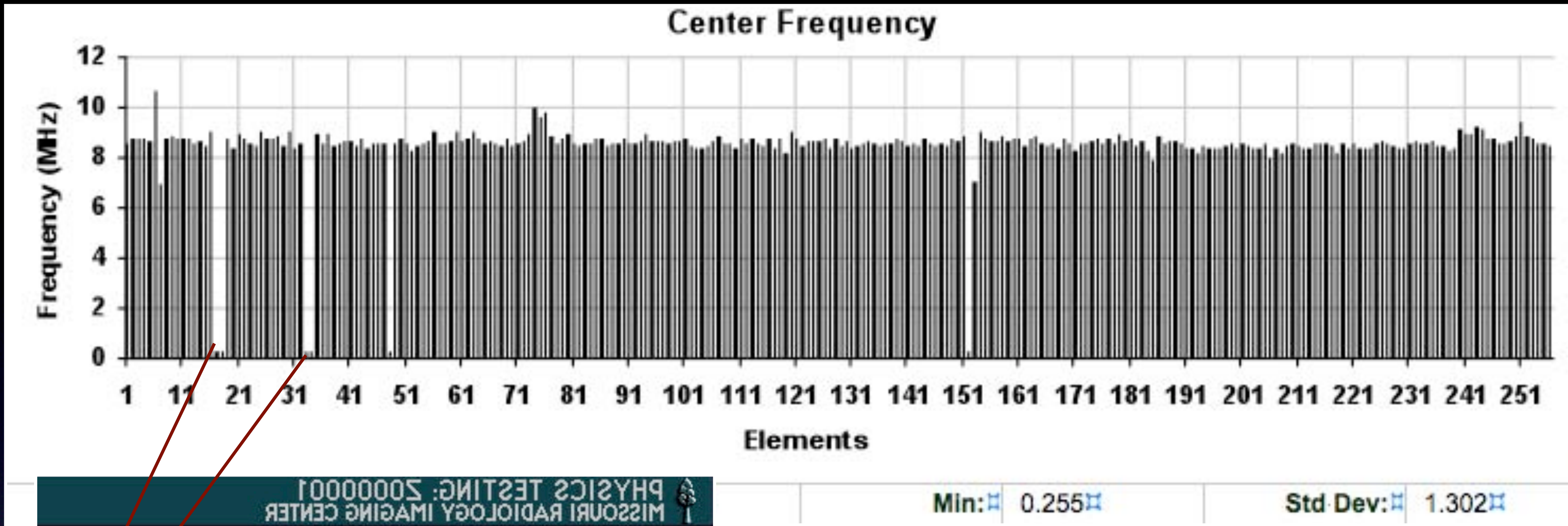

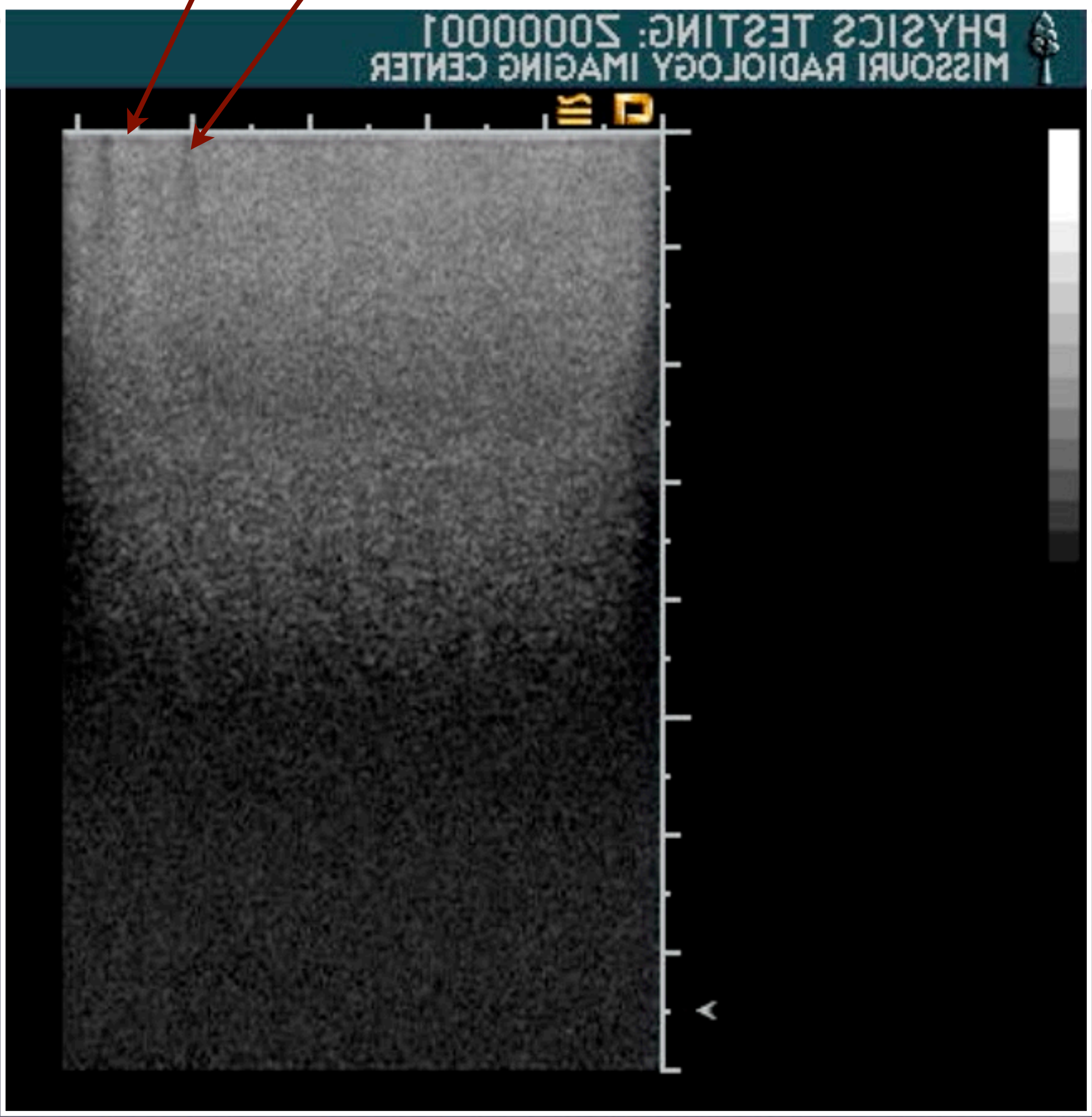

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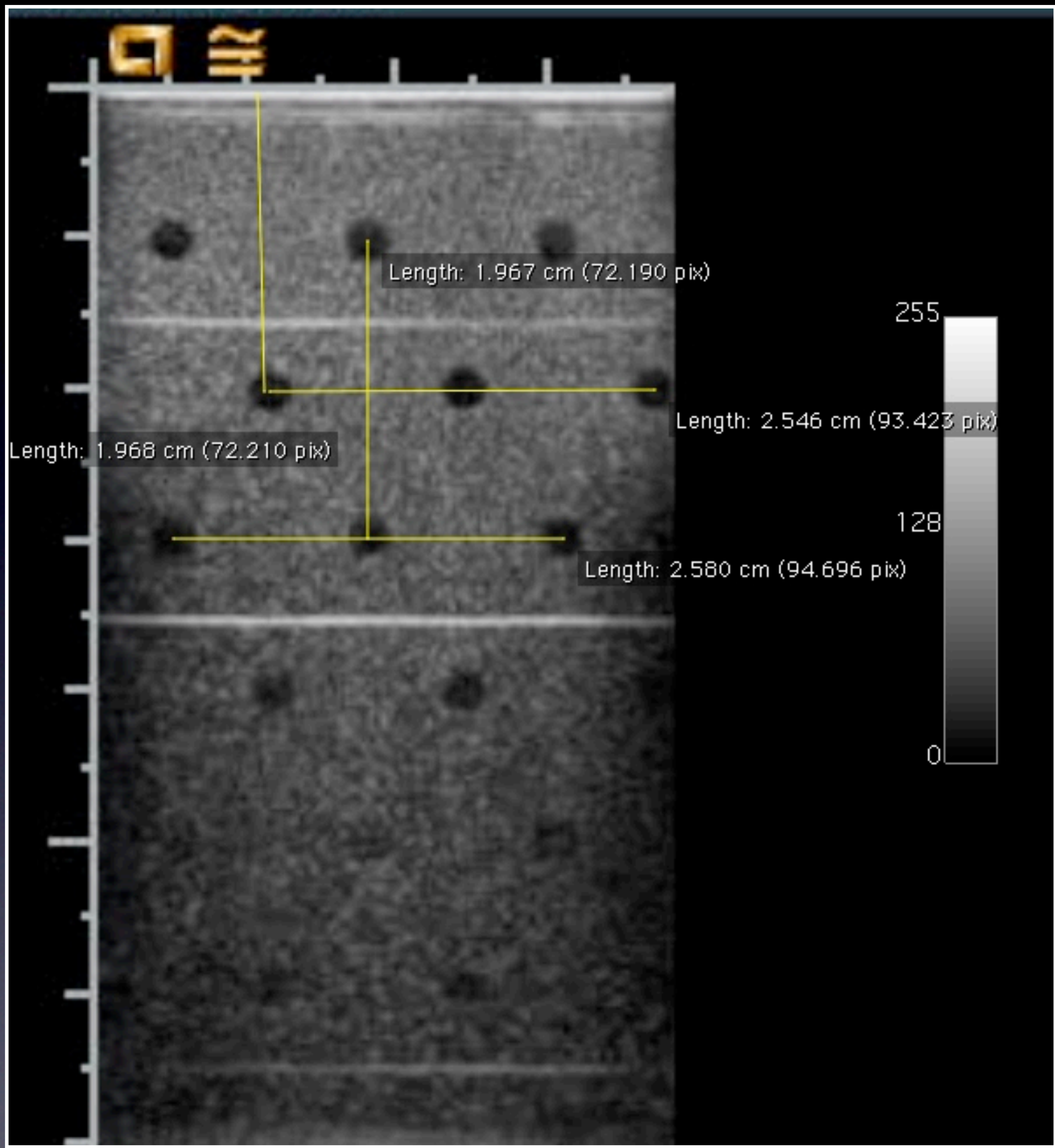
Spatial Accuracy

- Distance Measurements against known objects
- Vertical
  - Less prone to drift with digital equipment
- Horizontal
  - Distortion may cause errors
- Area and volume measurements
- Treatment planning

Spatial accuracy has long been a part of QC tests. The distance calipers are used to generate quantitative (size) data from clinical studies and should be evaluated to assure that this accuracy is within ±2 mm of expected distance.



Distance Measurements

Distance measurements can be taken across the phantom horizontally and with depth vertically. Both should be confirmed. One can avoid errors resulting from problems at the skin surface by doing vertical measurements between objects embedded within the phantom.

Contrast/Spatial Resolution

Contrast and spatial resolution are important, but can be difficult to evaluate with ultrasound. Speckle noise makes contrast resolution difficult to define, hence it becomes a subjective ("can I see it?") evaluation. Spatial resolution in US is a 3D problem.

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- Spatial resolution
  - Transducer (Frequency) dependent!
  - Depth dependent!
  - specify at a frequency and depth in a phantom
  - US resolution is really a 3D problem

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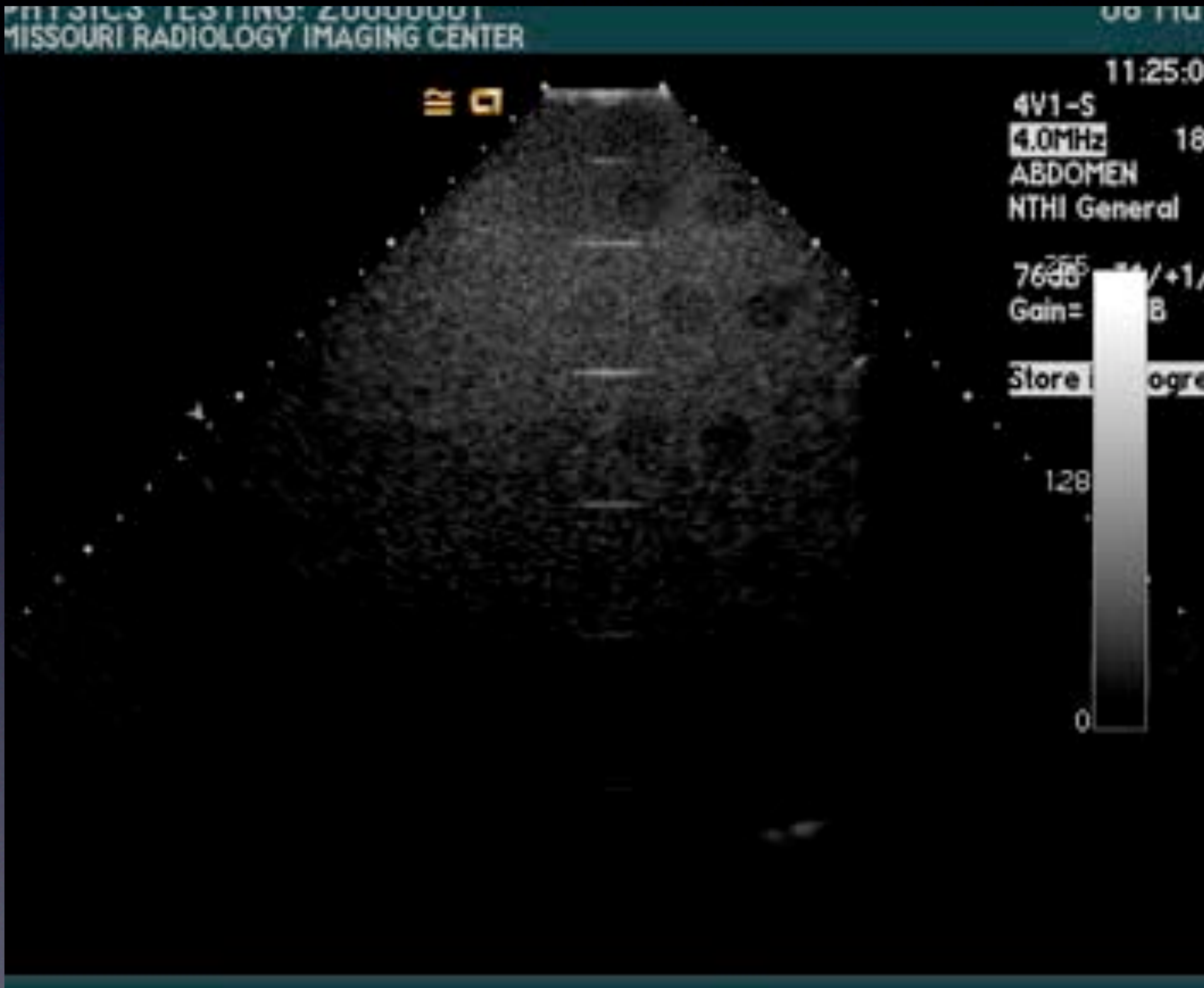
Contrast Resolution

Movie example showing 3 resolution rods in an phantom with decreasing scatter.

Contrast Resolution



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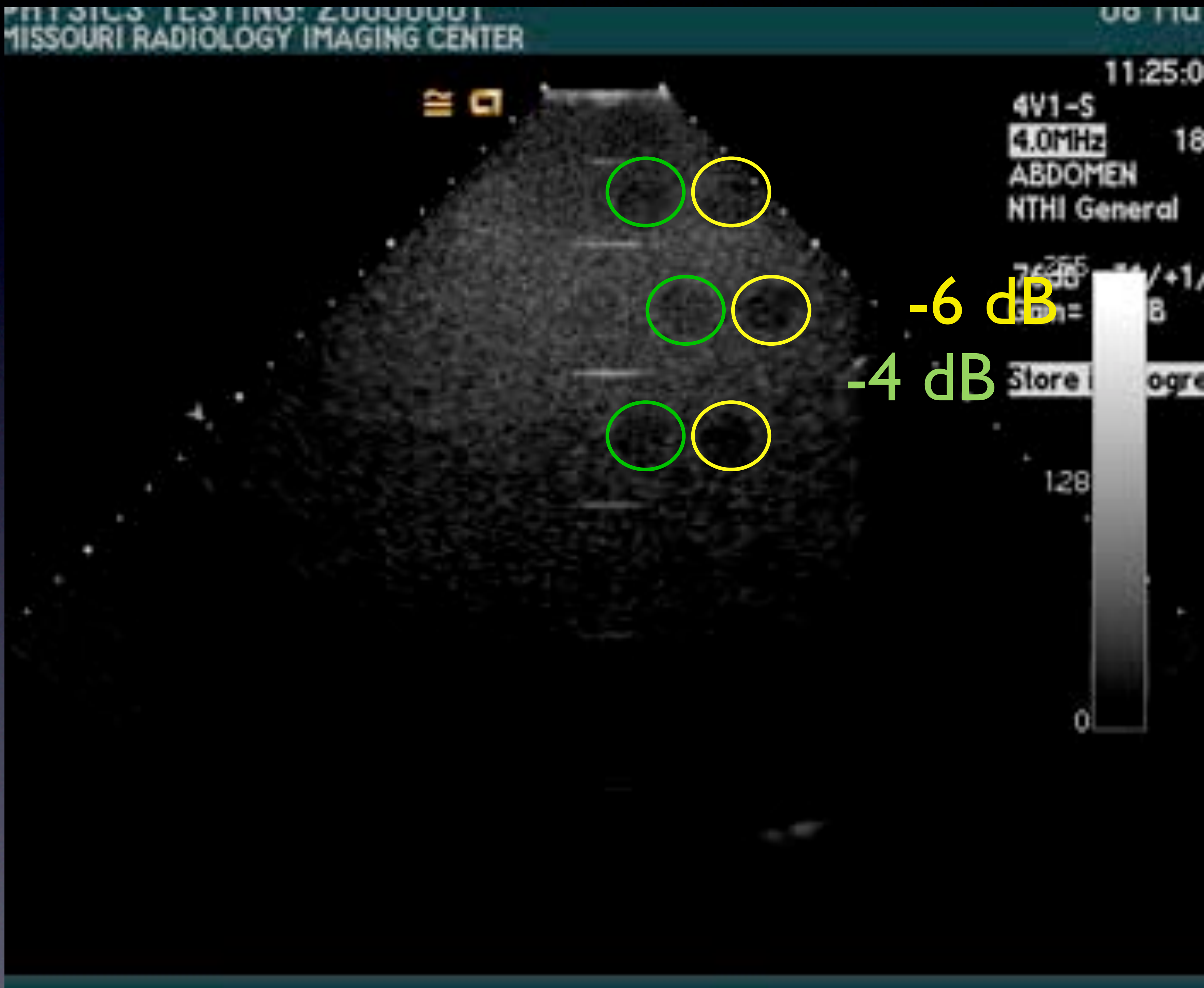

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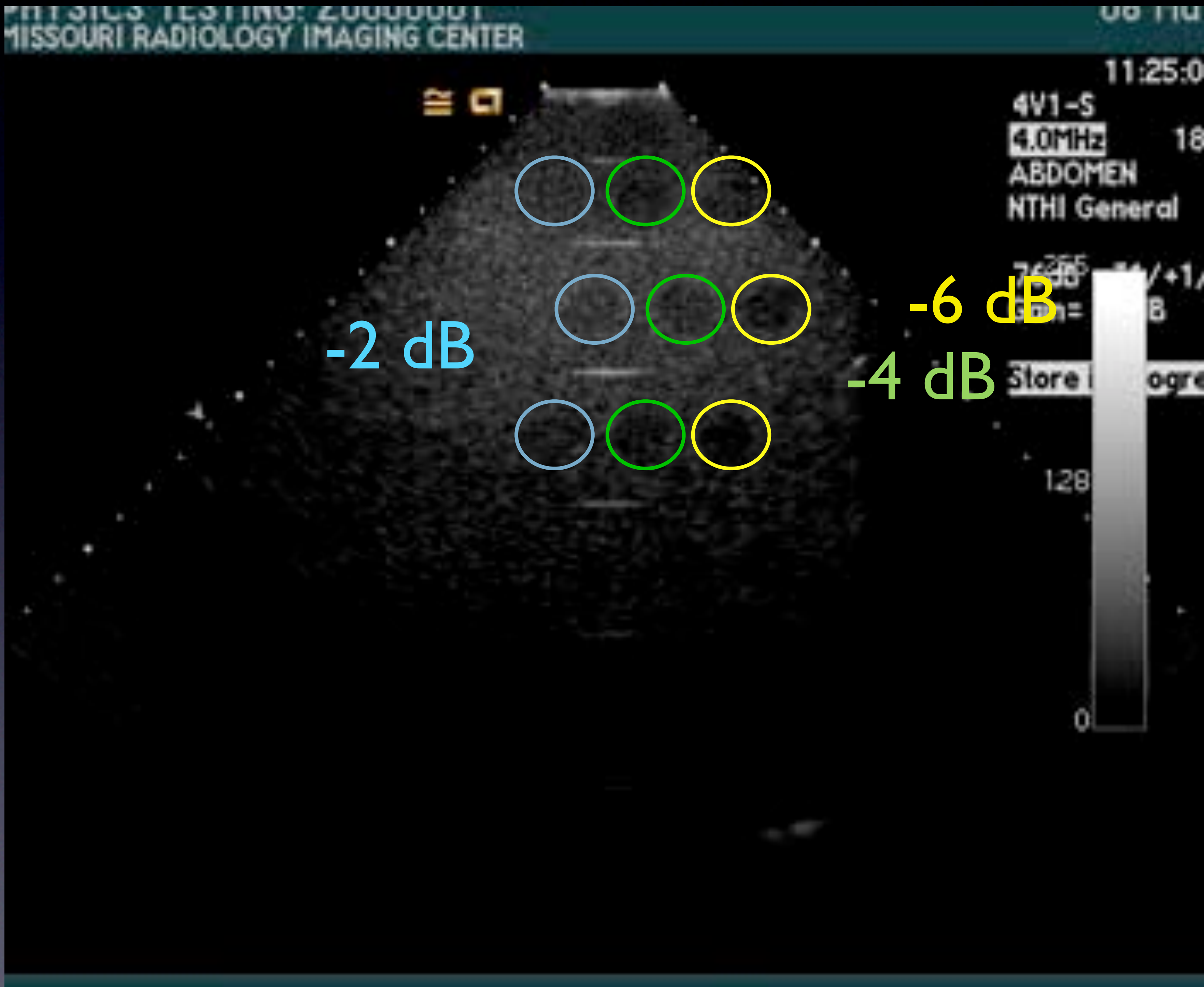

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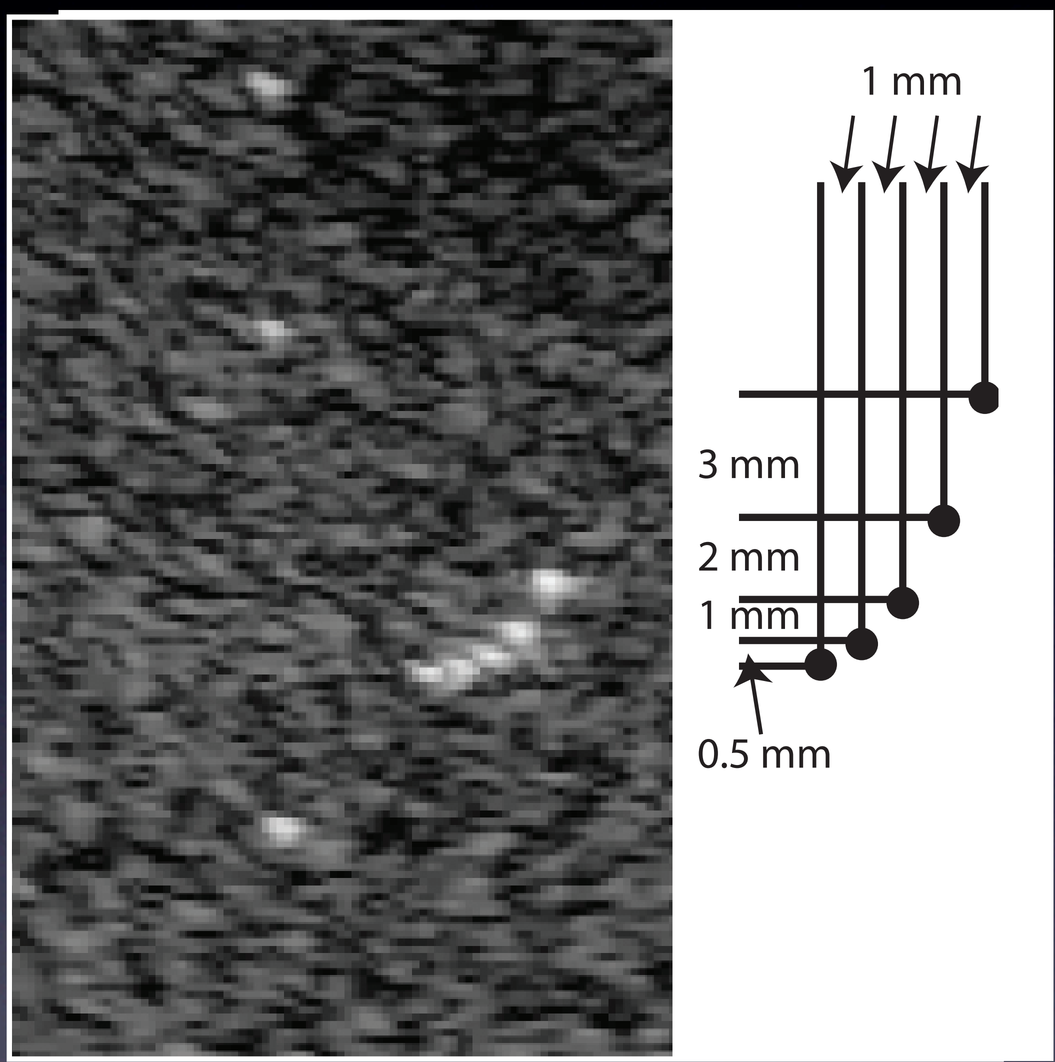
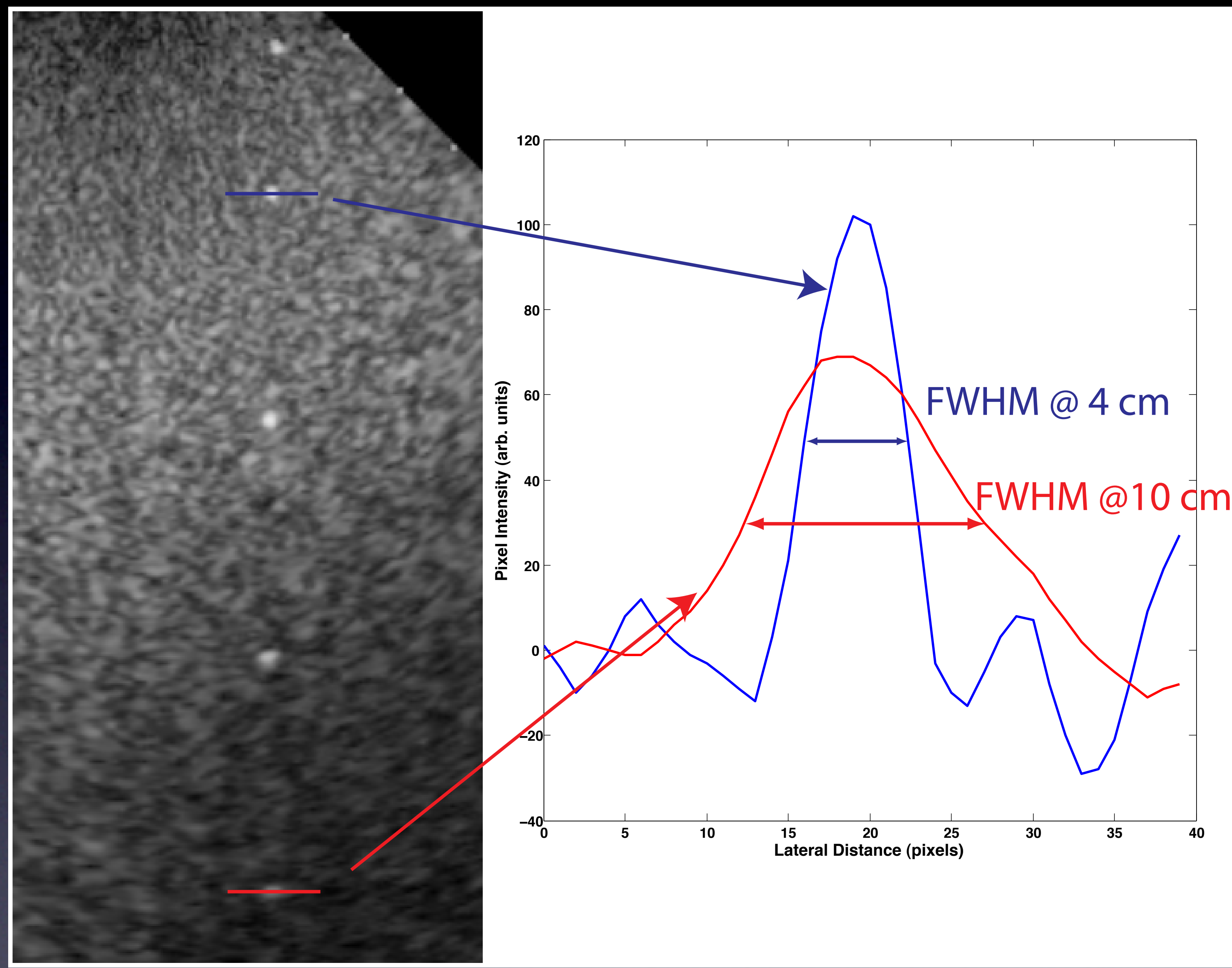


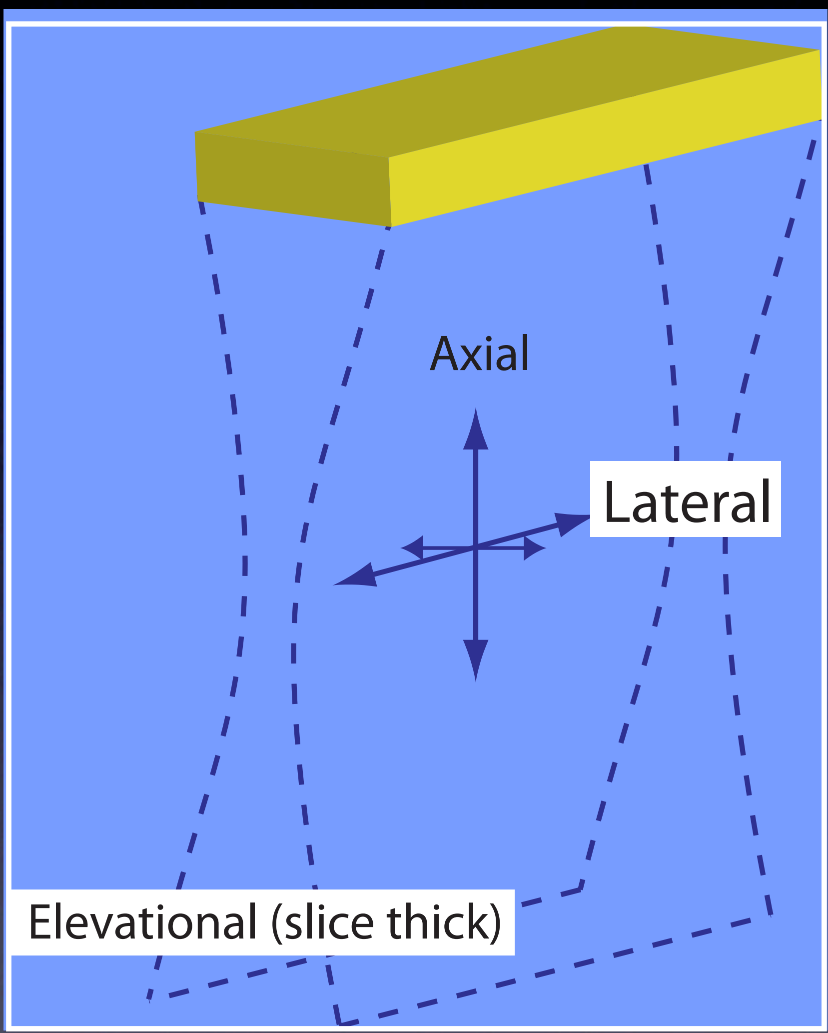
Qualitative

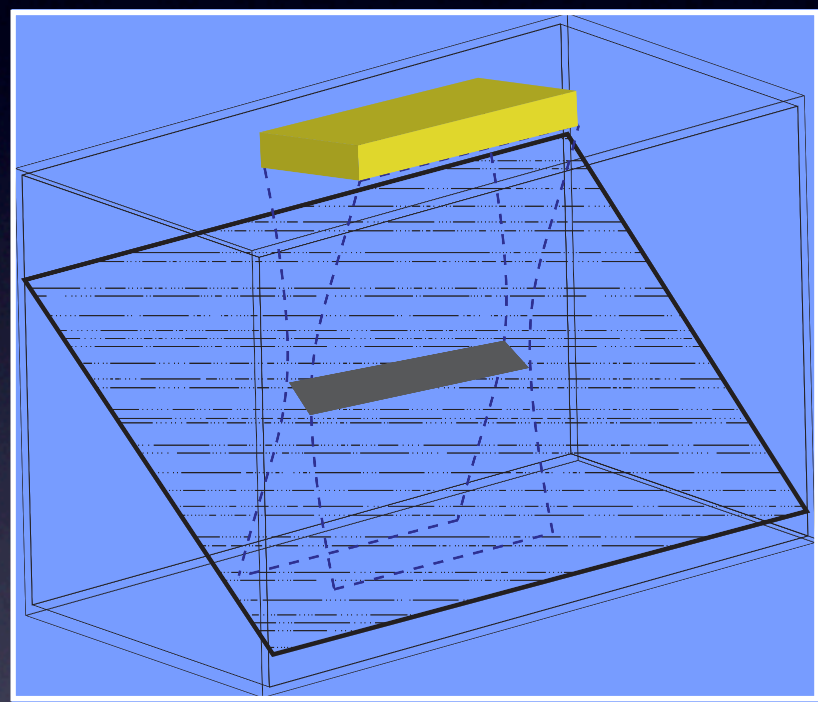


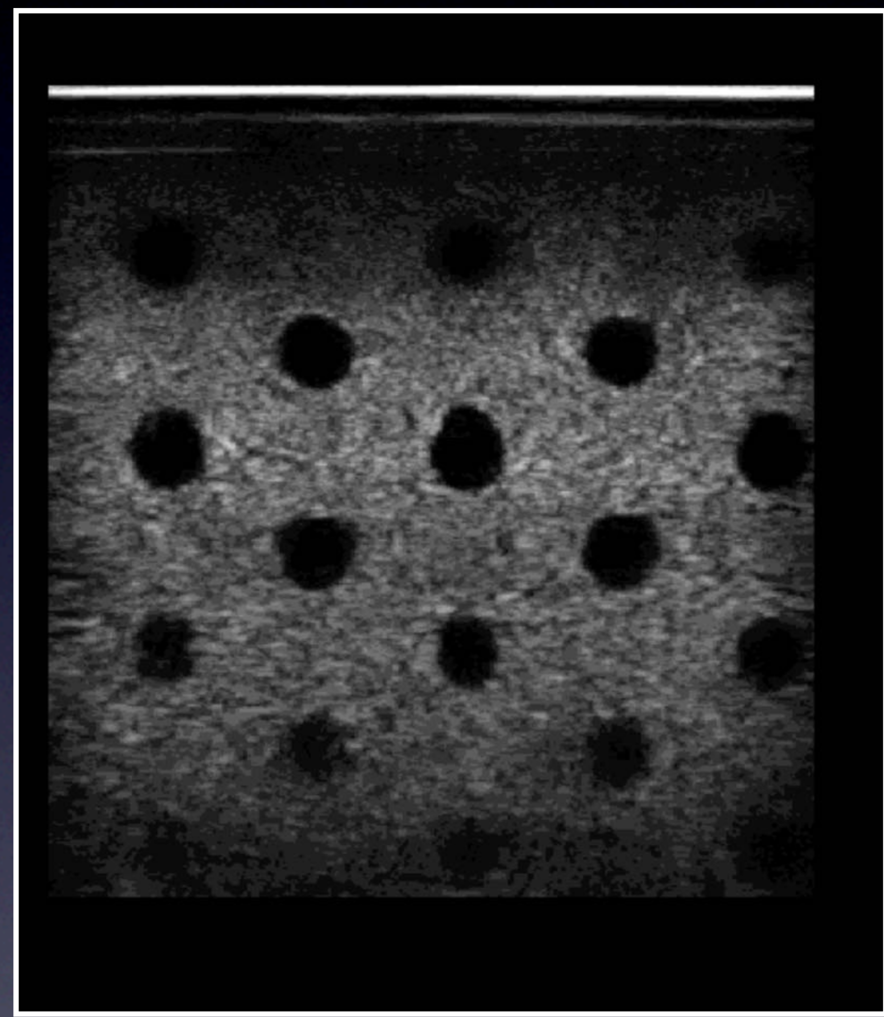
“semi”-Quantitative

Methods of spatial resolution measurement. Targets arranged together. Minimum spatial resolution is the smallest separation that can be seen on the image. Evaluation of spatial resolution might also be performed by using pixel data across a bright target, then plotting to determine FWHM. Both are affected by the gain and gray scale processing settings.

Spatial Resolution in ultrasound varies in three dimensions







Evaluation with a spherical void phantom

Ultrasound has resolution properties in 3 dimensions and the resolution properties change with depth. Methods of evaluating elevational thickness include a screen mesh phantom (center) or a spherical void phantom. For the latter, the range in which voids are most visible correspond to an elevational slice thickness that is less than the diameter of the void.

System effects on tests

Be careful doing QC tests - make sure the settings are the same each time.

System effects on tests

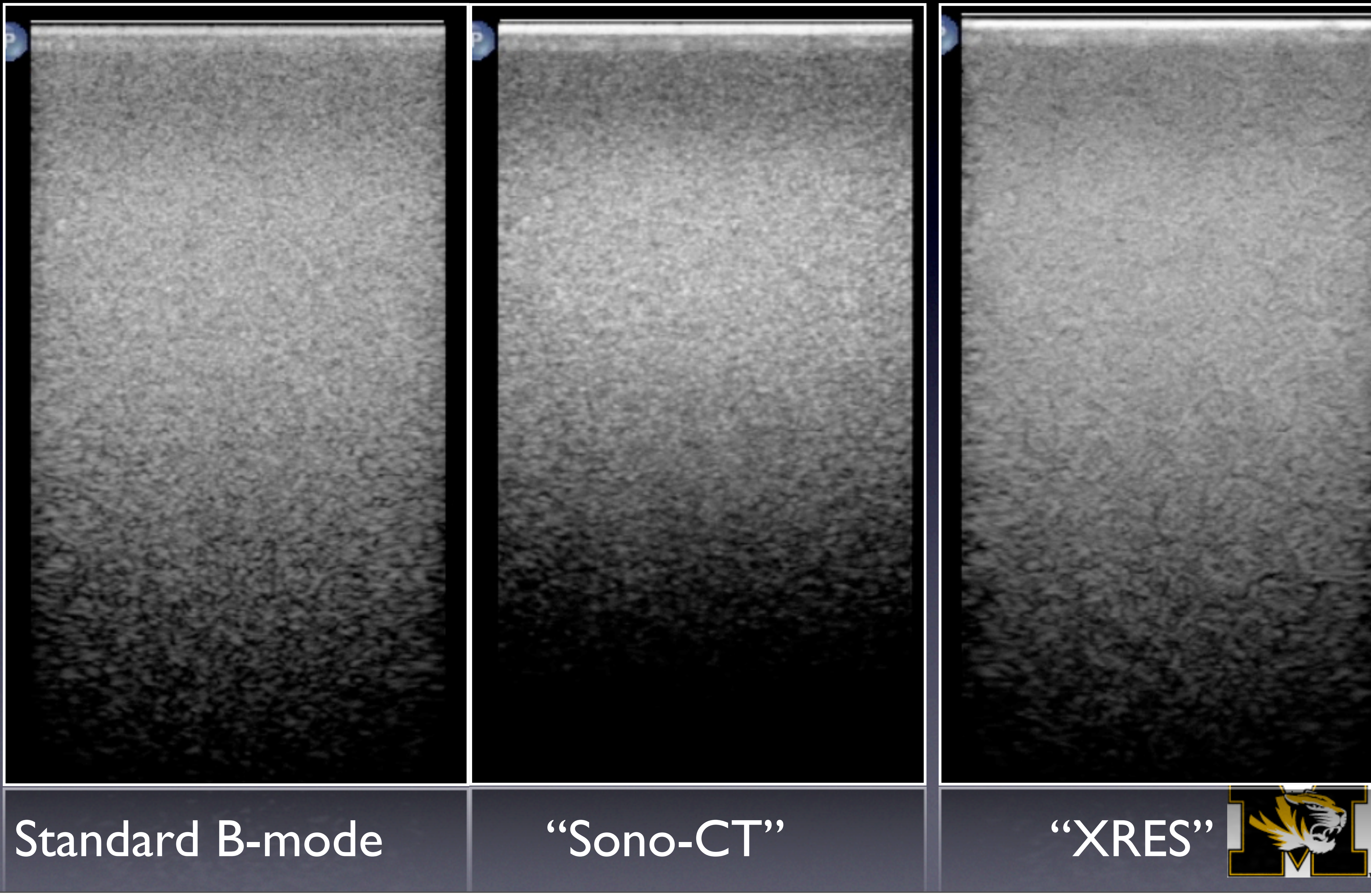
Rely upon experienced users to teach how various settings affect the image - or -

use a fixed, programmed and standard setting (e.g. "Carotid" in the upper right corner of this image

Be careful doing QC tests - make sure the settings are the same each time.

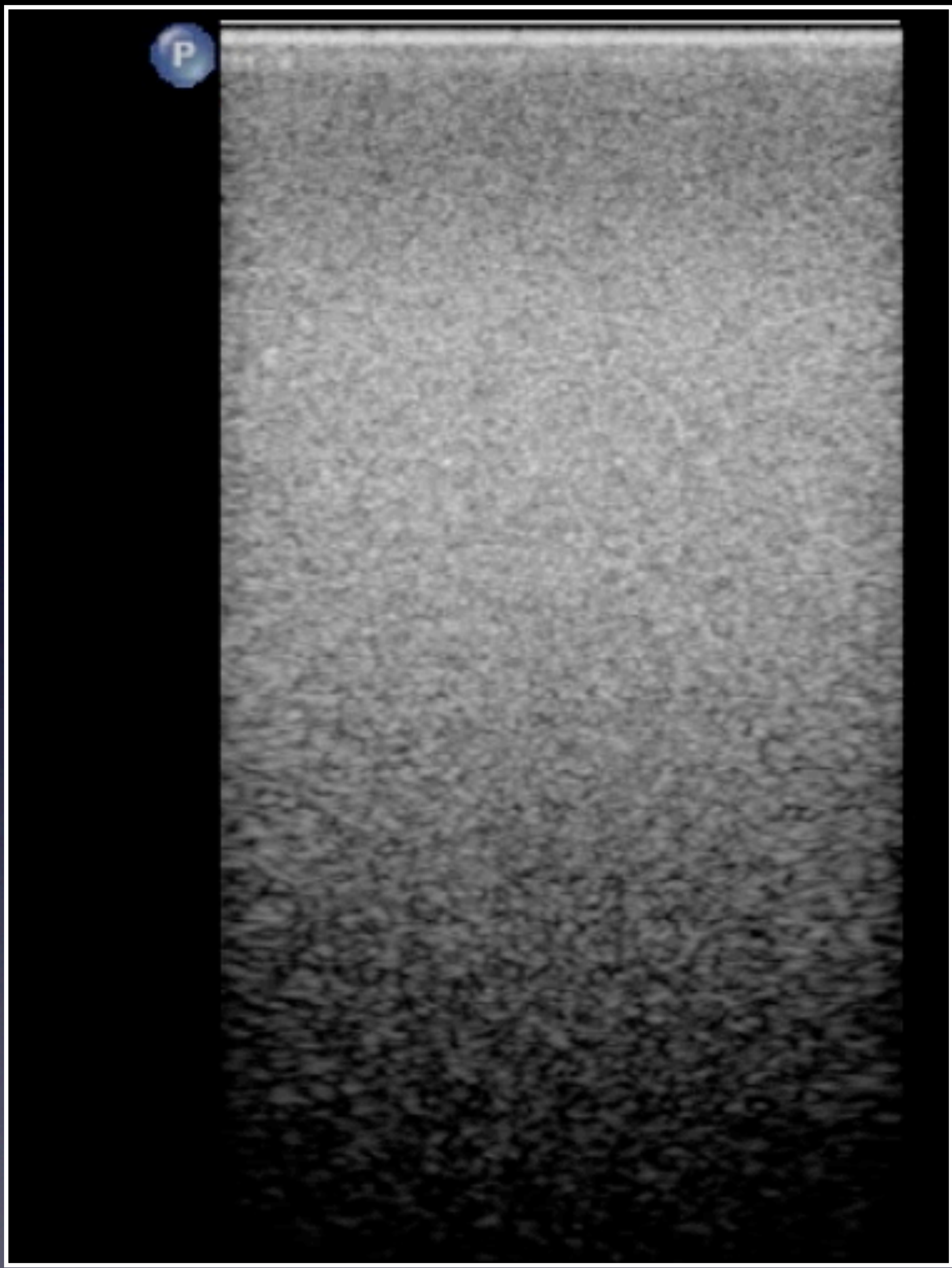
Imaging Settings

Same phantom - same transducer - one switch change



These are three separate settings for one type of scanner. The transducer was not moved nor changed. Only the “imaging mode”.

Normal B-mode versus Harmonic signal imaging



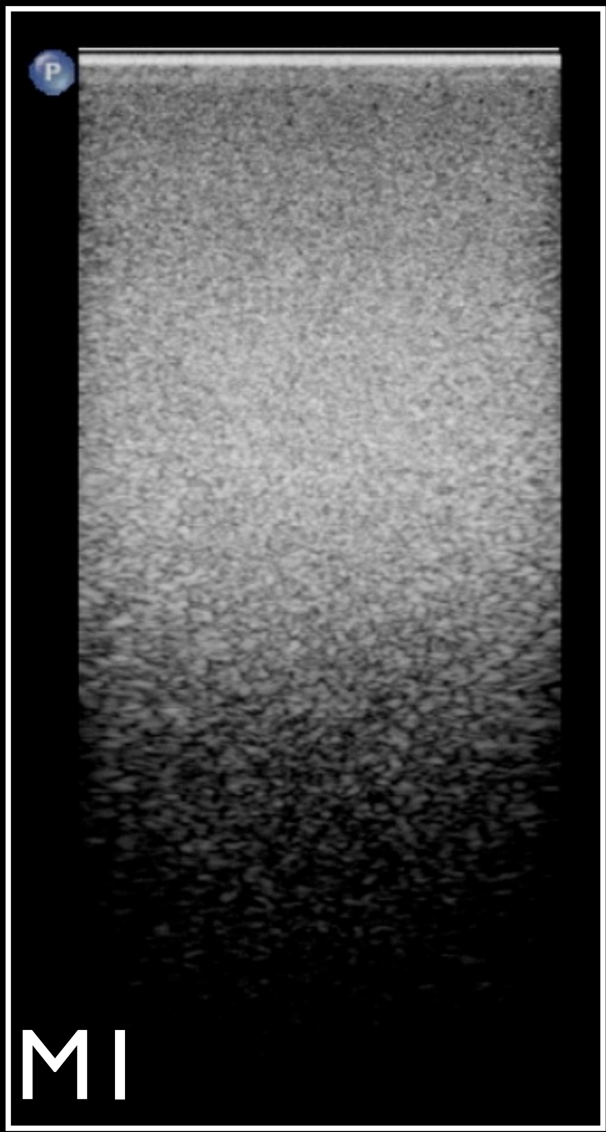
Harmonic imaging is another possible mode. Again, the same transducer has not been moved.

Gray Scale

M1

Post-processing of the gray scale - five possible settings on this particular scanner.

Gray Scale



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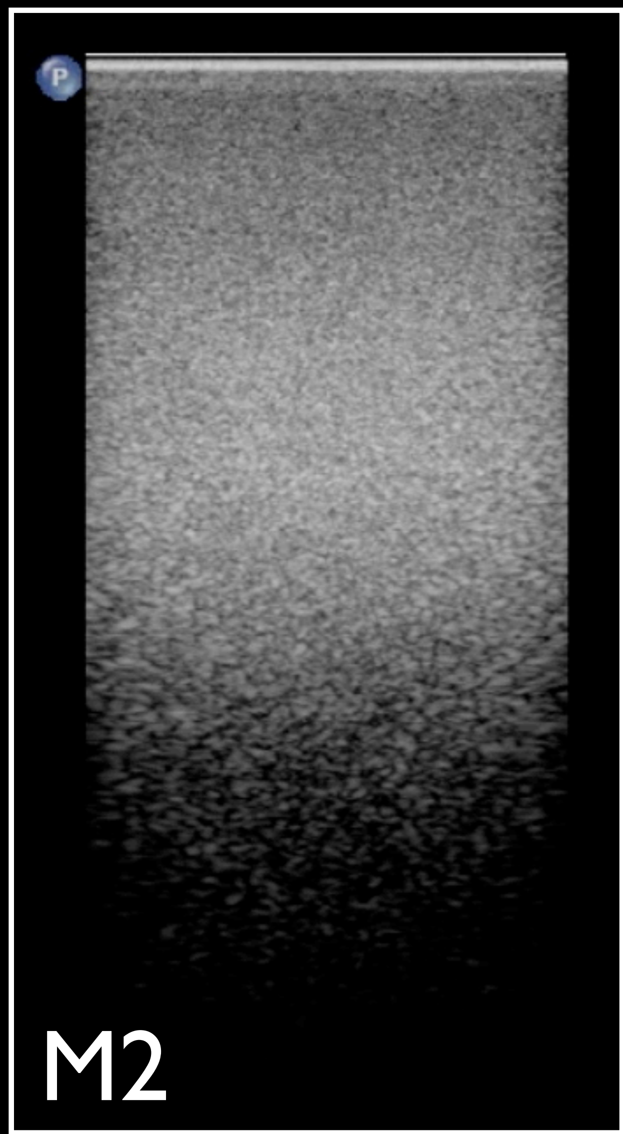
Gray Scale



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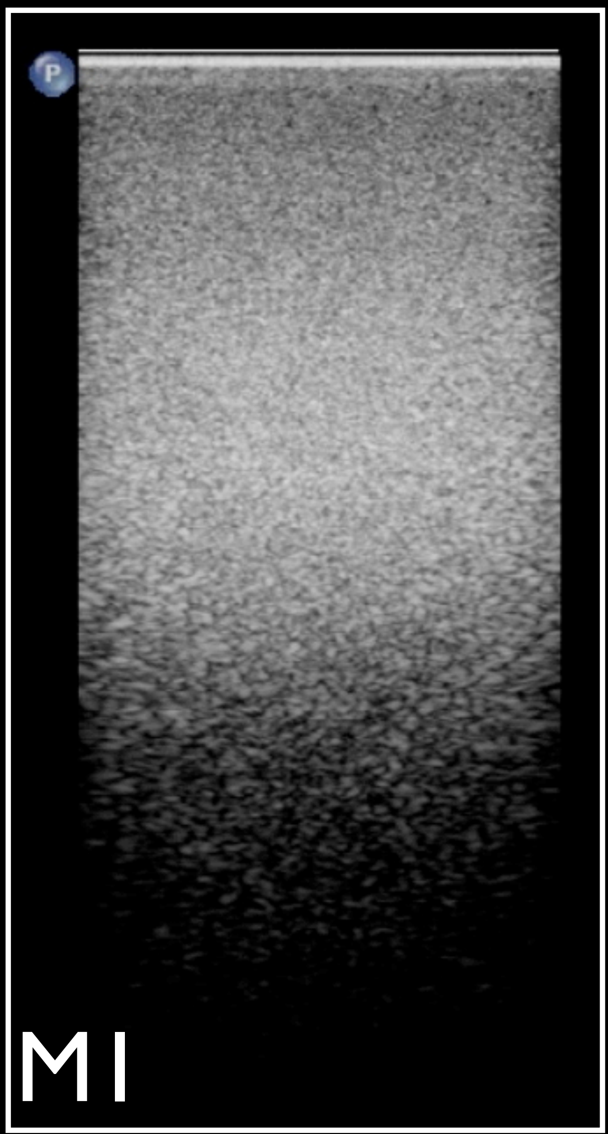

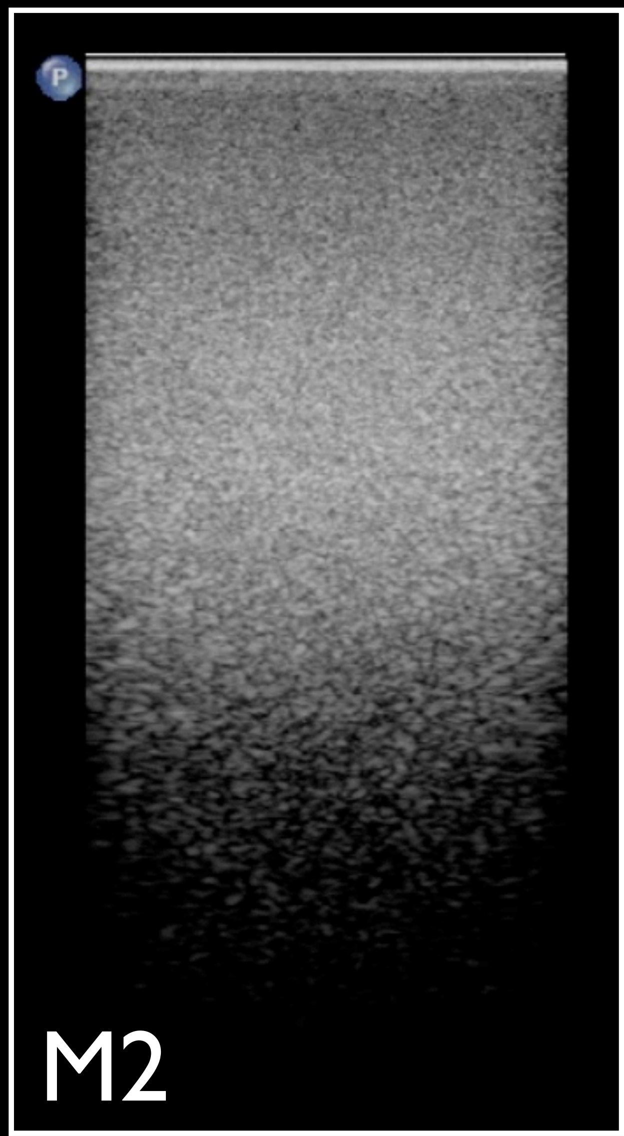

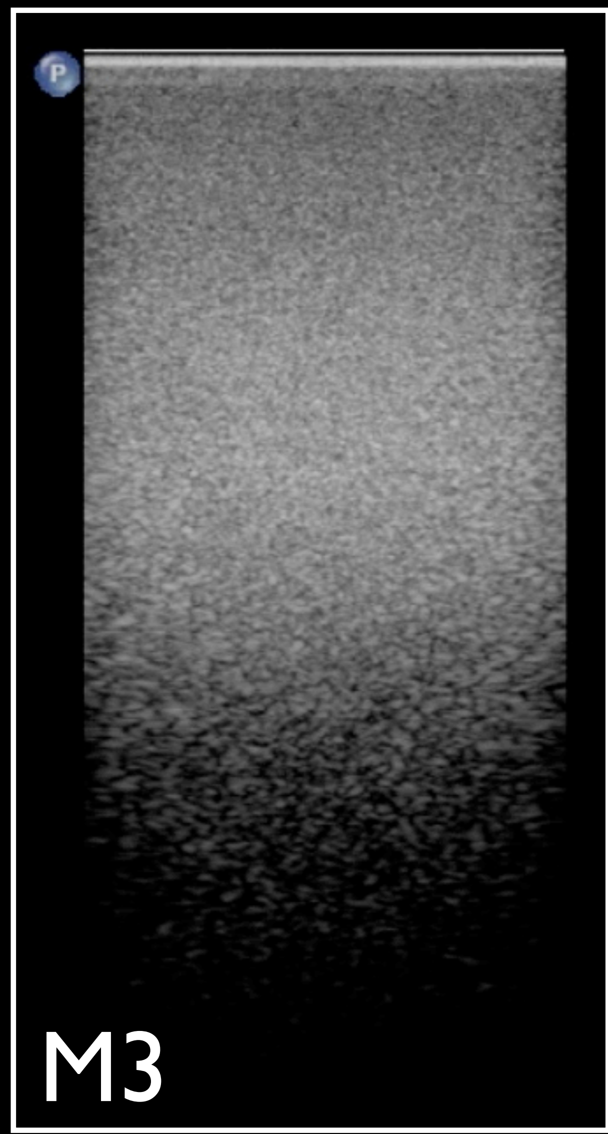

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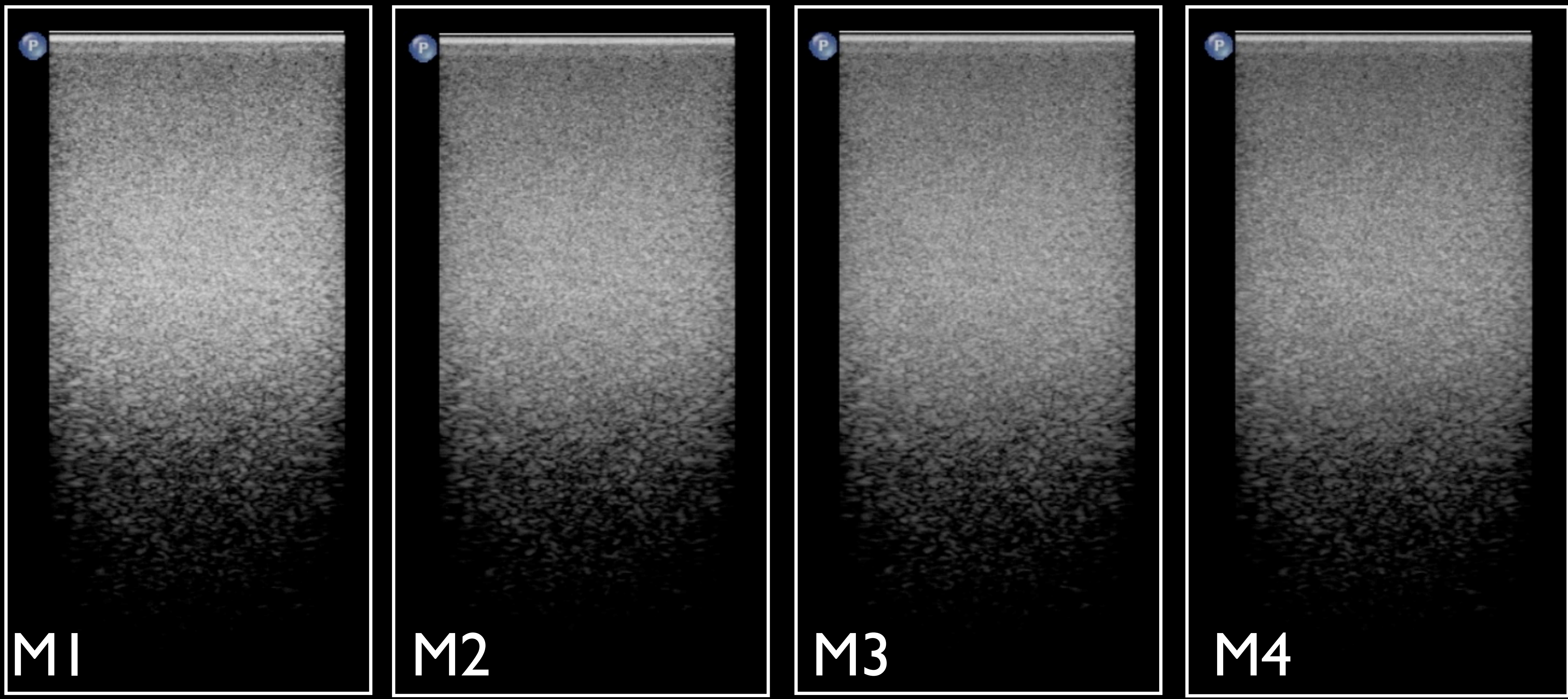

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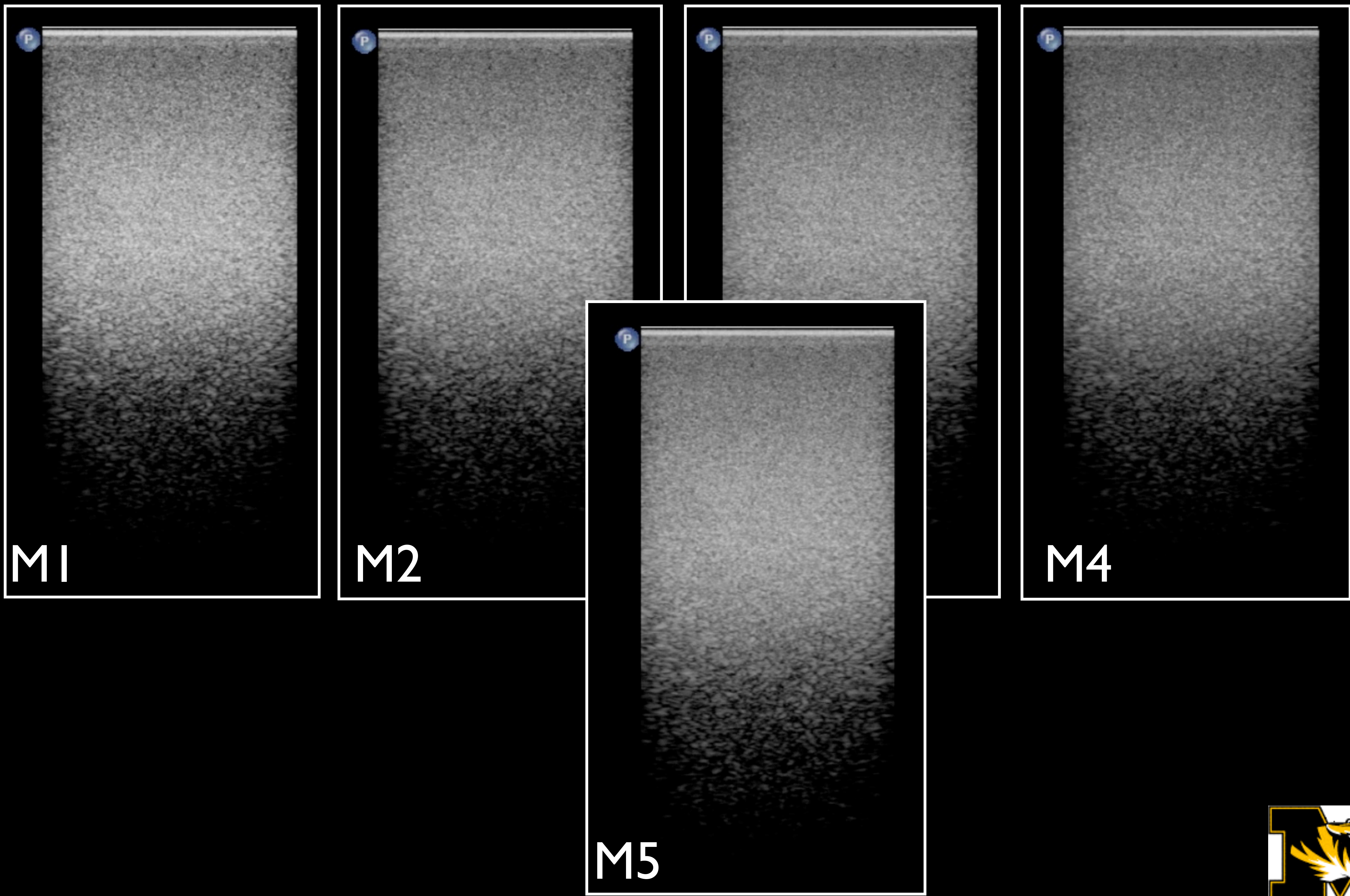

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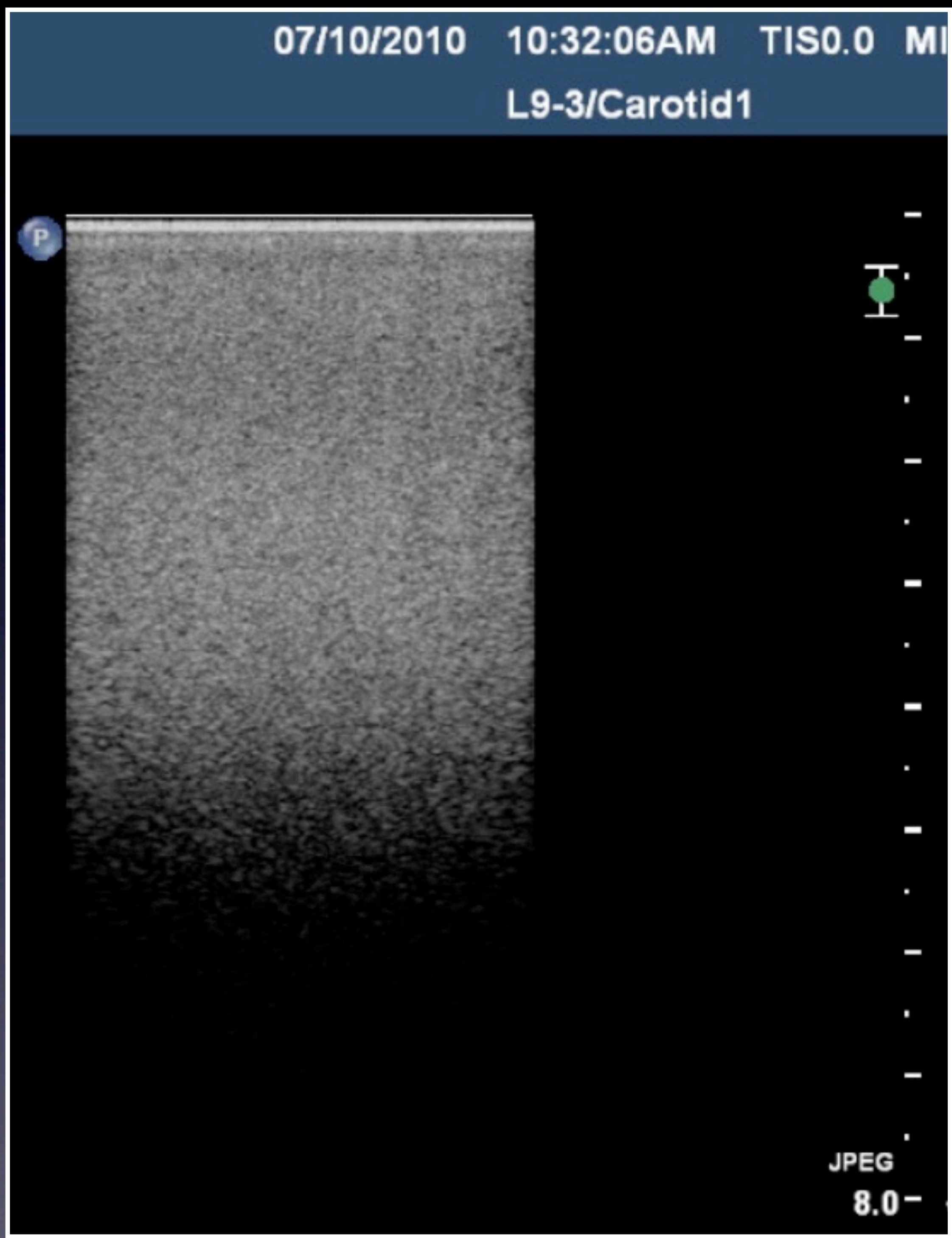
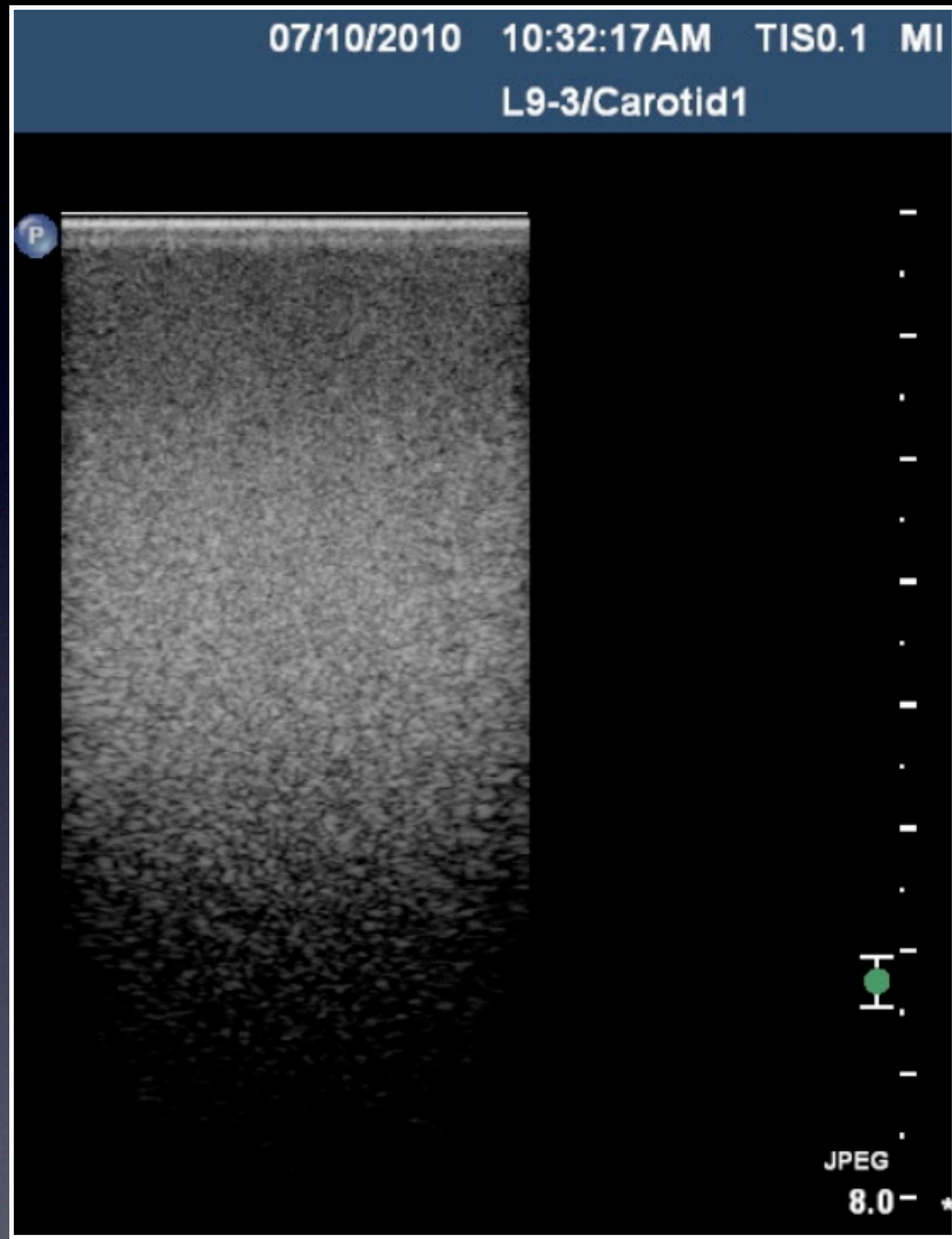
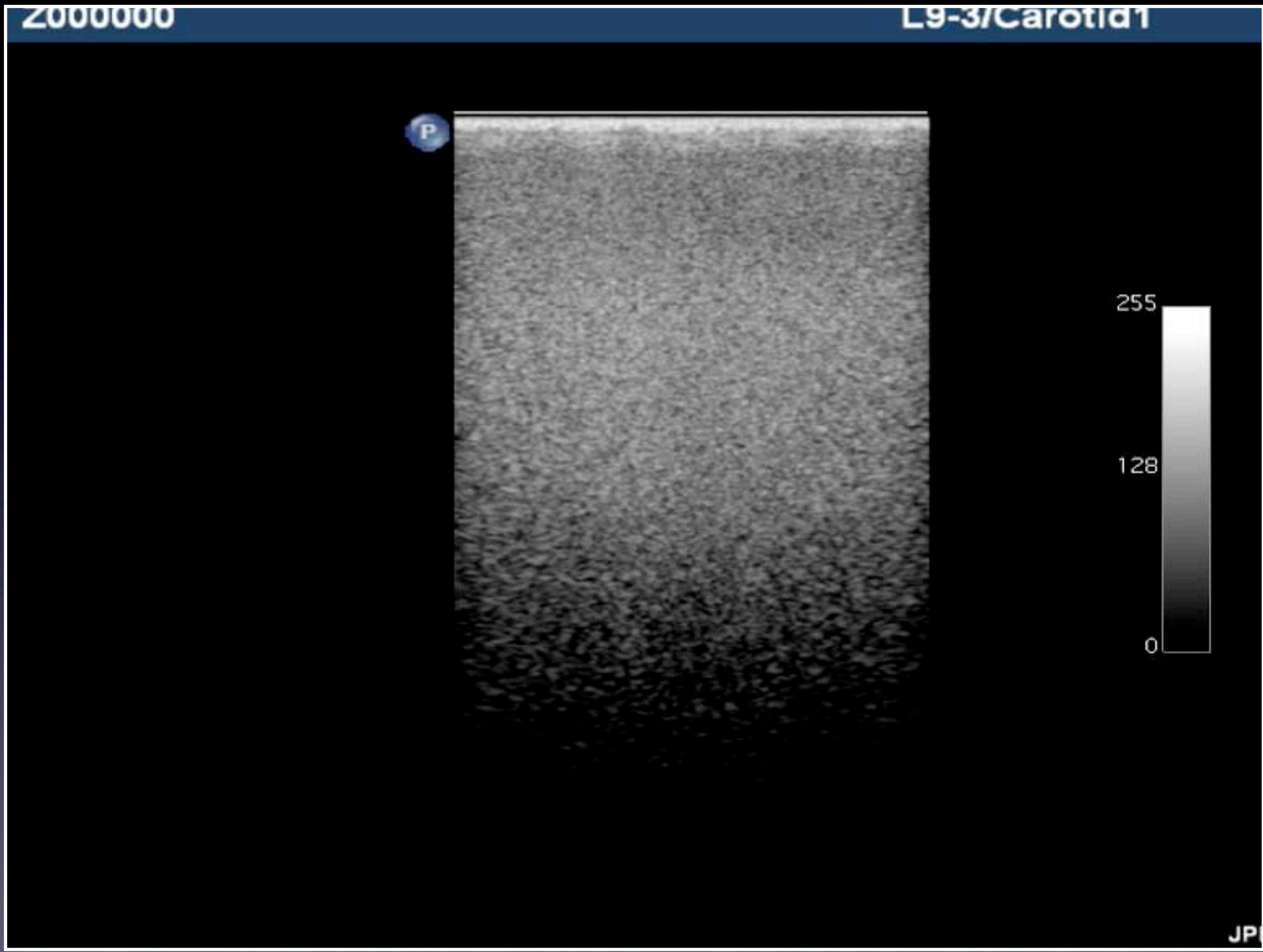
Shallow focus vs. Deep focus





Depth of the transmit focus..

Gain Adjustment



Movie showing adjustment of overall gain and its affect on the image.

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- Work with someone who users the ultrasound equipment on a regular basis - better still, coordinate with an applications person from the vendor
- Use identical settings each time the unit is evaluated - failure to do this will produce little confidence in your results

Other Tests

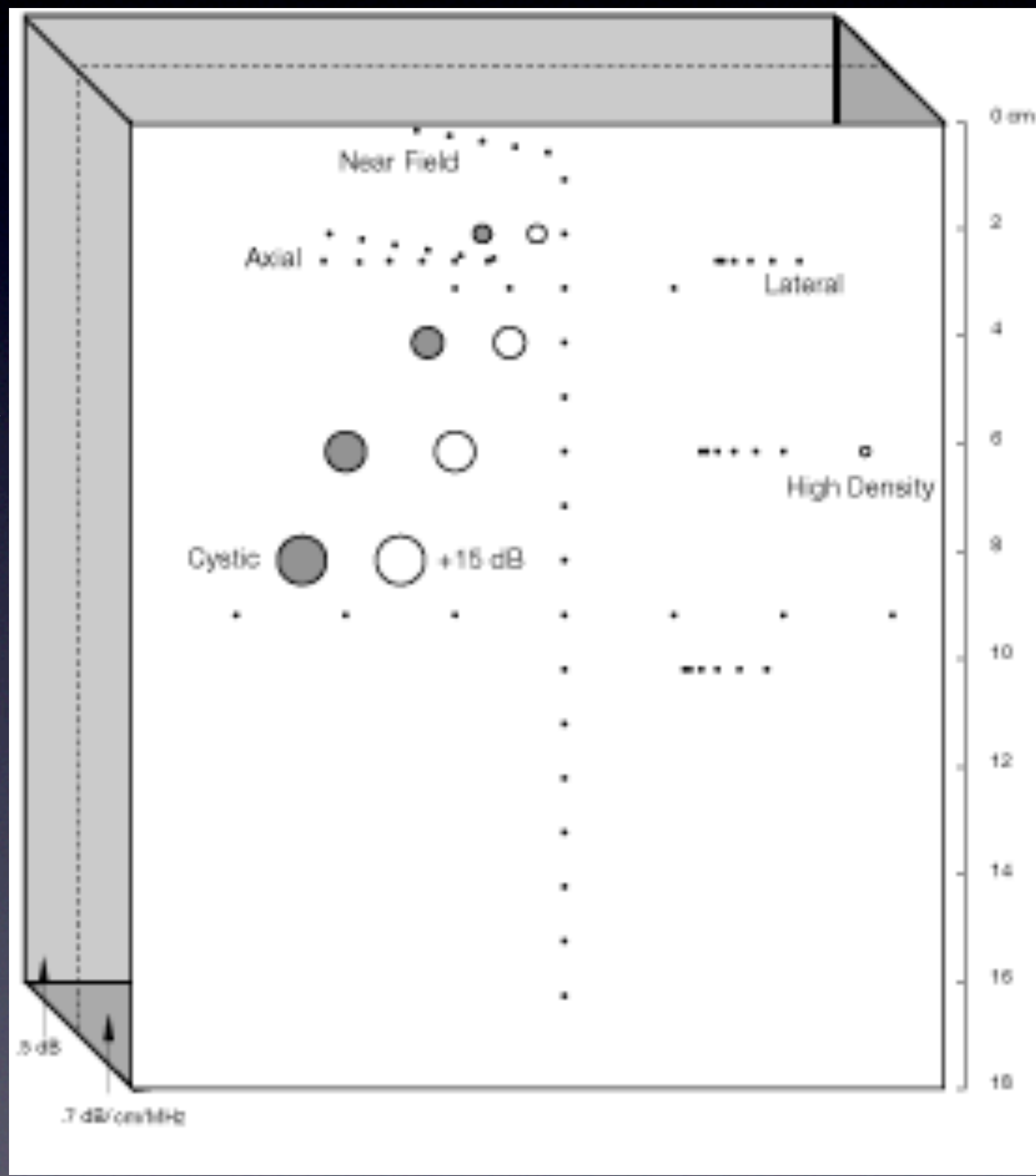
- Mechanical and Electrical Safety
  - assess condition of probes and connections
  - assess condition of air filters
  - damage to US unit body?
- Gray Scale and Hard Copy
  - Display on unit corresponds to interpreter's display!!! (B & C)
  - AAPM TG-18
  - Hard copy provisions - follow laser printer manufacturer guidance

Learning Objectives

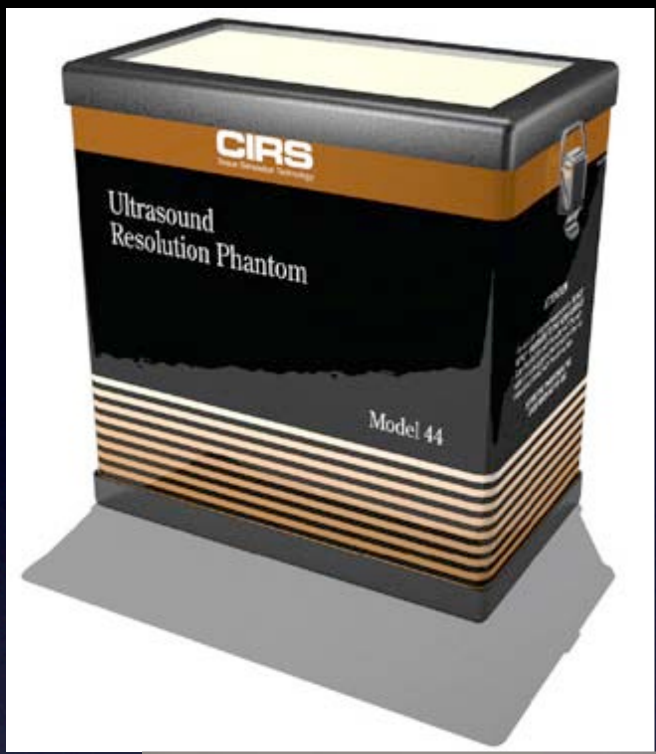
- Learners should:
  - Understand what the beginning steps are to implement a Quality Control program for ultrasound equipment
  - Know which tests are appropriate to assess clinical image quality
  - Know how to select test objects appropriate for these tests
  - Know how to establish objective criteria
  - have a basic introduction to accreditation bodies and standards for ultrasound QC

US Phantoms

- Ultrasound properties
  - speed of sound propagation = 1540 m/s
  - acoustic attenuation - 0.5 to 0.7 dB / MHz cm
  - acoustic backscatter approximately similar to liver tissue
  - small fibers as distance targets
    - near field "ringdown"
    - resolution
  - some have "voids" - regions with no scatter
  - some have varying backscatter in small rods or spherical objects for contrast evaluation



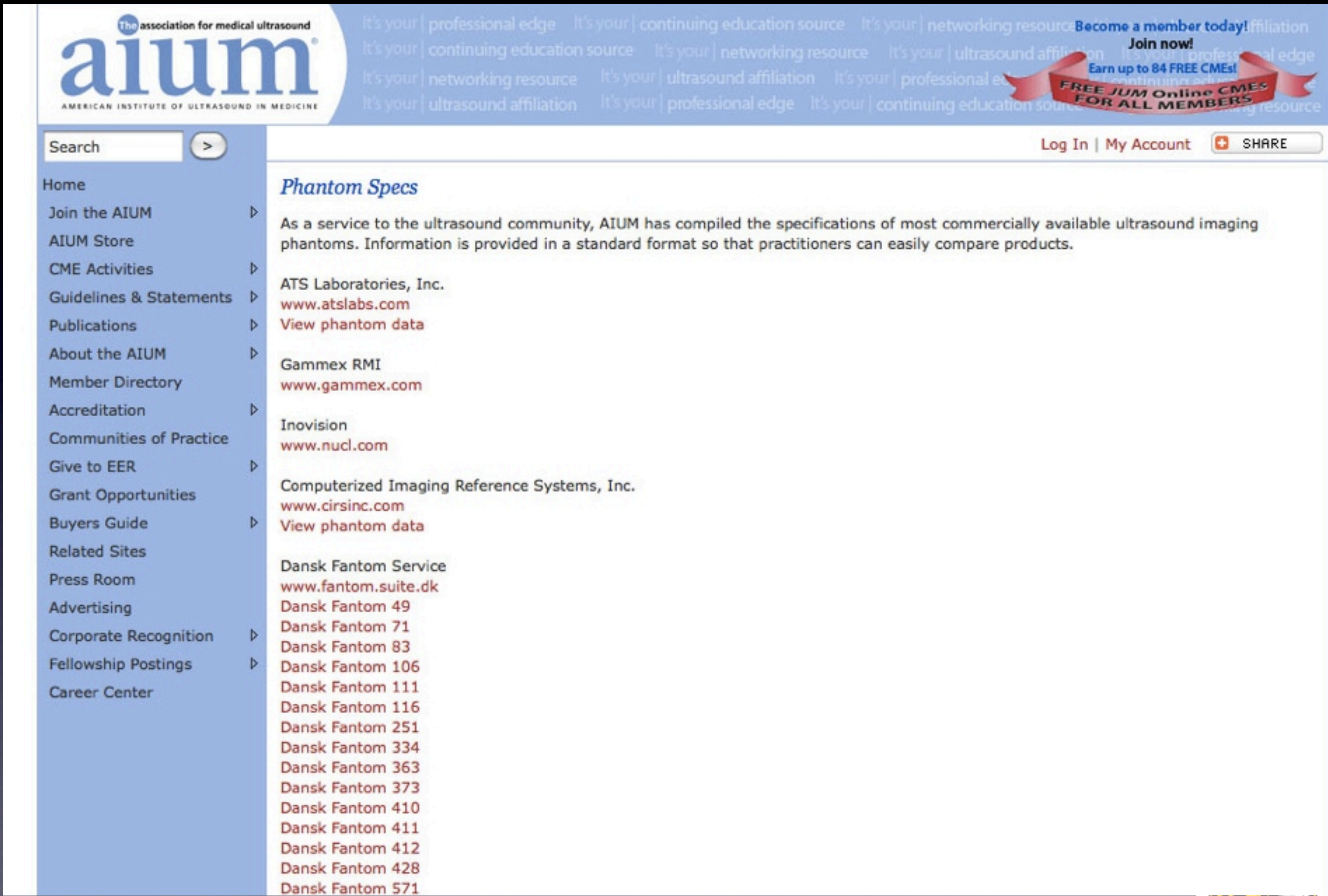
US Phantoms



agarose gel
or
urethane

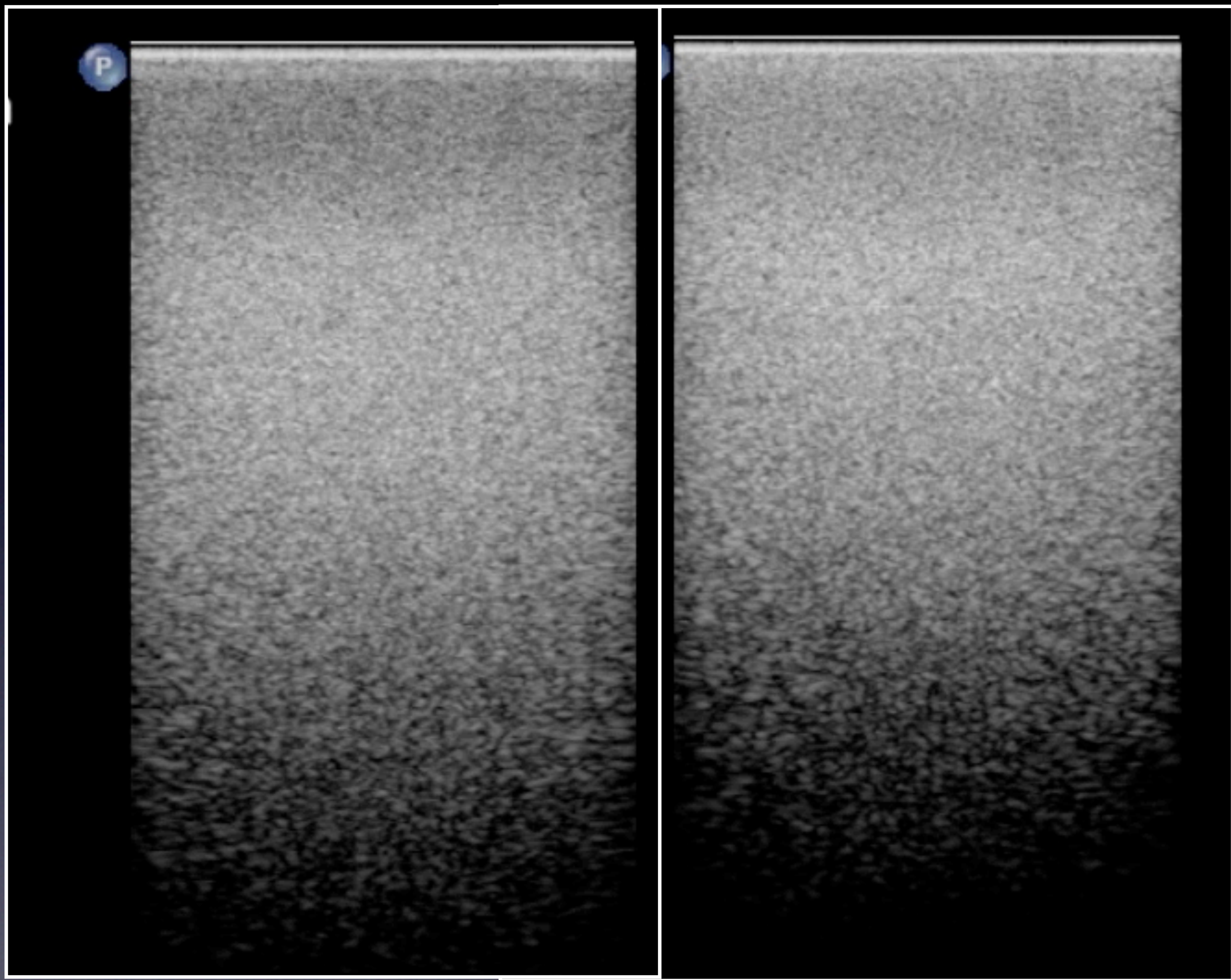
http://www.aium.org/publications/technicalStandards/phantomSpecs.aspx

Phantoms come from a number of vendors. The AIUM has done a service by posting specifications for phantoms on its website.



Here is the page that comes up when the prior link is selected.

Attenuation!



0.5 dB/cm MHz | 0.7 dB/cm MHz

Make sure you know what attenuation your phantom is using. In the case of the phantom I used, there are two different attenuation coefficients - these would give different results, depending on which section was being used.

Take Care of your Phantoms!

- Gel-based phantoms will dessicate over time
  - storage in controlled temperature and humidity
  - Preferably in sealed container to retain water content
- surface of the phantom is susceptible to damage - may affect uniformity measurements
- Don’t drop your phantom on your computer!

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Objective Measures?
Pass - Fail Criteria?

- Maximum Depth of Penetration (Sensitivity)
  - Account for Frequency
  - Not all units will have similar performance!
  - Baseline performance (as early as possible)
    - a decrease (or increase) by more than 2 cm should be investigated
- Sensitivity
  - banding (narrow or wide) across the transducer face must be evaluated further with respect to clinical impact

Computer Analysis?

- Programs are "out there"
  - Thijssen, Weijers and de Korte (UMB Vol 33(3) p. 460-471
  - http://www.umcn.nl/Research/Departments/ClinicalPhysicsLaboratory
    - see "Quality Assurance of Ultrasound Equipment" section
- Not well supported - $$
  - Research groups at work
- Some limitedautomated tests on board units
- Stay tuned...
  - MATLAB based
  - ImageJ based

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Accreditation

ACR is the only accreditation that “requires” US QC. The others suggest it. Even the BUAP of the ACR says that US QC “should” be performed.

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- Originated by professional societies
  - American College of Radiology
  - American Institute of Ultrasound in Medicine
  - Intersocietal Commission for the Accrediation of Vascular Laboratories (ICAVL)

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  - UAP (1995)
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  - b) ultrasound service engineer
  - No qualifications specified - anyone can do it!

ACR US Test Form

UAP Id No.____________

QUALITY CONTROL WORKSHEET UNIT#:_____ Performed By:____________________ Date: __________

PENETRATION (Required)

With system sensitivity set up for visualizing echogenicity as deeply as possible, what is the maximum depth you can visualize the background echographic pattern? **Mark the appropriate box.**

Transducer #1

o Less than 3 cm	o 6 cm	o 9.5 cm	o 13 cm
o 3 cm	o 6.5 cm	o 10 cm	o 13.5 cm
o 3.5 cm	o 7 cm	o 10.5 cm	o 14 cm
o 4 cm	o 7.5 cm	o 11 cm	o 15 cm
o 4.5 cm	o 8 cm	o 11.5 cm	o 16 cm
o 5 cm	o 8.5 cm	o 12 cm	
o 5.5 cm	o 9 cm	o 12.5 cm	

Transducer #2

o Less than 3 cm	o 6 cm	o 9.5 cm	o 13 cm
o 3 cm	o 6.5 cm	o 10 cm	o 13.5 cm
o 3.5 cm	o 7 cm	o 10.5 cm	o 14 cm
o 4 cm	o 7.5 cm	o 11 cm	o 15 cm
o 4.5 cm	o 8 cm	o 11.5 cm	o 16 cm
o 5 cm	o 8.5 cm	o 12 cm	
o 5.5 cm	o 9 cm	o 12.5 cm	

UNIFORMITY (Required)

With gains set to obtain a uniform image, freeze the image. Complete the questions regarding the uniformity of the image by marking the appropriate box using this key:

1) **Agree** 2) **Disagree, slight non uniformities present** 3) **Disagree, major non uniformities present**

Transducer #1

1) The average brightness at edge of the scan is the same as the average brightness in the middle.
   o1 o2 o3
2) There are no vertically or radially oriented shadows from array element dropout.
   o1 o2 o3
3) There are no brightness transitions between focal zones.
   o1 o2 o3

Transducer #2

1) The average brightness at edge of the scan is the same as the average brightness in the middle.
   o1 o2 o3
2) There are no vertically or radially oriented shadows from array element dropout.
   o1 o2 o3
3) There are no brightness transitions between focal zones.
   o1 o2 o3

ELECTRICAL AND MECHANICAL SAFETY AND CLEANLINESS (Required)

Are all cords and cables intact (no frays)?	**YES**	**NO**
Are all transducers intact without crack or delamination?	**YES**	**NO**
Are the transducers cleaned after each use?	**YES**	**NO**
Are the image monitors clean?	**YES**	**NO**
Are the air filters clean?	**YES**	**NO**
Are the wheel locks in working condition?	**YES**	**NO**
Are the wheels fastened securely to the US unit and do the wheels rotate easily?	**YES**	**NO**
Are all accessories (VCR, cameras, etc.) fastened securely to the US unit?	**YES**	**NO**

06/04/09

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  - Learning how to do it and doing it develops experience and expertise for the physicist
  - Greater communication with technical staff in the Radiology department as well as other departments
  - Not difficult nor expensive (relatively speaking) nor time consuming
  - Increased interaction with biomedical/clinical engineers
  - Accreditation push is on! General scrutiny of imaging QC from radiation "incidents" and US is getting swept in with other modalities

Thanks for your attention

- Questions?