

Medical Display Performance and Evaluation

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Objectives

- Review display function, QA metrics, procedures, and guidance provided by AAPM
- Understand the expectations and requirements for display QA from accrediting bodies
- Identify some limitations of current QA procedures and opportunities for improving display QA

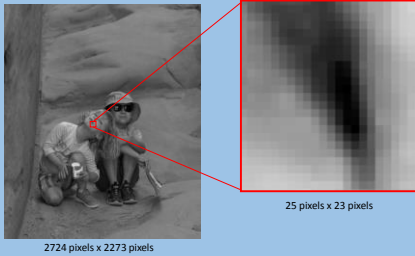
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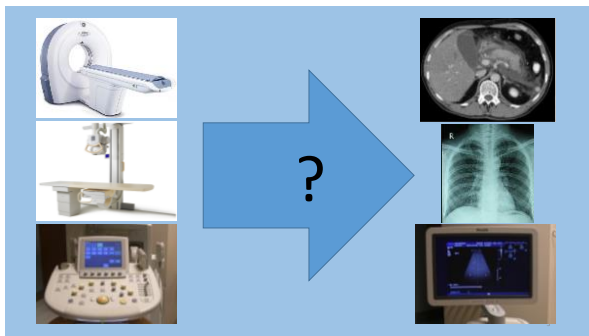
Outline

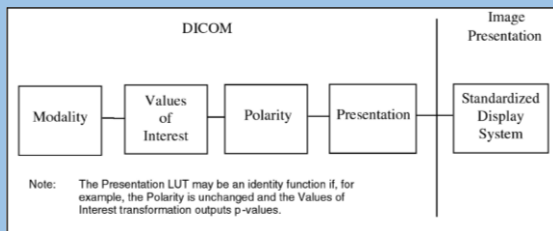
- I. Basics of Medical Image Display
 - a. Digital Image Display, Luminance, and Grayscale
 - b. LCDs and OLED Displays
- II. Performance and Quality Assurance Testing
 - a. Guidance Documents
 - b. QA Testing
- III. Expectations and Requirements
 - a. The Joint Commission
 - b. American College of Radiology
- IV. Clinical Implementation
 - a. Clinical Implementation and Observations
 - b. Questions and Issues

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What's a digital image?

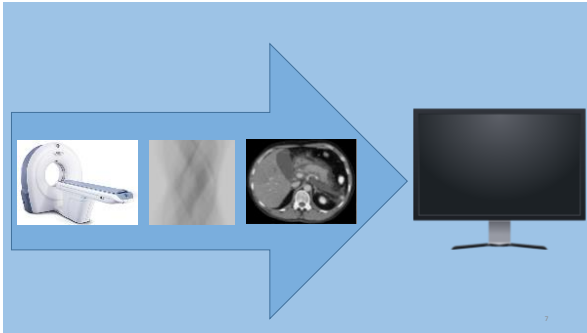


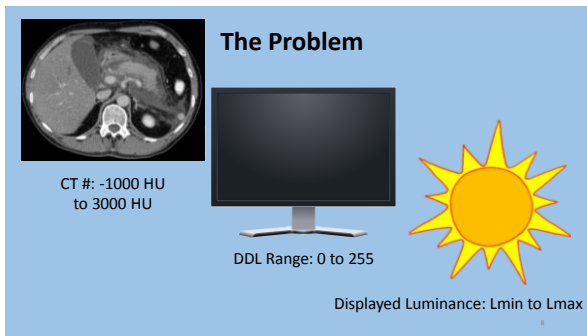


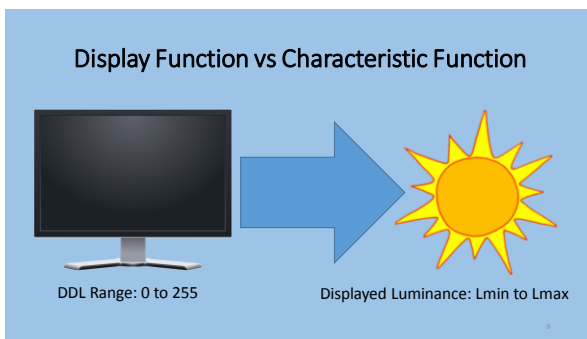


https://www.aspm.org/pubs/reports/OR_03.pdf

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The Problem:

Image data need to be converted to luminance

The Goal:

Consistent image presentation with regards to contrast

What can we do to get there?

1. Modify the conversion of P-values to Digital Driving Levels
2. Change the Hardware



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How do we get consistent image presentation?

"In order to have similar image appearance with respect to contrast, all display devices should have the same **luminance ratio** and the same **display function**."



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Luminance

- Minimum Luminance (L_{min})
 - Luminance at lowest gray level (Black)
- Maximum Luminance (L_{max})
 - Luminance at highest gray level (White)
- Ambient Luminance (L_{amb})
 - Results from background illumination and diffuse reflection from display

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Luminance Ratio

- L'_{min}
 - Minimum luminance in the presence of ambient light
 - $L'_{min} = L_{min} + L_{amb}$
- L'_{max}
 - Maximum luminance in the presence of ambient light
 - $L'_{max} = L_{max} + L_{amb}$
- Luminance Ratio (LR')
 - $LR' = L'_{max}/L'_{min}$
 - Do not confuse with "Contrast Ratio" claimed by manufacturers

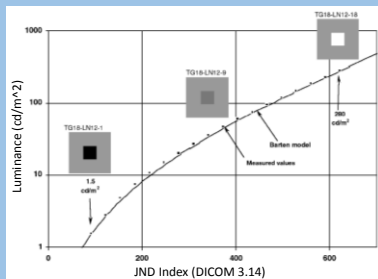
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DICOM Grayscale Standard Display Function

- NEMA-DICOM Standard (PS 3) 1984
 - Goal: Consistent image presentation
 - Recommendation: **Perceptual Linearization**
- Equal changes in P-values should result in equal changes in perceived brightness
- Just Noticeable Difference
 - How much does luminance need to change for you to notice it
 - Not linear with luminance

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- JND to luminance curve is based on the Barten Model
- JND index corresponds to a target luminance dependent on L'_{max}



https://www.aapm.org/pubs/reports/QR_03.pdf

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In order to obtain similar image contrast between different displays, what two performance characteristics should be the same?

- 20% 1. Minimum Luminance, Maximum Luminance
- 20% 2. Maximum Luminance, Maximum Luminance Deviation
- 20% 3. Minimum Luminance, Display Function
- 20% 4. Luminance Ratio, Display Function
- 20% 5. Display Function, Ambient Luminance

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Answer

- 4. Luminance Ratio, Display Function

• Ref: American Association of Physicists in Medicine, "Assessment of display performance for medical imaging systems," AAPM On-line Report No. 3 (AAPM, College Park, MD, 2005), p. 78

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What is the purpose of calibrating a display in accordance with the DICOM Gray Scale Display Function?

- 20% 1. To adjust the transformation between digital driving levels and displayed luminance
- 20% 2. To ensure constant luminance uniformity at all digital driving levels
- 20% 3. To ensure that equal changes in presentation values result in equal changes in perceived brightness
- 20% 4. All of the above
- 20% 5. None of the above

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Answer

- 3. To ensure that equal changes in presentation values result in equal changes in perceived brightness
- Ref: American Association of Physicists in Medicine, "Assessment of display performance for medical imaging systems," AAPM On-line Report No. 3 (AAPM, College Park, MD, 2005), p. 3

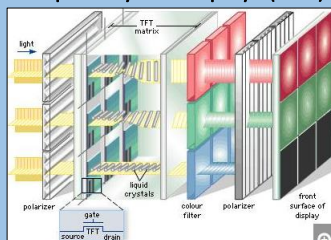
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Display Types

- Liquid Crystal Displays
- Organic Light Emitting Diode Displays
- ~~Cathode Ray Tube Displays~~

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Liquid Crystal Displays (LCD)

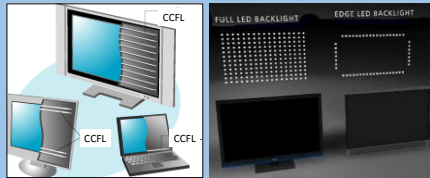


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LCD Backlight Method

Cold Cathode Fluorescent Lamps

Light Emitting Diode



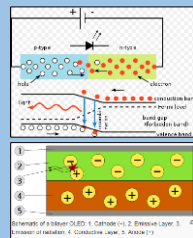
<https://nircorp.co.jp>

<http://www.homefuninc.com/led-vs-lcd>

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OLED Displays

- No backlight
- RGB OLEDs or white OLED with color filter
- Not a lot of OLED in service yet
- For QA purposes, we will treat these systems the same



<https://en.wikipedia.org/>

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Display QA: What is the goal?

1. To ensure we are in compliance with applicable regulations and requirements.
2. To attempt to standardize the display of medical images across platforms (within reason)
3. Ensure reliable image information is presented to physicians to allow accurate diagnoses

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TG-18

- Introduction to display technology (circa. 2005)
- Reviews prior efforts to standardize display evaluation
- Describes necessary equipment and test patterns
- Outlines QA procedures and methods
- Provides general performance specifications



https://www.aapm.org/pubs/reports/TG_18.pdf

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ACR-AAPM-SIIM Technical Standard For Electronic Practice of Medical Imaging

- Very Broad
 - Data Acquisition, Recording, Transmission
 - Data compression
 - Archival, retrieval, efficiency
 - Tele-radiology, off-site interpretation/supervision
 - Education
 - Image Quality
 - Equipment Performance Recommendations
- No Mammography
- We will come back to this when discussing requirements.



<http://www.acr.org/~/media/ACR/14800075064078102010110110000777.pdf>

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TG-196 Requirements and Methods for Color Displays in Medicine

- Provide **guidelines** to clinicians, medical physicists, developers, and engineers for proper implementation, utilization, and **performance testing of electronic color display monitors intended for medical use**
- Goals
 - Educate medical physicists
 - Define the minimum setup and performance requirements
 - Provide standard testing methods for color display devices
 - Facilitate communication between industry and medical professionals
 - Expand the role of medical physics in the growing areas of informatics, molecular imaging, and non-radiology image-based disciplines.

https://www.aspm.org/org/structure/default.asp?committee_code=TG196

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TG-270 Display QA

- Make recommendations for the assessment of display quality on workstations with flat panel monitors (LCD and OLED) that are used for the review or interpretation of medical images.
- Recommendations are to include the specific tests that should be performed and the expected results.

Categories:

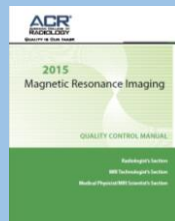
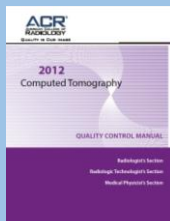
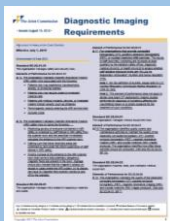
- (1) Modality monitors
- (2) Radiologist's workstations
- (3) Clinical spreadsheet workstations (ED, orthopedics, surgery)
- (4) EHR workstations (primary care, nursing stations, etc.)

https://www.aspm.org/org/structure/default.asp?committee_code=TG270

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TJC

ACR



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TG-18 Q. A. Tests

- Geometric Distortions
- Display Reflection
- Luminance Response
- Spatial and Angular Luminance Dependency
- Display Resolution
- Display Noise
- Veiling Glare
- Display Chromaticity
- Overall Evaluations (General QA, Low Contrast, Artifacts)

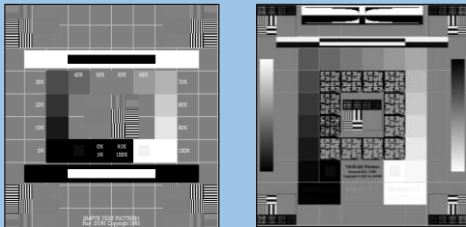
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Selected QA Tests

- Visual Evaluations
 - Resolution
 - Low Contrast
 - Artifacts
 - Other
- Luminance Response
 - Lmin, Lmax
 - Grayscale Calibration
- Spatial Luminance Dependency (Uniformity)

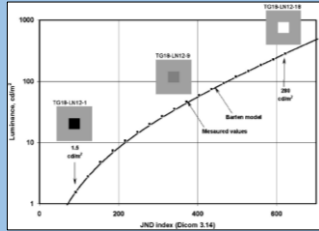
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Visual Evaluation



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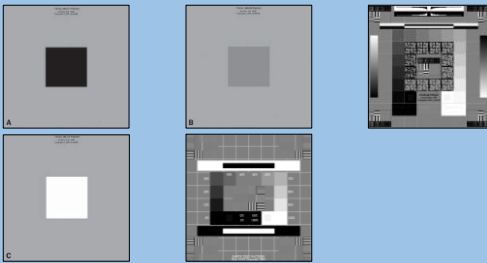
Luminance Response: Barten Curve



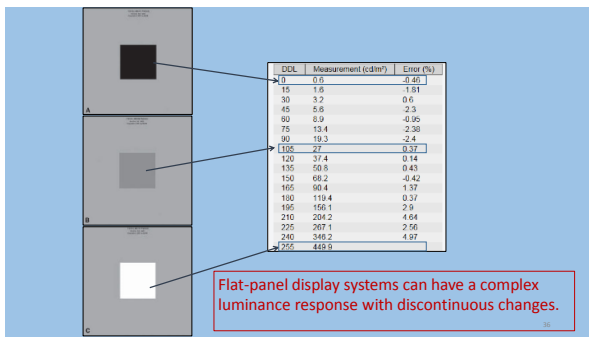
http://deckard.mc.duke.edu/~sames/tg18_files/tg18ex5.pdf

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Luminance Response Test Patterns

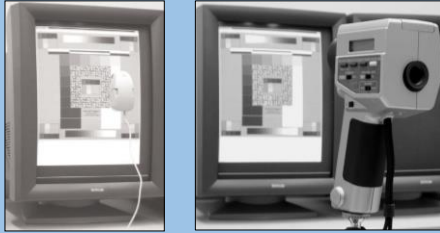


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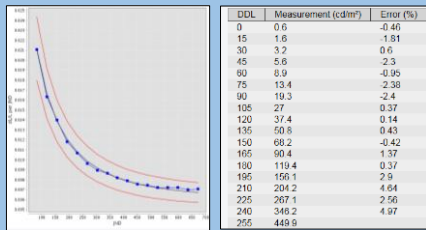
Luminance Meters



https://www.sagepub.org/pubs/reports/OR_03.pdf

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Vendor QA Software



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Luminance Uniformity

- Luminance measured in five (or nine) locations across display

- Maximum Luminance Deviation (MLD) calculated as:

$$MLD = \frac{L_{max} - L_{min}}{L_{max} + L_{min}} \times 200$$

- Alternate pattern for modality workstation: Word, Paint, other white screen



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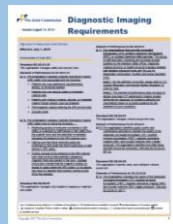
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The Joint Commission

- Annual Testing (p. 3)
 - Image Acquisition Displays
 - CT, MRI, NM, and PET
 - Medical Physicist or MRI Scientist
- Required Tests:
 - Min and Max Luminance
 - Luminance Uniformity
 - Resolution and Spatial Accuracy??

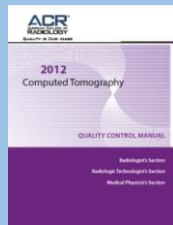


http://www.jointcommission.org/assets/1/18/AHC_DiagnosticImaging_MK_20110806.pdf

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ACR – Computed Tomography

- QMP Acceptance and Annual Testing
 - “CT Scanner Monitors” (p. 77)
 - Primary Interpretation (p. 25)
 - (No guidance for primary displays)
- Recommended Tools:
 - SMPTE Pattern
 - Calibrated Photometer

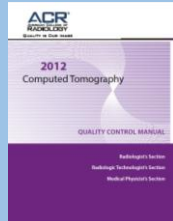


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ACR – CT Scanner Monitors

• Visual Evaluation

- Resolution (via line pairs)
- Contrast (Both patches visible)
- Geometric Distortion
- Black/White Transitions
- Loss of Bit Depth

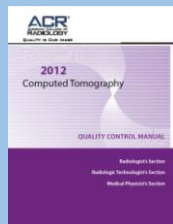


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ACR – CT Scanner Monitors

• Quantitative Evaluation

- Lmin ($< 1.2 \text{ cd/m}^2$)
- Lmax ($> 90 \text{ cd/m}^2$)
- Establish Luminance Response Curve
- Luminance Uniformity (MLD $< 15\%$)
(Test Pattern not specified)



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ACR – Magnetic Resonance Imaging

• Acceptance and Annual Testing

- "Soft-Copy (Monitor) QC" (p. 109)
- QMP or MRI Scientist
- Provides guidance for the performance of QA tests for modality and primary interpretation displays
- Refers user to TG-18 for a more thorough test (Luminance Response)

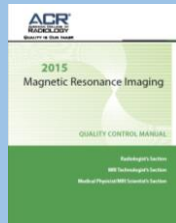


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ACR – Magnetic Resonance Imaging

- Visual Evaluation

- Resolution (via line pairs)
- Contrast (Both patches visible)
- Geometric Distortion
- Black/White Transitions
- Loss of Bit Depth

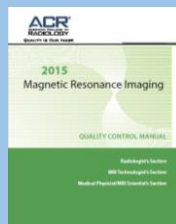


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ACR – Magnetic Resonance Imaging

- Quantitative Evaluation

- Lmin (< 1.2 cd/m²)
- Lmax (> 90 cd/m²)
- ~~Establish Luminance Response Curve~~
- Luminance Uniformity (MLD < 30%)
(at Maximum Luminance)



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ACR – Nuclear Medicine and PET

- Nuclear Medicine Accreditation Program Requirements (p. 9)

- Formatter/Video Display – Annually

“Performed to ensure that systems used to produce hard copy and monitors that are used for **interpretation of clinical studies** provide satisfactory image quality in terms of uniformity and spatial resolution.”



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Answer

- 3. 90 cd/m²

- Ref: 2015 ACR MRI Quality Control Manual, p. 111
2012 ACR CT Quality Control Manual, p. 78

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According to the 2012 ACR CT QA Manual, the Maximum Luminance Deviation for flat panel displays should be less than what value?

20%	1.	10%
20%	2.	15%
20%	3.	20%
20%	4.	25%
20%	5.	30%

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Answer

- 2. 15%

- Ref: 2012 ACR CT Quality Control Manual, p. 78

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According to the ACR-AAPM-SIIM Technical Standard for Electronic Practice of Medical Imaging, the luminance ratio for displays used for primary interpretation should always exceed what value?

20%	1.	50
20%	2.	100
20%	3.	250
20%	4.	300
20%	5.	500

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Answer

- 3. 250

• Ref: ACR-AAPM-SIIM Technical Standard for Electronic Practice of Medical Imaging, 2014, p. 9

According to the ACR-AAPM-SIIM Technical Standard for Electronic Practice of Medical Imaging, the contrast response for displays used for primary interpretation should be within what percentage of the DICOM GSDF?

20%	1.	5%
20%	2.	10%
20%	3.	15%
20%	4.	20%
20%	5.	25%

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Answer

- 2. 10%

- Ref: ACR-AAPM-SIIM Technical Standard for Electronic Practice of Medical Imaging, 2014, p. 9

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Modality Workstations: Luminance

Minimum Required Spec.

- $L_{min} < 1.2 \text{ cd/m}^2$
- $L_{max} > 90 \text{ cd/m}^2$
- MLD 15% CT, 30% MRI

Notes

- In absence of ambient light, this spec is trivial.
- Most newer LCDs will easily meet this spec. Some may require adjustment
- Quantitative measures of Uniformity are less important than visual assessment

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Primary Interpretation: Luminance

Minimum Required Spec.

- GSDF Compliance within 10%
- $L_{max} > 350 \text{ cd/m}^2$
- $MLD < 15\%$ (30%?)

Notes

- All primary interpretation displays should meet this. Vendor software can be useful but beware...
- Typically 450 or 500 cd/m^2
- Using the UN-80 test pattern (or 9-point pattern)

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Visual Evaluation

Minimum Required Spec.

- Contrast: Can I see patches on SMPTE or QC Pattern?
- Resolution
- Distortion/Spatial Accuracy
- Artifacts

Notes

- May be effected by Brightness/Contrast settings and ambient light
- Is this really appropriate?
- How would you fail this? Graphics Card?
- Local Non-Uniformity or bad pixels

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But what about...

- Ambient Light
- Luminance Ratio
- Photometer Type
- Brightness and Contrast settings
- Grayscale Calibration (Maybe within 20%?)
- Test Pattern Selection (Uniformity)
- Hot or Cold Pixels
- White Point

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Our Observations: Modality Displays

- 7 Digital Radiography (no mobile units)
- 5 CT Scanners
- 4 MRI Scanners
- 8 NM and PET Units
- 18 US Units

Note: These displays varied substantially in terms of their age and amount of use.

Accepted for Publication as : Imaging Acquisition Display Performance: An evaluation and discussion of performance metrics and procedures, JACMP

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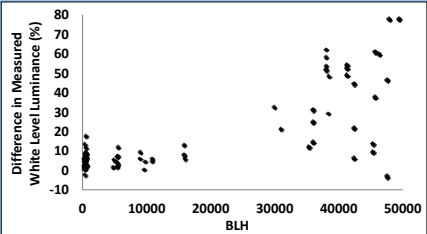
Our Observations: Modality Displays

	Minimum Luminance (cd/m ²)	Maximum Luminance (cd/m ²)	Luminance Uniformity (MLD)
Specification	< 1.2	> 90	< 15%
Mean	0.28	135.07	12.61
St. Dev.	0.13	33.35	4.85
Min	0.10	71.76	4.88
Max	0.63	236.40	28.88
# of Failures	0	4	7

Accepted for publication, Feb 2016, JACMP

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Our Observations: Primary Displays



Med. Phys. 40, 121902 (2013); <http://dx.doi.org/10.1118/1.4829497>

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