Medical Display Performance and Evaluation

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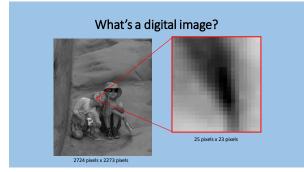
Objectives

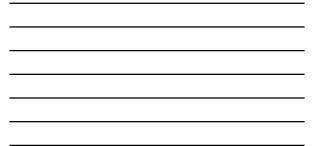
- Review display function, QA metrics, procedures, and guidance provided by AAPM
- Understand the expectations and requirements for display QA from accrediting bodies
- Identify some limitations of current QA procedures and opportunities for improving display QA

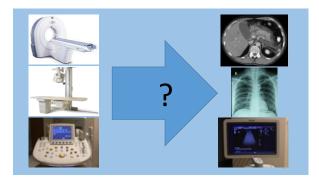
Outline

- Basics of Medical Image Display

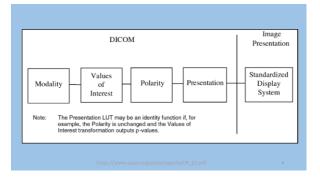
 Digital Image Display, Luminance, and Grayscale
 LCDs and OLED Displays
- II. Performance and Quality Assurance Testing a. Guidance Documents b. QA Testing
- III. Expectations and Requirements a. The Joint Commission b. American College of Radiology
- IV. Clinical Implementationa. Clinical Implementation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



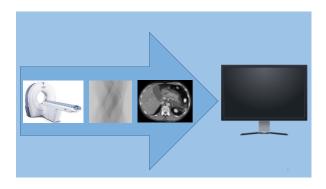


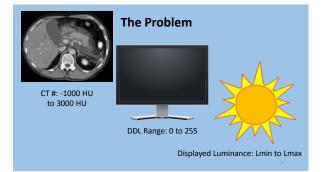


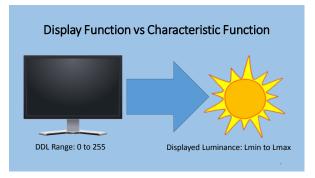














The Problem:

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



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."



Luminance

- Minimum Luminance (Lmin) -Luminance at lowest gray level (Black)
- Maximum Luminance (Lmax) -Luminance at highest gray level (White)
- Ambient Luminance (Lamb)

 Results from background illumination and diffuse reflection from display

Luminance Ratio

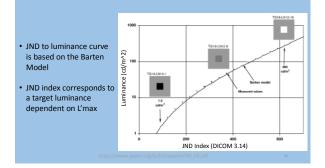
• L'min

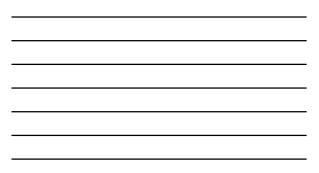
- Minimum luminance in the presence of ambient light - L'min = Lmin + Lamb
- L'max
 Maximum luminance in the presence of ambient light
 L'max = Lmax + Lamb
- Luminance Ratio (LR')
- LR' = L'max/L'min
 Do not confuse with "Contrast Ratio" claimed by manufacturers

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





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

	at is the purpose of calibrating a display in accordance i 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
<mark>20%</mark> 5.	None of the above

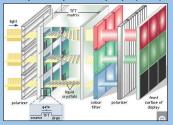
Answer

- 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

Display Types

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

Liquid Crystal Displays (LCD)



LCD Backlight Method



https://nfcorp.co.jp

http://www.homefuni

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

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Outline

- Basics of Medical Image Display

 Digital Image Display, Luminan
- 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 Radiolog
- IV. Clinical Implementation
 - a. Clinical Implementation and Observation
- b. Questions and I

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

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



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.

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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.

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.)





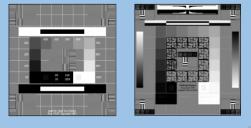
TG-18 Q. A. Tests

- 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)

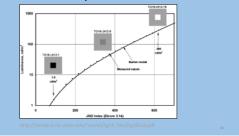
Selected QA Tests

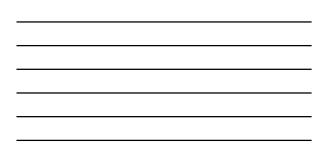
- Visual Evaluations -Resolution -Low Contrast -Artifacts -Other
- Luminance Response -Lmin, Lmax -Grayscale Calibration
- Spatial Luminance Dependency (Uniformity)

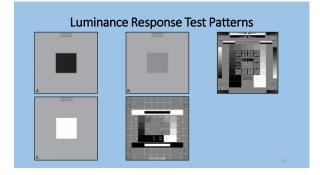
Visual Evaluation

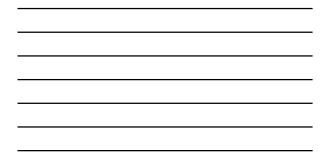


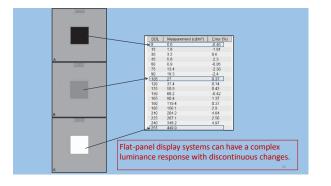
Luminance Response: Barten Curve







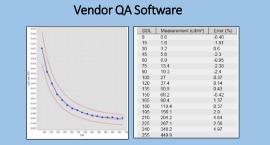






Luminance Meters





• Luminance Uniformity • Luminance measured in five (or nine) locations across display • Maximum Luminance Deviation (MLD) calculated as: $MLD = \frac{Lmax - Lmin}{Lmax + Lmin} \times 200$ • Alternate pattern for modality workstation: Word, Paint, other white screen

Outline

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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??



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



ACR – CT Scanner Monitors

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



ACR – CT Scanner Monitors

- Quantitative Evaluation
 - Lmin (< 1.2 cd/m²) - Lmax (> 90 cd/m²)
 - Establish Luminance Response Curve
 - Luminance Uniformity (MLD < 15%)
 - (Test Pattern not specified)



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)



ACR – Magnetic Resonance Imaging

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



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)



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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ACR – Ultrasound

- Ultrasound Accreditation Program Requirements (p. 7)
- "Ultrasound Scanner Electronic Image Display" and "Primary Interpretation Display
- Must be evaluated Annually

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ACR – Ultrasound

"Display characteristics that are evaluated may include gray scale response and luminance calibration, presence of pixel defects, and overall image quality"

"See ACR Technical Standard for Electronic Practice of Medical Imaging"

ACR Technical standard for electronic practice of medical imaging

• Luminance

- Ambient Luminance: Lamb < Lmin/4
- L'min > 1.0 cd/m² primary, > 0.8 cd/m² secondary
- L'max 350 cd/m² primary, > 250 cd/m² secondary
- LR 350 preferred, 250 Acceptable
- All Devices should have a similar LR

Grayscale Response

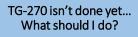
- Within 10% of GSDF for primary
- Within 20% of GSDF for secondary

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ACR Technical standard for electronic practice of medical imaging

- White point (CIE daylight standard D65)
- Pixel Pitch
- Matrix Size

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According to the American College of Radiology, for CT and MRI, the maximum luminance of a modality workstation should exceed what value?

20%	1.	1.2 cd/m ²	
20%	2.	75 cd/m ²	
20%	3.	90 cd/m ²	
20%	4.	350 cd/m ²	
20%	5.	500 cd/m ²	

Answer

• 3. 90 cd/m²

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

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

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	
		10

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% 2. 10% 20% 3. 15% 20% 4. 20%	20%	1.	5%	
	20%	2.	10%	
20% 4. 20%	20%	3.	15%	
	20%	4.	20%	
_{20%} 5. 25%	20%	5.	25%	

Answer

- 2. 10%
- Ref: ACR-AAPM-SIIM Technical Standard for Electronic Practice of Medical Imaging, 2014, p. 9

Outline

- IV. Clinical Implementationa. Clinical Implementation and Observationsb. Questions and Issues

Modality Workstations: Luminance

Minimum Required Spec.	Notes
• Lmin < 1.2 cd/m ²	 In absence of ambient light, this spec is trivial.
• Lmax > 90 cd/m ²	 Most newer LCDs will easily meet this spec. Some may require adjustment
• MLD 15% CT, 30% MRI	 Quantitative measures of Uniformity are less important than visual assessment



Primary Interpretation: Luminance

Minimum Required Spec.	Notes
GSDF Compliance within 10%	 All primary interpretation displays should meet this. Vendor software can be useful but beware
• Lmax > 350 cd/m ²	• Typically 450 or 500 cd/m ²
• MLD < 15% (30%?)	• Using the UN-80 test pattern (or 9-point pattern)

Visual Evaluation

Minimum Required Spec.	Notes
Contrast: Can I see patches on SMPTE or QC Pattern?	 May be effected by Brightness/Contrast settings and ambient light
Resolution	Is this really appropriate?
Distortion/Spatial Accuracy	How would you fail this? Graphics Card?
• Artifacts	Local Non-Uniformity or bad pixels

-			

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

Our Observations: Modality Displays

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

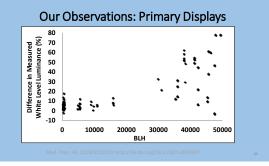
Note: These displays varied substantially in terms of their age and amount of use.

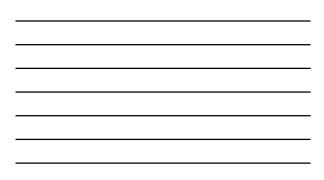
Accepted for Publication as : Imaging Acquisition Display Performance: An evaluation and discussion of performance metrics and procedures, JACMP

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





Our Observations: Primary Displays

	BLH		MLD	
Model Number	Mean	St. Dev.	Mean	St. Dev.
MDCG 3120-CB (New)	473.2	131.1	9.5	4.3
MDCG 3120-CB (Old)	36984.3	1902.8	11.2	6.5
MDCG 3420	40735.3	5045.5	42.5	9.1
MDCC 6230	50.9	34.4	10.3	2.4

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References

- American Association of Physicists in Medicine, "Assessment of display performance for (AAPA, College Park, MD, 2005), see <u>your atom care</u>.
 ACR: AAPA Mith Technical Standing for Electronic Practice of Medical Imaging (2014) http://www.accourg/imalian.P1.68000795402173.01079915(100077.adf https://www.acgom.org/rp/startscher/delutal arg/committee_coder:10136
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- M. Silosky and R.M. Marsh, "Constancy of built-in luminance meter measurements in diagnostic displays," Medical Physics 40 (12), 121902 (2013).