QC for Standard Displays

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Display Check

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Display QC

- Ensure consistent image presentation across the image review chain
  - Modality → Technologist → Radiologist → Clinician
- Performance tolerances and testing frequencies should consider use cases

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Display QC

- Many regulatory and compliance guidelines
  - AAPM TG18 Report
  - ACR-AAPM-SIIM Technical Standard for Electronic Practice of Medical Imaging
  - ACR modality-specific documentation (MR, CT, MG, etc.)
  - IEC 62563-1
  - Upcoming AAPM TG270 Report

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Outline

- Display Classifications
  - Diagnostic
  - Non-diagnostic
- Display Performance Evaluation
  - Luminance
  - Color (White Point)
  - Uniformity
  - Noise
  - Temporal
  - Spatial
- Display Quality Program

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Display Classification

- Four classifications based on use
  - Diagnostic Displays
  - Non-diagnostic Displays (TG18 “secondary displays”)
    - Modality Displays
    - Clinical Specialist Displays
    - Electronic Health Record (EHR) Displays

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Display Classification

- Diagnostic Displays (TG18 “primary displays”)
  - Primary interpretation of medical images
  - Improved performance characteristics
    - Luminance stability (both in level and uniformity)
    - Smaller pixel pitch
    - Lower noise
    - Greater bit depth
    - Self-testing functionality
  - Stringent performance criteria
  - High cost
  - Does not include navigation displays

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Display Classification

- Modality Displays
  - Displays used during acquisition and generation of medical images
    - May or may not be attached to modality
    - Only displays that show images (not for acquisition control)
- Clinical Specialist Displays
  - Review of images before or independently of primary radiology read
    - ER, surgical environments
    - Patient care decisions, often before primary read by radiologist

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Display Classification

- EHR Display
  - Images used to review images following interpretation
    - Referring physicians offices
    - Exam room with patient
    - Pre-surgical planning
- The goal of display QA is consistent image presentation across all displays (image review chain)
  - Similar goals, but different tolerances, tests, frequencies

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Display Performance Evaluation

- Display performance evaluation should measure multiple characteristics
- Includes qualitative and quantitative evaluation
  - Both used across all display types - use different frequencies
- Requires appropriate testing equipment
  - Photometer, colorimeter, loupe, software, patterns

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Display Luminance

- Assessment of display luminance includes measuring:
  - L_{amb}
  - L'_{min} (L_{min} + L_{amb})
  - L'_{max} (L_{max} + L_{amb})
  - Luminance ratio (L'_{max} / L'_{min})
  - Luminance response function
- Each of these is related to the others. Understanding these relationships is critical to proper display QA.

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L_{amb}

- Ambient luminance is due to reflected light from the display
  - Specular reflection
  - Diffuse reflection
- Setting and maintaining proper environmental lighting for consistent and predictable image presentation
- Setting ambient lighting in reading rooms to minimize visual strain
  - 25-75 lux

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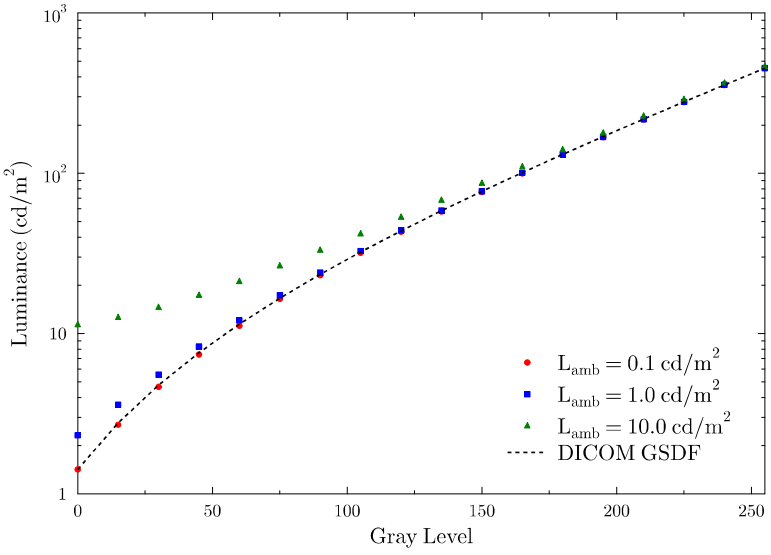
Display Luminance



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L_{amb} and L_{min}

- Avoid Lamb effects from obscuring darkest regions of image

$$L_{min} = 4 \cdot L_{amb}$$

- Approximately 80% of contrast seen with no ambient lighting is still visible with ambient lighting

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L'_{min}, L'_{max}, LR

- The minimum and maximum luminances are combined with the ambient luminance
  - L'_{min}, L'_{max}
- The ratio gives the luminance ratio LR

$$LR = \frac{L'_{max}}{L'_{min}}$$

- Recommended LR = 350
  - Set L'_{max} based on L'_{min} and LR, not maximum of display

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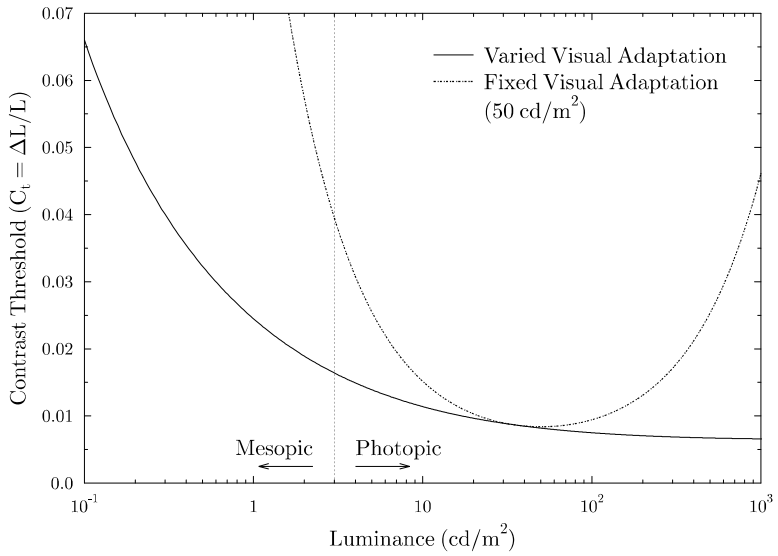
Display Luminance



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Luminance Response Function

- Measurement of luminance response function
  - 18-point (TG18 methodology)
  - 52-point
  - 256-point
  - 11-point (SMPTE pattern)
- Analysis of luminance should be of L', which includes the effects of ambient luminance

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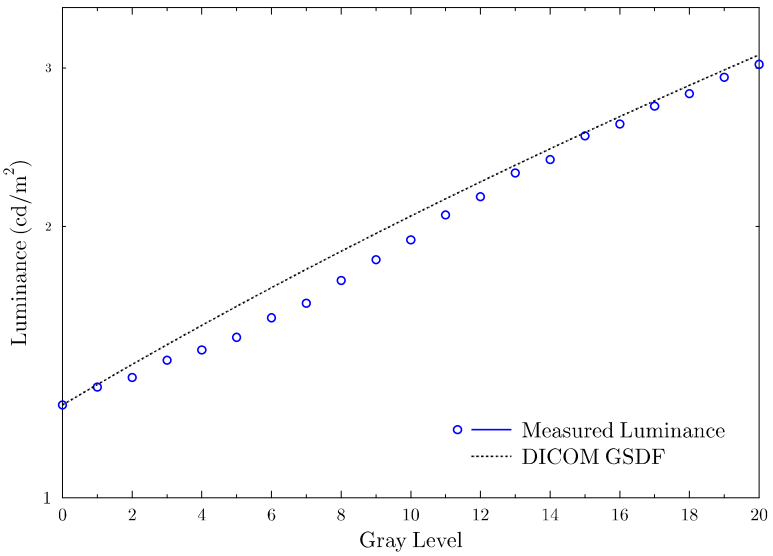
Display Luminance



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Luminance Response Function

- Confirm conformance with DICOM GSDF
  - Mean JND/GL
  - dL/L per JND
  - Both to within 10% for diagnostic displays, 20% for non-diagnostic

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Luminance Response Function

- Converting the luminance measurements to JND indices allows for a linear analysis of JND conformance
  - Each gray level change should result in an equal number of JND indices

$$\text{mean } \Delta\text{JND/GL} = \frac{j(\text{L}_{\max}) - j(\text{L}_{\min})}{\text{GL}_{\max} - \text{GL}_{\min}}$$

  - DICOM 3.14 describes the DICOM GSDF and equations to convert between luminance and JND index

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Measuring Luminance Response

Gray Level	Measured Luminance	Combined Luminance (L')	JND Index	ΔJND/GL
0	1.32	1.42	86.91	2.26
15	2.60	2.70	120.88	2.35
30	4.55	4.65	156.12	2.36
		⋮		
225	278.19	278.29	619.63	2.40
240	355.31	355.41	655.37	2.38
255	452.26	452.36	691.03	2.38

$$\text{mean } \Delta\text{JND/GL} = \frac{j(\text{L}_{\max}) - j(\text{L}_{\min})}{\text{GL}_{\max} - \text{GL}_{\min}} = \frac{691.03 - 86.91}{255 - 0} = 2.37$$

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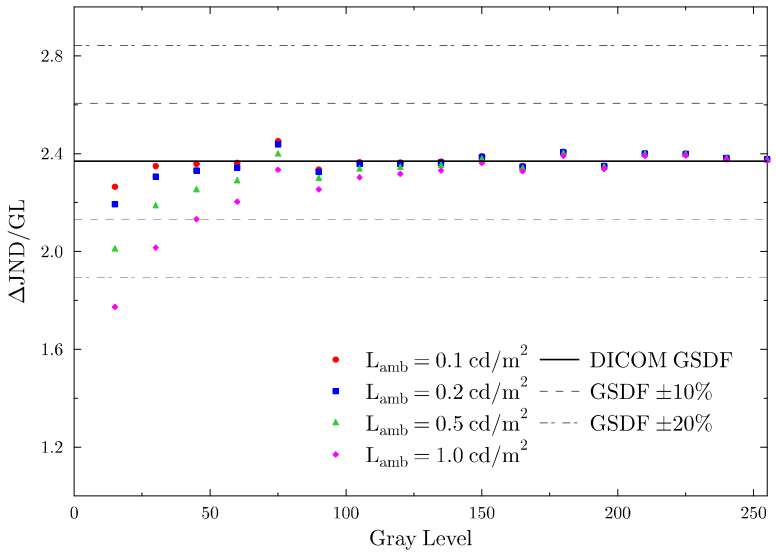
JND DICOM GSDF Analysis



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Luminance Response Function

- The DICOM GSDF adjusts the relative luminance change per JND along the GSDF curve
  - Decreases relative luminance change with increasing luminance
  - Compare the measured values to the ideal contrast response

$$\mathrm{dL/L\ \ per\ JND} = \frac{2\left(\mathrm{L}_i - \mathrm{L}_{i-1}\right)}{\left(\mathrm{L}_i + \mathrm{L}_{i-1}\right)\left(\mathrm{mean\ \ \Delta JND/GL}\right)\left(\mathrm{GL}_i - \mathrm{GL}_{i-1}\right)}$$

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Luminance Response Function

Gray Level	Combined Luminance (L')	JND Index	DICOM GSDF JND Index	DICOM GSDF Luminance	Measured dL/L per JND	DICOM GSDF dL/L per JND
0	1.42	86.91	86.91	1.42		
15	2.70	120.88	122.45	2.77	0.0175	0.0182
30	4.65	156.12	157.98	4.77	0.0149	0.0149
			⋮			
225	278.29	619.63	619.96	278.98	0.0070	0.0069
240	355.41	655.37	655.49	355.77	0.0068	0.0068
255	452.36	691.03	691.03	452.40	0.0068	0.0067

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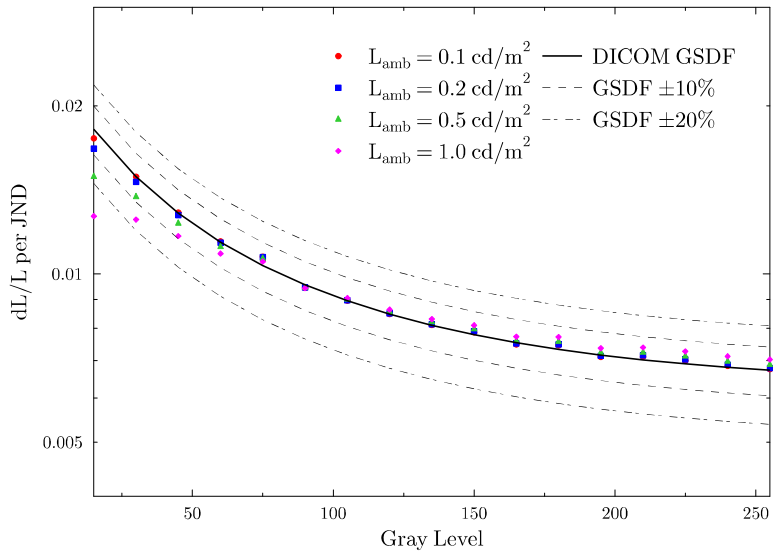
dL/L per JND DICOM GSDF Analysis



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Luminance Response Function

- More frequent qualitative verification
  - Test pattern based
    - TG270-sQC, TG270-pQC, TG18-QC
    - Verify contrast performance at multiples levels (especially in the darks)

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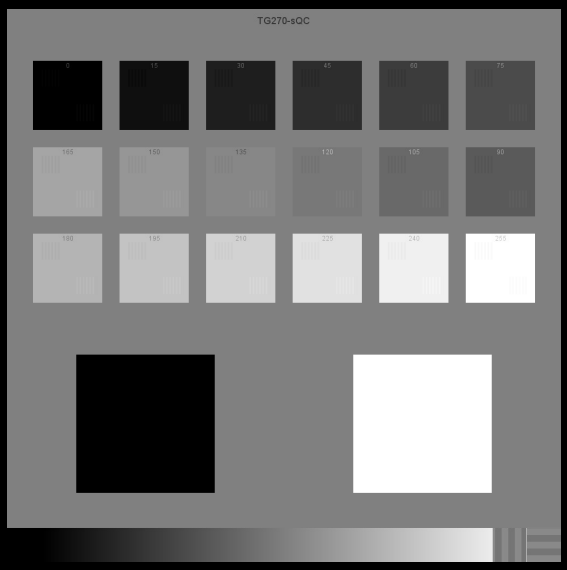
Qualitative Luminance Assessment

- TG270-sQC Pattern
  - Simple QC test pattern for routine checks by users, technologists, physicists



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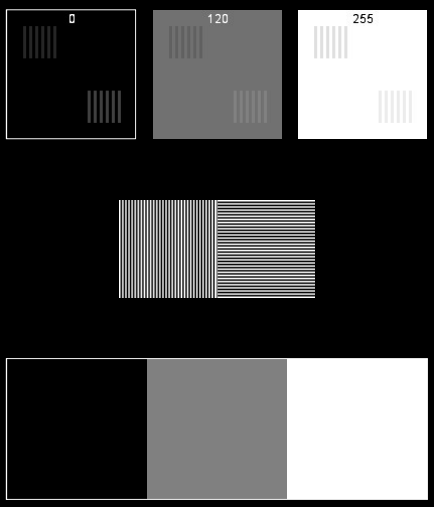
Qualitative Luminance Assessment

- Low contrast test patterns at multiple gray levels
- Spatial resolution verification
- Luminance patches for uniformity and min/max measurements



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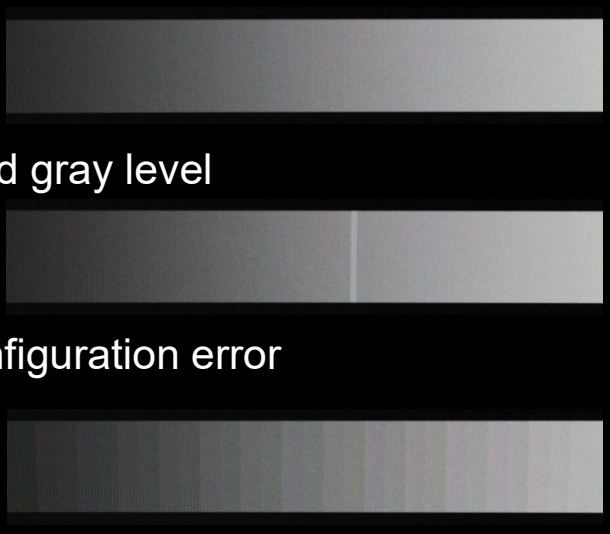
Qualitative Luminance Assessment

- No issues
- Mis-calibrated gray level
- Bit-depth configuration error



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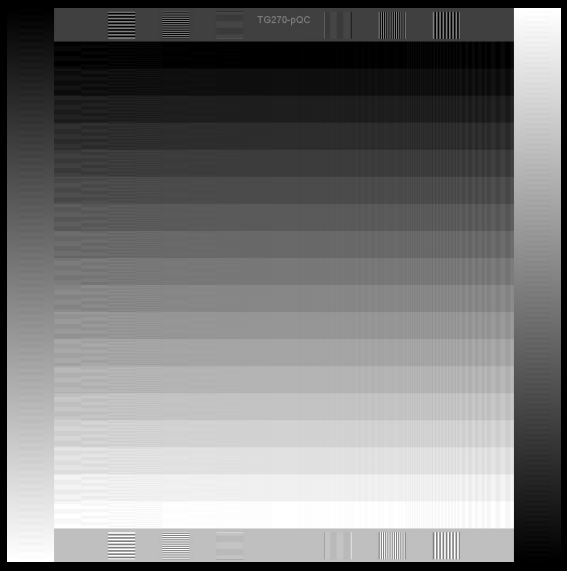
Qualitative Luminance Assessment

- TG270-pQC
  - Detailed QC pattern for physicists and other advanced users
  - Same gray levels as sQC, but with more contrasts and frequencies
  - Use as follow up to quantitative failures for context



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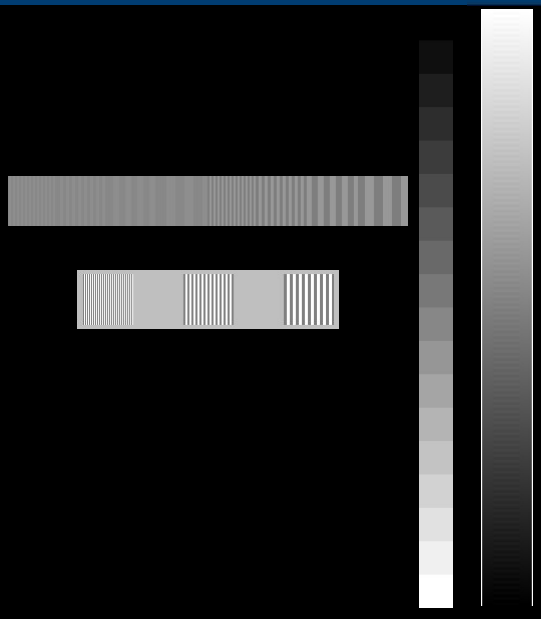
Qualitative Luminance Assessment

- Low contrast patterns at multiple gray levels
- Spatial resolution verification
- Luminance patches for 18-point measure
- Continuous ramp



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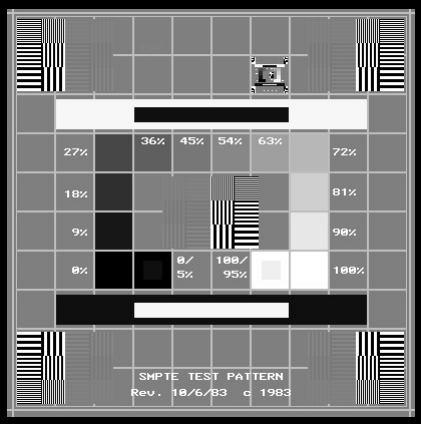
Qualitative Luminance Assessment

- SMPTE

"As a result of the pattern's grayscale insensitivity and CRT-specific features, this report considers the SMPTE test pattern deprecated for qualitative display evaluation in favor of either quantitative measurement or updated test patterns."



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Display Color (White Point)

- Color of the light output by the display throughout the grayscale
- Evaluate by measuring the color difference

$$\Delta = \sqrt{(u'_1 - u'_2)^2 + (v'_1 - v'_2)^2}$$

- Compared against
  - Other display
  - Standard illuminant (e.g., D65)
  - Full brightness (TG196 methodology)

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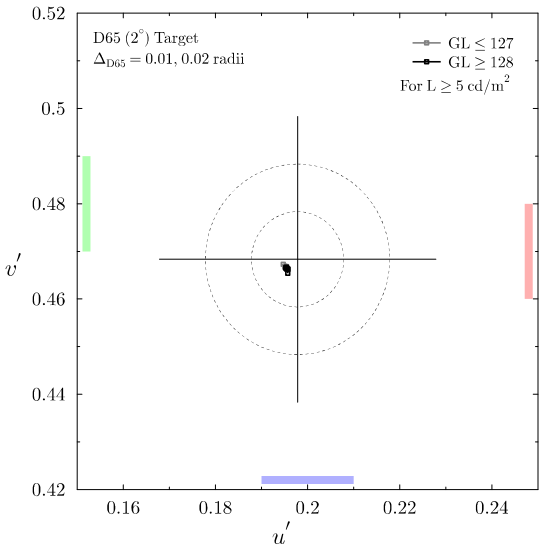
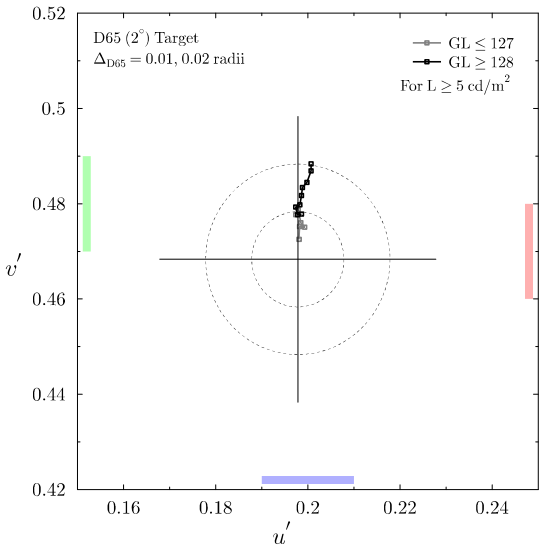
Display Color (White Point)





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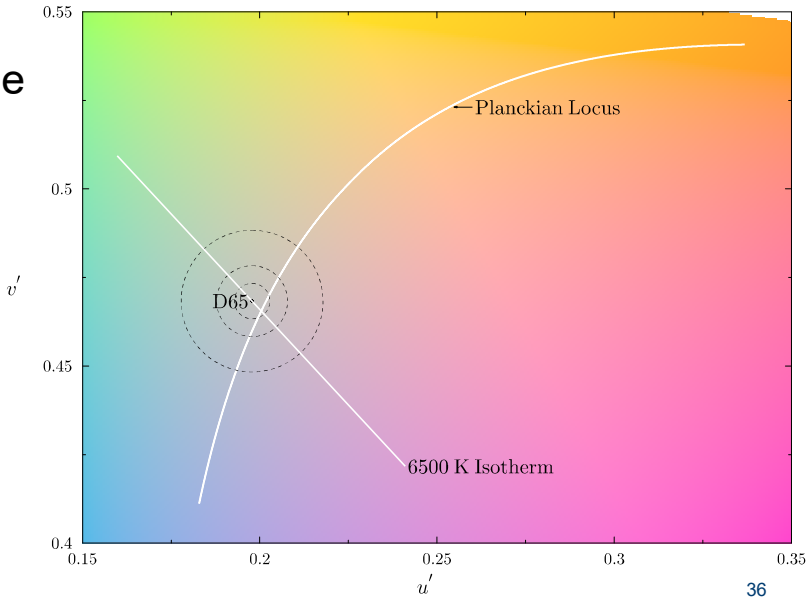
Display Color (White Point)

- Standard illuminant (e.g., D65) should be used instead of correlated color temperature (CCT)
  - CCT is defined as multiple points in color space
  - The maximum difference between the points is large



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Display Color (White Point)

- Comparing two displays

	Optimal Limit	Acceptable Limit
Same Workstation	$\Delta(u',v') \le 0.005$	$\Delta(u',v') \le 0.01$
Same Image Review Chain	$\Delta(u',v') \le 0.01$	$\Delta(u',v') \le 0.02$

- Comparing display to standard illuminant

	Optimal Limit	Acceptable Limit
Diagnostic Display	$\Delta_{D65}(u',v') \le 0.005$	$\Delta_{D65}(u',v') \le 0.01$
Non-diagnostic Display	$\Delta_{D65}(u',v') \le 0.01$	$\Delta_{D65}(u',v') \le 0.02$

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Display Uniformity

- Display uniformity evaluated both quantitatively and qualitatively
  - Quantitative assessment for global uniformity issues across display
  - Qualitative assessment for local non-uniformity
- Global uniformity is less important for clinical image review
  - Global non-uniformity is low frequency, likely not to be confused with anatomy
  - Local non-uniformities are common failures with flat panel displays, and are of similar size/contrast as image features

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Display Uniformity

- New methodology for evaluating global uniformity

$$\mathrm{LUDM} = \max\left(100 \times \frac{\left|\mathrm{L}_n - \mathrm{L}_{\mathrm{med}}\right|}{\mathrm{L}_{\mathrm{med}}}\right)$$

- Evaluates all measured points against the median value
  - Measure 9 points (corners, edges, center)
  - Median less affected by outliers
  - LUDM < 30% for passing. At 15%, clinical impact should be evaluated visually

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Display Uniformity

- Local non-uniformities
  - Mura
  - Bad pixels (stuck pixels)
  - Image burn-in
- Evaluated qualitatively
  - Must be done on site
  - Use multiple gray levels to evaluate

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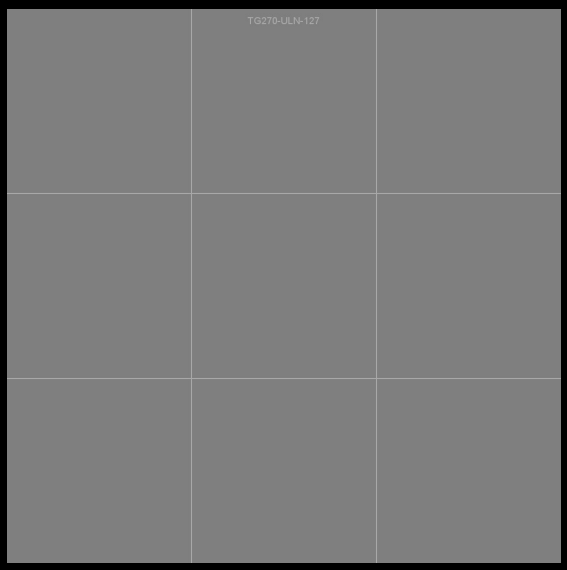
Display Uniformity

- TG270-ULN
  - Replaces the TG18 LN and UN pattern series
  - Generated for all 256 8-bit gray levels
  - Grid for quantitative uniformity measures



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Display Uniformity

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Display Noise

- Qualitative noise assessment for product evaluation
  - Test pattern (e.g., TG18-AFC) for pixel-by-pixel variation

  - Use clinical images for evaluation of clinical impact

- Unnecessary for routine display quality assurance

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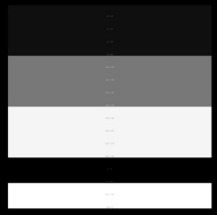
Display Temporal Performance

- Several scales of temporal performance
  - Long term (luminance stability, uniformity)
  - Medium term (warm up time, image retention)
  - Short term (response time, input latency)
- Qualitative evaluation of short term performance
  - Evaluate impact of display performance on the viewing of dynamic images
    - Fluoroscopy, ultrasound, etc.



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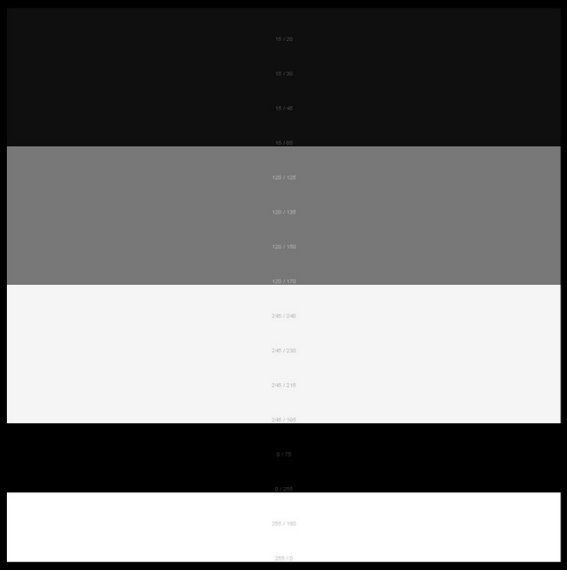
Display Temporal Performance

- TG270-TR Pattern
  - Temporal resolution pattern for qualitative evaluation of short-term temporal resolution
  - Use to help guide purchasing decisions, display usage, latency effects
  - Used with digital camera to capture frames



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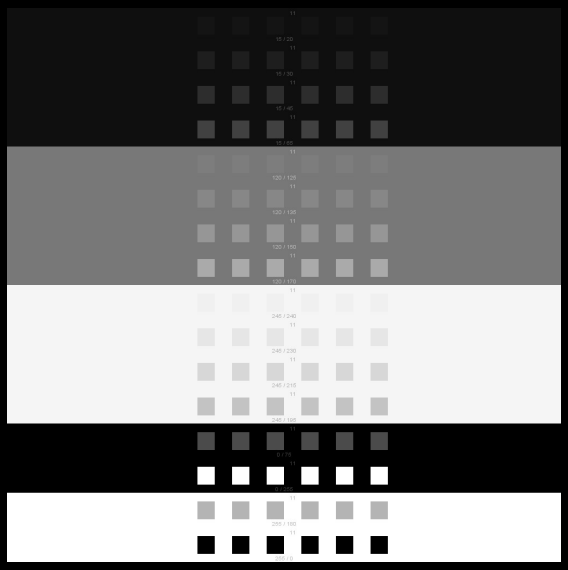
Display Temporal Performance



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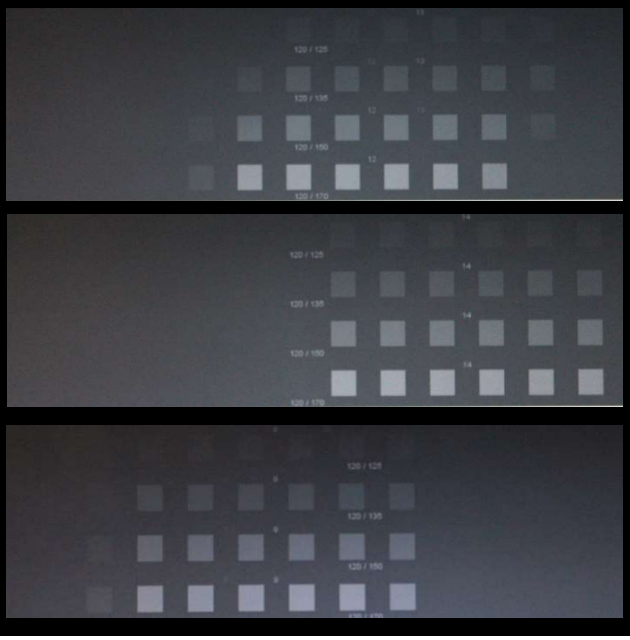
Display Temporal Performance



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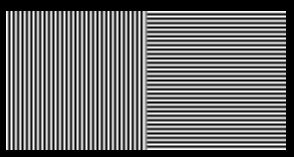
Display Spatial Resolution

- Modern flat-panel displays have discretized pixel structures, with little light dispersed into neighboring pixels
- Quantitative measures of spatial resolution unnecessary assuming:
  - Advanced pixel structure (e.g., IPS, VA)
  - Digital graphic interfaces (e.g., DVI-D, DisplayPort)
- Visual verification of driver settings to native display resolution
  - Magnifier, loupe is helpful



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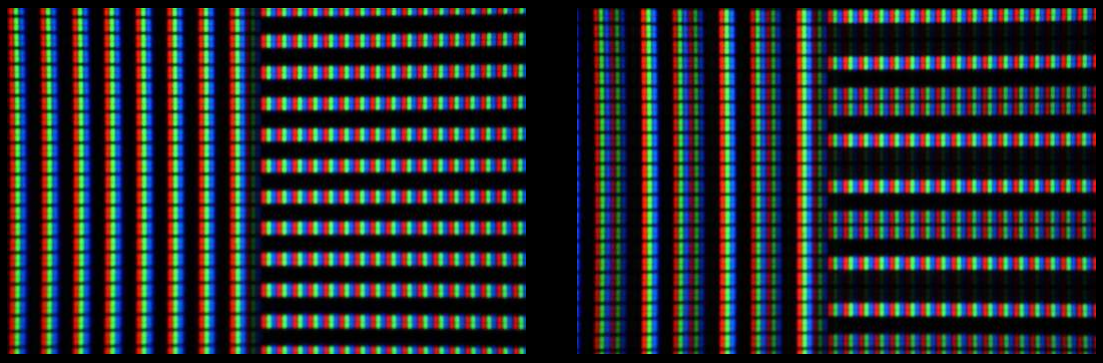
Display Spatial Resolution



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Display Spatial Resolution

- Pixel pitch selected depending on use and viewing distance
  - Minimize the appearance of pixel structure
  - Radiologist workstation recommended distance of 65 cm
    - Minimize eye strain
  - Other workstations often have larger viewing distance
    - Larger pixel pitch is acceptable

	Radiologist Workstation	Modality, Other Clinical Workstation
Pixel Pitch	< 210 µm	< 250 µm

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Display Quality Control Program

- Display quality control should leverage display technology
  - Automated routine QC tests
- Combine similar tests and analysis to minimize clinical impact
- Establish goals based on user requirements
  - One size does not necessarily fit all
- May be controlled by local regulations

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Testing Frequencies

- Table XII in TG270 report

Test	Diagnostic	Modality	Clinical Spec.	EHR
Qualitative Luminance Response	Quarterly	Quarterly	Annually	Annually
Qualitative Ambient Lum/Illum	Quarterly	Annually	Annually	Annually
Qualitative Uniformity	Quarterly	Annually	Annually	Annually
Qualitative Spatial Resolution	Quarterly	Annually	Annually	Annually
Quantitative L_{min} and L_{max}	Annually	Annually	Annually	Acceptance
Quantitative Luminance Response	Annually	Annually	Acceptance	Acceptance
Quantitative Color	Annually	Annually	Acceptance	Acceptance
Quantitative Ambient Lum/Illum	Annually	Acceptance	Acceptance	Acceptance
Quantitative Uniformity	Acceptance	Acceptance	Acceptance	Evaluation
Qualitative Noise	Evaluation	Evaluation	Evaluation	Evaluation
Qualitative Temporal Res	Evaluation	Evaluation	Evaluation	Evaluation
Diffuse Reflective Coeff	Evaluation	Evaluation	Evaluation	Evaluation

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Conclusion

- Display quality control is an important part of general quality control across all of medical imaging
- Awareness of current standards and guidelines is critical for appropriate quality control

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