





#### 1.0 - AAPM Task Group 18 report (OR-03)

#### Assessment of display performance for medical imaging systems

- Med. Phys. 32 .4., April 2005
- AAPM On-line Report 03, 2005
- 1. INTRODUCTION
- 2. OVERVIEW OF ELECTRONIC DISPLAY TECHNOLOGY
  - At the time of writing, CRT devices were in wide use.
  - · The report is thus emphasizes testing of CRT devices.
  - LCD devices are acknowledged as emerging technology

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#### 1.0 - AAPM Task Group 18 report (OR-03)

# Assessment of display performance for medical imaging systems Med. Phys. 32.4., April 2005

- AAPM On-line Report 03, 2005
- AAT M OII-line Report 05, 2005

3. GENERAL PREREQUISITES FOR DISPLAY ASSESSMENTS

- 1. Assessment Instrume
- 2. Test Patterns
- 3. Software
- 4. Initial Steps for Display Assessment

#### A large set of test images in DICOM and tiff format



# 1.0 - AAPM Task Group 18 report (OR-03)

Assessment of display performance for medical imaging systems

X Many of the tests

described are not

relevant for flat panel

devices (LCD and OLED)

Display noise is difficult

to measure in the field

and has not been

commonly used.

- Med. Phys. 32 .4., April 2005
- · AAPM On-line Report 03, 2005

#### 4. ASSESSMENT OF DISPLAY PERFORMANCE

- 1. X Geometric Distortions
- 2. Display Reflection
- 3. Luminance Response
- 4. Luminance Spatial and Angular Dependencies
- 5. X Display Resolution
- 6. ? Display Noise
- 7. X Veiling Glare
- 8. Display Chromaticity
- 9. X Miscellaneous Tests
- 10. Overall Evaluations

Visual, quantitative, and advanced tests with expected response



#### Assessment of display performance for medical imaging systems

- Med. Phys. 32 .4., April 2005
- AAPM On-line Report 03, 2005
- 5. ACCEPTANCE TESTING OF A DISPLAY SYSTEM
- 6. QUALITY CONTROL OF A DISPLAY SYSTEM

The recommended schedule of tests are CRT centric and thus no longer relevant.

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### 1.0 Adoption of TG18/IEC

TG18/IEC test methods and patterns have been widely adopted

- JESRA X-0093: "Quality Assurance (QA) Guideline for Medical Imaging Display Systems" formulated by Japan Industries Association of Radiological Systems (JIRA).
- <u>European Commission/EUREF</u>: EC "European guidelines for quality assurance in breast cancer screening and diagnosis" and EUREF "Monitor QC Test Patterns
- <u>DIN V 6868-57, PAS 1054</u>: "Requirements and Testing of Digital Mammographic X-ray Equipment".

# 1.0 Software for tg18 tests

# TG18/IEC test methods have been widely used by monitor suppliers. MediCal QA Web CFS WebSuite

Dome Cxtra

<ul> <li>Barco:</li> </ul>
----------------------------

- <u>Canvys</u>:
- Dome by NDSsi:
- Double Black Imaging:
- X CAL • Eizo: RadiCS
- <u>NEC</u>:
- GammaComp MD, OSD in some models

Diagnositic products now typically contain a bezel mounted photometer and can report monitor test results to central management systems.

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#### 1.0 DICOM calibration significance.

#### Krupinski 2009

Krupinski EA; Medical Grade vs Off-the-Shelf Color Displays: Influence on Observer Performance and Visual Search, Journal of Digital Imaging, Vol 22, No 4 (August), 2009

- statistically significant difference (p=0.047) between the medical-grade color display and the COTS color display.
  - Medical: Barco mean ROC Az=0.9101
  - COTS: Dell 2405 mean ROC Az=0.8424
- · The results of this study suggest that after just 1 year of use, the COTS display may degrade enough to negatively impact diagnostic and visual search performance.
- ... color monitors of any type need to be calibrated and evaluated on a regular basis.
  - once every 6 months for the first 2 years.
- every 4 months thereafter.

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# DISPLAY 1.5

#### DISPLAY 1.5 Recently published guidelines





#### 1.5 ACR Display 1 (b), JDI pg 43 - Display Technology

#### **1. Workstation Characteristics**

- 1(b) Liquid crystal display (LCD) technology
- "TN devices should not be used."
- "Several advanced pixel structures are now available to provide improved viewing angle performance;
  - Vertical Alignment (VA),
  - In-Plane Switching (IPS) .."
- "The viewing angle characteristics of any LCD device should be evaluated using contrast transfer test patterns prior to purchase."



#### 1.5 ACR Display 1 (b), JDI pg 43 - Display Technology

#### 1 (c) - Graphic Interface

- "The interface between the graphic controller and the LCD device should transfer the image data using a digital format such as
  - <u>DVI-D (either single-link or dual-link)</u> or
  - <u>Display Port.</u>"
- "... the graphic controller device driver should always be set to the native rows and columns of the LCD device."
- <u>DisplayPort</u> is a digital display interface standard put forth by the Video Electronics Standards Association (VESA) as a replacement to DVI.
- Supports 30 bit graphics (10 bits per channel)
- A high bandwidth (17.3 Gb/s, v1.2) supports quad HD displays
   3840 × 2160 × 30 bpp @ 60 Hz



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#### 1.5 ACR Display 1 (b), JDI pg 43 - Display Technology

#### 1 (d) - Image presentation size

"the interpolation of each displayed pixel, whether up- or down-sampling, should consider more than the closest four acquired pixel values."

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minification with noise reduction (low-pass filter).

- Alternatively, minification is often done using multi-scale

representations of the image with progressive presentation.

#### 1.5 ACR Display 2 (b), JDI pg 45

#### 2. Display Characteristics

2. (b) - Pixel Pitch and Display Size

2. (b) 1. - <u>Pixel Pitch</u> Recommended pitch for which the pixel structure is not visible (i.e. continuous tone)

2. (b) 2. - <u>Display Size</u> Recommended maximum size for which scene details remain in the visual field of view.

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#### 1.5 ACR Display 2 (b) 2, JDI pg 45 - Display Size

#### 2. (b) 2. - Display size:

"When interpreting images, the attention of the viewer is not limited to the center of the display but extends to the edges as well via peripheral vision."

Good visualization of the full scene is achieved when <u>the</u> <u>diagonal display distance</u>

is about 80 % of the viewing distance."

#### This corresponds to a viewing angle of 44 degrees.

Maintaining an arms length viewing distance minimizes eye fatigue since the resting point of vergence and of accommodation is about 2/3 meter.

ACR Display 1 (f) 5 – "The display devices should be placed to maintain the viewers at an arm's length from the display (i.e., about 2/3 m)."

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#### 1.5 ACR Display 2 (b) 2, JDI pg 45 - Display Size

- Radiologists at workstations with multiple monitors are typically at a viewing distance of about 30 inches.
- Monitors are commonly about 22" in size (i.e. ~3/4th).







#### 1.5 ACR Display 2 (b) 2, JDI pg 45 - Display Size

# For a specific viewing distance the diagonal dimension should be about 3/4th of the viewing distance (42°). • THX<sup>1</sup> home entertainment recommendations.

<u>Task</u>	Viewing Distance Inches (cm)	Diagonal Size Inches (cm)	
Small Handheld	10 (25)	7.5 (19)	
Tablet handheld	15 (38)	11 (29)	
Laptop	20 (51)	15 (38)	
Workstation	30 (76)	22 (57)	

The diagonal size of 22.5 inches for the workstation is similar to a traditional 14" x 17" radiographic film, 22.0"

1 - http://www.thx.com/consumer/home-entertainment/home-theater/hdtv-set-up

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1.5 ACR Display 2 (b) 2, JDI pg 45 - Display Size

- 21 inch (diagonal) monitors with a field of 32 x 42 cm provide an effective size at a normal distance (30", 76 cm).
- 30 inch (diagonal) wide format (16:9) monitors provide effective image size when split into two frames of 20" size.



<u>Eizo GX1030</u> 30" diagonal, 4096 x 2560, 0.158 mm pitch

Eizo GX540 dual 21" diagonal, 2048 x 2560, 0.165 mm pitch

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#### 1.5 ACR Display 2 (b) 2, JDI pg 45 - Display Pitch

#### 2. (b) 1. - Pixel pitch:

"For monitors used in <u>diagnostic interpretation</u>, it is recommended that the pixel pitch be about 0.200 mm and not larger than 0.210 mm."

"For this pixel pitch, individual pixels and their substructure are not visible and images have continuous tone appearance."

"No advantage is derived from using a smaller pixel pitch since higher spatial frequencies are not perceived."

Retina Display is a brand name used by Apple for liquid crystal displays that, according to Apple, have a high enough pixel density that the human eye is unable to notice pixelation at a typical viewing distance. (http://en.wikipedia.org/wiki/Retina\_Display)

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#### 1.5 ACR Display 2 (b) 2, JDI pg 45 - Display Pitch

For pixel pitches that are too large for the viewing distance used, pixel structure details appear as a texture pattern.

















#### 1.5 ACR Display 2 (b) 2, JDI pg 45 - Display Pitch

- The visual spatial frequency limit and associated pixel size can be defined as that for which Cs = 10% of maximum (100 cd/m<sup>2</sup>).

The pixel size of a display system that matches the resolving power of the human eye depends on the observation distance.

5) 7.5 (19 8) 11 (29	e) 78 e) 117	327 218
8) 11 (29	9) 117	218
1) 15 (38	8) 156	163
6) 22 (57	7) 233	109
	1) 15 (38 6) 22 (57 ycle are assumed b	1)         15 (38)         156           6)         22 (57)         233           ycle are assumed based on the Nyquis

No advantage is gained by using smaller pixel sizes.

	$P_{p} = D_{V} / 3255$	=> 3255 = 2 x 57.3 x 28.4	Note: values are	
	P <sub>n</sub> = 0.307 D <sub>v</sub>	=> D <sub>v</sub> in meter & P <sub>p</sub> in mm	consistent with	
AAPM 2014			Apple retinal display.	8



#### 1.5 ACR Display 2 (b) 2, JDI pg 45 - Display Pitch

- The recommended pitch of 0.200 mm results in continuous tone display (i.e. no visible pixel structure) for viewing distances larger than 65 cm.
- At HFHS, most radiologist read at a distance slightly larger than 65 cm.





1.5 ACR Display 2 (b) 2, JDI pg 45 - Display Pitch

#### 2. (b) 1. - Pixel pitch: (continued)

"Monitors used by technologists and clinical care staff are often not viewed at a desk, and the viewing distance is larger than for diagnostic interpretation."

"For these monitors, a pixel pitch of 0.250 mm (not larger than 0.300 mm) is appropriate."

#### 2. (b) 1. - Pixel pitch: (continued)

"For the presentation of images with acquired detector element size different from the pixel pitch, zoom and pan display features should be used rather than moving closer to a display."

"Since the human visual system has maximum contrast sensitivity at about 0.5 cycles/mm, image zoom with interpolation can often reveal subtle detail not seen at true size."

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#### 1.5 ACR Display 2 (b) 2, JDI pg 45 - Display Pitch

- Image presentation is done with interactive zoom and pan to reveal full detail in areas of interest.
- · An arms length viewing distance is maintained.







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# 1.5 ACR Display 2 (a), JDI pg 44 - Luminance Response

#### 2. (a) 3. - Maximum Luminance (Lmax)

"The perceived contrast characteristics of an image depend on the ratio of the luminance for the maximumgray value (Lmax) to Lmin. This is the luminance ratio (LR)"

#### 2. (a) 4. -Luminance Ratio(LR)

- "The LR must be large for good image contrast; however, an excessively large LR will exceed the range of the adapted human visual system."
- "A LR of 350 is effective, which is equivalent to a film OD range from 0.20 to 2.75."
- "LR should always be greater than 250."











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#### 1.5 ACR Display 2 (a), JDI pg 44 - Luminance Response

se 350:1 → .1 to 2.65 OD 650:1 → .1 to 2.90 OD

- Medical images are effectively displayed using a luminance ratio (LR) of about 350:1.
- Images prepared for range of 350 that are display on a monitor with larger LR have poorly perceived contrast in dark regions.
- To improve contrast, use window level.

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# 1.5 ACR Display 2 (a), JDI pg 44 - Luminance Response

Summary						
Recommended Luminance Response Specifications						
Diagnostic Other						
L <sub>min</sub> :	1.0 cd/m <sup>2</sup>	0.8 cd/m <sup>2</sup>				
L <sub>max</sub> :	350 cd/m <sup>2</sup>	250 cd/m <sup>2</sup>				
Luminance ratio (LR)	~350 (>250).	~350 (>250).				
Luminance response	GSDF	GSDF				
GSDF tolerance	10%	20%				
Pixel pitch	210 mm	~250 (<300) mm				

- L<sub>amb</sub> less than 1/4th of L<sub>min</sub>.
- Diagonal size of 20-24 inches with 3:4 or 4:5 aspect
- D65 (6500 C) white point

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DISPLAY 2.0

# DISPLAY 2.0 Where do we need to go in the coming decade?

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#### 2.0 Clinical Medical Physics

#### Persons with diagnostic radiology clinical responsible need to understand whether they are responsible for the quality of images presented to all individuals:

- Technologists at modality stations.
- Radiologists interpreting studies.
- Clinical specialist managing patients (ED, Ortho,..).
- EHR distributed health records.

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#### 2.0 Clinical Medical Physics

#### If the answer is yes:

- · Display technology purchasing recommendations.
- Acceptance testing.
- QA program management.

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### 2.0 Clinical Medical Physics

#### If the answer is yes:

- Display technology purchasing recommendations.
  - IT staff (Radiology or Enterprise) are generally not well informed about display technology or OS display configurations.
  - · Professional 'enthusiasts' are often influenced by popular trends.
  - Inventory management services need to track 'moving' monitors and check OS configuration settings.

#### 2.0 Clinical Medical Physics

#### If the answer is yes:

- Acceptance testing.
  - Purchasing contracts need to have a clear understanding of specifications (LR, uniformity, defects, ...).
  - Requirements for advanced quantitative tests.
  - Electronic documentation of accepted performance.

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#### 2.0 Clinical Medical Physics

#### If the answer is yes:

- QA program management.
  - Delegation of test responsibility.
  - · Automated reporting of results.
  - Specific criteria for repair/replacement.

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# 2.0 Display QA

#### Quality Assessment (QA)

- · We are beginning to see requirements for display QA.
- The New York State Department of Health QA guide for Primary Diagnostic Monitors is an example;
  - <u>Biweekly</u> clean & visual check.
  - Quarterly Lmax & GSDF verification
  - <u>Annual</u>;
    - Licensed medical physicist (with photometer)
    - Luminance (Lmax) and Luminance Ratio (LR)
    - Viewing conditions
    - Review QC documentation
    - Document findings and recommendations.
- ACR accreditation, JCAHO(?)

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#### 2.0 Display QA

#### Quality Assessment (QA)

- AAPM recommendations are needed for Display QA.
  - Modality Displays.
  - Radiologists Display.
  - Clinical Specialists.
  - EHR Displays.
- A new AAPM task group has been proposed for Display QA.
- This is presently being considered by the imaging physics committee (IPC) of the Science Council (SC).
- Alternative consideration is being discussed by the professional guidelines sub-committee of the Professional Council (SC).

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#### 2.0 Calibration & QA software

#### Calibration & QA software

- In the past, display software was provided by monitor suppliers for use with their display devices.
- Current needs:
  - Calibration of professional/enterprise class monitors.
  - QA for both medical grade and professional/enterprise monitors

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# 2.0 Calibration & QA software

- <u>Verilum</u> calibration software created by Image Smiths.
   -> NO longer available <-</li>
- PerfectLum (QUBYX Ltd, Nice France):
  - Primarily designed for medical imaging.
  - · Support for Windows 7 and 8 (32 & 64 bit) and for Mac OS.
  - Luminance and color calibration.
  - Display verification and centralized QA.
  - Recent FDA approval for Dell U3014 bundle (30" quad HD)





2.0 Calibration & QA sof	tware - pd	<u>.</u>	EDID Profile (getEDID)		
Workstation	<u>Profile</u>	Hostnan Date: CPU_0: CPU_1:	e: HFH_PD_3_R4K 20130125 Intel(R)Xeon(R)CP Intel(R)Xeon(R)CP	6 UE5335@2.00GHz UE5335@2.00GHz	
Adapter display ID	DISPLAY2	DISPLAY3	DISPLAY1	DISPLAY4	
Adapter string	RealVisionVR/MD	RealVisionVR/MD	NVIDIAFX4600	NVIDIAFX4600	
Monitor Descriptor	MD21GS-3MP	MD21GS-3MP	DELL 2007FP	DELL 2007FP	
Extended S/N (L/R)	79E00741YW	79E00741YW	G324H95I2HDL	G324H06I2NV	
Week of manufacture	38	38	21	25	
Year of manufacture	2007	2007	2009	2010	
Max. horizontal image size (mm)	432	432	367	367	
Max. vertical image size (mm)	324	324	275	275	
Native vertical resolution	1536	1536	1200	1200	
Current vertical resolution	1536	1536	1200	1200	
Native horizontal resolution	2048	2048	1600	1600	
Current horizontal resolution	2048	2048	1600	1600	
Est. hor. pixel size (microns)	210.9	210.9	229.4	229.4	
Est, ver, pixel size (microns)	210.9	210.9	229.2	229.2	



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# 2.0 Color Display

Color presentation quality important for:

- Digital Pathology
- Surgery
- Dermatology
- Opthamology
- Medical Photography
- ...





#### 2.0 Color Display

# In 2013, after the ICC/FDA Color Summit, the ICC formed a Medical Imaging Working Group (MIWG, www.color.org)

- Badano et. al., Consistency and Standardization of Color in Medical Imaging: a Consensus Report, J Digit Imaging, published on line 09-July-2014.
- "This article summarizes the consensus reached at the Summit on Color in Medical imaging held at the Food and Drug Administratian (FDA) on May 8– 9, 2013, co-sponsored by the FDA and ICC (International Color Consortium)."



### 2.0 Color Display

sRGB, aRGB, and soon dRGB

AAPM TG196 (color display) is working with the ICC MIWG to define a medical ICC profile with DICOM GSDF luminance response.





#### 2.0 Handheld Display

- Mobile MIM Software
- GE Healthcare Centricity
- Calgary Scientific
- Osirix iPhone/iPad
- ...



The utility and performance of modern handheld devices has led to widespread interest in their use for image viewing. Current thinking is that handheld devices are secondary devices and not intended to replace full workstations.

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#### 2.0 Handheld Display

Investigators from the FDA CDRH Lab recently reported: "...handheld displays can have improved spatial resolution and noise characteristics compared to medical workstation displays .."

"However, ..the displayed image contrast is different from images radiologists and medical staff are familiar with viewing on their workstation displays."



Yamazaki A, Liu P, Cheng W, Badano A; Image Quality Characteristics of Handheld Display Devices for Medical Imaging, PLOS one, vol 8, No 11, Nov. 2013.

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#### 2.0 Handheld Display

- Current handheld devices (Apple OS, Android) do not expose the graphic image pipeline.
- Individual applications must device methods to adjust the presentation.







