A comparison between medical-grade liquid crystal display (LCD) and iPad color imaging

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Aims and objectives

The aim of this study was to evaluate the performance of colored monitors on which medical colored image was displayed, comparing medical-grade LCD and the iPad. To evaluate the performance of the monitor, we measured luminance [1], chromaticity diagram[2], modulation transfer function (MTF) [3], and noise power spectrum (NPS) [4].

Methods and materials

Monitor and Tablet PCs

A medical-grade LCD (RX220, Eizo Corp., Ishikawa, Japan) was used for this experiment, and grayscale calibration was adjusted to grayscale standard display function (GSDF). The grayscale curves of the GSDF using calibration software (RadiCS, Eizo Corp., Ishikawa, Japan) were used and a sensor for the monitor (UX1 Sensor, Eizo Corp., Ishikawa, Japan) on the basis of the grayscale standard display function curve of digital imaging and communications in medicine (DICOM) part 14 [1]. The iPads (Apple Inc., Cupertino, CA) used were of the first generation (iPad-1) and fourth generation (iPad-4). The manufacturer-specified characteristics of the monitor and tablet PC are summarized in Table 1.

Creating Measurement Images

The image for measurement of color patterns and MTF were made with Photoshop CS6 (Adobe Systems Inc., San Jose, CA). Each luminance and NPS color image consisted of a square of 450×450 pixels, and red, blue, and green color patterns. The black (TG18-LN8-01) and white (TG18-LN8-18) image is the TG18-LN pattern[5].

The MTF image of bar patterns consists of five segments, including five bars with 1-, 2-, 3-, 4-, and 5-pixel widths, and two uniform areas for measuring the bar and the background intensity located at just over and under the bar patterns. The frequency corresponding to each segment has a 1, 0.5, 0.333, 0.25, and 0.2 Nyquist frequency of the display, respectively [3],[6]. As for the color of the MTF image, the background is black, and the color bar patterns are white, red, blue, and green.

Luminance Measurement

In the three displays (medical-grade LCD, iPad-1, and iPad-4), luminance performance was measured using a CS-100A luminance and color meter (Konica Minolta Holdings Inc., Tokyo, Japan) pointed at the monitor center in a horizontal direction. The TG18-LN
pattern [5] and color patterns were placed at the display center, and the distance between the luminance meter and the display center was set at 100 cm on axis. The values of luminance and chromaticity for each pattern were determined by the averages of five measurements, all of which were performed in a darkroom (ambient lighting of zero lux). The luminance data were analyzed according to the AAPM TG18 methodology [5]. The chromaticity diagram was created with the chromaticity values of color pattern images.

**MTF and NPS Measurement**

The MTF and NPS were measured referring to a MTF and NPS image method proposed by Ichikawa et al. [3; 4; 6]. In the three displays (medical-grade LCD, iPad-1, and iPad-4), the MTF and NPS images were captured by a high-resolution single-lens reflex (SLR) digital camera (D90, Nikon Corporation, Tokyo, Japan) used with a close-up lens (Micro-Nikkor 60 mm F2.8D, Nikon Corporation, Tokyo, Japan) positioned at the monitor center in a horizontal direction. The camera has a Complementary Metal Oxide Semiconductor (CMOS) image sensor array with 4288 × 2848 elements and a contrast resolution of 12 bits. Image acquisition was performed five times, and the data were averaged.

The inherent noise characteristics of the medical-grade LCD and iPads used an NPS. A trend removal was applied to the averaged 256-point profiles by second-order polynomial fitting to correct for the background-luminance trend. We calculated NPS in the horizontal and vertical directions using a one-dimensional fast Fourier-transform (FFT) method from the background corrected profiles. Hanning window processing was applied to the FFT values to reduce spectral leakage errors.

**Images for this section:**
## Comparison of Liquid Crystal Display (LCD) and Tablet Personal Computers (PC)

<table>
<thead>
<tr>
<th>Type of LCD</th>
<th>medical-grade LCD</th>
<th>Tablet PC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Abbreviation</td>
<td>LCD</td>
<td>iPad-1</td>
</tr>
<tr>
<td>Manufacture</td>
<td>Eizo</td>
<td>Apple</td>
</tr>
<tr>
<td>Product Name</td>
<td>RX220</td>
<td>first-generation iPad</td>
</tr>
<tr>
<td>Screen Size (inch)</td>
<td>21</td>
<td>9.7</td>
</tr>
<tr>
<td>Matrix</td>
<td>1600 × 1200</td>
<td>1024 × 768</td>
</tr>
<tr>
<td>Contrast Ratio</td>
<td>1000 : 1</td>
<td>-</td>
</tr>
<tr>
<td>Max Luminance (cd/m²)</td>
<td>900</td>
<td>-</td>
</tr>
</tbody>
</table>

Table 1
Results

Fig. 1 on page 5 shows a comparison of the grayscale curve among the three displays (medical-grade LCD, iPad-1, and iPad-4). The luminance response of the iPad-4 was almost the highest of the three. However, medical-grade LCD was highest in the three displays from Pattern 1 to 3 (TG18-LN8-01 to 03). Specifications for medical-grade liquid crystal display (LCD), along with first generation (iPad-1) and fourth generation (iPad-4) iPads (Apple), are given in Table 1.

Fig. 2 on page 6 shows a comparison of the contrast response the three displays (medical-grade LCD, iPad-1, and iPad-4). The LCD fits DICOM curve, but two iPods do not fit it. Because iPads cannot do calibration with GSDF.

Fig. 3 on page 7 shows a comparison of the chromaticity diagram among the three displays (medical-grade LCD, iPad-1, and iPad-4). As for the chromaticity diagram, the area of iPad-4 was slightly larger than that of LCD. The characteristic of the chromaticity diagram was similar pattern to the iPad-4 and LCD. On the other hand, the area of iPad-1 was most narrow.

Fig. 4 on page 8 shows a comparison of the MTF among the three displays (medical-grade LCD, iPad-1, and iPad-4), using monochromic bar-pattern. The MTF was highest for iPad-4, followed by iPad-1 and LCD.

Fig. 5 on page 9 shows a comparison of the MTF among color images (red, blue, and green), using colored bar-pattern. The MTF of green was the highest among three monitors. The MTF of each color was similar, regarding LCD.

Fig. 6 on page 10 shows a comparison of the NPS of a black image among the three displays (medical-grade LCD, iPad-1, and iPad-4). The NPS of iPad-4 was the highest, followed by LCD, and iPad-1.

Fig. 7 on page 11 shows a comparison of the NPS among color images (red, blue, green, and white). Among the NPS of different colors, white was the highest for all three monitors. There was no difference not only among the three displays, but also among three colors in each monitor.

Images for this section:
**Fig. 1:** This graph showed the comparison of luminance response among three monitor types.
**Fig. 2:** This graph showed the comparison of contrast response among three monitor types.
Fig. 3: This graph showed the comparison of chromaticity diagram among three monitor types.
Fig. 4: This graph showed the comparison of modulation transfer function (MTF) among three monitor types. The bra pattern color is black.
Fig. 5: This graph showed the comparison of modulation transfer function (MTF) among bar pattern colors (red, blue, and green).
**Fig. 6:** This graph showed the comparison of noise power spectrum (NPS) among three monitor types. The color pattern is black.
**Fig. 7:** This graph showed the comparison of noise power spectrum (NPS) among color patterns (red, blue, green, and white).
Conclusion

The iPad-4 has the better luminance, chromaticity, MTF, and NPS than medical-grade LCD or iPad-1. With these excellent characteristics, it might be available for the diagnosis use of the color image with iPad-4 in clinical situation. However, further studies would be warranted to elucidate the role in clinical situation, using actual clinical images, for example on the receiver operating characteristic (ROC) analysis by several radiologists.

Personal information

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References