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INFLUENCE OF MONITOR LUMINANCE AND ROOM ILLUMINATION ON SOFT-COPY READING EVALUATION WITH ELECTRONICALLY GENERATED CONTRAST-DETAIL PHANTOM: COMPARISON OF CATHODE-RAY TUBE MONITOR WITH LIQUID CRYSTAL DISPLAY

HIDEYUKI MURAMOTO[1], KAZUHIRO SHIMAMOTO[2], MITSURU IKEDA[2], KAZUYUKI KOYAMA[3], HIROMICHI FUKUSHIMA[4] and TAKEO ISHIGAKI[4]

[1] Department of Radiology, Kasugai Municipal Hospital, 1-1-1 Takagi-cho, Kasugai Aichi 486-8510, Japan
[2] Department of Radiological Technology, Nagoya University School of Health Sciences, 1-1-20 Daikominami, Higashi-ku, Nagoya 461-8673, Japan
[3] Faculty of Radiological Technology, Fujita Health University School of Health Sciences, 1-98 Dengakugakubo, Kutsukake-cho, Toyoake, Aichi 470-1192, Japan
4) Department of Radiology, Nagoya University School of Medicine, 65 Tsuruma-cho, Showa-ku, Nagoya 466-8560, Japan

ABSTRACT

The influence of monitor brightness and room illumination on soft-copy diagnosis by both cathode-ray tube (CRT) monitor and liquid crystal display (LCD) was evaluated and compared using a contrast-detail phantom. Nine observers (7 radiologists and 2 radiological technicians) interpreted six types of electronically generated contrast-detail phantom images using a 21-inch CRT (2,048×2,560) and a 21-inch LCD (2,048×2,560) under 6 kinds of viewing conditions, i.e. monitor brightness of 330 cd/m^2 or 450 cd/m^2, and room illumination of 20, 100 or 420 lux at the center of the display. Observers were requested to determine the visible borderline of the objects. Between 330 cd/m^2 and 450 cd/m^2, no significant difference in the visible area was found under any of the three lighting conditions. However, in two low-contrast phantom images, the visible area on the LCD was significantly larger than that on the CRT, independent of both monitor brightness and room illumination. ($p<0.05$). The effect of room illumination was not significant, suggesting that the use of LCD at high room illumination is acceptable.

Key Words: Observer performance, Cathode-ray tube (CRT), Liquid crystal display (LCD), Image interpretation, Contrast-detail phantom

INTRODUCTION

Liquid crystal display (LCD) is now widely used as a replacement for cathode-ray tube (CRT) monitors in clinical soft-copy reading.[1-4] However, observer performance of monitor diagnosis is affected by several factors such as monitor brightness and room lighting.[5,9] In addition, the characteristics of LCD, such as viewing angle dependence on image contrast, are quite different

Corresponding author: Kazuhiro Shimamoto,
Department of Radiological Technology, Nagoya University School of Health Sciences, 1-1-20 Daikominami, Higashi-ku, Nagoya 461-8673, Japan

from those of CRT, and the best reading environment for LCD may not be the same as that for CRT.[4] Whether using LCD or CRT, it is essential to establish the appropriate environment for soft-copy reading. Furthermore, monitor degradation, which is evidenced by a decrease in the maximum monitor brightness, is important from the viewpoint of quality control of the monitor,[7-9], and the influence of monitor brightness on observer performance should also be clarified. Accordingly, in this study, to compare CRT and LCD we have evaluated the combined effect of monitor brightness and room illumination on image perception performance using a contrast-detail phantom.

MATERIALS AND METHODS

A 21-inch CRT monitor with a resolution of 2,048×2,560 and a maximum luminance of 600 cd/m^2 (MDG521, Barco, Belgium) and a 21-inch LCD with a resolution of 2,048×2,560 and a maximum luminance of 700 cd/m^2 (G51, Nanao, Tokyo) were used for the study. As for the LCD, two types of displays, i.e., with and without the protective cover, were prepared for comparison. The monitor luminance was measured and calibrated at 330 cd/m^2 and 450 cd/m^2. The calibration software used was Barco's Medical Pro version 2.02 for CRT and Data-Ray's DRKAL calibration deluxe version 3.01 for LCD. The room illumination was set at 20, 100, and 420 lux at the monitor center (20, 120 and 480 lux at the console desk, respectively) using a digital illuminance meter (IM-3, TOPCON, Tokyo). Accordingly, under a total of six viewing conditions (the combination of two kinds of monitor brightness level and 3 kinds of room illumination level), reading sessions were performed for each monitor. The DICOM viewing software was RS252DV (Konica-Minolta Ltd., Tokyo).

According to traditional contrast-detail methods, six phantom images with 2,500 (50×50) square targets on each image were generated as DICOM images by the computer (Figure 1). Each of these images had a 12-bit contrast resolution scale (0 = white, 4,096 = black) per pixel, and 50 rows and 50 columns of square targets; each row had targets of the same size with contrast increasing from left to right, and each column had targets of the same contrast with size increasing from top to bottom. In all six test images, the target sizes were from 1 to 50 (a step of 1) pixels. As shown in Table 1, the contrasts between the target and background were different among the six phantom images. For example, the target contrasts in the first image ranged from 1 to 50 (a step of 1) darker than the background, denoted as the pixel value difference between the target and the background; the target contrasts in the second image ranged from 1 to 50 (a step of 1) brighter than the background. The pixel value of the background with the targets darker than the background was 1,000, and that with the targets brighter than the background was 1,500.

Nine observers (seven radiologists and two radiological technicians) interpreted the phantom images. All observers had clinical over 10 years of experience. The order of 6 viewing conditions was randomized for all observers, each of whom interpreted the six phantom images at each reading session. The order of the six phantom images was also randomized.

At each reading session, observers were requested to determine the borderline beyond which the square target was no longer visible, and to draw this line directly using a marker on a transparent overlay attached to the monitor. This borderline was then traced on a white paper of the same size as the overlay. The weight of the paper to be used for the tracing was measured using an analytical balance. The paper was then cut along the borderline, and its weight was also measured. Finally, the ratio of the weight of the cut paper to that of the whole paper was calculated. Because this weight ratio is correlated with the detection rate of the targets in each

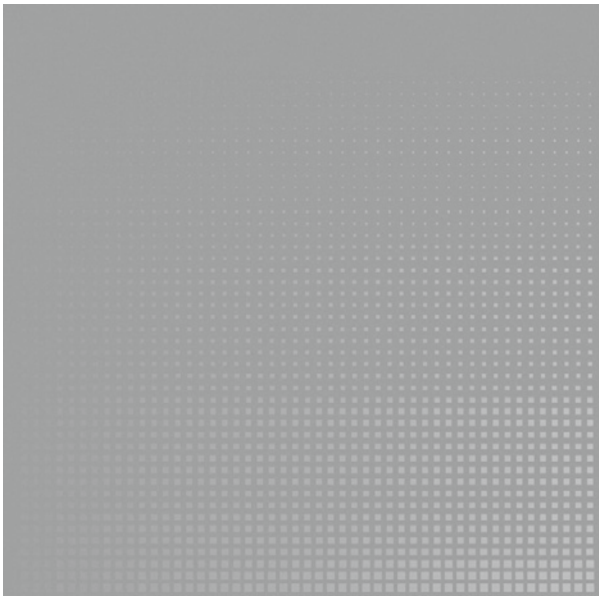

Fig. 1 Phantom image
Phantom image had 12-bit contrast resolution scale (0 = white, 4,096 = black) per pixel, and 50 × 50 columns of square targets. Number of phantoms corresponds to that in Table 1.

Table 1 Target contrast for each phantom image.

Number of phantoms	Background*	Target contrast*		
		Step	Minimal value	Maximum value
1	1000	1 darker	1	50
2	1500	1 brighter	1	50
3	1000	5 darker	5	250
4	1500	5 brighter	5	250
5	1000	10 darker	10	500
6	1500	10 brighter	10	500

*Each value indicates digital value at 12-bit contrast resolution scale (0=white, 4,096=black) per pixel.

test image, we used it as the index of image-perception performance. For statistical analysis comparing the image-perception performance among the 6 viewing conditions, we used two-way analysis of variance (ANOVA) with no repeated measures. The significance level was P less than 0.05.

RESULTS

Tables 2 and 3 summarize the detection rates of the targets under the six viewing conditions. For each phantom, no significant differences were found in the detection rates of the targets

Table 2 Average area under visible borderline of phantom image with monitor luminance of 450 cd/m^2.

Phantom	Room illumination (lux)	CRT (%)	LCD(-) (%)	LCD(+) (%)
	20	60.40	74.13	74.02
1*	120	60.17	74.79	75.21
	480	59.90	75.79	74.21
	20	63.52	75.79	74.82
2*	120	67.05	76.81	76.59
	480	62.44	76.21	75.53
	20	82.34	83.37	83.15
3	120	82.93	82.90	83.26
	480	82.95	82.29	83.67
	20	80.71	85.56	85.56
4	120	82.10	86.22	85.74
	480	80.90	86.24	86.11
	20	79.97	79.92	83.02
5	120	80.00	76.83	83.19
	480	80.37	75.37	83.10
	20	86.15	89.67	90.45
6	120	87.19	90.30	88.32
	480	85.98	89.85	90.12

For LCD, (–) = without protective cover; (+) = with protective cover.
*In phantoms #1 and #2, significant difference was found between CRT and LCD.

among the three lighting conditions, nor were any significant differences found to exist between 450 cd/m^2 and 330 cd/m^2. In both CRT and LCD readings, some of the six phantom images showed relatively higher target-detection rates under dark room conditions, whereas the others showed relatively better in a bright room. Among the six phantom images, no tendency was found implicating the influence of room lighting.

However, for two of the six phantom images with low-contrast targets (phantom #1 and #2), ANOVA showed that the detection rates of LCD were significantly better than those of CRT at both 450 cd/m^2 and 330 cd/m^2 ($p<0.05$). The presence or absence of a protective cover on the LCD did not affect the detection rate of the targets.

DISCUSSION

Generally speaking, monitor brightness as well as ambient room lighting can affect the physical response of the human eye's image perception. Several reports have suggested that raising the CRT brightness level results in relatively better observer performance for soft-copy reading of mammograms[5] or in the detection of solitary pulmonary nodules.[7,8] Similarly, luminance changes in a CRT monitor can cause a deterioration in the detection of pulmonary nodules.[7,8] However, in reports evaluating diagnostic performance,[1-8] when the objects were not homogenous, the effect of differences in the experimental design on the results was unclear. Therefore, in this study, we used traditional contrast-detail methods to evaluate the influence of monitor brightness and

Table 3 Average area under visible borderline of phantom image with monitor luminance of 330 cd/m^2.

Phantom	Room illumination (lux)	CRT0 (%)	LCD(-) (%)	LCD(+) (%)
	20	62.11	73.23	76.58
1*	120	65.38	74.64	77.32
	480	63.85	72.69	75.19
	20	58.79	74.89	74.02
2*	120	60.98	75.66	77.89
	480	60.04	74.81	77.39
	20	83.28	83.40	83.21
3	120	82.52	83.51	83.97
	480	83.10	83.90	83.93
	20	82.40	85.09	85.84
4	120	82.16	85.73	87.19
	480	83.00	86.43	86.70
	20	77.15	80.93	82.14
5	120	76.74	81.18	82.04
	480	75.66	81.64	82.75
	20	85.94	89.81	90.77
6	120	85.47	89.42	90.92
	480	83.85	90.59	90.86

For LCD, (–) = without protective cover; (+) =with protective cover.
*In phantoms #1 and #2, significant difference was found between CRT and LCD.

room illumination on image-perception performance.

Our previous study[8] revealed that, in conditions under which the maximum CRT luminance was 60.7% or below that of the standard display luminance, not surprisingly the number of correctly diagnosed pulmonary nodules deteriorated. In our present study, as for monitor degradation, no significant difference was found between 450 cd/m^2 and 330 cd/m^2. However, our 330 cd/m^2 was 73.3% of 450 cd/m^2, and there was no inconsistency between the two studies.

On the other hand, Itoh *et al.*[6] reported that the room illumination of 170 lux at the console desk was significantly better than that at 70 or 480 lux for detecting pulmonary nodules. As for the combined effect of room illumination and CRT brightness, Ishihara *et al.*[7] reported that 480 lux illuminance with 50 cd/m^2 CRT luminance degraded the detectability of pulmonary nodules significantly compared with 20 lux or 120 lux. However, with 200 cd/m^2 or 500 cd/m^2 CRT luminance, no significant difference was found among 20, 120 and 480 lux. The lighting conditions in the current study were the same as those in Ishihara's,[7] and no inconsistency was found between the two studies.

Although no statistically significant difference was found for the effect of room illumination, the detection rates of the targets differed among the three kinds of room lighting. However, the visual response for each phantom was different: some had relatively better detection rates of the targets under dark room conditions whereas others were relatively better in a bright room. These results suggested that a dark room is not always suitable for monitor reading, and that the use of LCD at high room illumination would be acceptable. Further investigations using clinical cases will be required to clarify the effects of monitor luminance and room illumination on LCD reading.

In comparisons of CRT with LCD, several reports have suggested that LCD exhibits a diagnostic performance equal to or better than CRT.[1-4] Our results revealed that LCD provided better visualization than CRT for low-contrast target independent of monitor brightness and room illumination. This could be explained by the fact that the modulation transfer function (MTF) of LCD is superior to that of CRT under the same matrix resolution.[4] Our results suggested that LCD could be used as a replacement for CRT in monitor diagnosis.

In conclusion, LCD may well be better than CRT with the same matrix resolution for observing low-contrast targets. The effect of room illumination was not significant, and the use of LCD at high room illumination has proven acceptable. LCD could be used as a replacement for CRT in soft-copy reading.

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