資　料

Effect of luminance non-uniformity caused by aged deterioration of a medical liquid-crystal display for low-contrast detectability

医用LCDの経年劣化による輝度の不均一がCDファントムの低コントラスト検出能に与える影響

TAKARABE Shinya[1),2)], TAKAHASHI Keita[1)], AKAMINE Hiroshi[1)], AWAMOTO Shinichi[1)], OGAWA Kazuhisa[1)], KATO Toyoyuki[1)]

1) Department of Health Sciences, Graduate School of Medical Sciences, Kyushu University Hospital
2) Department of Oral and Maxillofacial Radiology, Faculty of Dental Science, Kyushu University

Key words: Liquid-crystal display, Aged deterioration, Luminance uniformity, Contrast-detail phantom, Image quality figure (IQF)

【Abstract】
The purpose in this study is to examine the effect of the luminance non-uniformity caused by the aged-deterioration of medical liquid-crystal displays (LCDs) for the low contrast detectability using a contrast-detail phantom. Two medical LCDs of the same-type with different operating times were used. The first was operated for 38,000 h (aged-deterioration LCD) and the second for 200 h (non-deterioration LCD). These LCDs were calibrated to the grayscale standard display function with a maximum luminance of 170 cd/m^2. Contrast-detail images acquired under the same exposure conditions were displayed on each LCD and an observer study was performed by ten radiological technologists. The average image quality figures of the aged-deterioration and non-deterioration LCDs were 74.2 and 70.4, respectively and a significant difference was seen (p = 0.036). Our results indicated that the luminance non-uniformity caused by aged-deterioration of the LCD may affect the low contrast detectability.

【要 旨】
医用液晶ディスプレイ（LCD）の経年劣化による輝度不均一性が，低コントラスト検出能に与える影響を調査した．使用時間が38,000時間（劣化LCD）と200時間（未劣化LCD）の同一規格のLCDを使用した．2台のLCDを最大輝度170cd/m^{2}に校正した．同じ露光条件で取得されたCDファントム画像を各LCDに表示し，10人の診療放射線技師が観察実験を行った．劣化LCDと未劣化LCDのimage quality figureは74.2と70.4であり，paired-t検定で有意差を示した（p=0.036）．LCDの経年劣化が低コントラスト検出能に影響を与える可能性がある．

1 Introduction

In the past decade, liquid-crystal displays (LCDs) with cold-cathode fluorescent lamp (CCFL) backlights have increasingly been used, replacing the use of cathode ray tube monitors in medical settings as soft copy reading devices. However, according to investigations in Japan regarding the quality control of LCDs, the rate of performing quality control was low, implying that LCDs with degraded quality may be used in hospitals.[1)]

寶部 真也[1),2)]，髙橋 慶多[1)]，赤嶺 寛地[1)]，粟元 伸一[1)]，小川 和久[1)]，加藤 豊幸[1)]

1）九州大学病院医療技術部放射線部門
2）九州大学大学院歯学研究院口腔画像情報科学分野

Received June 26, 2022; accepted January 6, 2023

Aged-deterioration of LCDs can lead to a decrease in the maximum luminance (L_{max}), change in chromaticity, and luminance non-uniformity.[2)] Takahashi et al. examined the relationship between the L_{max} and operating time of the display backlight over a three-year period for 249 LCDs (initial L_{max} setting: 240 cd/m^2, color temperature: 7,500 K, (RadiForce® RX210), EIZO Co., Ishikawa, Japan).[3)] They reported that the L_{max} of 39 of the LCDs were less than 170 cd/m^2 because of aged-deterioration.[3)] Akamine et al. examined the color temperature of two same type LCDs (RadiForce® RX210) with different operating times (under 10,000 hours and over 20,000 hours). They reported that the color temperature was different between these LCDs due to deterioration of phosphor in the

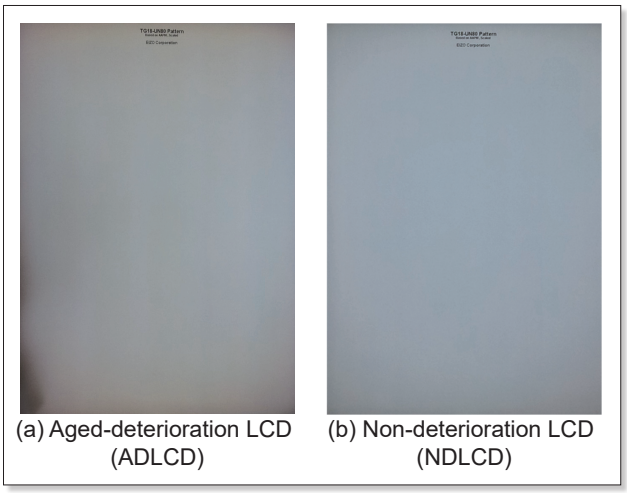
CCFL and color filter.[4)]

There is a case study report that display performance will degrade with increasing time in use, which in turn may degrade diagnostic performance.[5)] To the author's knowledge, there are no previous reports in the literature regarding the effects of luminance non-uniformity, caused by the deterioration of the medical LCD, on soft copy reading. We assumed that the luminance non-uniformity may affect the low-contrast detectability. As a preliminary study for exploring the effects of the LCD luminance non-uniformity, we used the contrast-detailed (CD) phantom and compared the low-contrast detectability for two same type LCDs with different operating times. The purpose of this study was to examine the effect of luminance non-uniformity caused by aged-deterioration for the detectability of low-contrast signals.

2 Materials and Methods

A case study approach was used to perform a physical evaluation and observer study for medical LCDs (RadiForce® RX210, EIZO Co., Ishikawa, Japan) Two same type color LCDs with different operating times were used in this study. The first was operated for about 38,000 hours [aged-deterioration LCD (ADLCD)] and the second for about 200 hours [non-deterioration LCD (NDLCD)] (Fig.1). Both LCDs were calibrated to the grayscale standard display function (GSDF) with a L_{max} of 170 cd/m^2 by using a quality-control software (RadiCS®, EIZO Co., Ishikawa, Japan) and a near-range luminance meter (RadiCS® UX1 Sensor, EIZO Co., Ishikawa, Japan).

First, we measured the luminance uniformity and variation of the luminance for the physical evaluation of the LCDs before performing an observer study to evaluate the low-contrast detectability of the LCDs.



(a) Aged-deterioration LCD (ADLCD) (b) Non-deterioration LCD (NDLCD)

Fig.1 The same type LCDs with different operation times displayed identical uniform test-patterns. The operating times of (a) and (b) were about 38,000 and 200 hours, respectively. A luminance non-uniformity was observed for the LCD with a longer operation time.

2.1 Measurement of luminance for physical evaluation

In terms of the luminance non-uniformity of medical LCDs, American Association of Physicists in Medicine (AAPM) Task Group 18 (TG18) required that to measure luminance of five points in the test pattern displayed on an LCD (Fig.2 (a)).[6)] However, such test pattern cannot evaluate the entire screen. Therefore, an original test-pattern was modified based on the TG18-UNL80 test pattern. The test pattern had the same pixel value as the TG18-UNL80 test pattern and was divided into 48 measurement regions (Fig.2 (b)); the luminance was measured corresponding to each rectangular region. The original test-pattern was displayed on the LCDs and the luminance was measured by use of a telescopic-type luminance meter (LS-100®, Konica Minolta Co., Ltd., Tokyo, Japan). The distance between the LCD and luminance meter was 150 cm. The ambient light at the center of the LCD measured by an illuminance meter (ANA-F9®, Tokyo Koden Co., Tokyo, Japan) was 0.1 lux. Luminance measurement in a telescopic-type luminance meter is

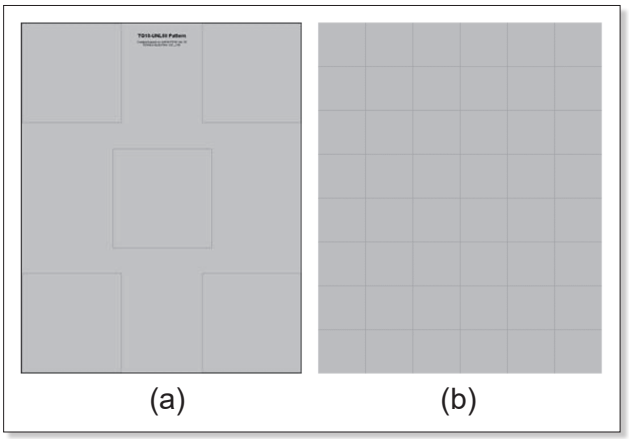


Fig.2 Test patterns used in this study. (a) and (b) are TG18-UNL80 test pattern and the original test pattern modified from TG18-UNL80 test pattern, respectively.

affected by stray light.[7, 8] To minimize the light emission from outside the focused area on the telescopic-type luminance meter, the region of the test pattern outside the measurement area was covered by solid fiberboard. The luminance was measured three times. The luminance uniformity is given by

$$\text{Luminance uniformity} = (Lm_{max} - Lm_{min}) / (Lm_{max} + Lm_{min}) \times 200; \quad (1)$$

where Lm_{max} and Lm_{min} are the measured maximum and minimum luminance including the reflected luminance. The luminance uniformity is calculated using only the Lm_{max} and Lm_{min}. To evaluate the luminance variation for the whole monitor screen, we also calculated the standard deviation (SD) of the luminance measured at 48 regions. Similarly, we measured luminance uniformity and the SD using TG18-UNL80 test pattern.

2.2 Observer study using CD phantom

The observer performance test was carried out with a CD phantom (Kyoto Kagaku Co., Ltd., Kyoto, Japan).[9] The CD phantom had signals (concave signals) of diameters ranging from 0.3 to 8.0 mm in 15 steps and depths from 0.3 to 8.0 mm in 15 steps. For the three largest diameters, there was a single signal in the center, similar to conventional CD phantoms. However, four-point selective CD phantoms were used for the remaining signals, comprising a signal in the center and in one of the corners. Three CD images were acquired. The exposure condition was 80 kV, 400 mA, and 25 ms and geometries are shown in Fig.3. A computed radiography (CR) system (IP: ST-VN, IP reader FCR 5000®, Fujifilm Co. Tokyo, Japan) was used for the X-ray detector. The CD images in DICOM format were displayed on both the ADLCD and NDLCD. The display function of these LCDs was calibrated GSDF with a L_{max} of 170 cd/m^2. The illuminance of the center of these displays were set to 350 lux. This illuminance determined based on the actual measured illuminance at the center of this ADLCD, which was used in the clinical practice. The window level and window width were set to 512 and 1024, respectively. Ten radiological technologists (1−11 years of experiences) participated in the observer study. They could observe the CD images at any distance, for as long as needed. Each observer recorded the depth at which each signal size in the CD phantom could be recognized with 50% confidence. The image quality figure (IQF)

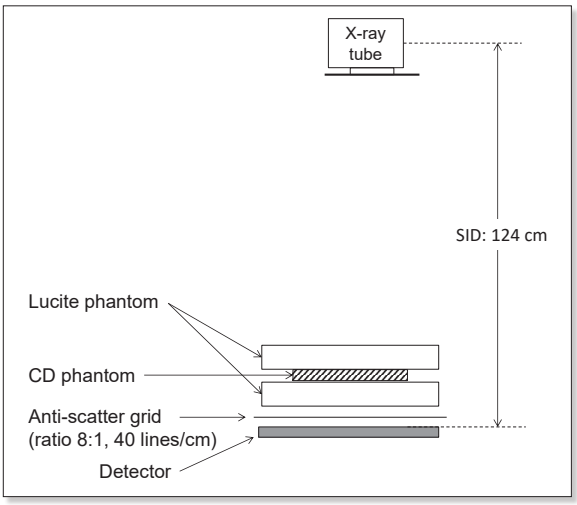


Fig.3 Geometries for acquiring CD with 7-cm-thickness lucite phantoms.

was calculated from individual observer data by the following equation;

$$IQF = \sum_{i=1}^{i=15}(C_i \cdot D_{i,th}), \quad (2)$$

where C_i represents the depth value (contrast) of the object (visible hole) in the column *(i)*, and $D_{(i,th)}$ denotes the corresponding smallest visible diameter (threshold diameter) in the column *(i)*. A small IQF value indicates high detectability with a low-contrast signal.[9–11] A paired t-test analysis was performed to examine the mean differences of IQF values between ADLCD and NDLCD.

3 Results

The results of the measured luminance using our original test pattern are shown in Figs.4 (a and b). Table 1 provides the values of Lm_{max}, Lm_{min}, luminance uniformities, and SD of the luminance value using the original test pattern. The luminance uniformities of ADLCD and NDLCD were 77.8% and 25.4%, respectively. The ADLCD displayed a significant non-uniformity. The SDs of the measured luminance for the ADLCD and NDLCD were 9.30 and 3.15, respectively. There was a significant difference in the SDs between the ADLCD and NDLCD (F-test, $p < 0.01$). On the other hand, for using TG18-UNL80 test pattern, the luminance uniformities of ADLCD and NDLCD were 23.2% and 10.6%, respectively. The SDs of the measured luminance for the ADLCD and NDLCD were 5.12 and 2.5, respectively. There was not a significant difference in the SDs between the ADLCD and NDLCD.

For the observer performance test, the IQF values of the ADLCD and NDLCD were 74.2 ± 14.7 and 70.4 ± 14.4, respectively. There was a statistical difference in the IQF values for the ADLCD and NDLCD (Fig.5) (paired t-test, $p = 0.036$).

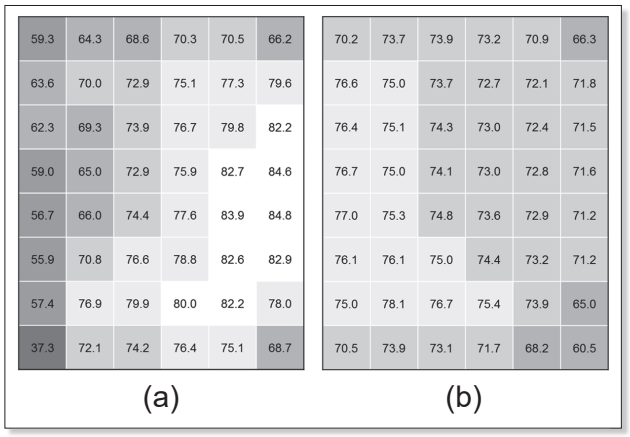


Fig.4 Luminance values (cd/m^2) measured using the original test pattern (Fig.2 (b)). (a) and (b) are the luminance values corresponding to small rectangular regions of the original test pattern (Fig.2 (b)) displayed on the ADLCD and NDLCD, respectively.

Table 1 Results of physical evaluation for ADLCD and NDLCD using the original test pattern

	ADLCD	NDLCD
Lm_{max}	84.8 cd/m^2	78.1 cd/m^2
Lm_{min}	37.3 cd/m^2	60.5 cd/m^2
Luminance uniformity	77.8%	25.4%
SD of luminance value	9.30	3.15

SD; standard deviation, ADLCD; aged-deterioration LCD, NDLCD; non-deterioration LCD

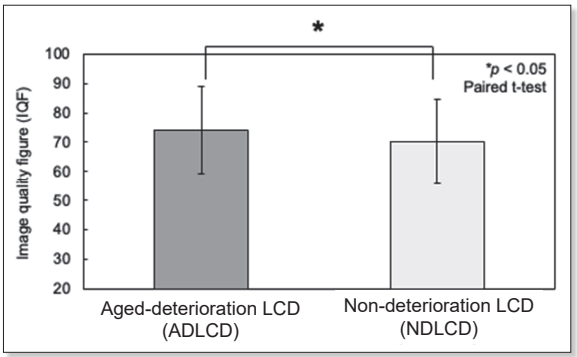


Fig.5 Comparison of image quality figures (IQF) between aged-deterioration LCD and non-deterioration LCD.

4 Discussion

We measured the luminance uniformity as physical evaluation and IQF as low contrast detectability, using two same type LCDs with different operating times in order to

investigate the effect of luminance non-uniformity due to aged-deterioration of the medical LCD.

For both test patterns (TG18-UNL80 test pattern and the original test pattern), the luminance uniformity of the ADLCD was poorer than that of the NDLCD because of the degradation of the backlight or impurities contained in the liquid crystal component (Fig.4 and Table 1). The criteria for the acceptance test of the luminance uniformity showed that the value of luminance uniformity should be within 30%.[6, 12] When TG18-UNL80 test pattern was used, the results of both ADLCD and NDLCD were within this reference value (23.2% and 10.6%, respectively). On the other hand, when our original test pattern was used, the results of only ADLCD exceeded this value (Table 1). The SD of the ADLCD was significantly higher than that of the NDLCD when the original pattern was used. This is because by increasing the number of measurement points for the luminance of the entire screen, the variation in luminance of the entire screen (non-uniformity), measured more accurately compared to using TG18-UNL80 test pattern.

There was a statistically significant difference between the ADLCD and NDLCD with the same L_{max} (170 cd/m^2) for IQF values (Fig.5). We estimated that the reason for the higher IQF values of the ADLCD was because the region with the non-uniformity, in particular the black spot overlapping the signals of the CD phantom, resulted in low detectability of the low contrast signals.

In this study, we did not evaluate the chromaticity of the monitor in detail. Krupinski et al. reported that there is no significant difference in the diagnostic ability of breast biopsy virtual slide regions of interest for calibrated color LCDs and uncalibrated color LCDs.[13] In our study, we calibrated the LCDs before the experiment and it is considered that the change in chromaticity has less influence on the detectability of simple signals using monochrome images.

Only one LCD was used as the aged-deterioration sample; however, to our knowledge, there are no reports in the literature regarding the effects of luminance non-uniformity caused by the aged-deterioration of the LCD. This study revealed that the non-uniformity of the LCD may degrade the detectability of the low contrast signals.

By measuring the luminance uniformity regularly, degradation in low contrast detectability due to aged-deterioration can be detectable, however determining the luminance uniformity is difficult because the use of telescopic-type luminance meters for measuring luminance uniformity is time consuming, and scientific-grade 2D luminance colorimeters are too costly for most users in hospitals. Practical and easier methods such as using commercially available digital cameras[14], should be contained in constancy tests in certain guidelines and regular measurements of the luminance uniformity is required.[6, 12]

5 Conclusion

Because of either the degradation of the backlight or impurities contained in the liquid crystal component, the luminance uniformity of ADLCD (77.8%) was degrade compared to NDLCD (25.4%). There was a statistically significant difference between the ADLCD and NDLCD with the same L_{max} (170 cd/m^2) for low contrast detectability (paired t-test, p = 0.036). The detectability of low-contrast signals may be lower due to the effects of luminance non-uniformity caused by the aged-deterioration of the LCD.

Acknowledgments

The authors are grateful to all members in division of radiology, department of medical

technology, Kyushu university hospital whose comments made enormous contribution to this study.

Funding

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Declarations Conflicts of interest

Not applicable.

Ethics approval

The observers of this study were explained about the outline and purpose of the study, the method of the experiment, and the possibility of presenting the results of the experiment at academic conferences and papers.

Informed consent

Not applicable.

References

1) T Shibutani, et al.: Current Situations and Problems of Quality Control for Medical Imaging Display Systems. Japanese Journal of Radiological Technology, 71(4); 356-361, 2015. (Japanese)
2) N. Hashimoto: Image display devices (3): LCD Monitor (Lecture of JSRT Member). Japanese Journal of Radiological Technology, 59(1); 21-28, 2003. (Japanese)
3) K Takahashi, et al.: Effective luminance deterioration of medical liquid crystal displays in clinical use. Radiological Physics and Technology, 10; 382-386, 2017.
4) H Akamine, et al.: Chromaticity and correlated color temperature of the white point in medical liquid–crystal display. Medical Physics, 39(8); 5127-5135, 2012.
5) LJ Caffery, et al.: The effect of time in use on the display performance of the iPad. British Journal of Radiology, 89(1063); 20150657, 2016.
6) E. Samei, et al.: Assessment of display performance for medical imaging systems. Report of the American Association of Physicists in Medicine (AAPM) Task Group 18, AAPM On-line Report No. 03, Med Phys, 2005.
7) J Morishita, et al.: Effect of test patterns on measurement of the luminance of LCD devices by use of a telescopic-type luminance meter. Radiological Physics and Technology, 1; 95-99, 2008.
8) T Shiiba, et al.: Effects of ambient-light correction in luminance measurements of liquid-crystal display monitors by use of a telescopic-type luminance meter. Radiological Physics and Technology, 3; 65-69, 2010.
9) T MAO, et al.: Manual: contrast-detail phantom Artinis CDRAD type 2.0. St. Radboud, The Netherlands: Project Quality Assurance in Radiology, Department of Radiology, University Medical Center Nijmegen, 1998.
10) M. McEntee, et al.: A comparison of low contrast performance for amorphous Silicon/caesium iodide direct radiography with a computed radiography: A contrast detail phantom study. Radiography, 13; 89-94, 2007.
11) S. Hatanaka, et al.: Comparison of viewing angle and observer performances in different types of liquid-crystal display monitors. Radiological Physics and Technology, 2; 166-174, 2009.
12) Japan Industries Association of Radiological Systems (JIRA): Japanese Engineering Standards of Radiological Apparatus (JESRA) X-0093*B-2017 quality assurance guideline for medical imaging display systems. JIRA, Tokyo; 2017.
13) E. A. Krupinski, et al.: Observer Performance Using Virtual Pathology Slides: Impact of LCD Color Reproduction Accuracy. Journal of Digital Imaging, 25(6); 738-743, 2012.
14) K Kawamoto, et al.: A method for evaluating luminance non-uniformity of displays by use of a commercially available digital camera. Radiological Physics and Technology, 10; 409-414, 2017.