Liquid-Crystal Display Monitors and Cathode-Ray Tube Monitors: A Comparison of Observer Performance in the Detection of Small Solitary Pulmonary Nodules

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Index terms:
Diagnostic radiology, observer performance
Lung, nodule
Radiography, digital

Korean J Radiol 2003;4:153-156
Received March 16, 2003; accepted after revision, July 8, 2003.

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Objective: To compare observer performance using liquid-crystal display (LCD) and cathode-ray tube (CRT) monitors in the interpretation of soft-copy chest radiographs for the detection of small solitary pulmonary nodules.

Materials and Methods: By reviewing our Medical Center's radiologic information system, the eight radiologists participating in this study (three board-certified and five resident) retrospectively collected 40 chest radiographs showing a solitary noncalcified pulmonary nodule approximately 1 cm in diameter, and 40 normal chest radiographs. All were obtained using a storage-phosphor system, and CT scans of the same patients served as the gold standard for the presence of a pulmonary nodule. Digital images were displayed on both high-resolution LCD and CRT monitors. The readers were requested to rank each image using a five-point scale (1 = definitely negative, 3 = equivocal or indeterminate, 5 = definitely positive), and the data were interpreted using receiver operating characteristic (ROC) analysis.

Results: The mean area under the ROC curve was 0.8901 ± 0.0259 for the LCD session, and 0.8716 ± 0.0266 for the CRT session ($p > 0.05$). The reading time for the LCD session was not significantly different from that for the CRT session (37.12 and 41.46 minutes, respectively; $p = 0.889$).

Conclusion: For detecting small solitary pulmonary nodules, an LCD monitor and a CRT monitor are comparable.

The transition from analog to digital imaging in radiology has been accelerated by the introduction of innovative digital imaging modalities (1, 2), and with the development of PACS and digital imaging, the interpretation of images in clinical radiology is changing rapidly from a procedure based on film and light boxes to one based on computers and monitors. Cathode-ray tube (CRT) monitor-based reading is currently thought to be as efficient and accurate as conventional film-based reading, and is now widely accepted in medical practice (3, 4).

The high-resolution LCD monitor is increasingly seen as a possible replacement for the CRT monitor, and radiologists have been inclined to accept LCD monitors for primary diagnostic tasks. To our knowledge, however, it is not known whether LCD monitors can provide the equivalent diagnostic performance and accuracy in routine radiologic practice as the CRT monitors or conventional films they are replacing.

The purpose of our study was to compare observer performance using liquid-crystal display (LCD) and cathode-ray tube (CRT) monitors in the interpretation of soft-copy chest radiographs for the detection of small solitary pulmonary nodules.

MATERIALS AND METHODS

By searching our Medical Center's radiologic information system, we identified chest CT scans, obtained after the administration of contrast medium and at 7 or 8 mm collimation, showing a small solitary noncalcified pulmonary nodule 0.4 to 1.5 (mean, 0.86) cm in diameter but no other abnormality. To confirm the CT reports, two board-certified radiologists with at least eight years' clinical experience reevaluated each scan. Forty chest radiographs of the selected patients, obtained no more than two weeks before or after the CT examinations, were selected to represent the disease group, while forty normal chest radiographs, collected in a similar fashion and confirmed at CT, served to represent the control group.

To obtain all these direct digital projection radiographic images, an FCR-9000 unit (Fuji, Tokyo, Japan), together with 14 ×17-inch ST-V imaging plates (Fuji) (202 μm/pixel, a matrix of 1760 ×2140 ×10 bits, and a pixel size of 0.2 mm) was used. Each image file was 2 Mbytes in size, and digital data were sent to a PACS server (Petavision; Hyundae Information Technology and Asan Medical Center, Seoul, Korea) and distributed to display workstations. Both CRT and LCD monitors were calibrated according to the manufacturers' specifications: the CRT monitor, with 2048 ×2560 ×10-bit pixels (BARCO; Dataray, Denver, Col., U.S.A.), operated at 71 Hz in an interlaced mode and with a calibrated brightness level of 490 cd/m^2, and the LCD monitor, with 1536 ×2048 ×10-bit pixels (DOME, Waltham, Mass., U.S.A.), operated at a typical brightness level of 700 cd/m^2. The images were interpreted in a dark room.

Our study involved two sessions: the interpretation of digital radiographs viewed on (1) the CRT monitor and (2) the LCD monitor. The images in each set were ordered differently. Eight radiologists participated in this study; three were board-certified and the others were senior residents, and all were accustomed to a PACS viewer because they used it in daily practice. Each was blinded to the CT findings, and each reading session was conducted independently and separately. A counter-balanced, randomized presentation design was used; four readers first interpreted the image set on the CRT monitor, while the others first interpreted the image set on the LCD monitor. To diminish learning effects, each reading session was seperated by at least one month, and the same image was never shown twice during any session. To simulate the routine clinical interpretation environment, readers were allowed to adjust the brightness and contrast of the images interactively. The use of other tools, such as magnification or edge enhancement, was not allowed. All functions used in the interpretation were included in the PACS viewer software.

The readers were asked to determine the presence or absence of a small solitary pulmonary nodule, using the following five-grade scoring system: 1 = definitely negative; 2 = probably negative; 3 = indeterminate; 4 = probably positive; and 5 = definitely positive. For statistical analysis, their responses were recorded and re-sorted, and the time taken for each reading session was also recorded.

Observer performance for the detection of a solitary pulmonary nodule using the two monitor systems was determined by means of receiver operating characteristic (ROC) analysis of individual and averaged reader data (5−10). To

Table 1. Comparison of Observer Performance in Detecting Small Solitary Pulmonary Nodules, and Average Reading Time for LCD Monitor and CRT Monitor

	Area Under the ROC Curve (Az)			Time (minutes)	
Reader	LCD	CRT	95% CI	LCD	CRT
1	0.9318 ±0.0300	0.9503 ±0.0241	–0.0720, 0.0346	56.50	62.45
2	0.9259 ±0.0294	0.8918 ±0.0377	–0.0241, 0.0917	32.30	61.10
3	0.8879 ±0.0437	0.8250*	–0.0582, 0.1878	59.45	53.15
4	0.8262 ±0.0477	0.7860 ±0.0547	–0.0550, 0.1355	39.20	35.35
5	0.8536 ±0.049	0.8555 ±0.0596	–0.1475, 0.1187	31.38	51.05
6	0.9347 ±0.0273	0.9095 ±0.0333	–0.0317, 0.0927	34.51	27.18
7	0.9088 ±0.0355	0.8394 ±0.0503	–0.0373, 0.1779	22.24	22.11
8	0.8434 ±0.0464	0.9057 ±0.0365	–0.1571, 0.0408	21.34	19.30
All	0.8901 ±0.0259	0.8716 ±0.0266	–0.0159, 0.0530	37.12	41.46

Note.— Data are Az values ±standard error; 95% CIs are for mean difference of Az values.
LCD = liquid crystal display monitor, CRT = cathode-ray tube monitor
Readers 1 - 3: Board-certified radiologists
Readers 4 - 8: Senior residents in the department of diagnostic radiology
* Standard error value was not given because the data were degenerative.

allow for generalization to the population of readers and cases, we used a multireader-multicase ROC approach (LABMRMC; Chicago University, Charles. E. Metz). The statistical significance of the results for both systems was reported as 95% CIs for mean differences in Az values for observer performance (11). Mean differences were regarded as statistically significant at the 5% level when the corresponding CI did not encompass zero. Differences between the monitor systems regarding the time taken for reading were compared using the paired t test.

RESULTS

Mean Az-values are given in the table, and indicate the performance of each reader. The 95% CIs for the differences between the monitor systems and reading time of each session are also provided. Five radiologists found that the Az-values from the LCD monitor-based readings were higher than those from the CRT monitor-based readings, and three found they were lower. However, neither Az-values determined by each reader nor averaged performance for the detection of a nodule was significantly different between the two monitor systems. The mean reading time for the LCD and CRT sessions was 37.12 and 41.46 minutes, respectively, findings which were not significantly different (paired t test, p value = 0.066).

DISCUSSION

For many decades, conventional film-screen systems have been the tools of choice for diagnostic procedures. Although a cathode-ray tube (CRT) monitor is relatively expensive and has limited spatial resolution and luminance compared to conventional film, computed radiographic technology can produce image quality that is adequate for interpreting posteroanterior radiographs of the chest, while offering the advantages of gray-scale manipulation and flexible image-processing. It is well accepted that the diagnostic performance of a CRT monitor is sufficient to replace conventional radiographs (12, 13); however, constant operation causes CRTs to degrade and to lose beam focus, spatial linearity, luminance, uniformity, brightness, and contrast. In addition, due to their high initial purchase price and the high maintenance expenditure needed for correction and calibration, CRT monitors are costly. They are, furthermore, not only heavy and bulky but also have high levels of heat dissipation and power consumption. In contrast, high- resolution liquid crystal display (LCD) monitors provide clear, cost-effective and energy-efficient display. The significant advantage of an LCD monitor is the consistency of image display throughout its lifecycle, and the absence of degradation over time. The luminance of an LCD monitor is high enough to locate the flat panel next to conventional medical light boxes, and its additional benefits include a slim and compact profile and the fact that it emits no low-level radiation.

Our results indicate that for the display and analysis of soft-copy images in the detection of a solitary pulmonary nodule, LCD and CRT monitors are comparable, but when interpreting our results, several considerations should be borne in mind. First, the LCD monitor was operated at a higher brightness level (700 cd/m^2) than the CRT monitor (490 cd/m^2), and this might have made the LCD results appear more favorable than they really were. Nonetheless, since the brightness of both monitor systems was set according to the recommendation of the suppliers, we believe that our results reflect real clinical practice. Second, in terms of contrast and focus, the LCD monitor is superior to the CRT monitor (14), so the former is less sensitive to ambient light. Even though all the reading sessions in our study were performed in a dark room, environmental light could influence image contrast during a CRT session. Third, the matrix number of the imaging plates used in this study was 1760×2140, which is similar to the resolution of the LCD monitor, with a matrix of 1536×2048. In addition, the detection of a pulmonary nodule is more dependent on contrast than spatial resolution, and so in our study, the superiority of the CRT monitor in terms of spatial resolution might not be an advantage. Fourth, despite the other merits of the CRT monitor, including less angle viewing dependence and far fewer artifacts, we considered that these factors did not influence visual comparisons between the LCD and CRT display when used to detect a solitary pulmonary nodule.

Pavlicek et al. (15) showed that compared with CRT monitors, LCD monitors have higher luminance and a shorter warm-up time, but the two types are of comparable uniformity, and are fully acceptable for clinical image viewing. However, they did not study their diagnostic performance, measuring only their display performance at actual clinical locations and administering a user questionnaire. A study by Siegel, presented at the American Roentgen Ray Society meeting on April 30, 2002, found no significant differences in overall sensitivity and specificity between LCD and CRT monitors used for the detection of pulmonary nodules on chest radiographs. Siegel did not, however, use receiver-operating-characteristic analysis to compare diagnostic performance between the two types of monitor, and to our knowledge, ours is the first study to use ROC analysis to compare the two types in terms of their ability to diagnose solitary pulmonary nodules. This study was designed to simulate daily clinical practice; readers used a commercial PACS viewer, and real-time adjustment of contrast and brightness, the most commonly used functions in daily practice, was allowed.

The major limitation of our study is that the performance comparison was limited to the detection of pulmonary nodules, which are less dependent on spatial resolution. We did not compare the performance of the two monitor systems in the detection of other pulmonary pathologic conditions such as the fine pattern occuring in interstitial lung disease, septal lines, and pneumothorax. The detection and characterization of these abnormalities are known to be highly dependent on spatial resolution, and in view of the difference in pixel size and number between the two types of monitor, the results might be different in a comparative study of the detectability of these linear structures. Accordingly, our results do not directly indicate that LCD monitors can replace CRT monitors for the diagnosis of all pathologic lung conditions. To ascertain whether this is so, further comparison between the two types is needed.

In conclusion, for the display of soft-copy digital images, LCD monitors and CRT monitors are comparable, and for the detection of small solitary non-calcified pulmonary nodules in medical practice, LCD monitors are acceptable replacements for the cathode-ray type.

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