Low-Cost Soft-Copy Display Accuracy in the Detection of Pulmonary Nodules by Single-Exposure Dual-Energy Subtraction: Comparison With Hard-Copy Viewing

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This study endeavored to clarify the usefulness of single-exposure dual-energy subtraction computed radiography (CR) of the chest and the ability of soft-copy images to detect low-contrast simulated pulmonary nodules. Conventional and bone-subtracted CR images of 25 chest phantom image sets with a low-contrast nylon nodule and 25 without a nodule were interpreted by 12 observers (6 radiologists, 6 chest physicians) who rated each on a continuous confidence scale and marked the position of the nodule if one was present. Hard-copy images were 7 × 7-inch laser-printed CR films, and soft-copy images were displayed on a 21-inch noninterlaced color CRT monitor with an optimized dynamic range. Soft-copy images were adjusted to the same size as hard-copy images and were viewed under darkened illumination in the reading room. No significant differences were found between hard- and soft-copy images. In conclusion, the soft-copy images were found to be useful in detecting low-contrast simulated pulmonary nodules. Copyright © 2000 by W.B. Saunders Company

KEY WORDS: dual-energy subtraction, computed radiography, pulmonary nodule, hard copy, soft copy.

AN IMPORTANT TASK for chest radiography is to detect pulmonary nodules such as lung cancer. Austin et al¹ reported that 22 of 27 potentially resectable bronchogenic carcinomas were obscured by 2 or 3 overlapping bones or by 1 rib and overlapping pulmonary vessels. We have reported that single-exposure dual-energy (SEDE) subtraction computed radiography (CR) images of the chest improve the performance in detecting pulmonary abnormalities such as nodules.^{2,3} In these studies, we used laser-printed films. In the environment of a picture archiving and communication system (PACS) or teleradiology, soft-copy images are more widely used than hard-copy images. However, soft-copy images have limitations of spatial resolution and dynamic range. The dynamic range is an important factor, especially in the case of display of low-contrast abnormalities such as early lung cancer.

The bone-subtracted images obtained by the SEDE subtraction method are useful for detection of pulmonary nodules that are obscured by overlapping ribs, but the signal-to-noise ratio of these images is inferior to that of conventional CR images.⁴⁻⁶

Our purpose in this study was to evaluate the utility of soft-copy images (in place of hard-copy images) for detection of pulmonary nodules by use of a SEDE subtraction method.

MATERIALS AND METHODS

The CR system which we used was the Fuji Computed Radiography system (FCR, model no. 7000; Fuji Photo Film, Tokyo, Japan). The intermediate filter was a copper foil (0.8 mm thick) that was sandwiched between the two photostimulable phosphor imaging plates (14 × 14 inches; ST III, Fuji Photo Film, Tokyo, Japan). Two images, one from the front imaging plate (low-energy image) and the other from the back imaging plate (high-energy image) were obtained and then transferred to a Sun 3/260 workstation (Sun Microsystems, Mountain View, CA), from which a subtracted image was obtained. An iterative noise-reduction algorithm of this SEDE process was used for making bone-subtracted images. This algorithm emphasizes noise reduction without decreasing image quality.²

We used 25 posteroanterior chest phantom (Kyoto Hyohon Corp, Kyoto, Japan) CR images with a low-contrast nylon nodule that was randomly placed on the phantom. The nylon nodules were sphere fragments (hemispheric in shape), 1.4 cm in diameter, and 0.5, 0.7, and 0.9 cm in thickness. We obtained 2 different images from each x-ray exposure. One was a conventional CR image obtained from the front storage phosphor imaging plate; the other was a bone-subtracted CR image obtained by use of the noise reduction algorithm. All exposures were made with a conventional CR chest x-ray unit under the conditions of 100 kVp, 100 mA, 80 ms, 180 cm film-focus distance, and Bucky 40 1/cm, 10:1. The entrance skin exposure was 19.5 mR (5.03×10^{-6} C/kg).

Evaluations were performed by 12 observers (6 radiologists, 6 chest physicians) with conventional CR and bone-subtracted CR images of 25 chest phantoms. The observers usually read conventional screen-film images in their daily clinical practice and sometimes read conventional CR images; however, they were not familiar with reading on a CRT monitor. We used only one lung (either the right or the left) of each phantom for the reading sessions because a single lung was thought to obviate the effect of comparing right and left lungs. Two image sets (a

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0897-1889/00/1301-0006\$10.00/0*

conventional CR image set and a bone-subtracted CR image set) of the 25 right lungs and 25 left lungs were divided into 2 reading subsets (right-lung session and left-lung session).

For the hard copy, the processed images were printed on films by a laser printer (CR-LP414, Fuji Photo Film). The film size was 7×7 inches. The values of the parameters are as follows: GT = E, GA = 0.9, GC = 1.6, GS = -0.2, RT = R, RE = 0.3, and RN = 0 (GT, gradient type; GA, gradient angle; GC, gradient center; GS, gradient shift; RT, response type; RE, response enhancement; RN, response rank). Commercially available CR images of the chest usually produce a pair of CR images. One is an image with a default mode that approximates the appearance of a conventional radiograph; the other is an image with a postprocessing mode such as an edge-enhanced mode or a SEDE subtraction mode. Thus, it was thought to be reasonable that the observer read a 7×7 -inch CR image for evaluation. When the right lung was evaluated, the left lung was covered with black paper.

For the soft-copy reading of the study, image data for one of the lungs obtained directly from the FCR system were displayed on a 21-inch noninterlaced color CRT monitor (ERGOVISION 2100LR, Taxan, Japan; $1,024 \times 768$, 8-bit pixels). In the soft copies, the contrast resolution is limited by the 8-bit display. Therefore, the dynamic range had to be optimized. We optimized the dynamic range as follows. We marked regions of interest (ROIs) in both lungs and set the minimum density value to 0 and the maximum density value to 255. Thus, 10-bit data images were converted to 8-bit data images for display. The mean luminance of the display with conventional CR images was 16.1 ± 9.5 foot-lamberts (maximum luminance, 28.4 foot-lamberts) and that with bone-subtracted CR images was 16.0 ± 12.6 foot-lamberts (maximum luminance, 32.2 foot-lamberts) under darkened illumination of the reading room. We measured the brightness with a photometer, under the same

conditions as used in the reading session. The one lung was displayed on CRT under darkened illumination of the reading room and the background on the monitor was adjusted to black. We measured three points: the upper lung, middle lung, and lower lung. The level and window of the display were fixed during the study. In the reading session, soft-copy images were fixed to the same size as hard-copy images and were viewed under darkened illumination of the reading room.

Each session was carried out at least 2 weeks after the previous session to minimize learning effects. All images were intermingled randomly in each image set for each session to alter the reading order. Each observer was asked to mark the location of the nodule (if one was present) on a separate sheet, and to describe separately the presence of a pulmonary nodule by using a continuous scale (1 to 100 level) of confidence. When the described nodule coincided with the actual nodule, the case was considered to be a true-positive (TP) one. No limit was imposed on viewing time.

The detectabilities of nodules were evaluated in terms of TPs, and the observer response data also were analyzed by receiver operating characteristic (ROC) techniques.⁷⁻¹⁰ The observer performance in the detectability of the nodules was described by the area under the ROC curve (Az).^{11,12} For statistical analysis, the averaged Az and standard deviation were obtained by individual fitting of ROC curves to the confidence ratings of each observer and by averaging the estimated areas across observers. We used the TPs and Az values to test the significance of the differences by means of the paired *t* test.

RESULTS

Figures 1 and 2 are examples of CR images of the chest phantom with a nylon nodule. Figure 1 is a case in which one of the 12 observers detected the

Fig 1. CR images of the chest phantom with a nylon nodule (arrow) in the right lung. (A) Conventional CR image. (B) Bone-subtracted CR image.

Fig 2. CR images of the chest phantom with a nylon nodule (arrow) in the left lung. (A) Conventional CR image. (B) Bone-subtracted CR image.

nodule in the conventional hard-copy image, and 7 observers detected it in the bone-subtracted hard-copy image. None of the 12 observers detected it in the conventional soft-copy image, and 9 observers detected it in the bone-subtracted soft-copy image. Figure 2 is a case in which 5 observers detected the nodule in the conventional hard-copy image, and all observers detected it in the bone-subtracted hard-copy image. On the other hand, 5 observers detected it in the conventional soft-copy image, and all observers detected it in the bone-subtracted soft-copy image.

No significant difference was found between the TPs for the conventional hard-copy images (13.33 ± 2.67 [nodules per 25 images]) and those for the conventional soft-copy images (13.58 ± 3.37 ; $P = .793$). The mean difference between them was -0.25 . The 95% confidence interval estimate of the difference in means extended from -2.30 to 1.80 . No significant difference was found between the TPs of bone-subtracted hard-copy images (21.17 ± 2.17) and the TPs of bone-subtracted soft-copy images (21.67 ± 1.50 ; $P = .410$). The mean difference between them was -0.50 . The 95% confidence interval estimate of the difference in means extended from -1.79 to 0.79 (Table 1).

Moreover, no significant difference was found between the Az of conventional hard-copy images

(0.795 ± 0.061) and that of conventional soft-copy images (0.745 ± 0.112 ; $P = .181$). The mean difference between them was 0.050 . The 95% confidence interval estimate of the difference in means extended from -0.027 to 0.128 . No significant difference was found between the Az of bone-subtracted hard-copy images (0.928 ± 0.036) and that of bone-subtracted soft-copy images (0.935 ± 0.027 ; $P = .621$). The mean difference between them was -0.007 . The 95% confidence interval estimate of the difference in means extended from -0.035 to 0.022 (Table 2).

These results indicate that no significant differences were detected between hard-copy and soft-copy images for both the conventional and the bone-subtracted images. However, the detection performance for bone-subtracted images was superior to that for conventional images with both hard- and soft-copy images ($P < .0001$).

DISCUSSION

No significant difference was detected for low-contrast nylon nodules between bone-subtracted hard-copy images and bone-subtracted soft-copy images. Also, the detection performance for bone-subtracted images was superior to that for the conventional images with both hard- and soft-copy images.

In previously published studies, varying conclu-

Table 1. Nodule Detection by 12 Observers in 25 Phantoms

Observer No.	Conventional CR		Bone-Subtracted CR	
	Hard	Soft	Hard	Soft
1	11	14	20	19
2	18	17	22	24
3	15	16	20	22
4	11	15	22	23
5	12	9	22	22
6	11	15	18	21
7	17	14	25	23
8	17	15	24	20
9	13	16	23	23
10	12	14	20	22
11	12	13	19	21
12	11	5	19	20
Mean $\pm$ SD	13.33 $\pm$ 2.67	13.58 $\pm$ 3.37*	21.17 $\pm$ 2.17†	21.67 $\pm$ 1.50‡§

Abbreviations: Hard, hard-copy CR images; Soft, soft-copy CR images.

*Not significantly different from conventional hard-copy images ($P = .793$).

†Significantly different from conventional hard-copy images ($P < .0001$).

‡Not significantly different from bone-subtracted hard-copy images ($P = .410$).

§Significantly different from conventional soft-copy images ($P < .0001$).

sions were reported. The results depend on the type of pulmonary abnormalities, such as interstitial pulmonary opacities and nodules. In this study we focused on low-contrast pulmonary nodules, the detection of which is an important role of chest radiography.

Hayrapetian et al¹³ showed that $2,048 \times 2,048$ -pixel soft-copy images are equivalent to hard-copy images for the detection of nodules. Slasky et al¹⁴ obtained the same results with a $1,536 \times 2,048$ -pixel monitor. Kehler et al¹⁵ reported that no significant differences were found between detection of simulated nodules on a $1,024 \times 1,024$ -pixel

workstation monitor and on a hard copy of a storage phosphor image. Lyttkens et al¹⁶ found no significant differences between detection of simulated nodules on a $1,024 \times 1,024$ -pixel monitor and a hard copy of a storage phosphor image. Takahashi et al¹⁷ noted that diagnosis with a $1,024 \times 1,024$ -pixel monitor was adequate for nodule detection in an image intensifier system. Otto et al¹⁸ reported that, in the detection of simulated nodules on peripheral lung fields, a $1,024 \times 1,024$ -pixel monitor with higher luminance was comparable to a $2,560 \times 2,560$ -pixel monitor with higher luminance and hard copies, but use of a $1,024 \times$

Table 2. Az Values for 12 Observers in 25 Phantoms

Observer No.	Conventional CR		Bone-Subtracted CR	
	Hard	Soft	Hard	Soft
1	0.768	0.886	0.959	0.918
2	0.863	0.834	0.900	0.976
3	0.879	0.723	0.924	0.894
4	0.729	0.739	0.923	0.909
5	0.690	0.561	0.959	0.923
6	0.725	0.771	0.897	0.955
7	0.864	0.741	0.995	0.954
8	0.826	0.840	0.955	0.968
9	0.819	0.691	0.947	0.961
10	0.769	0.840	0.851	0.932
11	0.777	0.794	0.904	0.915
12	0.833	0.519	0.925	0.912
Mean $\pm$ SD	0.795 $\pm$ 0.061	0.745 $\pm$ 0.112*	0.928 $\pm$ 0.036†	0.935 $\pm$ 0.027‡§

Abbreviations: Hard, hard-copy CR images; Soft, soft-copy CR images.

*Not significantly different from conventional hard-copy images ($P = .181$).

†Significantly different from conventional hard-copy images ($P < .0001$).

‡Not significantly different from bone-subtracted hard-copy images ($P = .621$).

§Significantly different from conventional soft-copy images ($P < .0001$).

1,024-pixel monitor with lower luminance was inferior to any other method. They stated that, for the detection of nodules in mediastinal, subphrenic, and peripheral lung fields, spatial resolution does not play an important role, but that luminance is important in the detection of structures with low contrast, particularly in regions of high absorption.

In this study, the dynamic range was optimized for detecting low-contrast pulmonary nodules. ROIs were set for dynamic-range optimization in both lung zones on CRT monitors, and 10-bit data were converted to 8-bit data. Also, images were viewed under the darkened illumination of the reading room. These steps can improve the contrast of soft-copy images for detecting low-contrast nodules. Spatial resolution appears to be less important for the detection of pulmonary nodules. In this study we used 7×7 -inch CR images, which are substantially smaller than 14×14 -inch images. However, we reported previously that size may not be a critical factor for CR images.¹⁹

Moreover, in our study, observers evaluated soft-copy images with a fixed level and window

setting. In general, a merit of soft-copy images is the ability to change the window and level of the images easily while reading radiographs. However, in daily clinical practice, many problems are involved in changing the level and window setting. Changing the level and window for diagnosis requires additional time. In a study by Otto et al,¹⁸ the average time for image analysis was 60 seconds for monitors without magnification and 125 seconds with magnification. Changing the level and window settings leads to an increase in false-positive results because normal structures are over-emphasized. In this situation it appears that soft-copy images lack the objectivity needed for diagnosis. On the other hand, with fixed level and window settings, radiologists and other physicians can concentrate on detecting the abnormalities in chest radiographs. They read the same images and can have common diagnostic criteria.

In conclusion, when the conditions are adjusted properly, soft-copy images are suitable, in place of hard-copy images, for the detection of pulmonary nodules.

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