Effect of Dose Reduction on the Ability of Digital Mammography to Detect Simulated Microcalcifications

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The purpose of this article was to report the relationship between radiation dose and the ability of sentence digital mammography to detect microcalcifications. All images were acquired by computed radiography and an anthropomorphic breast phantom. The tube voltage and anode/filter combination used were 28 kVp and Mo/Mo. Simulated microcalcifications with an approximate diameter of 250–350 μm were positioned on the phantom. Groups of six microcalcifications were arranged in one of two patterns, a line cluster 1 cm long or a hexagonal cluster 4 mm wide. One of the six microcalcifications was removed to create a negative control. Each cluster was placed on 25 different points. Four levels of milliamperes-second (mAs) values were applied: 100%, 50%, 25%, and 12.5%. Five staff radiologists participated in an observer performance test. All observers used a workstation with a 3-megapixel monochrome LCD monitor. The areas under the receiver-operating characteristics curves (AUC) were used to compare diagnostic performance among the four doses. The overall AUC scores were 0.97 with 100% mAs, 0.93 (n.s.) with 50%, 0.90 ($p < 0.05$) with 25%, and 0.81 ($p < 0.01$) with 12.5% mAs. Among the negative series, the percentage of images on which observers were able to identify the removed microcalcification point decreased from 88.8% with 100% mAs to 83.6% (n.s.) with 50%, 74.8% ($p < 0.001$) with 25%, and 67.2% ($p < 0.001$) with 12.5% mAs. A certain level of dose reduction in digital mammography may be an option.

KEY WORDS: Digital mammography, computed radiography, observer performance, radiation dose, ROC-based analysis, phantoms, imaging

INTRODUCTION

Screen-film mammography with high spatial resolution has been the modality of choice for screening programs for many years. Recently, numerous studies have reported that the diagnostic performance of digital mammography has been as good as that of screen-film mammography for

detecting breast cancer.^{1–6} Furthermore, digital mammography was more accurate than screen-film mammography in women younger than 50 years, women with radiographically dense breasts, and pre- or perimenopausal women.^{1,6} Additionally, the digital systems have other advantages over screen-film systems, such as the preservation of data and the ability to perform computer-assisted diagnosis or remote diagnosis.⁷ Therefore, digital mammography will become an important screening modality in the near future.

In current clinical practice, the radiation dose of digital mammography systems is approximately the same as that of screen-film systems. This may be due in part to several characteristics of screen-film systems. In screen-film mammography, it is important to maintain an appropriate radiation dose in order to maintain diagnostic performance because screen-film image receptors have a limited range of acceptable exposures to the image receptor. However, digital mammography has a

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far wider dynamic range and higher detection efficiency than screen-film combinations.^{8,9} Thus, digital mammography is limited only by the acquired image contrast-to-noise ratio, and the radiation dose does not directly influence the optical density. It would also be desirable to reduce the present radiation dose in breast cancer screening if the diagnostic performance could be preserved at a certain noise level.

One benefit of reducing the dose in screening mammography would be a decrease in radiation risk. Breast cancer screenings using mammography are generally begun on women at normal risk at about 40 years of age.^{10,11} Because an upper age limit for screening has not been established, ongoing screenings will expose most women to radiation for many years. Additionally, the female breast is one of the most radiosensitive organs. A review of the 2007 recommendations of the International Commission on Radiological Protection (ICRP) showed that the tissue weighting factor for breast has been increased from 0.05 in the 1990 ICRP recommendations to 0.12 in light of both recent epidemiological findings and the focus on cancer incidence in the detriment calculations.¹² For those reasons, and because the female breast is one of the most radiosensitive organs, it is important to reduce the dose for individual mammographies, especially when they are used for screening purposes. The practical dose in mammography should be optimized based on clinical diagnostic performance.

Thus, the purpose of our study was to consider the possibility of a dose reduction within a range that can maintain digital mammography's ability to detect microcalcifications.

MATERIALS AND METHODS

Imaging Systems and Phantom

All images were acquired with a mammography system (Mermaid; Toshiba, Tokyo, Japan) and a computed radiography system (FCR PROTECT CS; Fujifilm, Tokyo, Japan). The tube voltage and anode/filter combination were 28 kVp and molybdenum/molybdenum. All images were acquired using an anthropomorphic breast phantom (RMI 165; Gammex RMI, Middleton, WI, USA). This

phantom of 5-cm breast thickness consists of 50% adipose and 50% glandular breast tissue of 5-cm breast thickness. A 63 milliamper-second (mAs) was taken as the 100% mAs value under automatic exposure control. Therefore, we examined four levels of mAs value: 63 mAs as the 100% value, 32 mAs as the 50%, 16 mAs as the 25%, and 8 mAs as the 12.5% value under manual control.

Simulated Microcalcification Phantom

Simulated microcalcifications with an approximate diameter of 250–350 μm were positioned on the breast phantom (Fig. 1). Microcalcifications were made from eggshells, which were crushed and measured with a microscope. The microcalcifications were placed at intervals of 2 mm in groups of six to form two patterns: a 1-cm-long line cluster or a 4-mm-wide hexagonal cluster as a positive signal (Fig. 2). These arrangements were modeled after those in a past study.¹³ Microcalcifications were surrounded with a 2-cm² wire because there was a possibility that observers could not identify the location of microcalcification at a lower radiation dose and because the statistical analysis was simply performed using receiver-operating characteristics (ROC) analysis. Furthermore, we confirmed that this cue square could not interfere with the observer's discrimination of microcalcifications in the image beforehand. To create a negative control, one of the six microcalcifications was removed (Fig. 3). Each microcalcification cluster (positive signal and negative signal in two types of patterns) was placed on 25 different positions that did not overlap each other and covered almost the whole area of the phantom (Fig. 1). Finally, two cluster patterns (line and hexagonal) were constructed of two signals (positive and negative images) obtained with four levels of radiation dose in 25 positions as mentioned above, and 400 images were obtained.

Observer Performance Test

Soft copies of all images were displayed on an exclusive workstation MV-SR657 (Fujifilm) with a 3-M monochrome liquid crystal display (LCD; SL-IC 300; Fujifilm) at random. We used a 3-megapixel monochromatic LCD monitor that met the practice

Fig 1. The anthropomorphic breast phantom used in this study. **a** Each microcalcification cluster was placed at 25 different positions on the anthropomorphic phantom. **b** Microcalcifications were placed in an area 2 cm² surrounded by a wire. All observers were permitted to magnify the image with a tool that their exclusive workstation was equipped with.

guidelines of the American College of Radiology.¹⁴ Each observer was permitted to magnify the images using a tool equipped in the workstation.¹⁵ Each image was displayed at life size on the monitor without magnification and at three magnifications with the tool. Five staff radiologists participated in the observer performance test. A dedicated viewing station was set up in a room with low ambient light, nearly 25 lx. The hexagonal and line cluster pattern images were tested separately. Within two sessions, 200 images with four dose levels were displayed at random. In order to familiarize the radiologists with the observer study and the display software tools, a training session involving ten images, not used in the actual study, was given at the beginning of each viewing session. Observers estimated the number of microcalcifications and were asked to rate each image on a scale of 0 to 100 for the likelihood of six positive microcalcifications. Observers were not permitted to change the image window levels or widths. When

observers diagnosed an image as negative, the locations of the removed calcifications were written down.

Data Analysis

ROC were analyzed and the areas under the ROC curves (AUC) were used to compare the diagnostic performance of each of the four doses.¹⁶ The jackknife ROC (LABMRMC) procedure was used to compute the statistical significance of the estimated differences.¹⁷ Furthermore, among the 25 negative images of each radiation dose series, the percentages of the images on which each observer identified the missing calcification properly was calculated. The average of each observer's percentage was calculated for the four-dose series. These differences with radiation dose were evaluated with Fisher's exact test. The differences were considered statistically significant when $p < 0.05$.

Fig 2. The hexagonal cluster pattern of microcalcifications at the four dose levels. The mAs values were 100% (a), 50% (b), 25% (c), and 12.5% (d). The number of microcalcifications was six as a positive signal.

RESULTS

There was a deterioration in the overall accuracy as mAs decreased (Table 1). The overall AUC scores for the four mAs values were 0.97 at the 100%, 0.93 (n.s.) at the 50%, 0.90 ($p < 0.05$) at the 25%, and 0.81 ($p < 0.01$) at the 12.5% values (Fig. 4). The differences in the diagnostic performance between the full and half mAs values were not significant, but the deterioration in diagnostic performance was significant between the full and quarter mAs values ($p < 0.05$). However, although there was no statistically significant difference between full and half mAs values, some of the observers showed nearly equal differences in diagnostic performance as large as the change from full to quarter mAs values. Furthermore, the AUC scores decreased from 0.95 at 100% mAs to 0.92 at 50%, 0.89 at 25%, and 0.75 at the 12.5% value on the line cluster pattern, and they decreased from 0.97 at 100% to 0.96 at 50%, 0.91 at 25%, and 0.87 at 12.5% on the hexagonal

cluster pattern. The diagnostic performance tended to be similar between the two simulated microcalcification cluster patterns.

Among the 25 negative images of each radiation dose series, the percentages of images on which every observer was able to identify the removed microcalcification point decreased from 88.8% at the 100% mAs value to 83.6% (n.s.) at 50%, 74.8% ($p < 0.001$) at 25%, and 67.2% ($p < 0.001$) at 12.5%. Accuracy deteriorated significantly for the transition from full to quarter mAs, and the deterioration was notable but not significant for the transition from full to half mAs.

DISCUSSION

Past studies on digital mammography have reported that image quality deteriorated by added artificial noises according to reducing dose.^{18,19} However, in order to choose the most appropriate screening modality, it is important to investigate

Fig 3. The line cluster pattern of microcalcifications at the four dose levels. The mAs values were 100% (a), 50% (b), 25% (c), and 12.5% (d). The number of microcalcifications was five as a negative signal. White arrows indicate the removed microcalcification.

whether or not dose reduction affects diagnostic performance. The purpose of screening mammography is to detect breast cancer with high sensitivity and specificity. However, it would also be desirable to reduce the radiation dose in breast cancer screening provided that the diagnostic performance could be preserved. Thus, although the present study did not examine diagnostic performance in detecting nodules or masses, the effect of dose reduction on the ability of digital mammography to detect microcalcifications and the range within which the diagnostic performance is maintained were investigated.

The results demonstrated that a screening's ability to detect simulated microcalcifications was not affected by a dose reduction of 50%, irrespective of the pattern in which the simulated microcalcifications were arranged. Earlier studies have reported similar results with regard to the effect of dose reduction on digital mammography.^{19–25} Samei et al.²⁰ reported that a reduction of dose from 100% to 50% did not have a statistically significant effect on the ability of the screening to

detect simulated microcalcifications, while the decrease from 100% to 25% dose did have a significant effect. Chawla et al.²¹ used mathematical model observers and reported that a dose reduction of 50% did not have a statistically significant effect on the detection of microcalcifications. These studies used electronically simulated microcalcifications that were inserted into mammographic backgrounds and also simulated radiation dose levels. However, the present study used four actual different dose levels, and the results were in agreement with the past computer simulation studies.

Table 1. Results of Overall AUC Scores by All Observers

Observer	100% mAs	50% mAs	25% mAs	12.5% mAs
1	0.96	0.96	0.93	0.88
2	0.97	0.95	0.89	0.85
3	0.98	0.92	0.91	0.82
4	0.98	0.94	0.91	0.84
5	0.94	0.87	0.88	0.66
Mean	0.97	0.93	0.90	0.81

Fig 4. The overall ROC curves. The overall AUC scores were 0.97 at the 100% mAs value, 0.93 at 50%, 0.90 at 25%, and 0.81 at 12.5%.

On the other hand, another study suggested that anatomical variability, rather than a certain degree of system noise, could be the biggest factor limiting the detection of breast cancer.²² Image noise is highly dependent on the amount of X-ray exposure. Thus, the study suggested that dose levels in mammography can potentially be reduced with a lesser impact on the detectability of lesions than that caused by anatomical variations. Bochud et al.²⁶ reported that anatomical variability was more influential than system noise for mass detection. Thus, dose reduction may have less influence on the detection of nodules or masses than on that of microcalcifications. For these reasons, if the ability to detect microcalcifications can be maintained, a certain level of dose reduction in digital mammography may be an option. The diagnosis of breast cancer is based mainly on the forms of nodules and masses or of microcalcifications. The present study did not investigate the relationship between the radiation dose and the observer diagnostic performance for nodules or masses. However, with regard to the ability to detect simulated nodules or masses, some studies have suggested that a certain level of dose reduction may be possible.^{19,20,23} Specifically, these studies suggested that 30–50% reduction

may be possible for the detection of benign or malignant nodules or masses.

These results, when taken together with the results of the present study, suggest that a dose reduction may be possible; the diagnostic performance did tend to decline at certain levels of dose reduction. Thus, dose reduction must be executed carefully in clinical screening. However, Svahn et al.²⁷ suggested that a dose reduction of 50% would result in nine fewer breast cancer fatalities per 100,000 women undergoing annual screening from the age of 40 to 49 years. They indicated that it may be possible to reduce the dose to the breast by 50% of the level currently used without affecting diagnostic performance for the detection of nodules or masses and microcalcifications.

The present study had several limitations. First, we used simulated microcalcifications consisting of two patterns of clusters with six microcalcifications. However, the morphology, distribution, and number of calcifications are much more variable in clinical practice. Second, wire frames were placed around the microcalcifications in the present study. In clinical practice, observers would not know the positions of microcalcifications beforehand. Third, this study did not examine diagnostic performance in detecting nodules or masses. Finally, we used only one phantom, which consisted of 50% adipose and 50% glandular breast tissue, and the dataset consisted of only 25 different anatomical backgrounds. We assumed that 25 different regions of interest are an appropriate number to avoid overlapping in this phantom. There is a possibility that the density of the breast tissue had a substantial influence on the screening's ability to detect calcifications. These limitations should be addressed in experimental or clinical studies in the future.

CONCLUSION

The findings of the present study suggested that the ability of digital mammography to detect simulated microcalcifications was not significantly affected by a 50% mAs value reduction, suggesting that radiation dose reduction may be an option in digital mammography, although observers differed in their performance reduction rates.

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