QUALITY CONTROL OF DIGITAL MAMMOGRAPHY EQUIPMENT AT KING CHULALONGKORN MEMORIAL HOSPITAL

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ABSTRACT

Mammography equipment has been used to display Thai women's breast image for more than 30 years. The quality control of the equipment performed by technologists was started no longer than 5 years. The program covers the darkroom cleanliness, processor quality control and mammographic phantom imaging. The quality control tests performed by medical physicist is firstly responsible by the government inspector from Department of Medical Sciences, Ministry of Public Health. The visit is upon requested annually to verify the system performance prior to certification. Very few tests had been conducted according to the limited number in human resources, knowledge and test tools. Digital Spot Mammography system was firstly installed in 1995, follow by the Digital Full-Field Mammography System in 1999 at King Chulalongkorn Memorial Hospital. The quality control program followed the manufacture guideline for MQSA and Non-MQSA Facilities was started after the system installation. Two parts from the QC program are prepared for technologists and medical physicists. The first part was performed and the data from June 2002-2003 was collected, analyzed and presented in this report. The objective of this study is to stress the important of image quality, the safety standards, economical criteria of film retake rate as well as the patient dose reduction. The result shows that most data are in the acceptable limit. The system is well maintained by the service engineer under the service contract. The program for medical physicist covers the system performance study, the hardware assessment such as the collimation, the monitor, viewing facilities, the radiation dose measurement and the overall image quality parameters. More test tool and radiation detector are required for the second part. Furthermore, the test should be performed and evaluated by the experienced medical physicist in this field to fulfill the objective.

Keyword: Quality Control, mammographic equipment, image quality

INTRODUCTION

Mammography is the x-ray examination of the breast. Low energy x-ray is used to provide adequate contrast in the image because various tissues of the breast have similar attenuation co-

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efficients.[1,2] In Thailand, the majority of mammographic images are produced using a screen film combination, exposed to x-rays generated at peak voltages in the range of 25 to 30 kV. The first digital mammography equipment, Digital Spot Mammography System, Bennett, was installed and used on 26th October 1995 at the Department of Radiology, King Chulalongkorn Memorial Hospital. In December 1999, Full Field Digital Mammography System was installed at the same department to replace digital spot mammography system. This system was not only first full field digital mammography in Thailand but also in Asia. Followed by the installation of the same model at the mammography center, Siriraj Hospital in the year 2000. The quality control of the mammographic equipment is scarcely performed at very few centers. The major problem is the lack of qualified medical physicist, well trained technologists and the proper training in this facility as well as the lack of test tools. A one-day workshop on quality control of mammography system was arranged at the department with 20 participants from several centers in Thailand. The objective of the workshop is to educate technologists and initiate the quality control program as well as the MQSA (Mammography Quality Standards Acts) in Thailand.

MATERIAL AND METHOD

The Full Field Digital Mammography equipment used in this study is Senographe 2000D (GE Medical Systems Waukesha Wisconsin 53188, USA.) The system is installed at Department of Radiology King Chulalongkorn Memorial Hospital in the year 2001.

Mammography QC phantoms had been used in this study is Inovision/Victoreen Nuclear Associates (100 Voice Road,Carle Place, NY 11514-1593 USA) Model No.76-001 as shown in figure 1.

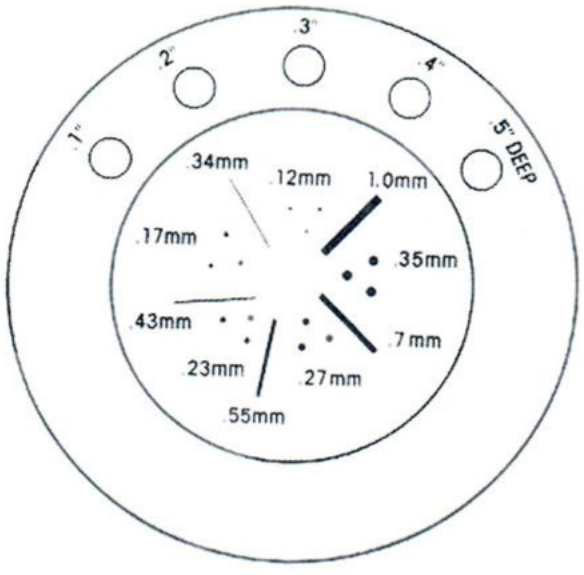

Fig. 1 Mammographic Quality Control phantom

The recommended procedures[3] for conducting Quality Control tests for radiological technologist are shown in Table 1:

Table 1: Quality Control tests and their frequencies as performed by radiological technologist

Test	Frequency
1. Monitor Cleaning	Daily
2. Viewing Conditions Check for the Review Work Station	Daily
3. Flat Field Test	Weekly
4. Image Quality Checks	Weekly
5. Modulation Transfer Function Measurement (Consistency and contrast)	Monthly
6. Automatic Optimization Parameter Mode and SNR Check	Monthly
7. Visual Checklist	Monthly
8. Monitor Calibration Check	Monthly
9. Repeat Analysis Check	Quarterly
10. Compression Force test	Semi-annually
11. Printer Check	Semi-annually

1. Monitor cleaning. The objective is to ensure the good image quality by keeping the monitor screen clean. Dry, soft, lint-free cloth is used for cleaning all monitor screens on the day when clinical image acquisitions or reviews are planned. Check the screen to verify that it is free from dust, fingerprints and other marks then initial in the log book.

2. Viewing conditions check for review workstation. The objective is to ensure optimal viewing conditions. Check the reading room for optimal conditions then initial in the log book.

3. Flat Field Test. This test should be performed before phantom study. Five tests are carried out when flat field test is selected. Those are brightness uniformity, high frequency modulation (HFM), Signal-to-noise-ratio (SNR) uniformity, bad region of interest (ROI) and bad pixel verification. The material used for this test is 19x23 cm acrylic (PMMA) of 2.5cm thickness to cover the entire image receptor. The acrylic must be clean and free from imperfections in order to avoid false results. Use large field of view, remove the compression paddle, Bucky or breast holder. Place the acrylic in the field of view and directly on the image receptor. Select large focal spot, Mo/Mo as target and filter, 26 kV and 200mAs then make two exposures. The results will be processed and displayed. Record all results in the log book.

4. The phantom image quality test. The objective of this test is to check the consistency of the Contrast-to-Noise Ratio (CNR) and to ensure adequate and consistent quality of images acquired by the detector and displayed on the acquisition work station (AWS) monitor, the review work station (RWS) monitor and the printer. As recommended by the American College of Radiology[3] (ACR), the phantom image quality test for screen-film imaging systems includes a test for consistency of image contrast as represented by the density difference between the image of an added test object of 4 mm thick acrylic disk and the background density of the

phantom. In digital imaging the relative level of a signal or contrast to the image noise is the more relevant measure of image quality. Hence, the measure of consistency of Contrast-to-Noise Ratio (CNR) is chosen. The test procedure includes the installation of the grid then position the breast phantom in the field of view of the image receptor. The phantom edge must be flush with the chest wall edge with the 9 cm x 9 cm X-ray field size and use light localizer to center the phantom laterally. Reset collimator to the maximum field of view. Apply 5 daN of compression force to the phantom. Select large focal spot, Mo/Mo target/filter, 26 kVp, 125 mAs, make an exposure.

4.1 Change in Contrast-to Noise Ratio Measurement The measurement should be performed on five consecutive days and use the average as the new CNR01. Select the phantom raw image, set zoom factor to 1, set a window width between 125 and 175. Create a first region of interest (ROI) and position at centered over the large mass of the phantom. Ensure that the ROI is completely within and centered on the image of the largest mass. Create a second ROI with its default size and position it on the background. Record the mean signal in the first ROI as mean_mass , the mean signal in the second ROI, mean_background, the standard deviation of the signal in the second ROI,sd_background. Calculate the CNR as (mean_background-mean_mass) / sd_background. Calculate the change in CNR as 1-(CNR/CNR_{01}) if CNR is smaller than or equal to the CNR_{01}. In the case that CNR is larger than CNR_{01} the change in CNR is (CNR/CNR_{01})-1. The limit of CNR change is less than or equal to 0.2.

4.2 Phantom IQ test on AWS. Process phantom image on the acquisition workstation (AWS) screen, score the objects under optimal viewing conditions. Scores must include deduction of artifacts. Use the zoom, rotation, magnifying glass, brightness and contrast control so that the most accurate score can be obtained. Record the display setting and results.

4.3 Phantom IQ test on RWS. Process phantom image on review workstation (RWS), score the objects under the optimal conditions. Scores must include deduction of artifacts. Use the zoom, rotation, magnifying glass, brightness and contrast control so that the most accurate score can be obtained. Record the display setting and results.

5. Modulation Transfer Function Measurement. The objective of this test is to ensure that the contrast is adequate over the 0-5 lp/mm spatial frequency range by obtaining an estimate of the MTF values near 2 and 4 lp/mm. Resolution bar pattern including spatial frequency groups of 2 ± 0.1 lp/mm and 4 ± 0.1 lp/mm with a thickness of at least 0.1 mm of lead is used in this test. Install the Bucky on the digital detector, the grid must be presented and the compression paddle must be removed. Place the resolution pattern in the field of view on the Bucky. Position the pattern along a direction parallel or perpendicular to the chest wall side. Select the large focal spot, Rh/Rh for target/filter, 30 kV, 28 mAs, left breast lateral. Make an exposure then choose the raw image, set Zoom factor to 1adjust Contrast and brightness for optimum visibility of the test object. Use the ellipse tool for ROI for 2 and 4 lp/mm. Adjust the size of ROI to include as much of the line pair pattern. Record ROI standard deviation,$sd_{2lp/mm}$, $sd_{4lp/mm}$, ROI mean, $mean_{bar}$. Select a ROI of the default size and containing only space material in the pattern of figure 2, record ROI mean, $mean_{space}$.

$$MTF_{2lp/mm} = \frac{sd_{2lp/mm}}{mean_{space} - mean_{bar}} x222$$

$$MTF_{4lp/mm} = \frac{sd_{4lp/mm}}{mean_{space} - mean_{bar}} x222$$

The test is successful if MTF2lp/mm is greater than 58% and MTF4lp/mm is greater than 25%

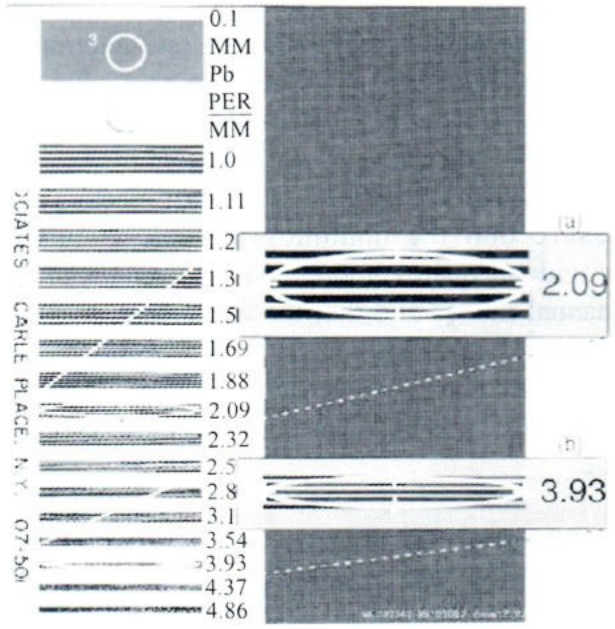

Fig. 2 MTF Measurement

6. Automatic Optimization of Parameters Mode and SNR Check. The objective is to check the correct choice of parameters in AOP mode and the correct level of Signal-to-noise ratio (SNR) in the image.

Set of acrylic plates (PMMA) 20x20 cm size with thickness of 25 ± 0.1 mm, 40 ± 0.1 mm, 60 ± 0.1 mm are used. Begin with 25 mm thick, place the acrylic plate on the Bucky. Align one edge of the plates with the chest wall edge of the detector. Center the plates left-to-right, apply a compression force of 5 daN to the plates. Select Left breast laterally and take an exposure. Record the exposure parameters then repeat these steps for the 40 and 60 mm thickness. Select the raw image for review with the default zoom. Use the ellipse ROI tool to measure the mean value and the standard deviation, s.d., of the image in the region close to the chest wall edge and laterally centered. Calculate the SNR as mean / s.d. The exposure parameters are as in the table 2:

Table 2: Exposure Parameters

Acrylic Thickness (mm)	Target/Filter	Exposure Parameters For AOP STD mode only mAs	kV
25	Mo/Mo	20-60	27
40	Mo/Rh	50-100	28
60	Rh/Rh	50-100	32

The value of SNR must exceed 50.

7. Visual Checklist. The objective is to assure that mammographic X-ray system indicator lights, displays and mechanical locks and detents are working properly and the system mechanically stable. The procedures are reviewed each item on the visual checklist and indicate its status. Initial and date record in the checklist.

8. Monitor Calibration Check. The objective is to assure that the monitor is calibrated and the brightness and contrast settings are at an appropriate level for the reading of mammographic images on the review workstation. The SMPTE (Society of Motion Picture Test Equipment) test pattern is displayed on the RWS. A white square

appears in the middle of the left monitor and an SMPTE pattern appears on the right monitor. At the very top of the left monitor screen is a menu bar. Click on View then Test pattern and SMPTE pattern, a SMPTE patterned will be displayed on both monitors.

8.1 Verify that 0% - 5% contrast is visible.

8.2 Verify that the 95% - 100% contrast is visible.

8.3 Verify that each gray level step from 0% - 100% can be distinguished from the adjacent squares. Verify that the 0% square can be distinguished from 10% square or the 90% square can be distinguished from the 100% square.

8.4 Verify that the alphanumeric characters appear on the pattern are sharp and in focus.

8.5 Verify that the high contrast line pair images at the center and corners of the SMPTE pattern are distinguishable.

9. Repeat Analysis Check. The objective is to determine the number and cause of repeated digital mammograms and to improve the system efficiency as well as reduce digital image retakes and patient exposure.

Identify all exposures which had to be repeated. Record by entering Study number, cause of repeated exposure, date. Estimate the total number of exposures taken during the analysis period. Calculate the overall repeat rate as the total of repeated exposure divided by the total number of exposures during the analysis period multiplied by 100%. Determine the percentage of repeats in each category by dividing the number of repeats in the category by the total number of repeated exposures from all categories. Record all completion of the repeat analysis check in log book. The action must be taken if the total repeat rate or reject rate change from the rate determined for the previous analysis period by more than 2% of the total exposures included in the analysis. The reason for the change must be determined.

10. Compression Force Test. The objective is to assure that the mammographic system can provide adequate compression in power driven and manual modes and that the equipment does not allow too much compression to be applied. The maximum compression force for the initial power driven must be between 11 and 20daN (25 to 45 lb).

11. Printer. The objective is to ensure optimal quality of the film printer output. Follow the QC program developed by the manufacturer of the device.

RESULT

The result of all tests during June 2002 to June 2003 were collected, processed and displayed in this study.

The monitor cleaning and the viewing conditions on the day the mammographic system used had been initial in the checklists.

Flat Field Test. Five weekly tests on acquisition workstation, of 52 week- collection are as the followings:

A. Brightness uniformity. The result shows the range of brightness uniformity from 0.97-4.93 where the mean is 3.20. The maximum limit is 10.00.

B. High Frequency Modulation. The range of high frequency modulation is from 0.49 to 0.8 where the mean is 0.66. The maximum limit is 0.8

C. Bad pixel ranges from 0-6 where the mean is 2.13 and the maximum limit is 100.00.

D. Bad ROI is recorded as 0 and no limit allow in this test.

E. Signal-to-Noise-Ratio (SNR) Uniformity. The range of signal-to-noise-ratio uniformity is from 25.34 to 35.46 where the mean is 33.96 and the maximum limit is 40.00

All five studies are within the acceptable range.

IMAGE QUALITY TEST RESULT

A. The Contrast-to-Noise-Ratio (CNR) Measurement. The result on phantom study is as in the table.3

Table 3 Contrast to noise ratio measurement and the change in CNR

Mean_mass	Mean_background	SD_background	CNR	CNRChange
828.40	780.05	10.73	4.51	0
827.97	779.66	10.57	4.57	0.01
822.62	776.82	10.31	4.44	0.004
822.19	774.93	10.41	4.54	0.007
828.41	779.16	10.37	4.75	0.05

The change in CNR of less than 0.2 shows the system consistency on the image quality of AWS. The important thing is the window width is set at 150 which is within the range between 125-175.

B. Phantom Study. The phantom contains 5 masses, 5 speck groups and 6 fibrils. The visualization of the mass, speck and fibrils show the average of total scores of 13.90 where the lowest score is 13 and the highest is 14. The acceptable range is between 11 and 16. The review workstation displayed better image quality and the average score was 14.15 (14.0-14.5).

Modulation Transfer Function (MTF) Measurement. The average MTF2lp/mm is 73.13 % where the requirement needs the MTF of greater than 58% and the average MTF4lp/mm is 41.51 % where the requirement needs the MTF of greater than 25%.

Automatic Optimization Parameter Check. The result in the checklist is all pass for 25, 40 and 60 mm acrylic thickness. The measurement of SNR is averaged of 84.76, 83.80 and 71.46 for 25, 40 and 60 mm acrylic thickness. The acceptable limit of SNR is greater than 50.

Visual Checklist. The system has been daily checked and initial in the log book for the complete function on indicator lights, displays, mechanical locks and detents.

Monitor Calibration Check. This monthly check on SMPTE test pattern on RW monitor is shown in figure 3.

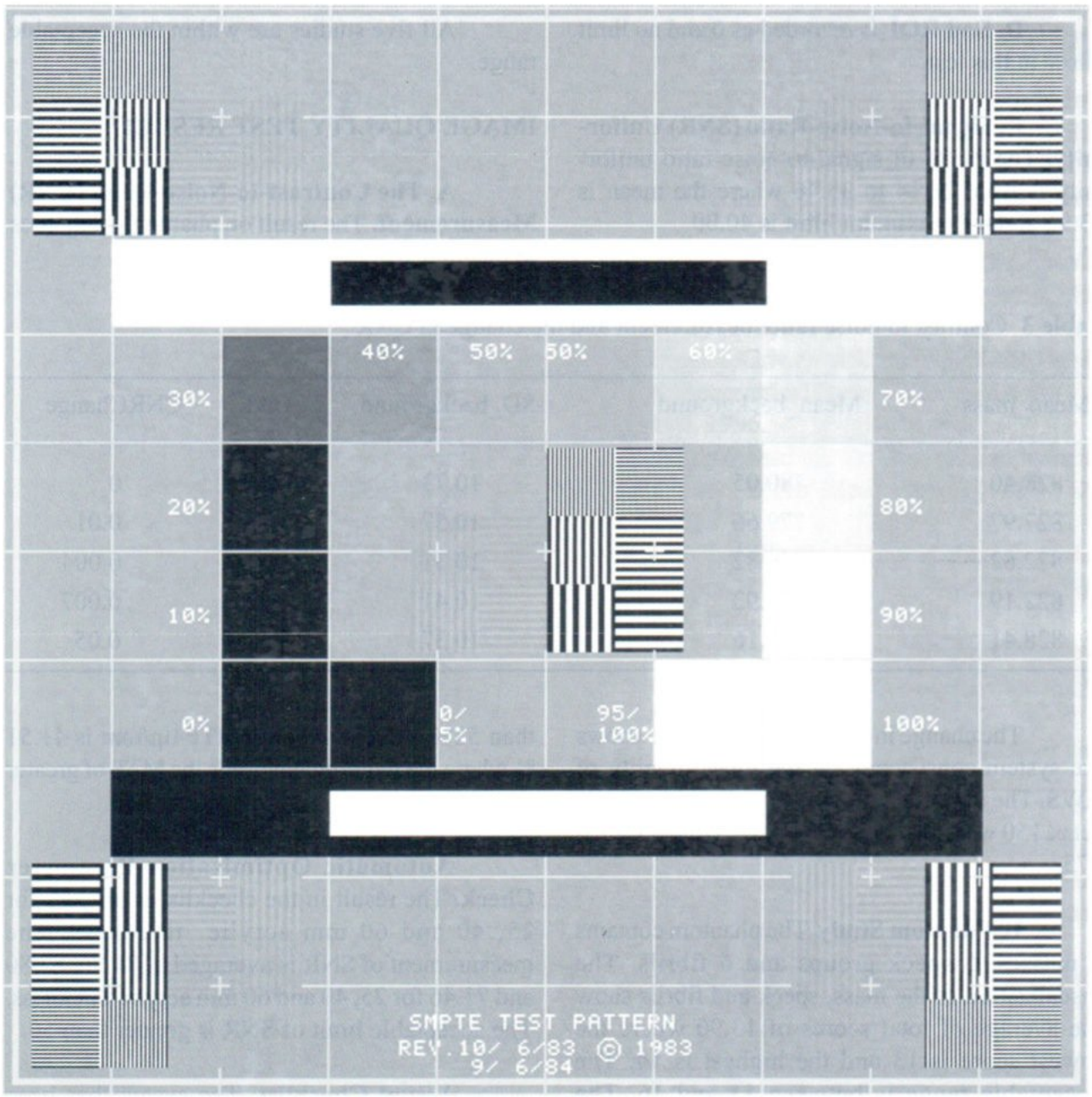

Fig. 3 SMPTE test pattern for the calibration of left and right RW monitors

The following result has been verified such as:

A. 0-5%contrast is visible

B. 95-100% contrast is visible.

C. Each gray level step from 0-100% is distinguished from the adjacent square. 0% square is distinguished from 10% square and 90% square is distinguished from 100% square.

D. All alphanumeric characters are visible.

E. The high contrast line pair images at the corners and the center are visible.

Repeat Analysis Check All repeated exposures that caused the patient to receive additional dose beyond that of the normal study had been collected from July 2002 to June 2003. The result is shown in table 4

Table 4 Repeat Analysis Check

Cause	Number of Repeat Exposure	Percentage of repeat by category
1 Positioning	37	53.6
2 Patient Motion	6	8.7
3 Improper Detector Exposure	12	17.4
4 Incorrect Patient ID	-	-
5 X-ray equipment failure	8	11.5
6 Software failure	6	8.7
7 Blank Image	-	-
Total of Repeat Exposure	69	
Total of All Exposures	22168	
Repeat Exposure Percentage	35%	

Compression Force Test The quarterly check showed the maximum force is not greater than 20 daN and the variation of force at 4-6 daN for normal Thai force is less than 10%

Printer The printer has been calibrated according to the Kodak operating manual and the test pattern is shown in figure 4

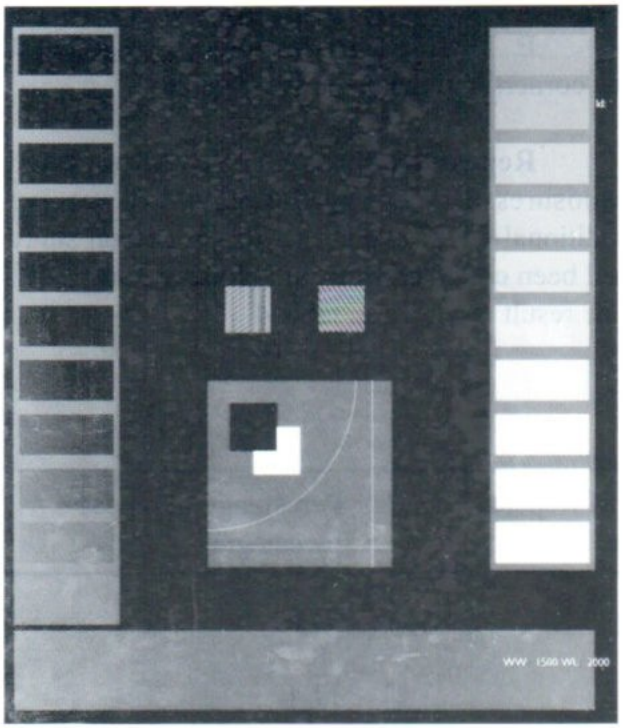

Fig. 4 Kodak test pattern for printer calibration

DISCUSSION

The success of screening-mammography depends on the production of high quality image with optimum patient dose. The result of this study indicates the close watch of the total system parameters concerning the production of the image and the determination of the image quality in the terms of contrast to noise ratio, MTF, the image uniformity and etc. It is very important for the mammographic technologists perform the test consistently as recommended by the manufacture or the international standards. Furthermore, they should keep an eye on the result obtained as well as the careful observation on the mammographic phantom image for the little changes or artifacts on the image. They should rectify the problem immediately or consult the medical physicist or service engineer before using the system in clinical study.

CONCLUSION

This is the pioneer effort to establish the quality control of mammographic system in Thailand. It is well recommended that the quality control program for technologist must be performed regularly and the record must be keeping well in the log book in order to compare the current result to the result on the reference test. Action must be taken after reviewing the result. Quality control of the mammography system for technologist is encouraged to improve the image quality and patient dose reduction as in standards act.

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