A Quantitative study in Mammography with Air Gap

Rachmat W. Adi, Supriyanto A. Pawiro, Maya Nurningsih

Department of Physics, Faculty of Mathematics and Sciences, University of Indonesia, Depok, Indonesia

ABSTRACT

A quantitative study based on slightly modified Bernstein and Muntz method in combination with a qualitative MQSA method has been done on the influence of air gap on image quality in mammography. Work was accomplished on a Senographe mammography unit. The method uses Low Shield Contrast with variety of air gaps on 26 kVp and 18 mAs, SIDs (Source to Image Distance) set up at 63 cm, field sizes at 13.5 x 13.5 cm^2 and automatic processing unit. The modification used PMMA phantom, but with the different voltages for additional thicknesses for different exposures. The calculation result is that with increasing gap, S/P (Scatter to Primary ratio) decreased only slightly. For subsequent air gap thicknesses of 1 cm, 2 cm, 3 cm, 4 cm, and 5 cm the S/P values decreased by 6.96%, 12.95%, 18.13%, 22.62%, and 26.54%. In addition, the MQSA qualitative method is suggesting that the image quality is increased markedly. Further work also showed that the image quality also decreased as the phantom thickness increased.

I. INTRODUCTION

Mammography is radiographic technique for breast imaging with specific X-ray machine at operational voltage 25-35 kVp. Mammography is a commonly used screening method for breast cancer detection where the high quality image is very urgently needed. High image quality depends on many parameters such as contrast, optimum operating voltage, and film processing stability. Contrast is an essential physical parameter to control image quality. Maximum contrast can generally be obtained by limiting scattered radiation[1,2].

The goal of this type of work is to evaluate the air gap technique for improving image quality of mammography by minimizing scattered radiation. The quantitative evaluation was done by calculating the ratio of scattered and primary radiation (S/P). Krol *et. al.* performed evaluation of air gap technique to image quality using Bernstein and Muntz methods[3]. Our work these based on the same method with Krol work and with a qualitative study using PMMA phantom measurement of MQSA standard for image quality assessment. [4]

II. THEORY

Scaterred radiation occurs abundantly in X-ray imaging and may reduce the image contrast significantly. There exists some common methods that can reduce scattered radiation such as optimizing beam and patient orientation or using grid and air gap technique. Krol *et. al.* reported that air gap technique can improve system resolution and reduce scattered radiation[3]. The useful parameters to calculate scatter to primary ratio are:

a. Gamma film (γ)

Film Gamma is slope of film's sensitometric curve in the linear region of interest.

b. Radiation Fluence *(O/P)*

The ratio of radiation fluence that were transmitted by low shield contrast to the primary fluence can be calculated using [3]

$$O/P = 10^{\Delta D'/\gamma} \quad \ldots\ldots \quad (1)$$

where $\Delta D'$ is the difference between optical density due to attenuated beam by low shield contrast disk and non-attenuated pencil beams. In the experiment pencil beam was simulated by using a small opening lead collimator.

c. Scattered to Primary Ratio $(S/P)_o$

The ratio of scattered radiation to primary beams $(S/P)_o$ at without air gap (g = 0) can be defined using the following formula.[3]

$$\left(\frac{S}{P}\right)_o = \frac{1 - (O/P) \cdot 10^{\Delta D/\gamma}}{10^{\Delta D/\gamma} - 1} \quad \ldots(2)$$

where ΔD is experimentally defined by the optical densities difference between the image of the object and the surrounding area.

d. The Virtual Source Model (S/P)

The virtual scatter source model postulates that all scattered photon originate from a single virtual source of scatter positioned on the central axis between the exit surface of the patient (or phantom) and primary X-ray source. For constant source to image distance (SID) the virtual source of scatter model gives rise to the following relation between S/P and the gap distance g: [3]

$$\frac{S}{P} = \left(\frac{S}{P}\right)_o \times \frac{\delta^2}{(|\delta| + g)^2} \times \frac{SID^2}{(SID - g)^2} \quad \ldots\ldots (3)$$

where δ is the distance of virtual source of scatter from the exit surface of the patient or phantom, $(S/P)_0$ is S/P ratio at the exit surface of the phantom, and g is the air gap thickness.

Krol *et. al* presented that the virtual source distance δ, exhibit linear increase proportional to radiation field size (W).

$$\delta(W) = a + b \bullet W \qquad (4)$$

where a and b are parameter. Based on Krol data[3], we can use the means value of a = 11.8 and b = 0.038 in all calculation and independent of the phantom thickness.

III. MATERIALS AND METHODS

In this work we utilize a well tested good condition Senographe mammography machine, phantom of PMMA, *Low Shield Contrast* test object, mammography film-cassette, and some additional acrylic slabs situated on top of the test object to increase scatter intentionally. Source to image distance was set at 63 cm. For image capture we use KODAK film Min-RS 18 x 24 cm^2, KODAK cassette Min-R 2190, and automatic film processor KODAK X-Omat 2000 with developer temperature stabilized within 21-22^{o}C. Two objects were used, the 3 mm thick low shield contrast and PMMA mammography phantom with 4.5 cm thickness (MQSA standard). The low shield contrast has 4 different size or diameter holes of 1, 3, 5 and 7 cm respectively. The images captured in the film will be used to calculate S/P values using equation 2 for zero air gap and equation 3 for non zero air gap.

Two methods were used:

A. Bernstein and Muntz Method

1. Broad beam method

The method was used to expose low shield contrast on cassette film with 26 kVp, 18 mAs and field size 13.5 x 13.5 cm^2 for air gap thicknesses of 0, 1, 2, 3, 4, and 5 cm respectively. We obtained ΔD (difference of optical densities of object and its surrounding) using densitometer

2. Measure $\Delta D'$ with pencil beam method

The pencil beam was obtained using lead slab or collimator bored 0,04 cm^2 in the centre and mounted on collimator tray. Air gap was set to 32 cm thickness. The measurements were performed with operating condition of 26 kVp and 18 mAs with and without the low shield contrast object. From this measurements, $\Delta D'$ was determined.

B. Image Quality Assessments

The image quality assessment used PMMA phantom. For standard MQSA, the phantom test object was exposed on cassette film with 28 kVp, 180 mAs for air gap of 0, 1, 2, 3, 4, and 5 cm respectively.

Breast thickness variation can be evaluated by using additional acrylic slabs of 1 cm (exposed to 30 kVp and 200mAs), 2 cm (exposed to 32 kVp and 250 mAs), and 3 cm (exposed to 33 kVp and 280 mAs) respectively. Air gaps were set to 0, 1, 2, 3, 4, and 5 cm respectively.

IV. RESULT AND DISCUSSION

The kVp accuracy test indicated mammography machine was in good performance. The difference kVp value from measurements and set up in control panel indicated in the range of 1.06 % up to 5.55 %. Other preparation performed is gamma film measurements. It was found that the gamma film is 2.52.

A. *(O/P)* and *(S/P)$_o$* Value

The result of *ΔD'* measurement is -0.02 and the resulting O/*P* value is 0.98. The ratio of scattered radiation to primary beams at zero air gap or *(S/P)$_o$* values are calculated using equation 2 and found to be 0.05, 0.7, 0.7, and 0.7 for hole diameters of 1, 3, 5, and 7 cm respectively as shown in Table 1.

B. *(S/P)* Value

The S/P values at non zero air gap were calculated by using equation 3 for δ value of 18.7. Table 1 showed that the *S/P* value of X-ray beams from 1 cm hole is lower than S/P values of the larger holes due to much larger absorption by the phantom. The curves of S/P values as a function of air gap for Bernstein and Muntz method with different size hole objects are generally decreasingly linear with increasing air gap as shown in Figure 1- 4. It physically means the scattered radiation reached the film less and less with increasing air gap.

Table 1. *(S/P)* Values of X-ray beams for different diameter holes

Gap (cm)	ΔD hole ∅ = 1 cm	ΔD hole ∅ = 3 cm	ΔD hole ∅ = 5 cm	ΔD hole ∅ = 7 cm
0	0.05	0.70	0.70	0.70
1	0.04	0.65	0.65	0.65
2	0.04	0.61	0.61	0.61
3	0.04	0.57	0.57	0.57
4	0.03	0.54	0.54	0.54
5	0.03	0.51	0.51	0.52

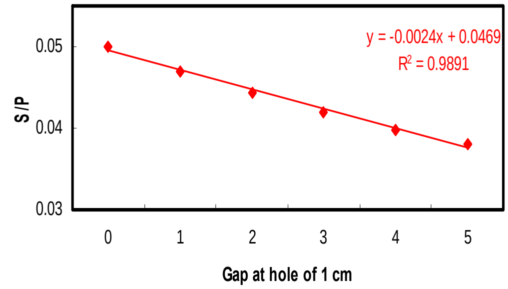

Figure 1 S/P curve for 1 cm diameter hole

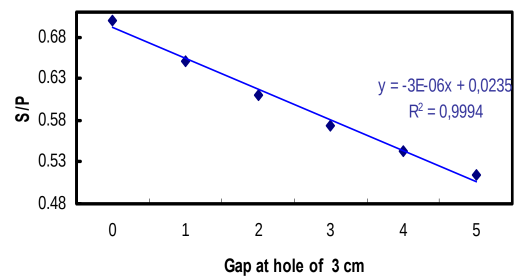

Figure 2 S/P curve of 3 cm diameter hole

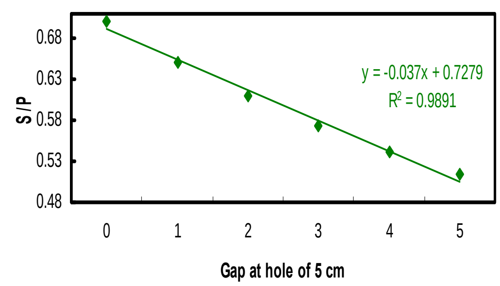

Figure 3 S/P curve of 5 cm diameter hole

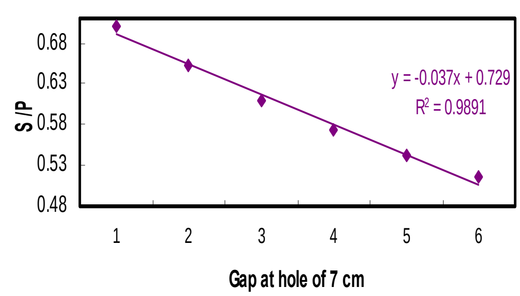

Figure 4 S/P curve of hole diameter 7 cm

C. Image quality test f

Table 2. Image quality test for MQSA mammography phantom without additional acrylic

Gap (cm)	Without acrylic			
	Fiber	calcification	Mass	TOTAL
0	3	2	2	**7**
1	4	2	2	**8**
2	4	3	2	**9**
3	4	3	3	**10**
4	4	3	3	**10**
5	4	3	4	**11**

Table 3. Image quality test for MQSA mammography phantom with 1 cm additional acrylic slab

Gap (cm)	1 cm acrylic slab added			
	Fiber	calcification	Mass	TOTAL
0	3	2	1	**6**
1	3	2	1	**6**
2	4	2	2	**8**
3	4	2	2	**8**
4	4	3	2	**9**
5	4	3	2	**9**

Table 4. Image quality test for MQSA mammography phantom with 2 cm additional acrylic slabs

Gap (cm)	2 cm acrylic slabs added			
	Fiber	calcification	Mass	TOTAL
0	3	2	1	**6**
1	3	2	1	**6**
2	3	2	2	**7**
3	3	2	2	**7**
4	3	2	2	**7**
5	3	3	2	**8**

Table 5. Image quality test for MQSA mammography phantom with 3 cm additional acrylic slabs

Gap (cm)	3 cm acrylic slabs added			
	Fiber	calcification	Mass	TOTAL
0	1	2	0	**3**
1	1	2	0	**3**
2	1	2	0	**3**
3	2	2	0	**4**
4	2	2	1	**5**
5	2	2	1	**5**

Table 2 -5 showed the results of image quality test taken with different thickness absorbers. In general the total number of objects can be seen in the film tends to increase with increasing air gap which means that the image quality is qualitatively increasing with air gap size. In addition, the Tables explained that the total object seen in the film decreases with increasing absorber thickness at same air gap. These facts showed the image quality decreases with increasing phantom thickness.

According to MQSA recommendation, that acceptable image qualities of a PMMA phantom on the film should have unconditionally contained at the minimum 10 objects combining 4 fibers, 3 calcifications, and 3 masses[1]. Our data thus suggested a justification that the image quality of mammography taken with air gap technique will generally qualitatively be better than the standard imaging of PMMA phantom with zero air gap.

The result of this work thus showed that the air gap technique will generally improve image quality as has also been the subject of discussion in many basic textbooks of radiology or imaging physics. On the other hand, radiation dose consideration and mammography film size will eventually prevail as the limiting factor for general mammography exposures involving air gap technique since mammography is the most common method in breast cancer screening among high risk middle age female population.

V. CONCLUSION

The quantitative Bernstein and Munts method for calculating S/P values with or without air gap has been combined successfully with MQSA qualitative method to assess the use of air gap with different thickness absorber in mammography exposures. Both results showed consistently and convincingly the improvement of image quality with increasing air gap. It also proved that the thicker the absorber the less image quality obtained. On the other hand further study to determine radiation dose increase as the result of air gap technique is highly necessary.

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