The Application of X-ray Parameters for Calculation of Mean Glandular Dose from Mammography Examination

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Abstract

The primary purpose of this research was to develop a series of equations derived from x-ray parameters to calculate the mean glandular dose (MGD) for patients who underwent mammography in real time. A mammography x-ray generator at Buddhachinaraj Hospital in Phitsanulok, Thailand, was employed in this study. The half value layer (HVL) and exposure dose were measured by a 6-cc, ionization chamber (10x5-6M, Radcal Corporation) according to the American College of Radiology (ACR) recommendations. The measured HVL was found significantly correlated with the tube voltage. The equations for calculation of radiation exposure dose were derived from tube voltage, tube current and compressed breast thickness for both rhodium and molybdenum filters. Further, the correction factor derived from the tube voltage was used to convert exposure dose to the MGD. Thus, the MGD can be determined in real time from the tube voltage, tube current and compressed breast thickness of the patient.
Keywords: Dose calculation; Mean glandular dose; Mammography; X-ray parameters

Introduction

In Thailand, breast cancer is the second most frequently diagnosed following cervical cancer. The estimate incidence rate is 17.2 per 100,000 (National Cancer Institute, 1997). X-ray mammography is the technique of choice for detecting non-palpable breast cancer (Miller, 2005). However, the breast is a radiosensitive organ and has a tissue weighting factor of 0.05 for the estimation of an effective dose (International Commission on Radiological Protection, 1991). Since the glandular tissue of the breast is more radiosensitive than adipose tissue, the estimation of the mean glandular dose (MGD) has become an area of concern (Faulkner et al., 1995).

A screening mammography performed every one to two years is recommended for women in their forties. While women in their fifties should receive a screening mammography once every year (Miller, 2005). Screening mammography typically involves taking two views of the breast, from above (cranial-caudal view, CC) and from an oblique or angled view (mediolateral-oblique, MLO) (Hackshaw, 2000). The principle of radiation protection requires that any x-ray dose be justified and optimized (Bushong, 1993). The risk of carcinogenesis from the radiation dose to the breast is of much concern, particularly in screening examinations because of the large number of women receiving the exam.

A previous study on measurement of the MGD from CC and MLO views in patients who underwent mammography on six mammography x-ray generators in the lower region of northern Thailand reported that the MGD per film was 1.42$\pm$0.80 mGy for the CC projection and 1.56$\pm$0.86 mGy for the MLO projection (Sookpeng & Kettted, 2007).

The American College of Radiology (ACR) advocates that the maximum MGD by mammography must not exceed 3 milligrays (mGy) or 0.3 rad. Moreover, breast entrance exposure and MGD is one of the ACR's quality control tests (American College of Radiology, 1999; Frank, 2005; Suleiman et al., 1999). As direct estimation of

MGD is impossible, MGD in millirads (mrad) is calculated from radiation exposure (Roentgen; R) to the breast multiplied by an exposure to the dose conversion factor that depends on tube voltage and the half value layer (HVL) combination for various targets and filter combinations (American College of Radiology, 1999). Table 1 and 2 show the glandular dose (mrad) for 1 R entrance exposure for 4.2 cm breast thickness, 50% adipose and 50% glandular breast tissue, with a molybdenum/molybdenum (Mo/Mo) and molybdenum/rhodium (Mo/Rh) target-filter combination, respectively. However, it cannot be adapted to real time calculation. Therefore, the primary purpose of this study was to develop a series of equations derived from x-ray parameters to calculate the MGD in mammography in real time. With this equation, the MGD can be calculated immediately after x-ray mammography.

Table 1. The glandular dose (mrad) for 1 R entrance exposure for 4.2 cm breast thickness, 50% adipose and 50% glandular breast tissue, with a molybdenum/molybdenum target-filter combination (American College of Radiology, 1999)

	Mean glandular dose (mrad)										
Tube voltage (kVp) / HVL	23	24	25	26	27	28	29	30	31	32	33
0.23	116										
0.24	121	124									
0.25	126	129	131								
0.26	130	133	135	138							
0.27	135	138	140	142	143						
0.28	140	142	144	146	147	149					
0.29	144	146	148	150	151	153	154				
0.30	149	151	153	155	156	157	158	159			
0.31	154	156	157	159	160	161	162	163	164		
0.32	158	160	162	163	164	166	167	168	168	170	171
0.33	163	165	166	168	169	170	171	173	173	174	175
0.34	168	170	171	172	173	174	175	176	177	178	179
0.35		174	175	176	177	178	179	180	181	182	183
0.36			179	181	182	183	184	185	185	186	187
0.37				185	186	187	188	189	190	191	191
0.38					190	191	192	193	194	195	195
0.39						196	197	198	198	199	200
0.40							201	202	203	204	204
0.41								206	207	208	208
0.42									211	212	212
0.43										215	216
0.44											220

Table 2. The glandular dose (mrad) for 1 R entrance exposure for 4.2 cm breast thickness, 50% adipose and 50% glandular breast tissue, with a molybdenum/rhodium target-filter combination (American College of Radiology, 1999)

Tube voltage (kVp) / HVL	Mean glandular dose (mrad)										
	25	26	27	28	29	30	31	32	33	34	35
0.28	149	151	154								
0.29	154	156	158	159							
0.30	158	160	162	162	163						
0.31	163	164	166	166	167	167					
0.32	167	169	171	171	171	172	172				
0.33	171	173	175	176	176	176	176	177			
0.34	176	178	179	179	180	180	180	181	181		
0.35	180	181	183	183	184	185	185	186	187		
0.36	185	186	187	187	188	188	189	190	191	191	
0.37	189	190	191	191	192	193	193	194	195	195	
0.38	193	194	196	196	197	197	197	198	199	199	200
0.39	198	199	200	200	201	201	202	202	203	203	204
0.40	202	203	204	204	205	205	206	207	208	208	208
0.41	206	207	208	208	209	209	210	211	212	212	212
0.42	211	211	212	212	213	213	214	215	216	216	217
0.43	215	216	217	217	218	218	219	219	220	220	221
0.44	220	220	221	221	222	222	223	223	224	224	225
0.45	224	224	225	225	226	226	227	227	228	228	229
0.46		228	229	229	230	231	231	232	233	233	234
0.47			233	233	234	235	235	236	237	237	238
0.48			238	238	239	240	240	241	241	242	242
0.49				242	243	243	244	244	245	245	246
0.50					247	247	248	248	249	250	251
0.51						251	252	253	254	254	255
0.52							257	257	258	258	259
0.53							261	261	262	263	264
0.54								265	266	267	268
0.55								269	270	271	272
0.56									275	276	276
0.57									279	280	281
0.58										284	285
0.59										288	289
0.60											293

Materials and Methods

A mammography x-ray generator at Buddhachinaraj Hospital, Phitsanulok, Thailand (Lorad M-IV) was employed in this study. It has a focus-to-film distance (FFD) of 650 mm and two anode/filter combinations: molybdenum/molybdenum (Mo/Mo) and molybdenum/rhodium (Mo/Rh). The feature of automatic exposure control is used in routine mammography examinations. Automatic selection of appropriate anode/filter/tube potential combinations is based on the compressed breast thickness, which correlates to the position of the compression plate prior to the exposure.

The ionization chamber system employed consisted of a 6-cc chamber (10x5-6M, Radcal Corporation) with a radiation monitor controller model 9010 electrometer.

The quality control of the mammography system was evaluated for beam quality assessment (HVL measurement), tube voltage (kVp) and time accuracy, and reproducibility according to ACR recommendations (American College of Radiology, 1999).

Radiation exposure and output were measured using an ionization chamber placed in the x-ray beam in such a position that its center lay on the axis from the tube focus to a point 4 cm in from the chest wall edge. To reduce the effects of scattered radiation, the beam size was limited to the size of the chamber's sensitive area. A range of tube voltages between 25 kV and 32 kV and the tube current from 16 to 200 mAs were used for the Rh filter. A range of tube voltages between 23 kV and 29 kV and the tube current from 20 to 200 mAs were used for the Mo filter. Figure 1 shows the placement of the ionization chamber for measurement of breast entrance exposure; the center of the breast should be at the same height as the top surface of the breast.

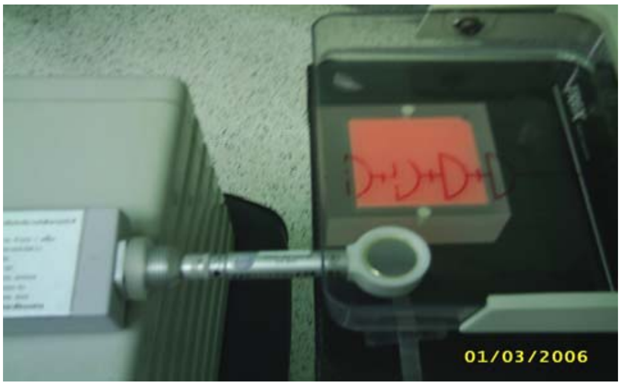

Figure 1. Placement of the ionization chamber for measurement of breast entrance exposure.

Multiple regression analysis was used to determine the relationship between variables. A p-value of 0.05 was considered statistically significant.

Percentage of error was used to show the difference between radiation exposures determined from the 2 methods. Percentage of error was calculated by

$$E = \frac{Exp\,2 - Exp\,1}{Exp\,1} \text{x}100 \quad ;$$

where E = Percentage of error,
$Exp\ 1$ = Radiation exposure calculated by equation,
$Exp\ 2$ = Radiation exposure from direct measurement.

Finally, the radiation exposure was converted to MGD using the ACR correction factor (American College of Radiology, 1999). The table for correction factor recommended by ACR was converted into a regression equation form. The radiation exposure and MGD calculated from the equation was checked by comparison with direct measurement. The direct measurement of exposure was collected from women undergoing mammography examination over the period from February to April 2006.

Results

Accuracy and reproducibility of tube voltage and time of exposure was acceptable. The measured HVL are shown in Table 2. The HVL was significantly correlated with kVp as shown by equations (1) and (2).

For the Rh filter,

$$HVL = 0.01\text{kVp} + 0.13 \quad (1)$$

For the Mo filter,

$$HVL = 0.01\text{kVp} + 0.04 \quad (2)$$

Table 2. HVL for rhodium and molybdenum filters

		Tube voltage (kVp)									
	Filter	23	24	25	26	27	28	29	30	31	32
HVL	Mo	0.27	0.28	0.29	0.30	0.31	0.32	0.33			
	Rh			0.38	0.39	0.40	0.41	0.42	0.43	0.44	0.45

The output values of the Mo and Rh filters measured by the ionization chamber for different tube voltages are shown in Figure 2.

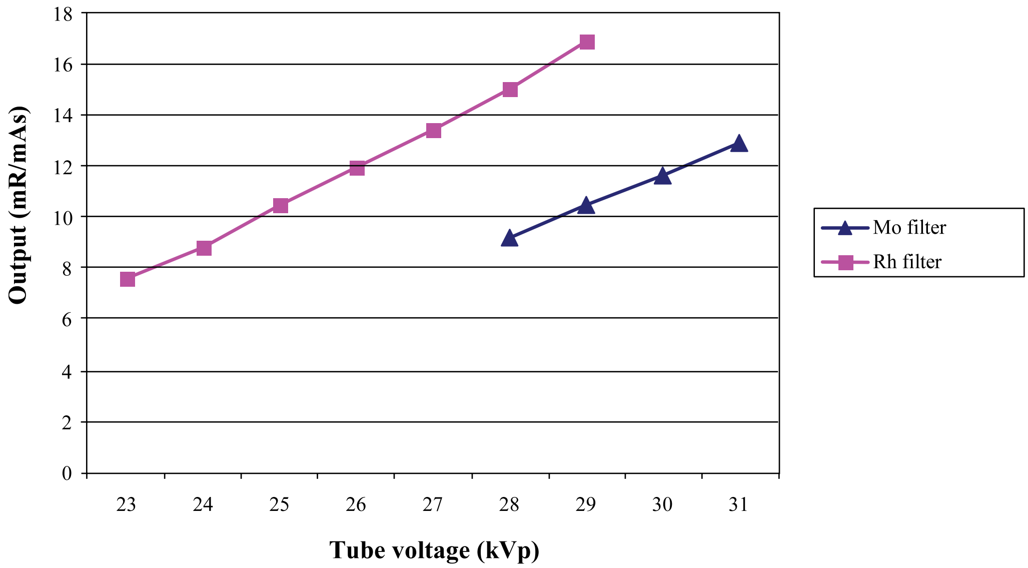

Figure 2. The output values of Mo and Rh filters.

When kVp is significantly related to output ($r = 1.000$, $p = 0.01$), the output which can be determined from dosimetry per 1 mAs (mR/mAs) can be expressed in equations (3) and (4).

For the Rh filter,

$$\text{Output} = 1.223\text{kVp} - 24.977 \quad (3)$$

For the Mo filter,

$$\text{Output} = 1.542\text{kVp} - 28.051 \quad (4)$$

Exposure dose (mR) can be determined from output and mAs as expressed in equations (5) and (6).

For the Rh filter,

$$Exp. = (1.223\text{kVp} - 24.977) \text{ x } mAs \quad (5)$$

For the Mo filter,

$$Exp. = (1.542\text{kVp} - 28.051) \text{ x } mAs \quad (6)$$

Since compressed breast thickness of each patient affects the source-skin distance (SSD), compressed breast thickness determines the exposure dose in accordance with the inverse square law. In these cases, the compressed breast thickness is 4.2 cm (breast phantom). Thus, the exposure dose can be determined from equations (7) and (8).

For the Rh filter,

$$Exp. = (1.223\text{kVp} - 24.977) \text{ x } mAs \ \frac{(60.8)^2}{(65 - CBT)^2} \quad (7)$$

For the Mo filter,

$$Exp. = (1.542\text{kVp} - 28.051) \text{ x } mAs \ \frac{(60.8)^2}{(65 - CBT)^2} \quad (8)$$

After the equation for calculation of exposure was constructed, a comparison of radiation exposure between direct measurement from the patient and calculations from the equation was made. Data were collected from 9 women (25 films) for the Rh filter and 18 women (62 films) for the Mo filter. The results revealed that the percentage of error was $\pm$3.07 for the Rh filter and $\pm$4.22 for the Mo filter.

Figures 3 and 4 show the relationship between direct measurement of exposure and calculations from equations for the Rh and Mo filters.

To convert from radiation exposure in Roentgen to mean glandular breast dose, the radiation exposure is multiplied by the exposure to dose conversion factor.

Finally, MGD (in mrad) can be determined using mAs obtained from mammography, output, source-skin distance compensation factor and MGD conversion factor (C.F.) according to the equations (9) and (10).

For the Rh filter,

$$\text{MGD} = [(1.223\text{kVp} - 24.977) \text{ x } mAs \ \frac{(60.8)^2}{(65 - CBT)^2}]. \text{(C.F.)} \quad (9)$$

For the Mo filter,

$$\text{MGD} = [(1.542\text{kVp} - 28.051) \text{ x } mAs \ \frac{(60.8)^2}{(65 - CBT)^2}]. \text{(C.F.)} \quad (10)$$

MGD conversion factor (C.F.), is estimated as follows:

For the Rh filter,

Conversion factor = 0.628kVp + 422.367 (HVL) + 17.543

When HVL = 0.01kVp + 0.13

Conversion factor = 0.628kVp + 4.22367kVp + 54.90771 + 17.543

= 4.85167kVp + 72.45071 (11)

For the Mo filter,

Conversion factor = 1.159kVp + 433.382(HVL) - 6.368

When HVL = 0.01kVp + 0.04

Conversion factor = 1.159kVp + 4.33382kVp + 17.33528 – 6.368

= 5.49282kVp + 10.96728 (12)

Since 1 Gy = 100 rads,

For the Rh filter,

$$MGD \text{ (mGy)} = (1.223\text{kVp} - 24.977) \text{ x } mAs \frac{(60.8)^2}{(65 - CBT)^2} \text{ x } \frac{(4.85167\text{kVp} + 72.45071)}{100{,}000}$$

For the Mo filter,

$$MGD \text{ (mGy)} = (1.542\text{kVp} - 28.051) \text{ x } mAs \frac{(60.8)^2}{(65 - CBT)^2} \text{ x } \frac{(5.49282\text{kVp} + 10.96728)}{100{,}000}$$

The error of MGD equation calculation was 1.94±1.7% for the Rh filter and 1.8±1.74% for the Mo filter.

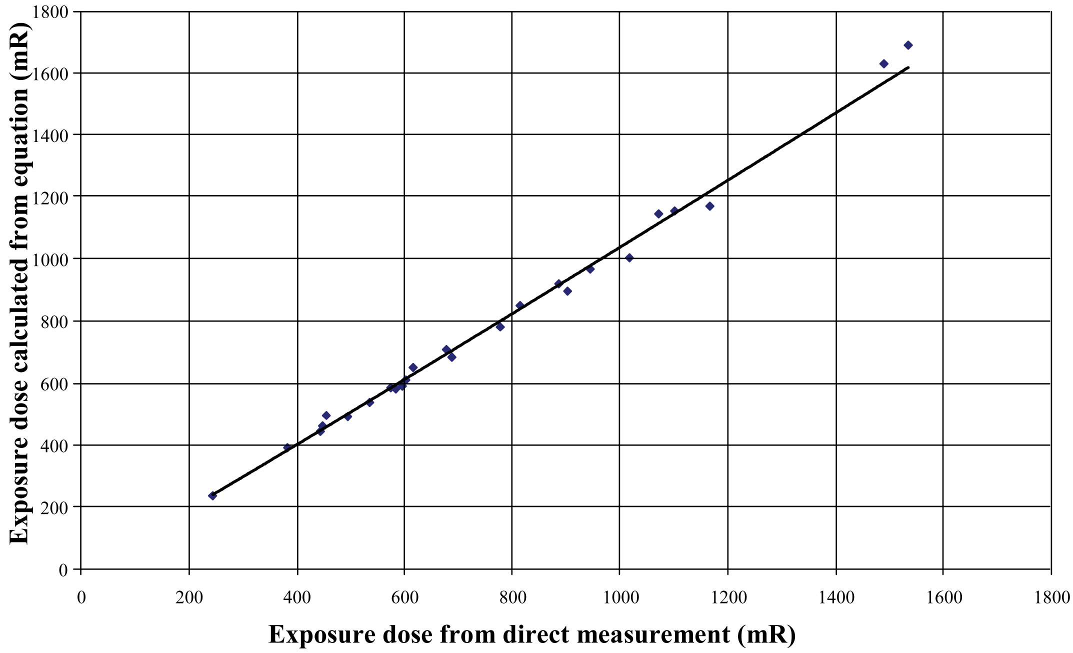

Figure 3. The correlation of exposure dose derived from direct measurement and calculations from the equation for the Rh filter.

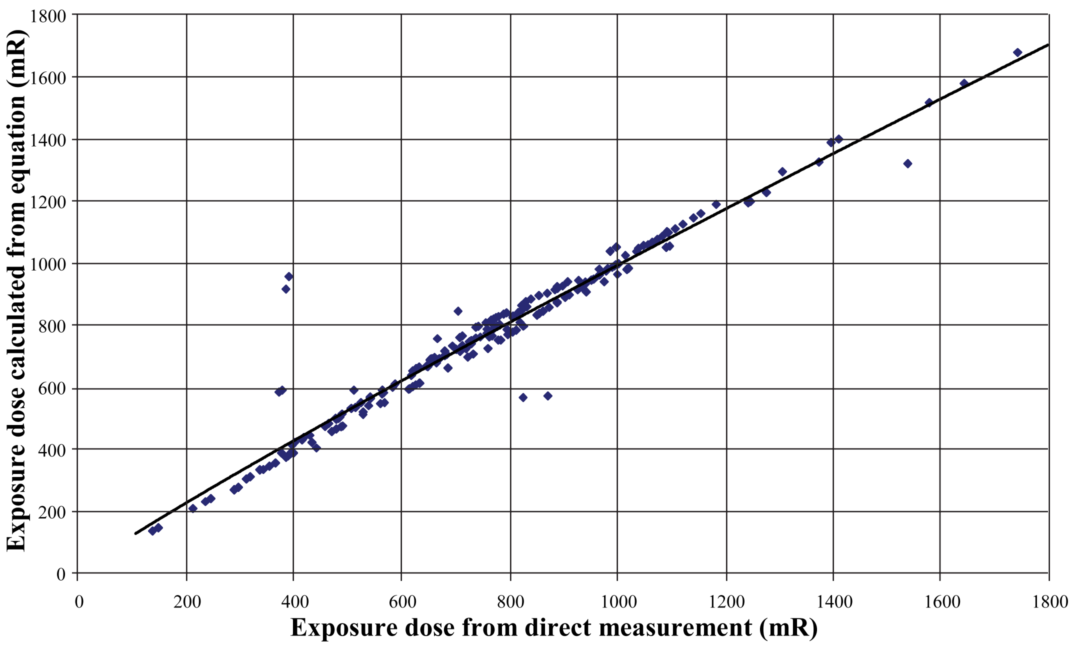

Figure 4. The correlation of exposure dose derived from direct measurements and calculations from the equation for the Mo filter.

Figures 5 and 6 showed the relationship between MGD which was obtained from direct measurements of exposure and converted to MGD using the ACR correction factor and MGD which was obtained from calculations with the MGD equation.

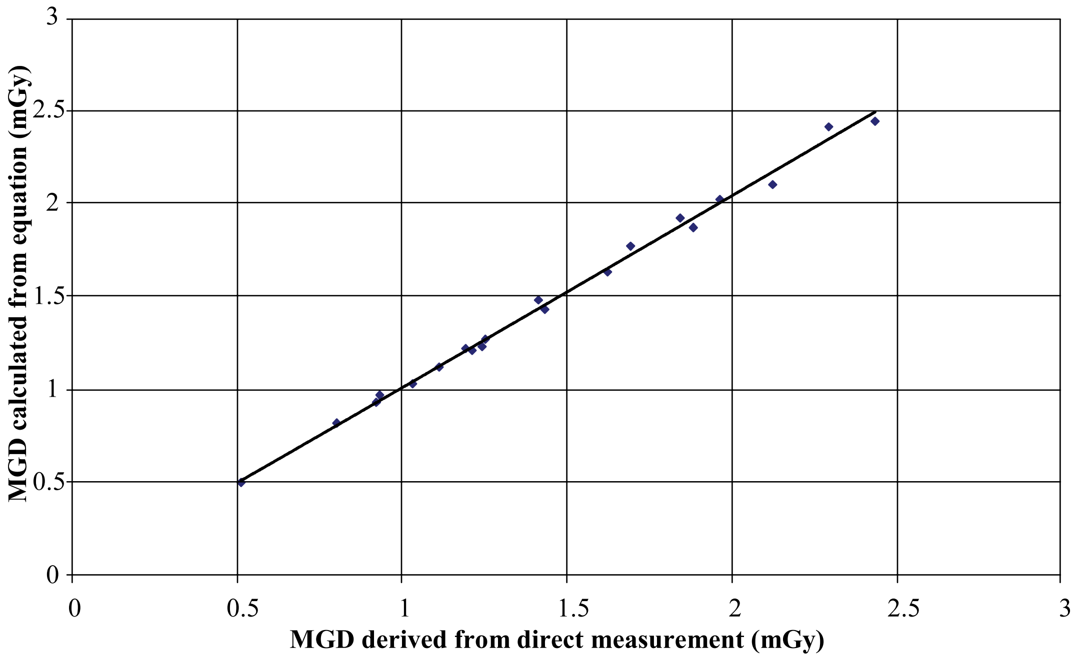

Figure 5. The correlation of MGD derived from direct measurements of exposure converted to MGD by ACR correction factor and the MGD calculated from the MGD equation for the Rh filter.

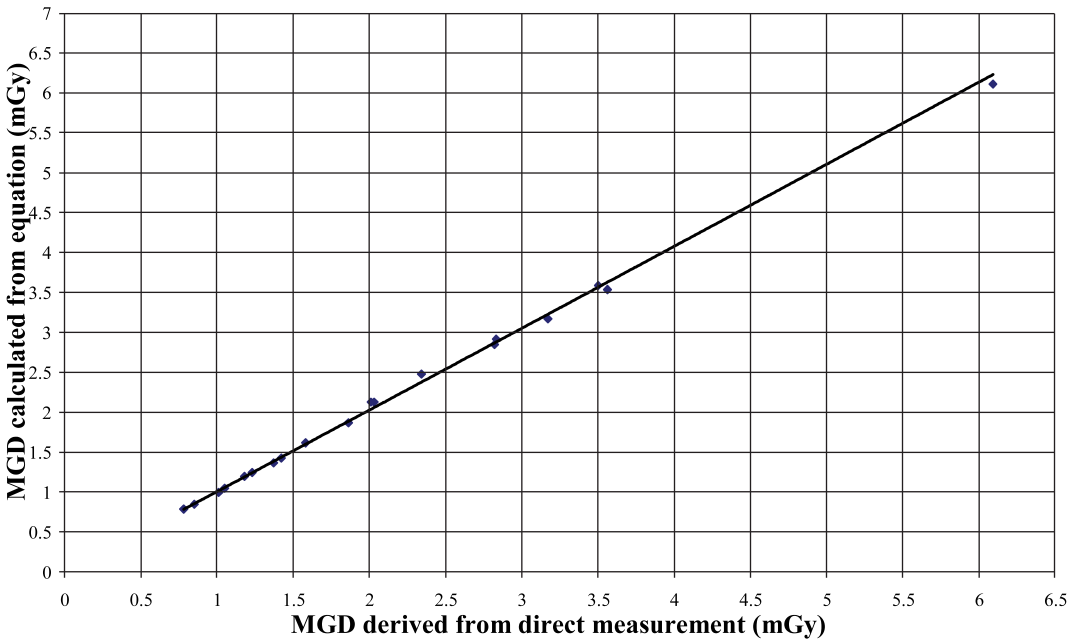

Figure 6. The correlation of MGD derived from direct measurements of exposure converted to MGD by ACR correction factor and the MGD calculated from the MGD equation for the Mo filter.

Discussion and Conclusion

The limitation of this study is the conversion factor used. The ACR-recommended conversion factor was for 4.2 cm breast thickness and composition of 50 % adipose and 50% glandular breast tissue. However, from the previous study of 515 women who underwent mammography on six mammography x-ray generators in the lower region of northern Thailand, the CBT had a mean value of 3.74$\pm$1.43 cm for a CC projection and 3.77$\pm$1.64 cm for a MLO projection (Sookpeng & Kettted, 2007). Thus, an error in calculation might occur. Moreover, the ratio of adipose and glandular tissue depends on age. In the present study we investigated only one mammography equipment, therefore the results may not be typical. In the future, data obtaining from a large number of mammography equipment would be obtained to construct a numerical model to evaluate MGD in typical mammography examination.

In conclusion, we have constructed an equation to evaluate MGD in mammography at Buddhachinaraj Phitsanulok Hospital having a percentage error of 1.94$\pm$1.7% for the Rh filter and 1.8$\pm$1.74% for the Mo filter. This MGD equation was determined using tube voltage (kVp), tube current (mAs), and CBT of the patient obtained from mammography. With this equation the MGD can be calculated in real time; thus after mammography it is possible to reply immediately to patient's questions on the MGD.

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