

Original Article

A survey of average glandular dose to patients undergoing screen/film mammography—the influence of age

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The aim of this study was to investigate age-related changes in average glandular dose (AGD) for Taiwanese women. A retrospective review of 4092 craniocaudal screen/film exposures was conducted. Subjects' age range was 30-79 years. The radiographic factors of each exposure were analyzed to determine the patient AGD. The results show that age has a strong modifying effect on glandularity, while the compressed breast thickness (CBT) and beam quality needed varied only slightly with age. The average values of CBT, glandularity, and AGD were 4.2 cm, 54%, and 1.70 mGy, respectively. The values of patient AGD for the age bands 55-59 and 75-79 years were factors of 0.96 and 0.70, respectively, compared to the age band 30-34 years. In conclusion, age appears to have a small effect on AGD for women surveyed in the age interval 30-59 years. As age differences increase, variation in AGD increases.

Key words: mammography, age, average glandular dose

Introduction

The determination of average glandular dose (AGD) to patients is an important study issue in mammography^[1,2]. The reduction of AGD for patients helps to minimize their risk of radiation-induced cancer associated with mammography. Therefore, many studies have investigated patient AGD under clinical circumstances using large cohorts of patients^[3-6]. Results from these studies

provide useful information for determining appropriate strategies for dose reduction and for developing optimized imaging technique in mammography.

The AGD for patients is affected by many factors, including compressed breast thickness (CBT), breast composition, radiographic factors used, and the mammographic X-ray unit. Since these factors could vary substantially from mammogram to mammogram, variation of AGD between patients can be substantial in a mammographic dose survey. Numerous studies have investigated patient AGD using radiographic factors and breast parameters. A common finding from these studies was that patient AGD increases with increasing CBT.

It is clear that the CBT and breast composition are related to patient age. As age increases,

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the proportion of breast volume occupied by parenchyma decreases and the amount of adipose tissue increases. To accurately estimate AGD from different age groups of patients, some studies have investigated the age-related changes in patient AGD^[7-9]. Results from these studies show that patient AGD decreases with increasing patient age.

At present, little information has been reported on the effect of age on patient AGD in Asian countries^[10]. Results from our previous study^[11] found that the breast dimensions (CBT, compressed breast width, and chest-wall-to-nipple distance) and breast composition of Taiwanese women vary with patient age (age range: 30-69 years). Since the previously surveyed average values of CBT and breast composition of Taiwanese women differed from those of Western women, it is debatable whether the age-related changes in AGD for Asian women are comparable to those reported in previous studies of Western women. In view of the lack of such studies, the goal of this study was to investigate the age-related changes in AGD for Taiwanese women.

Materials and methods

Instruments and baseline measurements

In this study, a screen/film (SF) mammographic X-ray unit (Mammomat 3000; Siemens) combined with Fuji SF cassettes (AD Mammo Screen-Fine and UM-Mammo cassettes; ADM Film) were used. The beam energy selection of the SF X-ray unit is dependent on the CBT, for which the target/filter combinations of molybdenum/molybdenum (Mo/Mo) at 25 kV, Mo/Mo at 26 kV, molybdenum/rhodium (Mo/Rh) at 26 kV, and tungsten/rhodium (W/Rh) at 26 kV were selected for breasts with a CBT < 3 cm, $3 \leq \text{CBT} < 4.5$ cm, $4.5 \leq \text{CBT} < 6$ cm, and CBT ≥ 6 cm, respectively.

At the start of the survey, the half value layers (HVLs) for the clinically used beam energies were measured using a mammographic ionization chamber (Magna 1 cc; RTI Electronics, Sweden) and high purity aluminum filters. To measure the HVLs, the compression paddle was used and the mammographic ionization chamber was placed 4.5 cm above the breast support table and 4 cm from

the chest wall edge of the breast support table. The test procedures followed those suggested in the American College of Radiology (ACR) protocol^[1].

To estimate the breast dose for each patient exposure, the incident air kerma of each beam energy was measured using a compression paddle. The ionization chamber was positioned 4 cm in from the chest wall edge of the breast support table and centered transversely in the X-ray field. The measured dose for each exposure was used to calculate the incident air kerma per unit tube loading (mGy/mAs).

Patient data collection and correction

A retrospective review of 4092 craniocaudal (CC) SF exposures from 2450 Taiwanese women (age range: 30-79 yrs) was performed. All exposures were collected from the Mammomat 3000 X-ray unit. The tube loadings (mAs), tube voltage (kV), target/filter combination, CBT, and patient age of each exposure were recorded.

In this study, the patient CBT records displayed on the imaging system were corrected. A 6-cm thick BR-12 phantom (Nuclear Associates, Carle Place, NY) was used to obtain the CBT correction factors. Variations in the compression paddle flex with compression forces were measured and the difference between the displayed thickness and the phantom thickness was calculated. Therefore, an additional 0.4, 0.5, 0.6, and 0.7 cm were added for the applied forces of 100-119, 120-139, 140-159, and 160-179 N, respectively. These CBT correction factors were then applied to adjust the displayed patient CBT records.

Estimation of breast composition

The standard breast model of a superficial layer of adipose tissue 0.5 cm thick was used. Glandularity was defined as the percentage by mass of glandular tissue in the central region of the standard breast model^[5]. The glandularity of each breast was evaluated by comparing the exposure data from the patients with a series of exposure factors of calibration exposures for breast tissue equivalent materials.

The calibration exposures were acquired using a series of breast tissue equivalent attenuation slabs (Computerized Imaging Reference Systems,

Norfolk, VA) at four thicknesses (2, 4, 6 and 8 cm) of varying composition (0%, 30%, 50%, 70%, and 100% glandularity)^[5]. A least-squares fit with a four-variable function was used to obtain the fitted parameters of the calibration exposures. The fitted equation was constrained to give glandularities of 0-100% to ensure compliance with the breast model used. The fitted equation is expressed as:

$$Glandularity = (a + \frac{b}{CBT}) \times \ln(mAs) - (c + \frac{d}{CBT}) \quad (1)$$

where a, b, c, and d are fitted parameters.

Calculation of AGD

Before determining the AGD, the incident air kerma at the entrance surface of the breast was computed for each exposure. The incident air kerma of each exposure (mGy) was calculated by multiplying the measured incident air kerma per mAs (mGy/mAs) by the mAs value used, and by an inverse square law correction depending on each CBT.

In our previous study^[12], 10% of patient exposures were performed with a CBT ≤ 2.8 cm. As conversion factors of AGD assessments for breast thicknesses < 3 cm are not given in the ACR tabulation, the conversion factors reported by Dance et al.^[8] were used because the published tables of conversion factors cover a thickness range of 2-11 cm.

This study used the AGD assessment approach used by Dance et al.^[8] The AGD of each patient exposure was calculated on the basis of the incident air kerma obtained above (K_f) multiplied by a series of appropriate conversion factors. The AGD can be expressed as:

$$AGD = K_f \times g \times c \times s \quad (2)$$

where g is the incident air kerma to the AGD conversion factor for a breast of 50% glandularity, the conversion factor c corrects for the difference in breast composition from 50% glandularity, and the conversion factor s corrects for the difference due to the use of a target/filter combination different from Mo/Mo.

To evaluate age-related changes in breast doses, the incident air kerma and AGD to patients were grouped by age in 5-year bands. The average and SD values of the incident air kerma and AGD to

Table 1. Measured values of half value layer (HVL) and radiation output at each beam quality selected by the automatic exposure control (AEC).

Target/Filter Combination	Tube Voltage (kV)	Measured half value layer (mm Al)	Measured radiation output (mGy/mAs)
Mo/Mo	25	0.32	0.0775
Mo/Mo	26	0.33	0.0887
Mo/Rh	26	0.39	0.0716
W/Rh	26	0.51	0.0311

patients in each age band were calculated and analyzed.

Results

Performance of the X-ray unit and patient exposures

Table 1 summarizes the measured values of HVL and radiation output at each beam energy. These measured values were used to determine the AGD to patients.

Figure 1 shows the average CBT and glandularity of patient exposures surveyed at each age band. The average values of CBT and glandularity were 4.2 ± 1.0 cm and $54\% \pm 26\%$, respectively. The patient CBT changed slightly with age and the maximum CBT increment was 0.5 cm between the ages of 30 and 59 years; then the CBT decreased 0.7 cm between the ages of 59 and 79

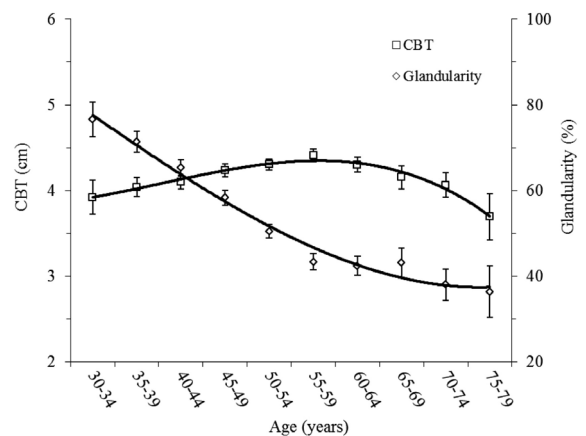


Figure 1. The average values of compressed breast thickness (CBT) and glandularity of patients surveyed. The error bars in the figure are 95% confidence intervals of each mean value.

years. The glandularity decreased rapidly between 30 and 59 years of age, and appeared to decrease gradually with age after that. The difference in average glandularity between the age bands 30-34 and 55-59 years was 34%.

Beam quality and incident air kerma of patient exposures

A different CBT can result in switching of the target/filter combination and in a change of kV value, and therefore the selection of beam energy in clinical practice can be affected by the age-related changes in CBT. Figure 2 shows the average HVL for patient exposures at each age band. The HVL varied slightly with age, with average HVL of patient exposures being 0.341 ± 0.044 mmAl.

The incident air kerma of each patient exposure was estimated. As can be seen in Figure 3, a plot of average incident air kerma versus age, the average incident air kerma obtained at each age band decreased with increasing age. The incident air kerma of patient exposures was found to vary from 1.36 to 40.13 mGy with an average \pm SD value of 7.98 ± 3.33 mGy. The values of incident air kerma for the age bands 55-59 and 75-79 years were factors of 0.91 (8.0/8.8) and 0.57 (5.0/8.8), respectively, both lower than that of the age band 30-34 years.

Conversion factors

In order to analyze age-related changes in AGD, it is important that the relationships between age and each conversion factor be clarified. The conversion factors g and c obtained in each age band are shown in Figure 4. The range and average value of the conversion factor g were 0.125-0.503 mGy/mGy and 0.227 ± 0.046 mGy/mGy, respectively. The results show that the conversion factor g decreased as age increased in the age interval 30-59 years, and increased with age thereafter. For the conversion factor c, the range and average values were 0.811-1.306 mGy/mGy and 1.000 ± 0.105 mGy/mGy, respectively. As the figure indicates, the conversion factor c increases rapidly with age in the age interval 30-59 years, and increases slightly in the age interval 60-79 years thereafter. Additionally, the conversion factor s remained consistent across age bands in this study

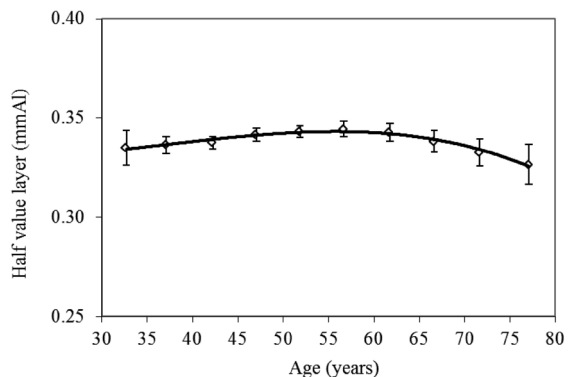


Figure 2. Variations of beam quality of patient exposures in relation to age. The error bars in the figure are 95% confidence intervals of each mean value.

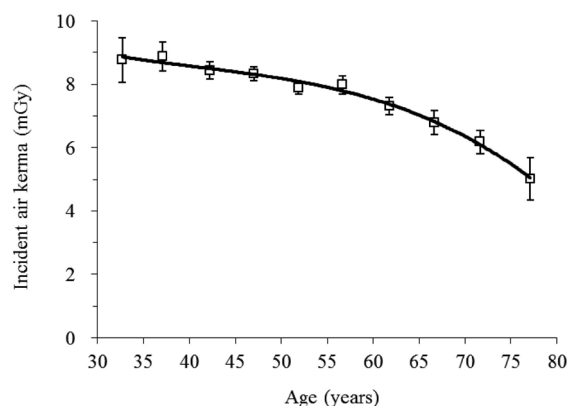


Figure 3. Variation of incident air kerma with age for the patient exposures surveyed. The error bars in the figure are 95% confidence intervals of each mean value.

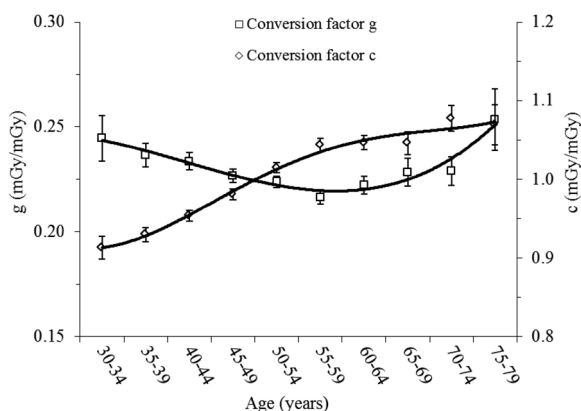


Figure 4. Variations of conversion factors g and c in relation to age. The error bars included in the figure are 95% confidence intervals of each mean value.

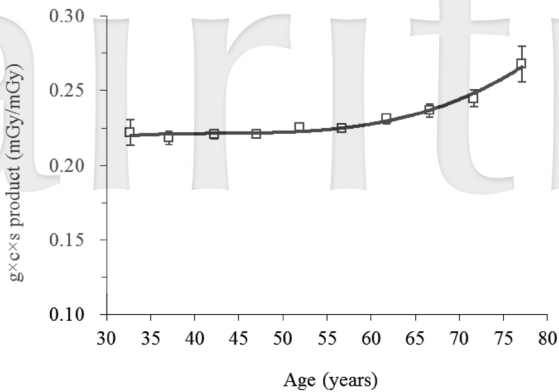


Figure 5. Variation of the $g \times c \times s$ product with age for the patient exposures surveyed. The error bars in the figure are 95% confidence intervals of each mean value.

with an average value of 1.02 ± 0.105 mGy/mGy.

Figure 5 shows variations in the product of conversion factors ($g \times c \times s$) of patient exposures with respect to age. The $g \times c \times s$ product of patient exposures ranged from 0.151 to 0.464 mGy/mGy, and the average value was 0.225 ± 0.035 mGy/mGy. The result showed that the average $g \times c \times s$ product of each age band remained consistent for the age interval 30-59 years, after which it increased with age.

Average glandular dose

Figure 6 shows the patient AGD at each age band. The AGD to patients ranged from 0.56 to 6.22 mGy (mean 1.70 ± 0.50 mGy). The patient AGD

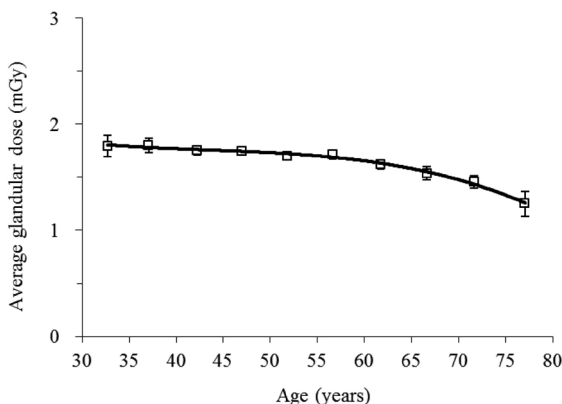


Figure 6. Variations of AGD to patients with respect to age. The error bars in the figure are 95% confidence intervals of each mean value.

decreased slightly with age in the age interval 30-59 years, and decreased rapidly with age after that. The values of patient AGD for the age bands 55-59 and 75-79 years were factors of 0.96 (1.72/1.79) and 0.70 (1.25/1.79), respectively, both lower than that of the age band 30-34 years.

Discussion

Age-related changes in breast parameter

This study found that age had a strong modifying effect on glandularity for the Taiwanese women surveyed. The trend observed in the present study is similar to that reported by previous studies^[7,9], but the average glandularity obtained for each age band was higher than those reported in other previous studies^[13]. Additionally, the average glandularity for the age interval 50-54 years (50%) was equivalent to the glandularity of the standard breast.

Another finding of this study was that patient CBT changed slightly with age. This trend is similar to that reported by a previous study^[9], but the average CBT obtained in each age band was less than that reported previously. Additionally, the small difference found in the CBT may explain the slight difference in HVL observed in this survey.

Age-related changes in incident air kerma

Before discussing age-related changes in AGD, the variations in incident air kerma with respect to age have to be considered. As mentioned previously, the incident air kerma in the age interval 60-79 years changed more rapidly with age than in the age group 30-59 years. In the age interval 30-59 years, the combined influence of increasing CBT and decreasing glandularity led to a slight decline in incident air kerma. In the age interval 60-79 years, the tube loadings rapidly decreased due to slight declines in both CBT and glandularity. As a result, the incident air kerma at this age interval rapidly decreased with age.

Variations in conversion factors

The results obtained in the present study show that the age-related changes in CBT and glandularity can lead to substantial variations in conversion factors g and c , while they only cause

a slight change in HVL. As a consequence, the average $g \times c \times s$ product obtained at each age band remained consistent in the age interval 30-59 years. This effect can be explained by the fact that variations of conversion factors g and c with respect to age tend to cancel each other out in the age interval 30-59 years. For example, the conversion factor g for the age band 55-59 years was a factor of 0.89 (0.217/0.245, see Figure 4) lower than that for the age band 30-34 years, while the conversion factor c for the age band 55-59 years was a factor of 1.14 (1.043/0.913) higher than that for the age band 30-34 years. Therefore, the average $g \times c$ product for the age band 55-59 years was comparable to that for the age band 30-34 years. For women > 60 years of age, conversion factors g and c both increased with age. As a result, the $g \times c \times s$ product rapidly increased with age in the interval 60-79 years.

Since age-related change in glandularity is obvious, a small variation of CBT associated with age may not attract attention in a mammographic dose survey. Results from the present study demonstrate that variations in CBT and glandularity with respect to age are key factors in determining age-related changes in AGD.

Age-related change in AGD

As noted previously, patient AGD decreased with increases in age and the patient AGD for the age band 75-79 years was a factor of 0.70 lower than that of the age band 30-34 years. In other words, the dose reduction was 30% $((1-0.7) \times 100\%)$ for age range 30-79 years. In addition, the dose reduction was 5% between the age bands 50-54 and 60-64 years in this study. A similar study has reported that the AGD reduction was 3% between the age bands 50-54 and 60-64 years for women in the United Kingdom (UK) [3]. The authors also reported that age appeared to have a very small effect on dose for the age interval surveyed (50-64 years). In another study[9], a dose reduction of a factor of two over a wide age range (20-90 years) was reported for women in Germany. Therefore, it is clear that age-related changes in AGD become more significant if the women surveyed have a wide age range.

Uncertainty and limitation

The uncertainties associated with AGD assessment in this study primarily include errors in CBT correction^[14], and the curve-fitting process in glandularity assessment. The approaches used for CBT correction and glandularity assessment have been validated in a previous study^[5], and the results demonstrated that the uncertainties are acceptable in dosimetry assessment. For glandularity assessment, the coefficients of determination (R^2) of the fitted functions for calibration exposures were within the range of 0.979-0.996, and the error in the curve-fitting process was found to be $< 3\%$ in our previous study.

One limitation of this study is that the glandularity assessment was based on a relatively small tissue sample overlying the AEC detector[5]. It was assumed that the glandularity of this small tissue volume would be equivalent to that of the entire breast. Another limitation is that variations in patient AGD associated with different X-ray units and imaging settings used were not taken into account in this study because all patient data surveyed were collected from one mammographic X-ray unit. Therefore, the data reported in this study are only suitable for assessing age-related changes in AGD caused by the variations of CBT and glandularity of patients.

Conclusion

Results from the present study demonstrate that breast doses decrease with the increasing age of women. The age-related change in AGD is less than the variation in incident air kerma with respect to age. In this study, age appeared to have a small effect on AGD for Taiwanese women surveyed in the age interval 30-59 years. The age-related changes in AGD become more significant if the women surveyed encompass a wider range of ages. This survey may provide useful information for determining appropriate dose reduction strategies for Taiwanese women of different age intervals in mammography.

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評估接受底片式乳房攝影病患之平均乳腺劑量——年齡之影響

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本研究的目的為探討台灣女性年齡改變時對乳房攝影中平均乳腺劑量的影響，本研究回溯分析4092張頭腳方向之底片式乳房攝影影像，受檢者的年齡層介於30-79歲之間，分析每次攝影的暴露參數以計算出病人的平均乳腺劑量。結果顯示，乳房壓迫厚度和射束品質隨年齡的改變僅有些微變化，年齡對於乳腺比例卻有很大的影響。本研究中的乳房壓迫厚度、乳腺比例和乳腺平均劑量的平均值分別為4.2 cm，54%以及1.70 mGy。在病人年齡層為55-59歲和75-79歲之乳腺平均劑量分別為30-34歲病人之0.96和0.70倍。總而言之，在女性年齡層介於30-59歲時，年齡在乳腺平均劑量上顯現出較小的影響；而當年齡差異增加，乳腺平均劑量之變動也隨著增大。

關鍵詞：乳房攝影、年齡、平均乳腺劑量

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