Interpolation of Dance’s coefficients for the estimation of average glandular dose in mammography

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Abstract

Objective: The average glandular dose (AGD) is used to evaluate the radiation dosage in mammography. Dance et al. (2000) presented a computation formula to estimate the AGD based on several coefficient factors, such as compressed breast thickness, breast tissue composition, and half-value layers (HVLs). The objective of this study was to improve the preciseness of AGD estimation.

Materials and Methods: We interpolated the coefficients developed by Dance et al. to generate an approximation formula and reference datasets with higher granularity and breast thickness (2–6 cm) relevant to a Japanese population.

Results: The results from this study indicate that the incorporation of HVLs and breast thickness required in mammography densitometry leads to an advancement in the current method for estimating the average glandular dose.

Conclusions: We expect that these interpolated values will serve as a reference for other researchers and allow for a more accurate, detailed, and individualized AGD estimation.

Key words: average glandular dose, mammography, radiation dosage, breast thickness

Introduction

Ionizing radiation during mammography examinations increases the risk of radiation-induced cancer in the glandular tissue of the breast¹. In general, obese women, and those with large and/or dense breasts and highly compressed breast thickness, require multiple examinations and a higher radiation dose per examination and are therefore at an increased risk of radiation-induced cancer¹. The dosimetry of mammography is estimated using the breast entrance air kerma and several related conversion factors. It has been used for the optimization of mammography in Europe² and, more recently, in Japan³.

The average glandular dose (AGD) for a single mammography examination is one of the most important factors used in the quality control of mammography imaging systems⁴. The AGD is an estimate that uses compressed breast thickness, breast tissue composition (ratio of glandular and adipose tissue), tube voltage, type of target/additional filter, and half-value layers (HVLs) as parameters. Dance et al. developed conversion factors (Dance’s coefficients) to enable AGD estimation based on HVL and breast tissue composition for breast thicknesses ranging from 2 cm to 11 cm (in 1-cm increments). The HVL is typically estimated based on the thickness of absorptive materials, such as aluminum (mmAl), which reduces the amount of radiation in a gamma- or X-ray beam by half. Dance et al.’s AGD formula is expressed as follows⁵, ⁶:

\[ \text{AGD, D (mGy)} = K \cdot g \cdot c \cdot s \]  

(1)

where K is the entrance surface air kerma evaluated on the breast surface; g is the AGD conversion factor in a breast composed of 50% adipose and 50% glandular tissues, estimated by interpolating the breast thickness and HVL (Table 1); c is a correction factor for the mammary gland ratio, estimated in the tissue at the central region of the breast (Table 2); and s is a correction factor for X-ray quality.

However, precise AGD estimation requires prior knowledge of the glandular tissue ratio of each individual, and therefore, it is not practical in typical measurements. Most digital mammograph systems use formulae that clinicians...
and researchers are unaware of and display a real-time reference AGD value, which is based on automated calculations unique to every equipment manufacturer. Further, Dance’s coefficients were developed for a Western population with larger breast sizes and highly compressed breast thicknesses (up to 11 cm); therefore, it may not be directly applicable to the Japanese population with smaller breast sizes and compressed breast thickness (mean, 3–3.83 cm). This study aimed to calculate the formulae of conversion factors and their relationship with compressed breast thickness and interpolate the values for breast thickness typically encountered in Japanese women (2–6 cm, at 0.5 mm increments) to generate data that could be used for more accurate and individualized AGD estimation.

Materials and Methods

We plotted approximate curves for Dance’s coefficients vs. compressed breast thickness using the Microsoft Excel chart function (Microsoft Corporation, Redmond, Washington) and then performed interpolation of conversion factors by function approximation. The study protocol was approved by the ethics committee of our institution on June 20, 2015.

g-factor interpolation

The g-factor was plotted against breast thickness for seven sets of HVLs, ranging from 0.3 mmAl to 0.6 mmAl. The generated curve approximation formula is:

\[ y = -0.0008x^3 + 0.021x^2 - 0.19x + 0.69 \]  \hspace{1cm}(2)

Figure 1 illustrates the approximate curves of the g-factor vs. breast thickness for seven HVLs, ranging from 0.3 mmAl to 0.6 mmAl. The generated curve approximation formula is:

\[ y = -0.95x^2 + 1.5x + 0.017 \]  \hspace{1cm}(3)

The interpolated g-factors obtained by incorporating breast thicknesses (20–60 mm, 9 steps in 5-mm increments) and HVLs (0.3–0.45 mmAl, 16 steps in 0.01-mmAl increments) are provided in Table 3.

c-factor interpolation

The c-factor was plotted against breast thickness for five sets of tissue ratios, ranging from 0.1% to 100%. Next, the c-factor was plotted against the tissue ratio for nine sets of compressed breast thicknesses, ranging from 20 mmAl to 60 mmAl (5-mm increments). The approximate curves were plotted using the Microsoft Excel chart function, and interpolated c-factors were obtained from the respective approximation formulae.

Results

g-factor interpolation

Figure 1 illustrates the approximate curves of the g-factor vs. breast thickness for seven HVLs, ranging from 0.3 mmAl to 0.6 mmAl. The generated curve approximation formula is:

\[ y = -0.0008x^3 + 0.021x^2 - 0.19x + 0.69 \]  \hspace{1cm}(2)

Figure 2 illustrates the approximate curves of the g-factor vs. HVL for breast thicknesses ranging from 20 mm to 60 mm. The generated curve approximation formula is:

\[ y = -0.95x^2 + 1.5x + 0.017 \]  \hspace{1cm}(3)

The interpolated g-factors obtained by incorporating breast thicknesses (20–60 mm, 9 steps in 5-mm increments) and HVLs (0.3–0.45 mmAl, 16 steps in 0.01-mmAl increments) are provided in Table 3.

c-factor interpolation

Figure 3 illustrates the approximate curves of the c-factor vs. breast thickness for five sets of tissue ratios ranging from 0.1% to 100%. The generated curve approximation formulae are:

| Table 1  | g-factor for breast thickness (Dance’s original data) |
|----------|---------------------------------------------------------|
| Breast thickness (mm) | HVL (mmAl)         |
|          | 0.3  | 0.35 | 0.4   | 0.45  | 0.5   | 0.55  | 0.6   |
| 20       | 0.3900 | 0.4330 | 0.4730 | 0.5090 | 0.5430 | 0.5730 | 0.5870 |
| 30       | 0.2740 | 0.3090 | 0.3420 | 0.3740 | 0.4060 | 0.4370 | 0.4660 |
| 40       | 0.2070 | 0.2350 | 0.2610 | 0.2890 | 0.3180 | 0.3460 | 0.3740 |
| 45       | 0.1830 | 0.2080 | 0.2320 | 0.2580 | 0.2850 | 0.3110 | 0.3390 |
| 50       | 0.1640 | 0.1870 | 0.2090 | 0.2320 | 0.2580 | 0.2870 | 0.3100 |
| 60       | 0.1350 | 0.1540 | 0.1720 | 0.1920 | 0.2140 | 0.2360 | 0.2610 |
| 70       | 0.1140 | 0.1300 | 0.1450 | 0.1630 | 0.1770 | 0.2020 | 0.2240 |
| 80       | 0.0980 | 0.1120 | 0.1260 | 0.1400 | 0.1540 | 0.1750 | 0.1950 |
| 90       | 0.0859 | 0.0981 | 0.1106 | 0.1233 | 0.1357 | 0.1543 | 0.1723 |
| 100      | 0.0763 | 0.0873 | 0.0986 | 0.1096 | 0.1207 | 0.1375 | 0.1540 |
| 110      | 0.0687 | 0.0786 | 0.0887 | 0.0988 | 0.1088 | 0.1240 | 0.1385 |

HVL: Half-value layer.
Table 2  c-factor for breast glandularities (Dance’s original data)

| HVL  | Thickness (mm) | Breast glandularity | 0.1%  | 25%  | 50%  | 75%  | 100% |
|------|----------------|---------------------|-------|------|------|------|------|
| 0.3  | 20             | 1.130               | 1.059 | 1.000| 0.938| 0.885|
|      | 30             | 1.206               | 1.098 | 1.000| 0.915| 0.836|
|      | 40             | 1.253               | 1.120 | 1.000| 0.898| 0.808|
|      | 50             | 1.283               | 1.127 | 1.000| 0.886| 0.794|
|      | 60             | 1.303               | 1.135 | 1.000| 0.882| 0.785|
|      | 70             | 1.317               | 1.142 | 1.000| 0.881| 0.784|
|      | 80             | 1.325               | 1.143 | 1.000| 0.879| 0.780|
|      | 90             | 1.328               | 1.145 | 1.000| 0.879| 0.780|
|      | 100            | 1.329               | 1.147 | 1.000| 0.880| 0.780|
|      | 110            | 1.328               | 1.143 | 1.000| 0.879| 0.779|
| 0.35 | 20             | 1.123               | 1.058 | 1.000| 0.943| 0.891|
|      | 30             | 1.196               | 1.090 | 1.000| 0.919| 0.842|
|      | 40             | 1.244               | 1.120 | 1.000| 0.903| 0.816|
|      | 50             | 1.272               | 1.121 | 1.000| 0.890| 0.801|
|      | 60             | 1.294               | 1.132 | 1.000| 0.886| 0.793|
|      | 70             | 1.308               | 1.138 | 1.000| 0.886| 0.788|
|      | 80             | 1.312               | 1.140 | 1.000| 0.884| 0.786|
|      | 90             | 1.319               | 1.145 | 1.000| 0.884| 0.786|
|      | 100            | 1.319               | 1.144 | 1.000| 0.881| 0.785|
|      | 110            | 1.322               | 1.142 | 1.000| 0.882| 0.784|
| 0.4  | 20             | 1.111               | 1.054 | 1.000| 0.949| 0.900|
|      | 30             | 1.181               | 1.087 | 1.000| 0.922| 0.851|
|      | 40             | 1.227               | 1.105 | 1.000| 0.907| 0.825|
|      | 50             | 1.258               | 1.120 | 1.000| 0.899| 0.810|
|      | 60             | 1.276               | 1.125 | 1.000| 0.890| 0.798|
|      | 70             | 1.292               | 1.132 | 1.000| 0.887| 0.793|
|      | 80             | 1.302               | 1.136 | 1.000| 0.885| 0.790|
|      | 90             | 1.308               | 1.138 | 1.000| 0.884| 0.789|
|      | 100            | 1.311               | 1.138 | 1.000| 0.883| 0.788|
|      | 110            | 1.315               | 1.140 | 1.000| 0.885| 0.791|
| 0.45 | 20             | 1.099               | 1.052 | 1.000| 0.948| 0.905|
|      | 30             | 1.169               | 1.080 | 1.000| 0.924| 0.858|
|      | 40             | 1.209               | 1.102 | 1.000| 0.909| 0.829|
|      | 50             | 1.248               | 1.115 | 1.000| 0.898| 0.815|
|      | 60             | 1.267               | 1.125 | 1.000| 0.891| 0.801|
|      | 70             | 1.283               | 1.129 | 1.000| 0.820| 0.797|
|      | 80             | 1.298               | 1.137 | 1.000| 0.884| 0.799|
|      | 90             | 1.301               | 1.135 | 1.000| 0.887| 0.792|
|      | 100            | 1.305               | 1.138 | 1.000| 0.886| 0.791|
|      | 110            | 1.312               | 1.138 | 1.000| 0.885| 0.789|

HVL: Half-value layer.

mammary gland ratio

0.1% y = 0.0005x³ − 0.014x² + 0.13x + 0.93 (4.1)
25% y = 0.0003x³ − 0.0071x² + 0.062x + 0.97 (4.2)
50% y = 1.0 (4.3)
75% y = −0.0002x³ + 0.0055x² − 0.047x + 1.0 (4.4)
100% y = −0.0004x³ + 0.011x² − 0.089x + 1.0 (4.5)

Figure 4 illustrates the approximate curves of the c-factor vs. tissue ratio for nine sets of compressed breast thicknesses, ranging from 20 mmAl to 60 mmAl (5 mm increments). The generated curve approximation formulae are:

breast thickness

60 mm y = 2E-05x³ − 0.007x + 1.3 (5.1)
55 mm y = 2E-05x³ − 0.007x + 1.3 (5.2)
50 mm y = 2E-05x³ − 0.0065x + 1.3 (5.3)
45 mm y = 2E-05x³ − 0.0062x + 1.3 (5.4)
40 mm y = 1E-05x³ − 0.0057x + 1.3 (5.5)
35 mm y = 1E-05x³ − 0.0052x + 1.2 (5.6)
30 mm y = 8E-06x³ − 0.0045x + 1.2 (5.7)
25 mm y = 6E-06x³ − 0.0037x + 1.2 (5.8)
20 mm y = 4E-06x³ − 0.0028x + 1.1 (5.9)

The interpolated c-factors obtained by incorporating breast thicknesses (20–60 mm, nine steps in 5-mm increments), HVLs (0.3–0.45 mmAl, four steps in 0.05-mmAl increments), and breast glandularity (0.1–100%, eight steps) are provided in Table 4.
Discussion

The AGD calculation guidelines in Japan previously used a formula proposed by Wu et al., but they were replaced by Dance et al.’s guidelines in 2010; these new guidelines also incorporate the effects of the new target/additional filter introduced in the mammography equipment. Dance et al. used an inexpensive and easy-to-obtain polymethyl methacrylate (PMMA)-based breast model of the mammary gland ratio, corresponding to a composition of 50% adipose and 50% (50/50) glandular tissue. Using various correction and conversion factors (measured entrance surface air kerma of the breast model, g-factor, c-factor, and s-factor), Dance et al. developed a formula to calculate AGD.

However, Dance’s original coefficients were developed for a Western population and are available for compressed breast thicknesses of 20 mm to 110 mm (11 steps in primarily 10-mm increments) and HVL of 0.3–0.6 mmAl (seven steps in 0.05-mmAl increments). Determination of mammary gland thickness is a limitation in some mammography techniques that use X-ray devices in conjunction with computed radiography. The estimation of the average mammary gland dose for every subject can be difficult. We have used the approach by Dance et al. to estimate the average mammary gland dose ratio for each subject. In this study, we generated an approximation formula for Dance’s coefficients and interpolated values of g- and c-factors at a resolution higher than that available in the original reports by Dance et al. Dance et al. used clinical data to calculate the coefficients. The use of the excel graph function to obtain the approximate formula using clinical data will enable the use of highly reproducible coefficients. We interpolate values for each factor, at breast thicknesses of 20–60 mm (nine steps in 5-mm increments) and HVL of 0.3–0.45 mmAl (16 steps in 0.01-mmAl increments) to generate data that could be used for more accurate, detailed, and individualized AGD estimation. This enabled a detailed calculation of the AGD at a more individual level using coefficient interpolation.

Figure 2 g-factor for half-value layers. HVL: Half-value layer.

Figure 3 c-factor for compressed breast thicknesses [Half-value layer (HVL): 0.3 mmAl]. Fitted curves obtained by plotting breast thickness on the horizontal axis and c-factor of Dance et al. on the vertical axis for five ratios of breast compositions between 0.10% and 100% as shown by Dance et al.
pect that these interpolated values will serve as a reference for other researchers and make AGD estimation simpler and less vague.

In Europe and in the United States, breast X-ray equipment has transitioned from a screen film system to a fully digitalized version that uses a flat panel detector. In Japan, breast X-rays have moved to a flat panel system in conjunction with computed radiography. In flat panel devices, AGD, estimated by automatic calculation, is displayed in real time, whereas in computed radiography systems this is not possible. In Japan, X-rays using computed radiography mammography is widely used, and exposure management is an important challenge. It is difficult to calculate the AGD for each subject individually because the exposure received by the subjects using computed radiography is difficult to gauge. The interior interpolation of the coefficients will be useful for researchers to calculate the AGD of each subject individually. In addition, the interpolated factor and its approximation are useful not only for AGD calculation using PMMA, which is used for the quality control of general equipment, but also for AGD calculation using breast phantoms with different breast compositions. The emergency warning on digital mammography issued by the Japan Radiological Society also recommends a clear description of imaging conditions that allow AGD estimation, emphasizing the importance of understanding AGD in mammography.

### Table 3  g-factor obtained by interpolating compressed breast thickness and half-value layer (HVL)

| Compressed breast thickness (mm) | HVL (mmAl) | 0.3  | 0.31 | 0.32 | 0.33 | 0.34 | 0.35 | 0.36 | 0.37 | 0.38 | 0.39 | 0.4  | 0.41 | 0.42 | 0.43 | 0.44 | 0.45 |
|---------------------------------|------------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|
| 20                              |            | 0.390| 0.398| 0.407| 0.416| 0.425| 0.433| 0.442| 0.451| 0.459| 0.467| 0.473| 0.482| 0.490| 0.497| 0.504| 0.509|
| 25                              |            | 0.330| 0.337| 0.345| 0.353| 0.361| 0.368| 0.376| 0.384| 0.391| 0.398| 0.405| 0.413| 0.420| 0.426| 0.433| 0.438|
| 30                              |            | 0.274| 0.281| 0.288| 0.295| 0.302| 0.309| 0.315| 0.322| 0.329| 0.335| 0.342| 0.349| 0.355| 0.362| 0.368| 0.374|
| 35                              |            | 0.245| 0.250| 0.256| 0.263| 0.269| 0.274| 0.281| 0.287| 0.293| 0.299| 0.304| 0.311| 0.317| 0.323| 0.329| 0.333|
| 40                              |            | 0.207| 0.213| 0.218| 0.223| 0.229| 0.235| 0.240| 0.245| 0.251| 0.256| 0.261| 0.267| 0.273| 0.278| 0.284| 0.289|
| 45                              |            | 0.183| 0.188| 0.193| 0.198| 0.203| 0.208| 0.212| 0.217| 0.222| 0.227| 0.232| 0.238| 0.243| 0.248| 0.253| 0.258|
| 50                              |            | 0.164| 0.168| 0.173| 0.177| 0.182| 0.187| 0.191| 0.195| 0.200| 0.205| 0.209| 0.214| 0.219| 0.224| 0.228| 0.232|
| 55                              |            | 0.147| 0.148| 0.151| 0.155| 0.159| 0.158| 0.166| 0.170| 0.174| 0.179| 0.183| 0.187| 0.191| 0.195| 0.200| 0.202|
| 60                              |            | 0.135| 0.139| 0.142| 0.146| 0.149| 0.154| 0.157| 0.161| 0.164| 0.168| 0.172| 0.176| 0.180| 0.184| 0.188| 0.192|

### Figure 4  c-factor for breast compositions [Half-value layer (HVL): 0.3 mmAl]. Fitted curves obtained by plotting ratio of breast compositions on the horizontal axis and c-factor of Dance et al. on the vertical axis for nine types of compressed breast thicknesses ranging between 20 mm and 60 mm.

### Figure 4  c-factor for breast compositions [Half-value layer (HVL): 0.3 mmAl]. Fitted curves obtained by plotting ratio of breast compositions on the horizontal axis and c-factor of Dance et al. on the vertical axis for nine types of compressed breast thicknesses ranging between 20 mm and 60 mm.

### Conclusion

This study demonstrated a method for interpolation of HVLs and breast thickness required in dosimetry during mammography. Corresponding to the dosimetry that is routinely performed using devices with different HVLs, the method makes the current AGD estimation more convenient and accessible. The interpolation of factors by Dance et al.
will allow more accurate, detailed, and individualized AGD estimation and can be used to improve exposure control in mammography.

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**Table 4** c-factor obtained by interpolating compressed breast thickness and composition

| HVL (mmAl) | Compressed breast thickness (mm) | Breast glandularity (%) | 0.1 | 25 | 30 | 0.1 | 70 | 75 | 90 | 100 |
|------------|---------------------------------|-------------------------|-----|----|----|-----|----|----|----|----|
| 0.3        |                                 |                          | 1.130 | 1.059 | 1.049 | 1.000 | 0.953 | 0.938 | 0.910 | 0.885 |
| 0.35       |                                 |                          | 1.123 | 1.058 | 1.048 | 1.000 | 0.960 | 0.943 | 0.913 | 0.891 |
| 0.4        |                                 |                          | 1.111 | 1.054 | 1.044 | 1.000 | 0.960 | 0.949 | 0.920 | 0.900 |
| 0.45       |                                 |                          | 1.099 | 1.052 | 1.038 | 1.000 | 0.958 | 0.948 | 0.920 | 0.905 |

HVL: Half-value layer.

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**References**

1. Smith-Bindman R, Lipson J, Marcus R, *et al*. Radiation dose associated with common computed tomography examinations
and the associated lifetime attributable risk of cancer. Arch Intern Med 2009; 169: 2078–2086. [Medline] [CrossRef]

2. European guidelines for quality assurance in breast cancer screening and diagnosis. 4th ed. European Reference Organization for Quality Assured Breast Screening and Diagnostic Service 2005; 157–161.

3. The Japan Central Organization on Quality Assurance of Breast Cancer Screening Dejitaru mammografi hinsitsu kanri manyuuru (in Japanese). Igaku-Shoin 2009; 23–25.

4. Hammerstein GR, Miller DW, White DR, et al. Absorbed radiation dose in mammography. Radiology 1979; 130: 485–491. [Medline] [CrossRef]

5. Dance DR. Monte Carlo calculation of conversion factors for the estimation of mean glandular breast dose. Phys Med Biol 1990; 35: 1211–1219. [Medline] [CrossRef]

6. Dance DR, Skinner CL, Young KC, et al. Additional factors for the estimation of mean glandular breast dose using the UK mammography dosimetry protocol. Phys Med Biol 2000; 45: 3225–3240. [Medline] [CrossRef]

7. Ogasawara K, Date H. A numerical model for compressed breast of Japanese women in mammography. Igaku Butsuri 2001; 21: 215–222. [Medline]

8. Matsumoto M, Nishizawa K, Akiyama Y, et al. The mean breast thickness for Japanese patients for use in estimating the glandular dose in mammography. Japan Association of Breast Cancer Screening 2000; 9: 95–102. [CrossRef]

9. Asada Y, Suzuki S, Yamada M, et al. Effect of breast composition on patient exposure in mammography. Nippon Hoshasen Gijutsu Gakkai Zasshi 2004; 60: 1675–1681 (in Japanese). [Medline] [CrossRef]

10. Wu X, Barnes GT, Tucker DM. Spectral dependence of glandular tissue dose in screen-film mammography. Radiology 1991; 179: 143–148. [Medline] [CrossRef]

11. Wu X, Gingold EL, Barnes GT, et al. Normalized average glandular dose in molybdenum target-rhodium filter and rhodium target-rhodium filter mammography. Radiology 1994; 193: 83–89. [Medline] [CrossRef]

12. Tsai HY, Chong NS, Ho YJ, et al. Evaluation of depth dose and glandular dose for digital mammography. Radiat Meas 2010; 45: 726–728. [CrossRef]

13. Sobol WT, Wu X. Parametrization of mammography normalized average glandular dose tables. Med Phys 1997; 24: 547–554. [Medline] [CrossRef]

14. The Japan Radiological Society Dejitaru mammografi ni kansuru kinkyu kankoku [An emergency warning on digital mammography] (in Japanese). http://www.radiology.jp/member_info/guideline/20050702.html (Accessed May 1, 2016).

15. Frankenbergen D, Kelnhofer K, Bär K, et al. Enhanced neoplastic transformation by mammography X rays relative to 200 kVp X rays: indication for a strong dependence on photon energy of the RBE(M) for various end points. Radiat Res 2002; 157: 99–105. [Medline] [CrossRef]