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Breast dosimetry system in screen/film mammography

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Summary

The average glandular dose to glandular tissue in mammography is generally assumed to be a function of beam quality (HVL), x-ray tube target material, tube voltage, breast thickness, breast composition and, to a lesser extent, x-ray tube voltage waveform. The average glandular dose is generally determined from published tables with knowledge of the above function. Tables for a high frequency x-ray generator are not yet published. In our study, the lookup tables for the average glandular dose were made at 28 kV (high frequency x-ray generator), employing a breast simulating tissue (0-100% adipose tissue, 0-100% glandular tissue) phantom for an Mo target - Mo filter source assembly. We tried to estimate breast composition from x-ray mammograms by digital image processing techniques, also using the simulating tissue phantom. Then the system that automatically calculates the average glandular dose from digitized clinical x-ray mammograms was built. It is considered that this system can contribute to objective evaluation of the average glandular dose.

Key words : Screen/Film Mammography, Breast composition, Entrance skin exposure, Average glandular dose, Breast-equivalent material phantom

Introduction

The glandular tissue of the breast, including the acinar and ductal epithelium and associated stroma, is more vulnerable to radiation carcinogenesis than the skin, adipose tissue, or areola. Average radiation absorbed dose to glandular breast tissue represents a "true" mean dose to the most vulnerable tissue of the breast and most appropriately characterizes the radiation risk of carcinogenesis due to mammography. Many investigators have chosen to evaluate the average dose per view to the whole breast considering it to be a close approximation of a uniform phantom having the same average composition[1,2)]. The average radiation absorbed dose to glandular breast tissue (following, average glandular dose) is the most useful measure of radiation risk at x-ray mammography and is the currently accepted descriptor of dose to the breast[3~7)]. If the normalized average glandular dose, $\overline{D_{gN}}$ (the average glandular dose per unit entrance skin exposure) is known, the average glandular dose, $\overline{D}_g$, can be computed from the product of $\overline{D_{gN}}$ and the breast entrance skin exposure in air, X_a.

That is,

$$\overline{D}_g = \overline{D_{gN}} \times X_a \qquad (1)$$

where the respective units of $\overline{D}_g$, $\overline{D_{gN}}$ and X_a are grays, grays per (coulomb per kilogram) and coulombs per kilogram[1~6)].

The evaluation of the glandular dose delivered

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in a mammography examination is thus reduced to a measurement of the breast entrance skin exposure, X_a including scatter from the breast and an evaluation of $\overline{D_{gN}}$. The average glandular dose in mammography is generally determined from published tables with knowledge of the breast entrance skin exposure, x-ray tube target material, beam quality (HVL), breast-compressed thickness and breast composition[3]. Using a carefully designed and experimentally validated Monte Carlo simulation, Wu et al. showed that average glandular dose also depends on x-ray tube voltage and, to a lesser extent, on x-ray tube voltage waveform[5]. Therefore, the tables by Wu et al. are commonly used as look-up tables[6,7].

Mammography units that employ high-frequency x-ray generators are commercially available at present. In our study, the look-up tables were newly made for a high frequency x-ray generator, employing a simulating breast tissue phantom. In addition, we tried to estimate breast composition from x-ray mammograms by digital image processing techniques, also using the simulating breast tissue phantom. Furthermore, the system which automatically calculates the average glandular dose $\overline{D_g}$ from a digitized clinical x-ray mammographic image was built.

Methods

X-ray beam quality (in terms of aluminum half-value layer (HVL)) of the dedicated unit, MGU-10C (TOSHIBA MEDICAL SYSTEMS Co., Ltd.) with a high-frequency x-ray generator were measured with a specially designed mammography ion chamber and high-purity aluminum[8]. The following three look-up tables shown in Fig. 1-3 were prepared for the calculation of an average glandular dose.

1. Average glandular dose per unit entrance skin exposure, $\overline{D_{gN}}$

In our study, the look-up table of $\overline{D_{gN}}$ was newly made for a high frequency x-ray generator with a molybdenum target-molybdenum filter source assembly at 28 kV, employing simulating breast tissue phantoms. The phantoms are slabs of breast-equivalent material of differing known uniform adipose/gland mix. They are commercially available (Computerized Imaging Reference System, Inc.; Norfolk, VA, USA) and their configuration, 100×125 mm would be suitable for this purpose[6]. As for the ratios of uniform adipose(%)/gland(%) mixing 0/100, 20/80, 50/50, 80/20 and 100/0 were employed. Hereafter, this slab phantom is called breast-equivalent material phantom. Exposure as a function of depth (z) was measured in 6-cm-thick breast-equivalent

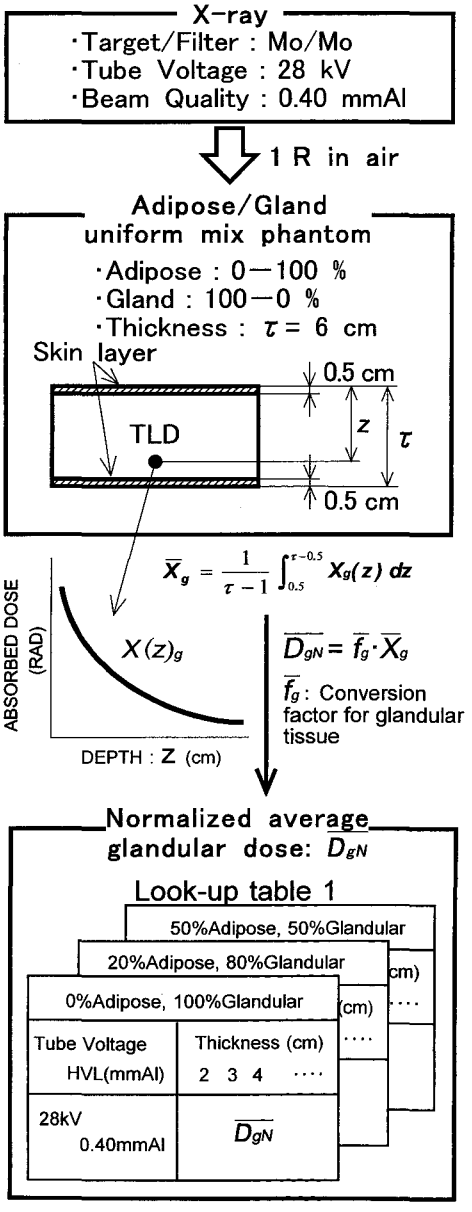

Fig. 1 Look-up table 1 for normalized average glandular dose

material phantoms, using thermoluminescent (TL) dosimeters consisting of 3.18×3.18×0.89 mm chips of LiF (TLD-100, Bicron Business Unit of Saint-Gobain Industrial Ceramics, Inc.). Six individual measurements of relative exposure ($X_g(z)$) were made at each 1 cm depth interval in each phantom as shown in Fig. 1. It is possible to express $\overline{D_{gN}}$ in terms of measurable quantities such as relative exposure vs. depth as shown in the equation below.

$$\overline{D_{gN}} = \frac{1}{\tau\text{-}1}\int_{0.5}^{\tau-0.5} \overline{f_g} \cdot X_g(z)dz \qquad (2)$$

where $\overline{f_g}$ is the conversion factor for glandular tissue (≈7.9 mGy/R)[1,2]. Look-up table 1 was made by calculating $\overline{D_{gN}}$, changing τ to 2-6 cm for each breast composition, which varied from 100% adipose to 100% gland.

2. Entrance skin exposure in air, X_a

The exposure difference between the off-axis geometry of the American College of Radiology (ACR) protocol and the central-axis geometry was reported by Kwan H. Ng. et al.[9]. The central-axis geometry was employed in this study and the exposure was measured by using the mdh-dosimeter (model 1015, ionization chamber : 10×5-6M, RADCAL Corp.). The procedure for measuring breast entrance skin exposure is to position the ionization chamber at the central axis of the x-ray beam, 4 cm from the chest-wall edge of the image receptor, and with the center of the chamber level with the top surface of the

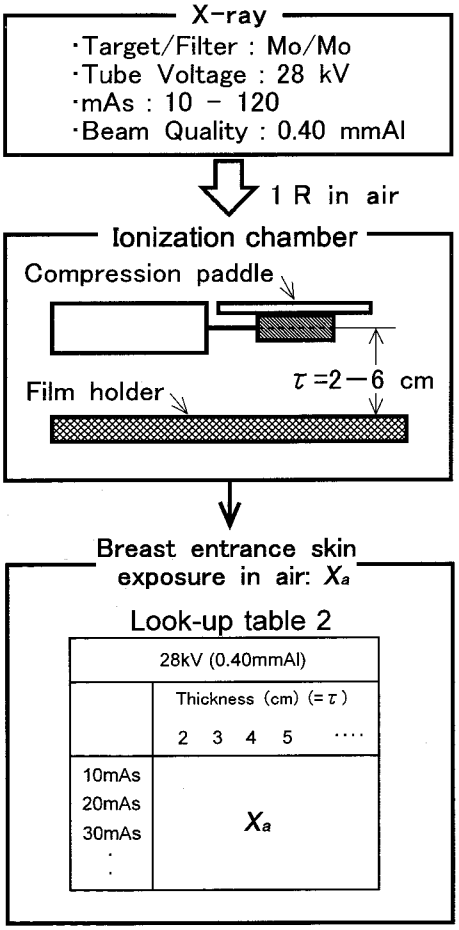

Fig. 2 Look-up table 2 for breast entrance skin exposure in air

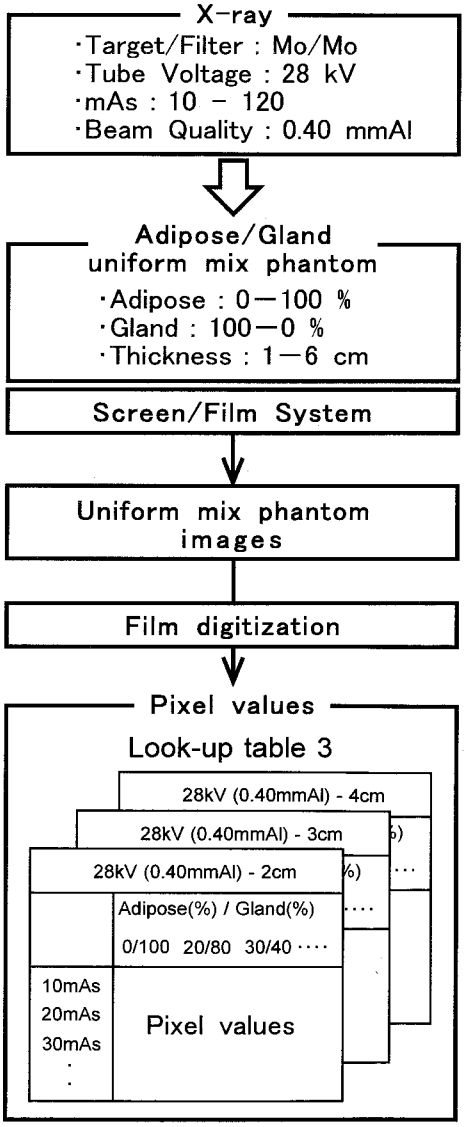

Fig. 3 Look-up table 3 of pixel value-adipose/gland for calculating breast composition

breast-equivalent material phantom[9]. Look-up table 2 of the entrance skin exposure, X_a as a function of kV, mAs, thickness was made as shown in Fig. 2. The exposures of samples were computed from exposure information (kV, mAs and breast-compressed thickness) recorded in clinical examination, using look-up table 2.

3. Breast composition vs. pixel value

Images of breast-equivalent material phantom of differing known uniform adipose(%)/gland(%) mix (0/100, 20/80, 50/50, 80/20, 100/0) and thickness (2-6 cm) were obtained with Kodak Min-R 2000/Min-R 2000 screen/film system at 28 kV, 10-120 mAs. The images were digitized with a pixel size 0.085×0.085 mm and 1024 gray-levels by Konica LD-4500. Look-up tables of pixel values as a function of kV, mAs, thickness and adipose(%)/gland(%) were made.

4. Average glandular dose $\overline{D}_g$

Fig. 4 illustrates the general scheme of our calculating average glandular dose $\overline{D}_g$. Clinical mammograms were also digitized under the same conditions as images of breast-equivalent material phantoms. The pixel values of digitized clinical mammograms were classified by the thresholds from the look-up table 3. Their breast compositions were calculated by the number of pixels at each adipose(%)/gland(%). $\overline{D_{gN}}$ of clinical mammograms were obtained by computer interpolation in look-up table 1 from the calculated breast compositions and thickness which had been recorded at the examination. Once the normalized average glandular dose $\overline{D_{gN}}$ is known, the average glandular dose $\overline{D}_g$ can be computed from the product of $\overline{D_{gN}}$ and the breast entrance skin exposure, X_a. X_a could also be obtained by computer interpolation in look-up table 2 from mAs and thickness which had already been recorded at the examination.

Results

Table shows the average glandular dose per unit entrance skin exposure at 28 kV, HVL 0.41 mmAl and with breast-equivalent material phantom obtained by the high-frequency x-ray generator. Values of Wu et al. shown in the table were obtained by computer interpolation of their table[5]. They have reported that the difference between doses obtained with constant-potential units and doses obtained with three-phase, six-pulse units by Monte Carlo simulation was less than 1%[5]. Close agreement was obtained within

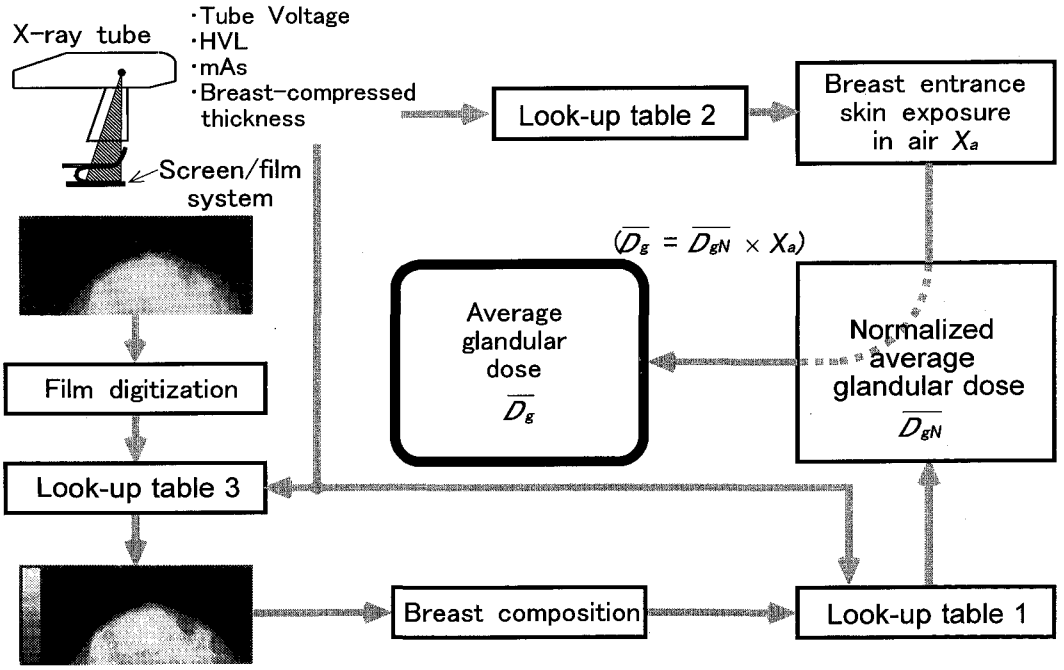

Fig. 4 General scheme of our calculating average glandular dose $\overline{D}_g$

Table The average glandular dose per unit entrance skin exposure

(mGy/R)

Glandular Ratio (%)	$Our Study					*Stydy of Wu et al.			
	Breast-compressed thickness (cm)					Breast-compressed thickness (cm)			
	2	3	4	5	6	3	4	5	6
100	3.14	2.19	1.63	1.28	1.05	2.23	1.66	1.31	1.08
80	3.36	2.39	1.80	1.43	1.17	2.40	1.82	1.44	1.20
60	3.60	2.60	2.00	1.60	1.32	2.59	2.00	1.60	1.33
50	3.72	2.72	2.10	1.68	1.39	2.69	2.09	1.68	1.40
40	3.84	2.84	2.20	1.77	1.47	2.82	2.19	1.76	1.48
20	4.10	3.08	2.41	1.97	1.64	3.02	2.40	1.95	1.64
0	4.35	3.32	2.62	2.19	1.83	2.24	2.62	2.16	1.83

$All values were measured at 28 kVp with HVL 0.4 mmAl.
*Interpolated dose based on Wu's table.

several percentages when our results were compared with the doses by Wu et al in consideration of the report.

Fig. 5 shows x-ray mammogram and the result image after classification by the thresholds from look-up table 3 and an analysis result of breast composition. Fig. 6 shows the distribution of breast composition. The result suggests that Japanese women are likely to have breasts of decreased adiposity compared to the reference composition (50% adipose and 50% glandular tissue). These results provided a close approximate value compared with the glandular rate presumed from a teaching atlas[10] or experience.

Fig. 7 shows the distribution of average glandular dose $\overline{D}_g$. The ACR recommends that the average glandular dose for a "typical breast" should be less than 4 mGy per film[4]and in Japan the maximum acceptable dose is 3 mGy[11,12]. Our results in Fig. 7 were clearly less than the value.

Discussion

When measuring the average glandular dose, the process which measures the average glandular dose per unit entrance skin exposure using TLD and breast-equivalent material phantom,

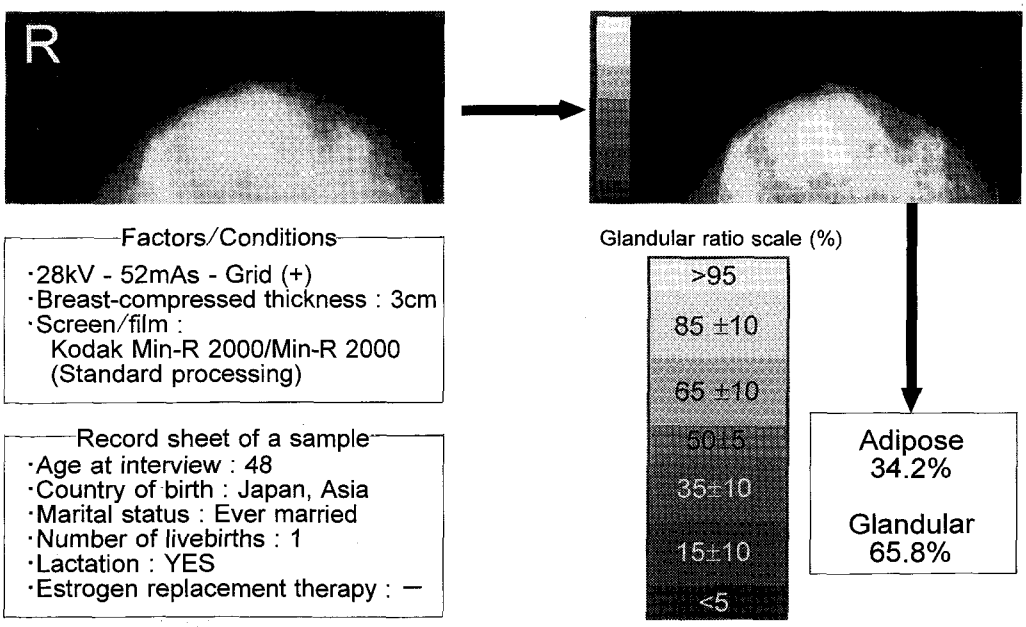

Fig. 5 X-ray Mammography (craniocaudal view) and the result image after classification by the thresholds from look-up table 3 and an analysis result of breast composition.

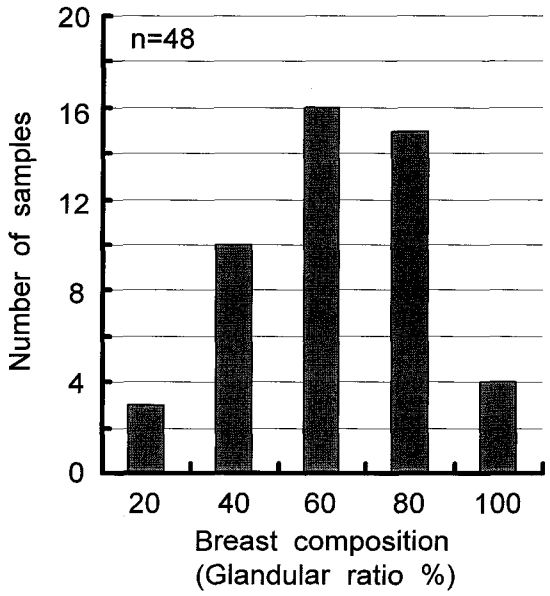

Fig. 6 Distribution of breast composition determined from x-ray mammograms

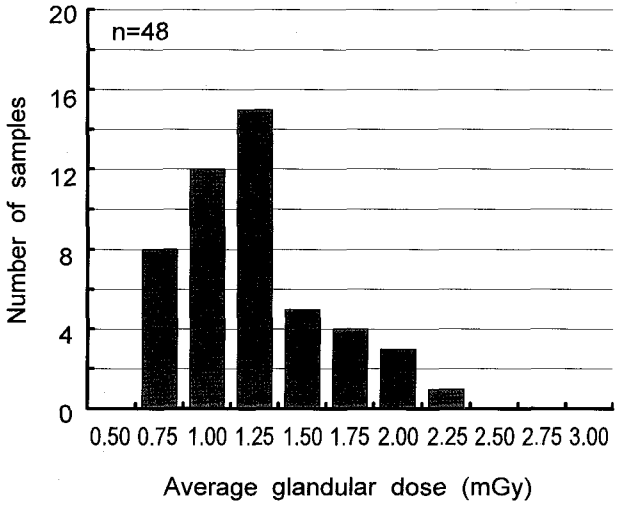

Fig. 7 Distribution of average glandular dose from x-ray mammograms

and the process which measures the breast entrance skin exposure further using a ionization chamber were fully discussed in a previous paper, or are defined in ACR protocol. It is important when measurement is carried out that the processes are followed correctly and faithfully. Since our overall result bears close comparison to the table of Wu et al., it is thought that the importance of correct procedure was made clear.

Next, if the cross sectional area of a phantom differs from that of a patient's breast, it can be considered that an error has occurred in the determination of the average glandular dose. In NCRP report no. 85, it was reported that an increase from 35 to 270 cm^2 changed the average glandular dose by less than 10%[3]. Furthermore, Wu et al. reported that they found that for a smaller breast section (12×4 cm), $\overline{D_{gN}}$ decreases by 2%, Likewise, for a larger section (22×10 cm), $\overline{D_{gN}}$ increases by only 0.6% on the basis of a semi-elliptical breast cross-section with a chest wall dimension of 18 cm and chest wall-to-nipple dimension of 8 cm[5]. So, it is thought that our system has 10% or less of an error factor including the error determination of breast composition.

At present how to investigate breast composition is not clearly specified, and breast composition is still decided subjectively. For this problem, we feel that our method of estimation of breast composition from a mammogram is useful for eliminating objective evaluation of patient breast composition and does not depend on a computer detection algorithm, though three tables employed as look-up tables must be used in each system. Furthermore, if our method of estimation applies to DR (digital radiography) and CR (computed radiography), the development process of film and the process of digitization will be unnecessary. If information of each content of a phantom and pixel value is stored in a computer once, it can then be used immediately to estimate the average glandular doses and breast composition at further clinical examinations.

At present there is a wide range in the recommended average glandular dose limits in screening mammography. The ACR recommends that the average glandular dose for a "typical breast" should be less than 10 mGy for a two view examination and the ACR accreditation guidelines are that the dose should be less than 4 mGy per film. The State of New York regulations require that the average glandular dose for a 4.5 cm compressed breast should not exceed 3 mGy when a grid is employed, and 1 mGy when a grid is not

employed. The AAPM (The American Association of Physicists in Medicine) recommends that the average glandular dose should be less than or equal to 1.8 mGy when a grid is employed to image a 4.2 cm PMMA (polymethyl methacrylate) phantom[13]. In Japan, 3 mGy per view in a 4.2 cm-thick 50% adipose/50% glandular compressed breast was recommended as the acceptable average glandular dose[12]. Although many more samples are required, the average glandular ratio of 3.8-4.5 cm-thick breasts was 47% and the mean average glandular dose was 1.5 mGy. Our results show that our mammographic system cleared not only the acceptable average glandular dose of Japan but also that of AAPM.

Finally, the average glandular dose to the breast in mammography depends upon : target/filter combination, tube voltage, beam quality, tube voltage waveform, breast-compressed thickness and breast composition. It also depends upon use, or not, of a grid, film/screen combination and film processing method. All of these factors were taken into account for each patient in our system. In reviewing the results for average glandular dose per view from our results, it should be noted that they reflect not only the types of women, in terms of their breast thickness and compositions but also the mammography units' performance characteristics.

Conclusions

The look-up tables for determining average glandular dose were newly made for a high frequency x-ray generator with a molybdenum target-molybdenum filter source assembly at 28 kV, employing a simulating breast tissue phantom. In addition, breast compositions were estimated from x-ray mammograms by digital image processing techniques, also using the simulating breast tissue phantom. Then the system was built, which automatically calculates the average glandular dose from digitized clinical x-ray mammographic images in each individual patient.

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（原　著）

スクリーン／フィルム乳房撮影法における乳房線量測定システム

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要　　約

乳房X線撮影法において乳腺組織に対する平均放射線吸収線量，すなわち平均乳腺線量は放射線のリスクの最も有用な測定法であり，現在，乳房に対する線量の評価に用いられている指標である。一般に，平均乳腺線量は線質(HVL)，X線管球ターゲット材料，管電圧，圧迫乳房厚さ，乳房構成および（ある程度）X線管電圧波形の関数であるとされている。平均乳腺線量は，上記の関数についての情報を備えた表が公表されており，一般にその表を使って決定されている。近年，インバータ式といわれる高周波X線発生装置が普及してきた。しかし，その装置用の表は，まだ公表されていない。我々の研究では，乳房組織をシュミレートするファントム（0～100%乳腺組織，0～100%脂肪組織）を使用して，28kVでMoターゲット—Moフィルタソースアセンブリーを備えた高周波X線発生装置のために，平均乳腺線量用のルックアップテーブルを作成した。同様に，乳房組織をシュミレートするファントムを使用して，乳房X線写真から，ディジタル・イメージプロセシング技術によって，乳房構成の評価を試みた。そして，ディジタイズされた臨床乳房X線写真から，平均乳腺線量を自動的に計算するシステムを構築した。サンプル数が少ないため断定はできないが，日本女性は，基準構成（50%の脂肪および50%の乳腺組織）と比較すると，脂肪が少ない傾向を分析結果は示唆していた。また，平均乳腺吸収線量の限度は，明確に規定されていないが，American College of Radiology（ACR）は4 mGyなどを推奨している。また日本では，3 mGyが推奨されているが，我々の撮影システムはこれらを十分満足していた。このように本システムは，平均乳腺線量の客観的な評価に寄与するとともに，DR (digital radiography) などに応用すると，すなわちルックアップテーブルをDRのコンピュータに保存しておけば，撮影後すぐに乳房構成および平均乳腺線量を算出できる可能性をもつ。

キーワード：スクリーン／フィルム乳房撮影法，乳房構成，平均乳腺線量，皮膚入射線量，乳房組織等価ファントム

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