Original Article

MEMOIRS HEALTH SCI. MED. KANAZAWA UNIV. Vol. 20
43~48 1996

Study of X-ray Quality in Absorption Materials for Mammography

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ABSTRACT

In order to evaluate the x-ray quality in each material, we obtained the values from one to five half-value layer with aluminum, bakelite, polymethyl methacrylate resin and BR-12 phantom, and investigated the change of x-ray quality (from first to fifth half-value layer) according to the attenuation in their materials. The un-homogeneity factor to first half-value layer in BR-12 phantom was slightly low than that in aluminum, and especially was not as high as that in aluminum for the ratio of fifth half-value layer to first half-value layer. X-ray quality passed through the breast may be higher than that of the breast surface because of the transmission in the breast tissue. So the subject contrast would be decreasing. The thickness of the breast under compression in the clinical practice correspond to about four or five half-value layer. Therefore the x-ray quality must be evaluated by BR-12 phantom, being composed nearly with the breast.

KEY WORDS

X-ray quality, Half-value layer, Subject contrast

INTRODUCTION

X-ray tubes for Mammography affect image contrast as a result of the application of different target and filter materials, whicn are molybdenum-target (Mo-target) and molybdenum-filter (Mo-filter), molybdenum-target and rhodium-filter (Rh-filter), rhodium-target (Rh-target) and rhodium-filter. The image contrast depends on both film contrast and subject contrast. In the film contrast[1–5], it has been researched on the intensifying screen, the x-ray film and the developer. On the other hand, the subject contrast is essential to research on subject-tissue density, subject thickness, x-ray quality, K-absorption edge and et al., but the number of the study is a few[6]. Then we obtained the values from one to five half-value layer by the attenuation in aluminum, bakelite, polymethyl methacrylate resin and BR-12 phantom, and investigated the change of x-ray quality according to the attenuation in their materials.

Materials and Method

The dosimeter used for the measurement of the half value layer is the ionization chamber with the volume of 0.2cm^2 (N23344, PTW Corp.). Aluminum (the thickness from 0.0499 to 3.01mm, the density of 2.7g/cm^3), bakelite (2~50mm, 1.4g/cm^3), polymethyl methacrylate resin (5~45mm, 1.19g/cm^3)and BR-12 phantom (5~55mm, 0.99g/cm^3) for the absorption materials were used.

The used x-ray generator for the mammography is equipped with the x-ray tube of the target-filter combination as Mo with 30μm Mo.

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Table 1 Mass attenuation coefficient (cm²/g) to each energy in the four materials of aluminum, bakelite, polymethyl methacrylate resin, BR-12 phantom.

keV	Aluminum	Bakelite	Acrylate	BR-12
10	26.230	2.8600	3.3570	4.2950
15	7.955	0.9552	1.1010	1.3780
20	3.441	0.5089	0.5714	0.6889
30	1.128	0.2824	0.3032	0.3403

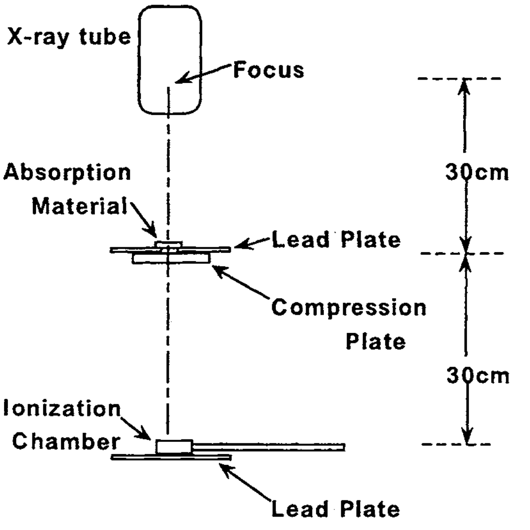

Fig. 1 Geometric arrangement to measure from one to five half-value layer.

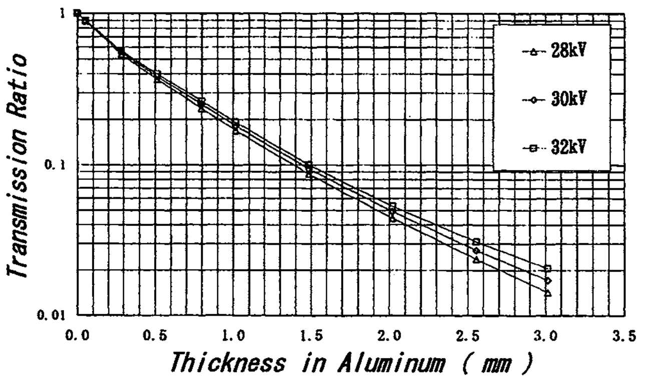

Fig. 2 Attenuation aspect passing through the material of aluminum for the tube voltage of 28kV, 30kV and 32kV.

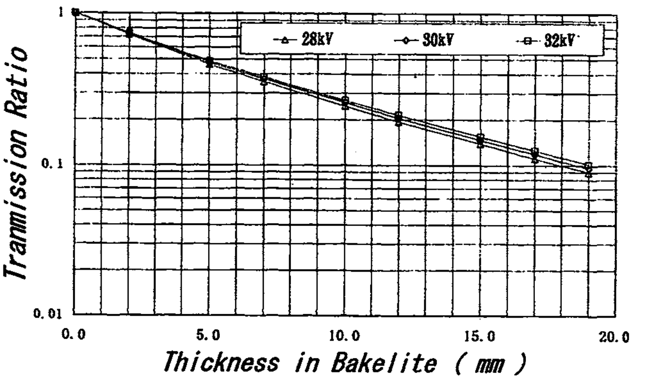

Fig. 3 Attenuation aspect passing through the material of bakelite for the tube voltage of 28kV, 30kV and 32kV.

The generator is able to select either 30μm thick Mo-filter or 25μm thick Rh-filter. In the x-ray intensity emitted from the anode of the x-ray tube for the mammography, the geometric arrangement to measure from one to five half-value layer shows Fig. 1. The focus-filter distance and the filter-detector distance were approximately equal, and 30cm respectively. The lead plate (the thickness of 1mm) made a hole of 18mm ϕ was placed at the position of the absorption filter, and x-ray beam was collimated because of that. The compression plate was kept in the field of the x-ray beam. In the x-ray tube loading factor, the preset of the tube voltage is from 28kV to 32kV, and the current time product is from 40mAs to 80mAs.

The mass attenuation coefficient of aluminum, bakelite, polymethyl methacrylate resin and BR-12 was used the value calculated by Hubbell[7] for the required x-ray quality. Table 1 shows the mass attenuation coefficient to each energy.

RESULT

The attenuation aspects passed through absorption materials of aluminum, bakelite, polymethyl methacrylate resin and BR-12 phantom show in Fig. 2, Fig. 3, Fig. 4 and Fig. 5. Their figures (Fig. 2-5) show the attenuation in order to their absorption materials in the x-ray tube voltage of 28kV, 30kV and 32kV, and the primary exposure is normalized at 100.

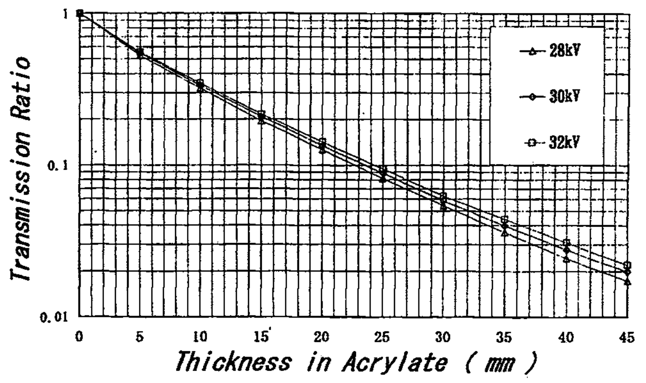

Fig. 4 Attenuation aspect passing through the material of polymethyl methacrylate resin for the tube voltage of 28kV, 30kV and 32kV.

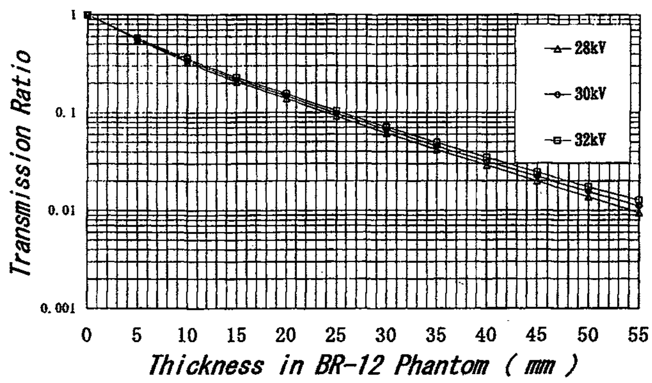

Fig. 5 Attenuation aspect passing through the material of BR-12 phantom for the tube voltage of 28kV, 30kV and 32kV.

Table 2 One to five half-value layer (mm) in the four materials for the tube voltage of 28kV, 30kV and 32kV.

	Aluminum			Bakelite			Acrylate			BR-12		
	28kV	30kV	32kV	28kV	30kV	32kV	28kV	30kV	32kV	28kV	30kV	32kV
1/2	0.319	0.334	0.349	4.47	4.65	4.78	5.96	6.19	6.38	6.15	6.36	6.60
1/4	0.700	0.732	0.761	9.29	9.66	9.94	12.43	12.95	13.32	12.87	13.32	13.80
1/8	1.202	1.258	1.303	15.50	16.11	16.60	20.16	20.92	21.57	21.23	21.97	22.65
1/16	1.754	1.823	1.879	—	—	—	28.32	29.31	30.31	29.82	30.81	31.75
1/32	2.335	2.452	2.578	—	—	—	36.99	38.53	39.93	38.93	40.20	41.52

Table 3 First to fifth half-value layer (mm) in the four materials for the tube voltage of 28kV, 30kV and 32kV.

	Aluminum			Bakelite			Acrylate			BR-12		
	28kV	30kV	32kV	28kV	30kV	32kV	28kV	30kV	32kV	28kV	30kV	32kV
I-HVL	0.319	0.334	0.349	4.470	4.650	4.780	5.960	6.190	6.380	6.150	6.360	6.600
II-HVL	0.381	0.398	0.413	4.820	5.010	5.170	6.470	6.760	6.940	6.720	6.960	7.200
III-HVL	0.502	0.526	0.542	6.220	6.450	6.650	7.730	7.970	8.250	8.360	8.650	8.850
IV-HVL	0.551	0.565	0.576	—	—	—	8.160	8.390	8.740	8.590	8.840	9.100
V-HVL	0.581	0.629	0.699	—	—	—	8.670	9.220	9.620	9.100	9.400	9.770

Table 2 shows the values from one to five half-value layer for their absorption materials. From tne result of these values, it was able to find the relation between the thickness of absorption materials and the x-ray quality at the thickness. In the comparison between BR-12 phantom and polymethyl methacrylate resin, the n half-value layer was slightly different at the same ratio. But, it was found that the difference of image evaluation was occurred.

Table 3 shows the values from first to fifth half-value layer for their absorption materials. As the thickness of their absorption materials was increased, it was found that the composition of long wave length was attenuated, and that of short wave length was almost occupied.

From the result of each half-value layer shown in Table 3, the mass attenuation coefficients were calculated by the next equation, and moreover the effective energy for n-th half-value

Table 4 Effctive energy (keV) to each half-value layer. Mass attenuation coefficients (cm^2/g) are shown in ( ).

	Aluminum			Bakelite			Acrylate			BR-12		
	28kV	30kV	32kV	28kV	30kV	32kV	28kV	30kV	32kV	28kV	30kV	32kV
I-HVL	14.94	15.18	15.40	13.31	13.55	13.72	15.80	16.06	16.29	15.10	15.33	15.58
	(8.050)	(7.684)	(7.364)	(1.242)	(1.193)	(1.161)	(0.978)	(0.942)	(0.913)	(1.084)	(1.048)	(1.010)
II-HVL	15.87	16.12	16.32	13.78	14.03	14.22	16.39	16.71	16.90	15.71	15.94	16.19
	(6.748)	(6.451)	(6.224)	(1.151)	(1.106)	(1.073)	(0.900)	(0.861)	(0.839)	(0.991)	(0.958)	(0.925)
III-HVL	17.46	17.73	17.92	15.48	15.74	15.96	17.71	17.95	18.22	17.28	17.54	17.71
	(5.112)	(4.885)	(4.738)	(0.892)	(0.860)	(0.833)	(0.754)	(0.731)	(0.706)	(0.797)	(0.770)	(0.754)
IV-HVL	18.03	18.18	18.30	–	–	–	18.14	18.37	18.70	17.49	17.71	17.94
	(4.657)	(4.547)	(4.461)	–	–	–	(0.714)	(0.694)	(0.666)	(0.776)	(0.754)	(0.732)
V-HVL	18.35	18.86	19.56	–	–	–	18.63	19.14	19.50	17.94	18.19	18.51
	(4.419)	(4.081)	(3.674)	–	–	–	(0.672)	(0.632)	(0.605)	(0.732)	(0.709)	(0.682)

Table 5 Un-homogeneity factor to first half-value layer in the four materials for the tube voltage of 28kV, 30kV and 32kV.

	Aluminum			Bakelite			Acrylate			BR-12		
	28kV	30kV	32kV	28kV	30kV	32kV	28kV	30kV	32kV	28kV	30kV	32kV
II／I	1.193	1.191	1.183	1.079	1.079	1.081	1.086	1.094	1.087	1.094	1.093	1.092
III／I	1.575	1.573	1.554	1.393	1.387	1.393	1.298	1.288	1.292	1.359	1.360	1.341
IV／I	1.729	1.690	1.651	–	–	–	1.370	1.357	1.370	1.398	1.389	1.380
V／I	1.822	1.883	2.004	–	–	–	1.456	1.491	1.507	1.480	1.477	1.482

layer by the non-linear interpolation method was required.

$$\mu/\rho = \ln(2)/(x_{1/2} \cdot \rho)$$

where μ/ρ is the mass attenuation coefficient (cm^2/g) of the absorption materials, $x_{1/2}$ is the thickness of the absorption materials which becomes half of primary exposure, and ρ is the density of the absorption material. The mass attenuation coefficient and effective energy to each half-value layer were shown in Table 4.

DISCUSSION

X-ray tubes affect the image quality especially with respect to contrast as a result of the application of different target and filter materials. But, the possibilities of adapting x-ray quality to subject thickness are vary limited in the conventional target-filter system. Since the introduction of the molybdenum anode-molybdenum filter system, the x-ray quality optimized with regard to image quality and exposure must be matched to the thickness (under compression) and tissue composition of the breast. Generally, as to the measurement of the x-ray quality, aluminum for the absorption material is used. However, this is the measurement of the x-ray quality at the entrance surface of the breast, and is not the measurement of the x-ray quality in the breast or through the breast tissue.

Then, the attenuation for each absorption material was required, and the changing x-ray quality was examined (Table 3 and Table 4). As to the comparison during each effective energy obtained by the first half-value layer, the effective energy with aluminum is nearly equal to that with BR-12, higher than that with bakelite, and lower than that with polymethyl methacrylate resin. The effective energy required from the half-value layer is essentially expected not to be different, even if the kind of the absorption material is defferent. Yet, the effective energy was different by the kind of the absorption material. This may be the reason that aluminum is a mono-element, but other materials are the mixture or the chemical compound, and the the absorption and the scattering for the component of the low energy are complicatedly changing in the absorption materials. Therefore, as the attenuation in the breast is evaluated, the effective energy required from the attenuation in the BR-12 phantom should be evaluated because to be nearly equal to that in aluminum.

Comparing from first to fifth half-value layer, the un-homogeneity factor to first half-value layer is different for each absorption material. Table 5 shows the variable un-homogeneity factor. As a result of the ratio of un-homogeneity factor to first half-value layer, the material with the highest ratio is aluminum. In polymethyl methacrylate resin and BR-12 phantom, the ratio is low than that of aluminum, and especially is not as high as that of aluminum for the ratio of fifth half-value layer to first half-value layer. As a result, aluminum is generally used to measure the x-ray quality at the skin surface, and but it is found that it is necessary to examine the change of x-ray quality with BR-12 phantom for the thick subject.

Additionally as the thickness of the absorption material is compared according to the value of n half-value layer (Table 2), it is seemed that the thickness of about 3 cm corresponds to forth half-value layer and that of about 4cm corresponds to fifth half-value layer in the BR-12 phantom. The subject contrast (C_{sub}) is defied as the following so that C_{sub} is the transmission ratio of the exposure.

$$C_{sub} = \mu_a \cdot x_a - \mu_b \cdot x_b$$

where μ_a and μ_b are the attenuation coefficient for the absorption materials, and x_a and x_b are the thickness. If the materials (a, b) are the same structure and the difference of the thickness of 5mm, the subject contrast is 0.534 on the condition that x-ray quality is required from first half-value layer in BR-12 phantom for the x-ray tube valtage of 30kV. When the value of γ is 3, the image contrast is represented as the following.

$$C = 0.434 \cdot \gamma \cdot C_{sub} = 1.302 C_{sub}$$

Consequently the difference of the contrast in the film density is 0.695. Here, if x-ray quality is required from fifth half-value layer in BR-12 phantom for the x-ray tube voltage of 30kV, the subject contrast (C_{sub}) is 0.362 and the image contrast (C) is 0.471. Namely, the difference of the density is 0.224 for the primary x-ray. As the content ratio of the scattered radiation is 20%, the image contrast required form the first half-value layer is decreased the density of 0.179. Thus, according to the determination for x-ray quality the evaluation of the image contrast is different. The x-ray beam passes througt the breast surface, but it is expected that x-ray quality is higher than that of the breast surface because of the transmission in the breast tissue. So the image contrast may be decreasing. When in fact the scattered radiation contribute to the film density, the image contrast would be decreasing further.

CONCLUSION

We required the values from one to five half-value layer with aluminum, bakelite, polymethyl methacrylate resin and BR-12 phantom, and investigated the change of x-ray quality according to the attenuation in their materials. The effective energy required from the half-value layer is essentially expected not to be different whether the kind of the absorption material is different. Yet, the effective energy was different by the kind of the absorption material. Therefore, as the attenuation in the breast is evaluated, the attenuation in the BR-12 phantom should be evaluated so that it is nearly equal to the effective energy required from the attenuation in aluminum. Aluminum is generally used to measure the x-ray quality at the skin surface, but it was found that it was necessary to examine the change of x-ray quality with BR-12 phantom for the thick subject. The x-ray beam passes through the breast surface, but it is expected that x-ray quality is higher than that of the breast surface because of the transmission in the breast tissue. So the subject contrast may be decreasing. Therefore, according to the determination for x-ray quality the evaluation of the image contrast is different.

REFERENCES

1) Haus, A.G. et al. : Image quality in mammography. Radiology, 125 : 77-85, 1977.
2) Kimme-Smith, C. et al. : Mammography screen-film selection. Med. Phys., 19 : 1195-1199, 1992.
3) Kimme-Smith, C. et al. : Mammographic dual-screen-dual-emulsion film combination. Radiology, 165 : 313-318, 1987.
4) Kimme-Smith, C. et al. : New mammography screen/film combination. Am.J. Roentgenol., 154 : 713-719, 1990.
5) Kimme-Smith, C. et al. : Mammographic film-processor temperature, development time, and chemistry. Am. J. Roentgenol., 152 : 35-40, 1989.
6) Sato, N. : Visibility of minute objects with low contrast. Jpn. J. Radiol. Technol., 38 : 869-890, 1982.
7) Hubbell, J.H., Seltzer, S. M. : Tables and graphs of photon mass attenuation coefficients and mass energy-absorption coefficients for photon energies 1keV to 20MeV for elements Z=1 to 92 and some dosimetric materials. 1th ed., Jpn. J. Radiol. Technol., Kyoto, 1995.

乳房撮影における吸収物質内の線質について

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要　　旨

被写体内での線質の変化を知るため，１半価層から５半価層までアルミニウム，ベークライト，アクリル，BR-12 ファントムを用いて求め，物質内の減弱より線質の変化（第１半価層から第５半価層まで）を調べた。BR-12 ファントムにおける第１半価層に対する不均等度はアルミニウム中のものよりわずかに低く，特に第１半価層に対する第５半価層の比はアルミニウムにおけるものと同じほど高くなかった。乳房を通過するＸ線の線質は，乳房組織を通過するため乳房表面より高くなるであろう。だから，被写体コントラストは減少するはずである。また，臨床で圧迫下での乳房の厚さは，４半価層から５半価層に相当する。それ故，臨床に近い BR-12 ファントムで線質を評価しなければならない。