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Measurement and Analysis of Apron Shielding Rate According to the Quality of General Radiography

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As the number of examinations in diagnostic radiology increases, direct or indirect medical radiation exposure for patients or workers has increased. To study the degree of medical radiation exposure, we measured and analyzed the lead apron's shielding rate on direct radiation dose according to the quality of radiation beam. The distribution of space dispersal dose at X-ray exam was also measured at X-ray test on chest (100 kVp, 4 mAs, 100 mA) and L-spine AP (76 kVp, 200 mA, 32 mAs) to find out a better method to shield the worker's radiation exposure. To measure the quality of X-ray in the scope of voltage generally used for X-ray exam in the hospital, half-value layer was estimated at the voltages which is ranged from 40 to 120 kVp. Effective energy was estimated at the same voltage range and the result was 12.5 keV~39.9 keV. The result of measuring radiation dose at increasing the voltage by 10 kVp each time on the range of 40~120 kVp, showed that the shielding rate of 0.50 mm Pb lead apron is superior to that of 0.25 mm Pb lead apron for all ranges of voltage. The difference of shielding rate between 0.50 mm Pb and 0.25 mm Pb lead apron increased as the voltage increased. The maximum difference was 10.2 % at 120 kVp. In conclusion, the lead apron will be able to shield the worker's radiation exposure, especially for high voltage application for the exam, with understanding of space dispersal dose.

Keywords : lead apron, radiation dose, effective energy, space dispersal dose

1. Introduction

Recent interest has led to exciting developments in the diagnostic facilities including digital radiography, ultrasonography, MRI (magnetic resonance imaging) and CT (computed tomography). Although diagnostic facilities have been developed, radiation exposure has gradually been increased [1-3].

According to the study which is conducted by KFDA (Korea Food and Drug Administration) in 2014, the annual radiation effective dose of worker in the Republic of Korea is 0.96 mSv, compared to 0.31 mSv in Japan, 0.11 mSv in Canada and 0.08 mSv in the UK(United Kingdom of Great Britain and Northern Ireland) [4]. It is recognized that it is important to provide for worker in the Republic of Korea. To protect workers from radiation exposure, the ICRP (International Commission on Radiological Protection) Publication stated protective aprons. If workers can't remain in the protected area when the x-ray machine is operated, they shall wear a protective apron of at least 0.25 mm lead equivalence. As far as is reasonably practicable they should occupy areas of the room where the levels of radiation exposure are low. Any person required standing within meter of the X-ray tube or patient when the machine is operated at the voltages above 100 kV should wear a protective apron of at least 0.35 mm lead equivalence [5].

To study the degree of medical radiation exposure, we measured and analyzed the lead apron's shielding rate on direct radiation dose according to the quality of radiation beam. The distribution of space dispersal dose at X-ray exam was also measured at X-ray test on chest (100 kVp, 4 mAs, 100 mA) and L-spine AP (76 kVp, 200 mA, 32 mAs) to find out a better method to shield the worker's radiation exposure.

2. Materials and Methods

The X-ray unit (TE-E7252X, TOSHIBA, JAPAN) having

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the focal spot size of 0.6 mm and 1.2 mm was used in this study. The operating voltage range was 40-125 kV. The angle was 12° and the inherent filter was 0.7 mm Al. The dosimeter was a Model 9095 electrometer (Radical, USA), which had a 10X9-60E ion chamber. Moreover, 30 cm × 30 cm × 1 cm acryl phantoms was used. To measure the HVL, 0.1 mm, 0.2 mm, 0.3 mm, 0.5 mm, 1 mm, and 2 mm Al (absorber thickness) were used. The X-ray protection aprons which were used had a 0.25 mm and 0.5 mm lead equivalence and were medium-sized (height: 100 cm; width: 60 cm; shoulder: 15.2 cm) according to Korean Industrial Standards.

2.1. Measurement of Half Value Layer (HVL) and effective energy by change of kVp

The beam quality of X-ray was estimated at the voltage which was range from 40 kVp to 120 kVp by increasing 10 kVp each time. The exposure was measured three times, and in each of times, it was examined at 30 seconds intervals. To determine HVL needed to reduce the quantity of penetrating X-rays to 50 %, mm of aluminum (mm Al) was increased by 0.1 mm. Shown below is the formula to estimate half value layer which is based on modern physics. Moreover, SRS-78 program was used to measure the effective energy of X-ray when kVp was increased.

$$I = I_0 e^{-ux}$$

$$\frac{1}{2} I_0 = I_0 e^{-ux_{1/2}}$$

$$ln2 = ux_{1/2}$$

$$x_{1/2} = \frac{0.693}{u}$$

I_0 = Incident beam
I = Transmitted beam
u = Linear attenuation coefficient
$x_{1/2}$ = Half Value Layer

2.2. Measurement of shielding rate of 0.50 mm and 0.25 mm X-ray protective aprons on direct radiation

To calculate shielding rate of protective aprons, we refer to Medical X-ray Protective Aprons P 6023 [6] and Testing Method of Lead Equivalent for X-ray Protective Devices A 4025 [7] which are reported in Korean Industrial Standards.

Figure 1 shows the experiment method for measuring exposure on direct radiation. FFD was 50 cm which was the distance between focal spot and Al filter. FDD was 100 cm which was the distance between focal spot and X-ray unit. In the experiment, kVp was within the range of 40 to 120, and mA was fixed at 200 mA. Exposure time

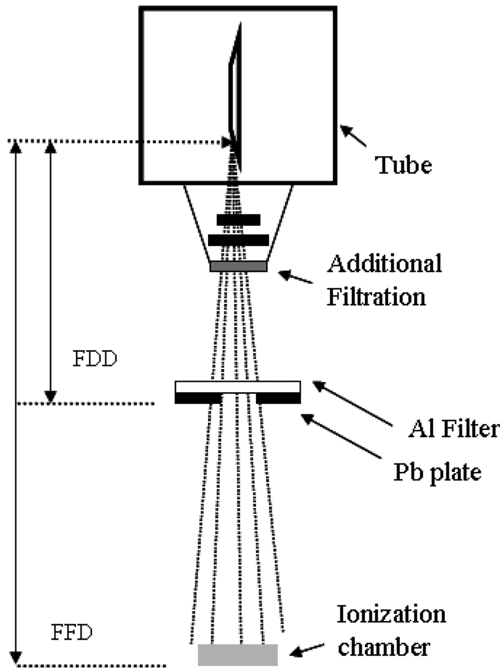

Fig. 1. Set up for measurement of direct X-ray.

was 0.2 seconds and exposure filed was 10 cm × 10 cm. Inherent filter was 0.7 mm and added filter was 1 mm, so that total filter was 2.7 mm. With the use of this experiment method and condition, direct radiation dose was measured. Also, we estimated shielding rate from direct radiation dose. The formula that was used for such measurement would be as follows.

$$\frac{\text{Dose without using an apron} - \text{Dose with using an apron}}{\text{Dose without using an apron}} \times 100(\%)$$

2.3. Measurement of space dispersal dose at X-ray test on chest and L-spine AP

We experimented with Chest (100 kVp, 100 mA and 4 mAs) and L-spine AP (76 kVp, 200 mA and 32 mAs) at X-ray test. It was difficult to measure space dispersal dose under the same condition at X-ray test. Therefore, it was important to maintain the same conditions when measuring space dispersal dose at each point [8-10].

Figure 2 shows the measured points. Space dispersal doses at certain points were measured by effecting an increase of 45° and 20 cm in the horizontal plane.

3. Results

Figures 3 and 4 show the HVL and effective energy measurements after increasing the voltage by 10 kVp in the range of 40 to 120 kVp. The result, also shown in Fig. 3 and Fig. 4, is that the HVL and effective energy increased when the kVp was likewise increased.

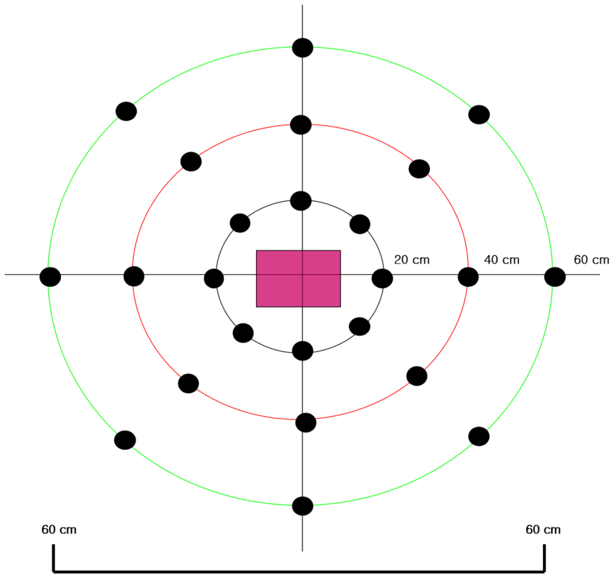

Fig. 2. (Color online) Measurement Points of scattered dose distribution for horizontal plane.

HVL is a measure of penetration ability of X-ray beam through matter. As such, the HVL thickness is often used to describe the penetrating power (quality, energy) of X-ray beam. The results showed that HVL increased when kVp was changed because of the more penetrating of X-ray beam. In other words, linear attenuation coefficient tends to decrease along with the effective energy. As the effective energy increased when the kVp was changed, HVL was increased by kVp. kVp is the energy of an electron when X-ray beam is formatted and keV is effective energy. If 10 kVp of X-ray is formatted, effective energy of X-ray will be continuous distribution, which is range from 0 keV to 10 keV. Therefore, the higher the kVp is, the greater the increase in the maximum energy of X-ray.

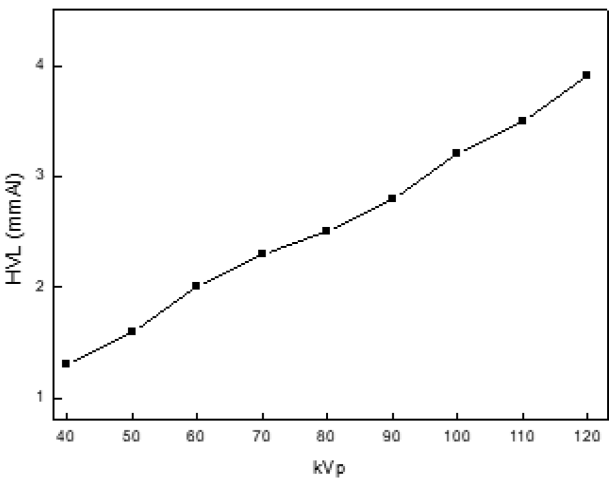

Fig. 3. Half Value Layer by change of kVp.

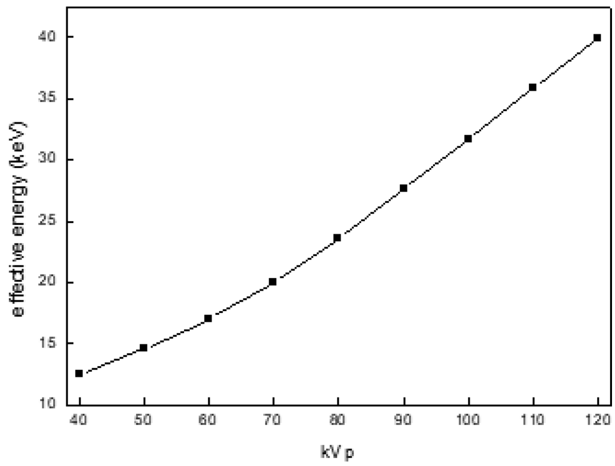

Fig. 4. Effective energy by change of kVp.

Table 1. Half Value Layer and Effective energy by change of kVp.

kVp	HVL (mm Al)	Effective energy (keV)
40	1.3	12.5
50	1.6	14.6
60	2	17.0
70	2.3	20.0
80	2.5	23.6
90	2.8	27.6
100	3.2	31.7
110	3.5	35.9
120	3.9	39.9

Shown in Fig. 4 is the result relating to the effective energy when the kVp was increased.

Table 2 shows that shielding rate of 0.50 mm and 0.25 mm X-ray protective aprons on direct radiation by increasing kVp. Considering this result, shielding rate of 0.5 mm X-ray protective apron was 0.25 % higher than that of 0.25 mm X-ray protective apron at minimum kVp. At maximum kVp, shielding rate of 0.5 mm X-ray protective apron was 10.2 % higher than that of 0.25 mm X-ray protective apron.

Furthermore, Fig. 5 shows that shielding rate of 0.50 mm and 0.25 mm X-ray protective aprons on direct radiation was decreased by increasing kVp.

Figure 6 and Fig. 7 show that distribution of dispersal dose at X-ray test on Chest (100 kVp, 100 mA, 4 mAs) and L-spine AP(76 kVp, 200 mA, 32 mAs). The measured distribution of dispersal dose at X-ray test on Chest was 0.46, 0.14 and 0.05 mR at 0°, respectively, compared to 1.79, 0.58 and 0.22 mR at X-ray test on L-spine AP. Shown in Table 3 is dispersal dose at X-ray test on Chest. The maximum dispersal dose of point A was at 0°, that of point B was at 45° and that of point C was at 90°. Shown

Table 2. Lead apron's shielding rate by change of lead apron's thickness and kVp.

kVp	without Apron (mR)	0.25 (mR)	0.50 (mR)	Shielding rate of 0.25 mm lead apron (%)	Shielding rate of 0.50 mm lead apron (%)
40	51.074	0.124	0	99.75	100
50	94.687	1.105	0	98.83	100
60	139.220	3.871	0.499	97.21	99.64
70	190.898	9.508	2.042	95.01	98.93
80	243.450	19.118	5.610	92.14	97.69
90	299.210	32.389	11.424	89.17	96.18
100	366.601	46.750	17.765	87.24	95.15
110	427.771	63.346	24.918	85.19	94.17
120	484.470	83.148	33.571	82.83	93.07

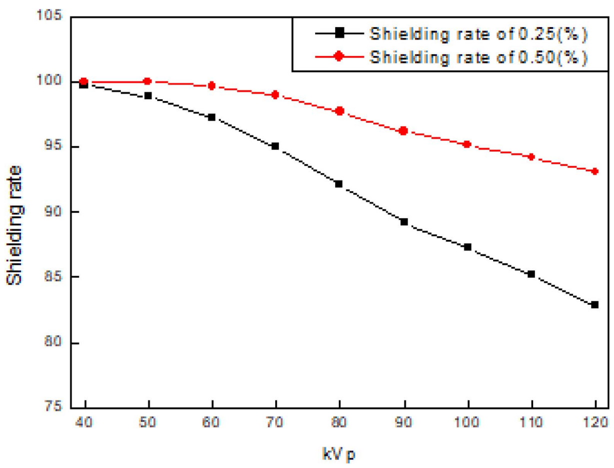

Fig. 5. (Color online) Lead apron's shielding rate on direct radiation.

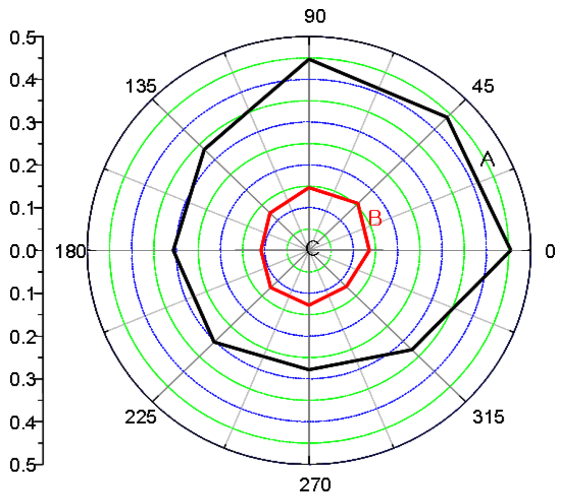

Fig. 6. (Color online) Distribution of space dispersal dose at X-ray test on Chest (A: 20 cm, B: 40 cm, C: 60 cm).

in Table 4 is dispersal dose at X-ray test on L-spine AP. The maximum dispersal dose of points A, B and C was at 45°.

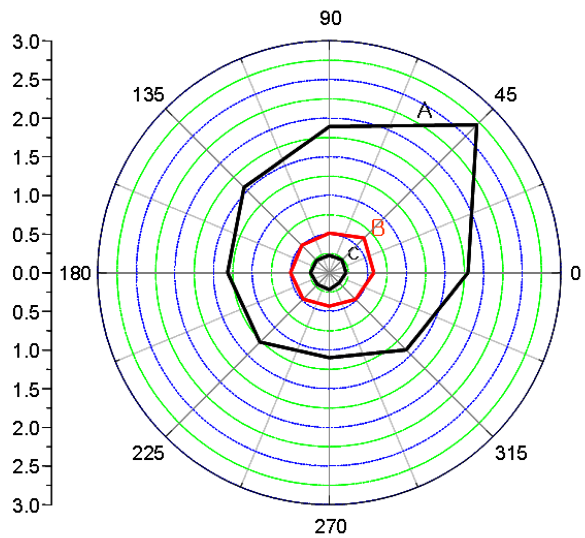

Fig. 7. (Color online) Distribution of space dispersal dose at X-ray test on L-spine AP (A: 20 cm, B: 40 cm, C: 60 cm).

Table 3. Space dispersal dose at X-ray test on Chest (A: 20 cm, B: 40 cm, C: 60 cm).

Distance / Angle	A (mR)	B (mR)	C (mR)
0°	0.455	0.136	0.0467
45°	0.440	0.156	0.0545
90°	0.447	0.147	0.0665
135°	0.334	0.125	0.0545
180°	0.306	0.108	0.0409
225°	0.303	0.122	0.0409
270°	0.279	0.128	0.0331
315°	0.328	0.119	0.0409
360°	0.455	0.136	0.0467

4. Conclusion

To become familiar with the ICRU (International Commission on Radiological Units) detailed requirement for

Table 4. Space dispersal dose at X-ray test L-spine AP (A: 20 cm, B: 40 cm, C: 60 cm).

Angle \ Distance	A (mR)	B (mR)	C (mR)
0°	1.799	0.579	0.218
45°	2.703	0.636	0.244
90°	1.889	0.514	0.225
135°	1.560	0.502	0.231
180°	1.317	0.502	0.239
225°	1.270	0.482	0.218
270°	1.099	0.434	0.220
315°	1.412	0.486	0.186
360°	1.799	0.579	0.218

radiation protection of workers in diagnostic radiology, workers are provided with suitable and adequate personal protective equipment including lead aprons. The reason of using lead aprons in hospital, lead has been found to be the best shield for the protection against diagnostic X-rays. It has the highest atomic number of any element that is nonradioactive. Given the fact that one is limited to this maximum atomic number (82) in choosing from the various elements, the density thickness of a lead apron then becomes the most important parameter in providing protection from diagnostic X-rays [11-13].

This study investigated the shielding rate of 0.50 mm and 0.25 mm X-ray protective aprons. The measured average dose when wearing 0.25 mm apron was within the range of 0.1 mR - 83.2 mR, compared to 51.1 mR - 484.5 mR without aprons. When wearing 0.50 mm apron, the measured average dose is range from 0 to 33.6 mR. Based on these results, it was determined that the minimum shielding rate of a 0.25-mm apron is 82.8 % and that its maximum shielding rate is 99.7 %. The minimum shielding rate of a 0.50-mm apron, on the other hand, is 93.1 %, and its maximum shielding rate is 100 %. When considering the difference in shielding rate in selecting an apron, one should be certain about the kVp and radiation exposure. At 40 kVp - 80 kVp in diagnostic X-ray tube voltage, lead equivalence of 0.25 mm is effective. However, Lead equivalence of 0.50 mm is recommended for workers at X-ray test on high voltage (above 100 kVp). This study also estimated the measurement of space dispersal dose at X-ray test on Chest (100 kVp, 100 mA, 4 mAs) and L-spine AP (76 kVp, 200 mA, 32 mAs). Considering this results, dispersal dose of L-spine AP (1.80, 0.58, 0.22 mR at 0°) was about four times higher than that of Chest (0.46, 0.13, 0.05 mR at 0°).

In conclusion, if it is inevitable to the radiation component of the working environment of a radiology department, workers to undertake work with radiation make sure wearing X-ray protective aprons for decreasing dispersal dose. Also, where there are no shielding facilities, workers should maintain appropriate distance of patients and should use X-ray protective Screen and Curtain for additional radiation protection. Moreover, this study for measurement apron shielding rate according to the quality of general radiography may need to be developed with further studies for large populations.

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