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The Necessity of Resetting the Filter Criteria for the Minimization of Dose Creep in Digital Imaging Systems

Kyo Tae Kim,[1] Kum Bae Kim,[1,2] Sang Sik Kang,[3] Ji Koon Park[3,*]

[1]Research Team of Radiological Physics & Engineering, Korea Institute of Radiological & Medical Sciences
[2]Department of Radiation Oncology, Korea Institute of Radiological & Medical Sciences
[3]Department of Radiological Science, International University of Korea

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ABSTRACT

Recently, Following the recent development of flat panel detector with wide dynamic ranges, increasing numbers of healthcare providers have begun to use digital radiography. As a result, filter thickness standards should be reestablished, as current clinical practice requires the use of thicknesses recommended by the National Council on Radiation Protection and Measurements, which are based on information, acquired using conventional analog systems. Here we investigated the possibility of minimizing dose creep and optimizing patient dose using Al filters in digital radiography. The use of thicker Al filters resulted in a maximum 19.3% reduction in the entrance skin exposure dose when medical images with similar sharpness values were compared. However, resolution, which is a critical factor in imaging, had a significant change of 1.01 lp/mm. This change in resolution is thought to be due to the increased amount of scattered rays generated from the object due to the X-ray beam hardening effect. The increase in the number of scattered rays was verified using the scattering degradation factor. However, the FPD, which has recently been developed and is widely used in various areas, has greater response to radiation than analog devices and has a wide dynamic range. Therefore, the FPD is expected to maintain an appropriate level of resolution corresponding to the increase in the scattered-ray content ratio, which depends on filter thickness. Use of the FPD is also expected to minimize dose creep by reducing the exposure dose.

KeyWords: filter, dose creep, flat panel detector, exposure dose, digital radiography

Ⅰ. INTRODUCTION

The medical imaging systems used in current clinical practice acquire diagnostic images using X-rays with continuous energy distributions. In such medical imaging systems, filters have been consistently used as a fundamental measure to reduce the radiation dose that the patient is exposed to. These filters reduce patient dose by reducing the ratio of low-energy photons in X-rays, which are unable to penetrate through the human body. When this approach is used in conventional analog systems, the filter thickness is limited in order to acquire medical images with sufficient quality to serve their clinical purpose. This poses a problem, as the patient dose cannot be sufficiently reduced while maintaining good image quality.[1] Thus, flat panel detectors (FPDs), which have wide dynamic ranges, have been recently used in medical imaging systems. These devices provide sufficient image quality even under poor conditions and reduce patient dose. However, current clinical studies use filter thicknesses recommended by the National Council on Radiation Protection and Measurements (NCRP). These thickness values are

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* Corresponding Author: Ji Koon Park E-mail: radiopjk@iuk.ac.kr Tel: +82-55-751-8301
Address: 965 dongburo munsaneup jinju gyeongnam, korea

based on information acquired in studies carried out using conventional analog systems. The NCRP suggests the use of 0.5 mmAl, 1.5 mmAl, and 2.5 mmAl filters for 50 kVp and below, 50-70 kVp, and 70 kVp and above, respectively.[2] This may be considered a dose creep phenomenon leading to unnecessary radiation exposure in patients even when the patient dose can be reduced. Dose creep is a phenomenon leading to the delivery of unnecessary radiation to patients, and may occur due to a medical examiner's lack of experience or negligence.[3] Thus, appropriate filter thicknesses for digital radiography should be redefined. This can be achieved by quantitatively analyzing the effects of filter thickness on medical images. Here we investigated the optimized filter thickness that can be used to minimize patient dose while retaining diagnostic capability by quantitatively evaluating the effects of filters on medical images using modulation transfer function (MTF) analysis.

Ⅱ. EXPERIMENTS

1. Experiment setup

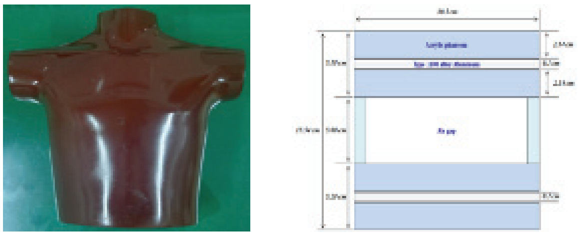

(A) RS-111 chest phantom (B) ANSI chest phantom

Fig. 1. Chest phantoms used for the experiments.[4]

In the present study, an aluminum-based additional filtration tool (Al filter, Purity: 99.5%, Germany) widely used in medical imaging systems (POSKOM Co., Korea) was installed at the bottom of a collimator. To evaluate the changes caused by the use of the Al filter, the filter thickness was controlled and ranged from 2.5 to 5.0 mm. An RS-111 chest phantom (Fluke Biomedical Co., USA) and a chest phantom suggested by the American National Standards Institute (ANSI) were selectively used to evaluate dosage and imaging parameters, respectively. Fig. 1 illustrates the RS-111 phantom and the ANSI phantom used in the present study. To model lungs filled with air, a 5.08-cm air gap was formed in the middle of the ANSI phantom.[5]

Average values reported by the Korea Food & Drug Administration were used to investigate chest AP (Anteroposterior); 85 kVp tube voltage and 8 mA tube current.[6]

2. Analysis of entrance skin exposure dose

In the present study, entrance skin exposure dose (ESD) was computed to investigate the possibility of optimizing patient dose when a filter is used for digital radiology. To evaluate ESD, an ion chamber (XR-Sensor, IBA Co., Germany) was placed on the RS-111 phantom and the absorption dose (AD) was measured. ESD was computed using the following equation based on the dose information acquired using the XR-Sensor[7]:

$$\begin{aligned}ESD_{Ion} &= AD\times(kV^{*}/kV)^{2}\times(mAs^{*}/mAs)\\ &\times(100/SSD)^{2}\times BSF\end{aligned} \qquad (1)$$

where ESDion is the ESDmeasured using an ion-chamber, kV is the tube voltage indication value, mAs is the tube current indication value; kV^{*} is the beam kVp recorded for any given examination, and mAs^{*} is the tube milli-Amp-current-time used for any given instance. An automatic X-ray exposure control device, which ensures that mAs is equal to the reference value, was utilized to minimize variables used to compute ESD. SSD denotes the source-to-skin distance and BSF denotes the back-scatter factor. The BSF value was 1.35, as recommended in EUR 16262.[8]

3. Qualitative evaluation of x-ray images

In the present study, qualitative analysis was performed by visual inspection to evaluate changes in the quality of medical images obtained using Al filters with different thicknesses. We used a commercially available FPD (FLAATZ 560, DRTech Co., Korea) to obtain the images and evaluate their quality. To obtain X-ray images, the FPD was placed under the RS-111 phantom.

4. Analysis of the modulation transfer function

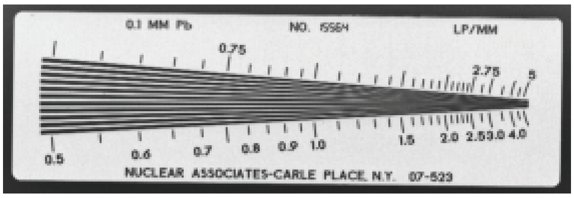


Fig. 2. X-ray bar pattern used for the experiments.

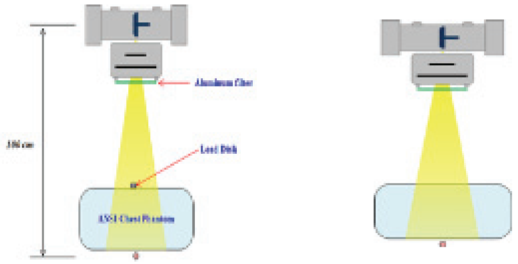
To quantitatively analyze the effect of the thickness of the Al filter on the medical images, MTF was analyzed using a contrast method utilizing a bar pattern (Flukebiomdeical Co., USA). Fig. 2 illustrates the bar pattern used in the present study.

To acquire a bar pattern image, the FLAATZ 560 was placed below the ANSI phantom, and the bar pattern was placed above the ANSI phantom. The bar pattern images were acquired using an FPD-based medical imaging system. Image processing was performed using Octave software (Octave Ver. 4.0.2, Free Software Foundation Inc., USA). After a profile plot was obtained, the pixel value of the FPD-based X-ray dose was analyzed based on the raw data. The profile plot was used to compute the image modulation required to analyze the MTF, where MTF was defined as the ratio of the output function to the input function. Image modulation was computed using the following equation, which is based on the profile plot information acquired from the bar pattern image[9]:

$$IM = (R_{max}-R_{min})/(R_{max}+R_{min}) \qquad (2)$$

where R_{max} indicates the maximum value in the acquired plot profile and R_{min} indicates the minimum value in the acquired profile plot. Also, IM is defined image modulation value. Interpolation was performed to obtain an MTF curve based on the image modulation computed in the present study. Sharpness and resolution were used as evaluation indices to analyze the MTF curve. Sharpness is defined as the spatial frequency corresponding to an MTF value of 0.5 in an MTF curve, and resolution is defined as the spatial frequency corresponding to an MTF value of 0.1.

5. Analysis of Scatter Degradation Factor



(A) Scattered radiation (B) Total radiation

Fig. 3. Schematic diagram of the experiment setup for the measurement.

We evaluated scatter degradation factor (SDF) to quantitatively analyze the effect of the thickness of the Al filter on the amount of scattered rays. Smaller SDF values indicating greater reductions in resolution due to scattering.[10] After placing an ion chamber at the bottom of the ANSI phantom, as shown in Fig. 3, AD were measured to evaluate SDF. A 0.3 mm Pb filter was positioned on top of the ANSI phantom as shown in Fig. 3 (A) to block the primary radiation. Based on the information obtained using the XR-Sensor, SDF was calculated using the equation below.[11]

$$SDF = (I_T - I_S) / I_T \qquad (3)$$

I_T is the total radiation intensity and I_S is the scattered radiation intensity. I_T can be expressed as the sum of the primary radiation intensity (I_P) and the scattered radiation intensity (I_S).

Ⅲ. RESULT AND DISCUSSION

1. Entrance skin exposure dose

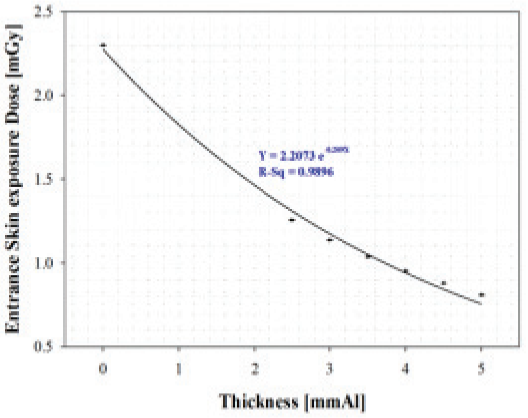


Fig. 4. Entrance skin exposure dose as a function of the thickness of the Al filter.

The ESD decreased exponentially in response to increases in the thickness of the Al filter, as illustrated in Fig. 4. Using a 0 mmAl filter resulted in an ESD of 2.30 mGy, a 2.5 mmAl filter resulted in an ESD of 1.25 mGy, and using a 5.0 mmAl resulted in an ESD of 0.81 mGy. A fit curve was drawn based on the computed ESD values, and the coefficient of determination (denoted as R-Sq) of the fit curve was calculated. The fit curve showed had an R-Sq value of 0.9896 and the following equation; $Y = 2.2073\ e^{-0.209X}$. Here, Y indicates the ESD and X indicates the thickness of the Al filter.

Based on these results, an approximately 19.3% reduction in patient exposure was achieved using a 5.0 mmAl filter when compared to a 2.5 mmAl filter, which the NCRP recommends.

2. Qualitative evaluation

We were unable to detect changes in the quality of the image in the presence or absence of the Al filter by visual inspection of the acquired image, as shown in Fig. 5.

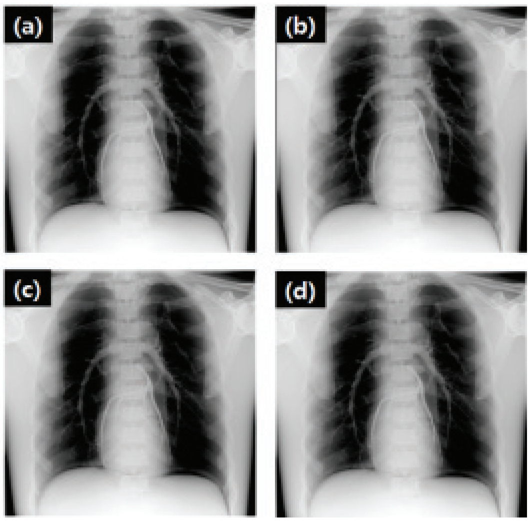


Fig. 5. RS-111 phantom images used for the analysis according to the thickness of the Al filter in the medical imaging system. (a) 0 mmAl, (b) 2.5 mmAl, (c) 4.0 mmAl and (d) 5.0 mmAl filter

3. Modulation transfer function

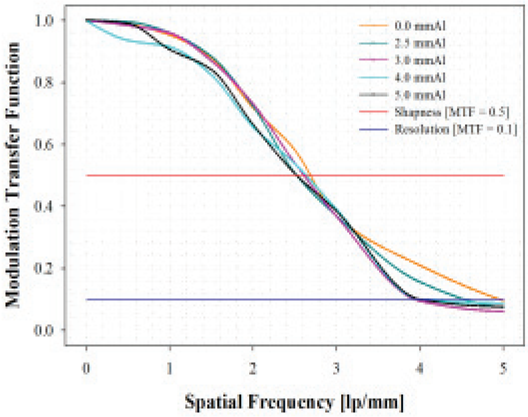


Fig. 6. Modulation transfer function as a function of spatial frequency.

The above analysis revealed that sharpness was decreased when a filter was used, as shown in Fig. 6. The sharpness was approximately 2.52 lp/mm when a 2.5 mmAl filter was used, 2.62 lp/mm when a 3.0 mmAl filter was used, 2.64 lp/mm when a 4.0 mmAl filter was used, and 2.52 lp/mm when a 5.0 mmAl filter was used. When medical images acquired in clinical practice are examined, these subtle changes in sharpness would not significantly lead to errors in judgment. Nevertheless, as shown in Fig. 6, the resolution was decreased when a filter was used. When no filter was used, the resolution value was 4.94 lp/mm. However, when a filter was used, the resolution value was 3.93 - 4.52 lp/mm. This represented a maximum change of 1.01 lp/mm.

The resolution value was approximately 4.52 lp/mm when a 2.5 mmAl filter was used, 3.93 lp/mm when a 3.0 mmAl filter was used, 3.97 lp/mm when a 4.0 mmAl filter was used, and 3.98 lp/mm when a 5.0 mmAl filter was used. The decrease in resolution is thought to be caused by an increase in the amount of scattered rays generated from the object, as the average energy of photons increases when a filter is used. I. Choi et al. reported an increase in the forward scattering rate generated from the object following an increase in the filter thickness.[12]

4. Scatter Degradation Factor

SDF decreased as a linear function of the thickness of the Al filter, as shown in Fig. 7.

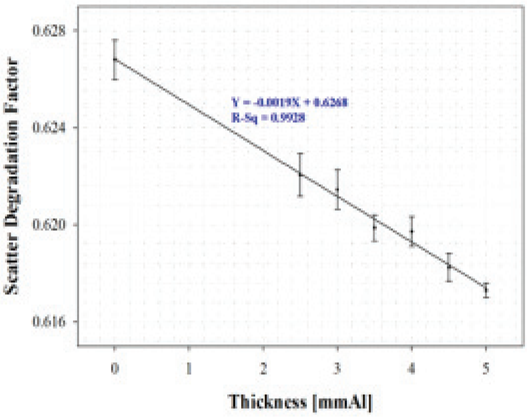


Fig. 7. Scatter degradation factor as a function of the thickness of the Al filter.

The SDF value was 0.627 when no Al filter was used, 0.622 when a 2.5 mmAl filter was used, and 0.617 when a 5.0 mmAl filter was used. A fit curve was drawn based on the calculated SDF values, and R-Sq for the fit curve was calculated. The fit curved had an R-Sq of 0.9928 and the equation Y = -0.0019 X + 0.6268, where Y is the SDF and X is the thickness of the Al filter. Based on these results, the performance degradation in medical images due to an increase in the amount of scattered rays was verified.

Ⅳ. CONCLUSION

Filter thickness values should be reset appropriately for use with digital radiology, which in increasingly used in the healthcare environment. However, there are as yet few studies on this topic. In the present study, the possibility of minimizing the dose creep phenomenon and optimizing the patient dose was verified by resetting the thickness of the Al filter during digital radiography. We found that a 5.0 mmAl filter was able to reduce the patient exposure dose by approximately 19.2% when compared to a 2.5 mmAl filter, which is recommended by the NCRP. However, a performance degradation in resolution caused by the scattered rays was also quantitatively verified. The results of the present study can thus be utilized to reset the thickness of the Al filter. Further, the results of this study are expected to contribute to national healthcare by minimizing the dose creep phenomenon in clinical practice.

Acknowledgement

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디지털 영상 시스템에서 선량 크리프 최소화를 위한 부가 필터 두께 권고 기준의 재설정에 대한 연구

김교태,[1] 김금배,[1,2] 강상식,[3] 박지군[3,*]

[1]한국원자력의학원 의학물리공학연구팀
[2]한국원자력의학원 방사선종양학과
[3]한국국제대학교 방사선학과

요 약

최근 넓은 동적 범위 특성을 제공하는 평판 디텍터 개발을 바탕으로 의료보건 환경이 디지털화되고 있는 현 시점에서 적절한 필터 두께의 재설정이 요구되고 있으나, 현 임상에서는 기존 아날로그 시스템에서 연구된 정보를 바탕으로 NCRP에서 제안한 권고 기준을 이용하고 있다. 이에 본 연구에서는 디지털방사선 촬영에서 알루미늄 필터를 이용하여 환자선량 최적화와 더불어 선량크리프의 최소화 가능성을 고찰하였다. 연구 결과, 알루미늄 필터의 두께를 증가함에 따라 유사한 선예도를 가지는 의료영상을 획득 시 피폭되는 피부입사선량을 최대 19.3% 저감할 수 있는 것으로 나타났으나, 영상학적 관점에서 중요한 해상력이 1.01 lp/mm의 큰 변화가 분석되었다. 이러한 해상력의 변화는 X선 빔 경화 현상으로 인하여 피사체에서 발생하는 산란선이 증가하기 때문으로 사료되며, 산란 열화 인자를 통하여 산란선량에 의한 영향이 증가하는 것을 정량적으로 검증하였다. 하지만, 최근 개발되어 광범위하게 적용되고 있는 평판 디텍터는 방사선에 대한 민감도가 높고 넓은 동적 범위 특성을 가지므로 필터 두께에 따라 산란선의 비율에 대한 증가분과 대응하여 적정한 해상력을 유지할 수 있을 것으로 사료되며, 더 나아가 피폭선량 저감을 통해 선량크리프를 최소화 할 수 있을 것으로 기대된다.

중심단어: 필터, 선량 크리프, 평판 검출기, 조사선량, 디지털 방사선영상

연구자 정보 이력

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