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The Performance Test of Anti-scattering X-ray Grid with Inclined Shielding Material by MCNP Code Simulation

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ABSTRACT

Background: The scattered photons cause reduction of the contrast of radiographic image and it results in the degradation of the quality of the image. In order to acquire better quality image, an anti-scattering x-ray gird should be equipped in radiography system.
Materials and Methods: The X-ray anti-scattering grid of the inclined type based on the hybrid concept for that of parallel and focused type was tested by MCNP code. The MCNPX 2.7.0 was used for the simulation based test. The geometry for the test was based on the IEC 60627 which was an international standard for diagnostic X-ray imaging equipment-Characteristics of general purpose and mammographic anti-scatter grids.
Results and Discussion: The performance of grids with four inclined shielding material types was compared with that of the parallel type. The grid with completely tapered type the best performance where there were little performance difference according to the degree of inclination.
Conclusion: It was shown that the grid of inclined type had better performance than that of parallel one.

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Keywords: Anti-scattering x-ray grid, Grid type, Inclined, Scattered photon

1. INTRODUCTION

It is needed to minimize exposure time and lower the energy of incident x-ray in radiographic system to reduce patient dose. But, in order to obtain an image which has sufficient resolution and contrast to read, the scattered photon from the patient should be removed as many as possible. The scattered photons cause reduction of the contrast of radiographic image and it results in the degradation of the quality of the image. In order to acquire better quality image, an anti-scattering x-ray gird (also called radiographic grid) should be equipped in radiography system [1].

There are two major methods to fabricate the anti-scattering grid. The one is substrate type by sawing or etching on penetrative material and filling shielding material in the groove. The other one is freestanding type by using lithography which can blow out the support material [2-5]. Freestanding type has benefit of grid ratio. Generally, anti-scattering grid has higher performance as increasing of aspect ratio.

There are few types of anti-scatter grid. According to their top pattern, linear type and crisscross type is generally used. According to their cross-sectional shape, parallel type and focused type is generally used [6]. Focused type has difficulty in fabrication because of its angle distribution.

To improve this, tapered shielding material type grid is suggested. Details will be explained in next section. Simply saying, it is a hybrid model of focused and parallel type grid. The performance of this hybrid type is simulated by Monte Carlo N-Particle transport code, MCNP.

2. MATERIALS AND METHODS

2.1 Grid design

Figure 1 showed suggested geometry of the grid. It was based on an idea that the hybrid of focused and parallel type of grid. The gird was designed where

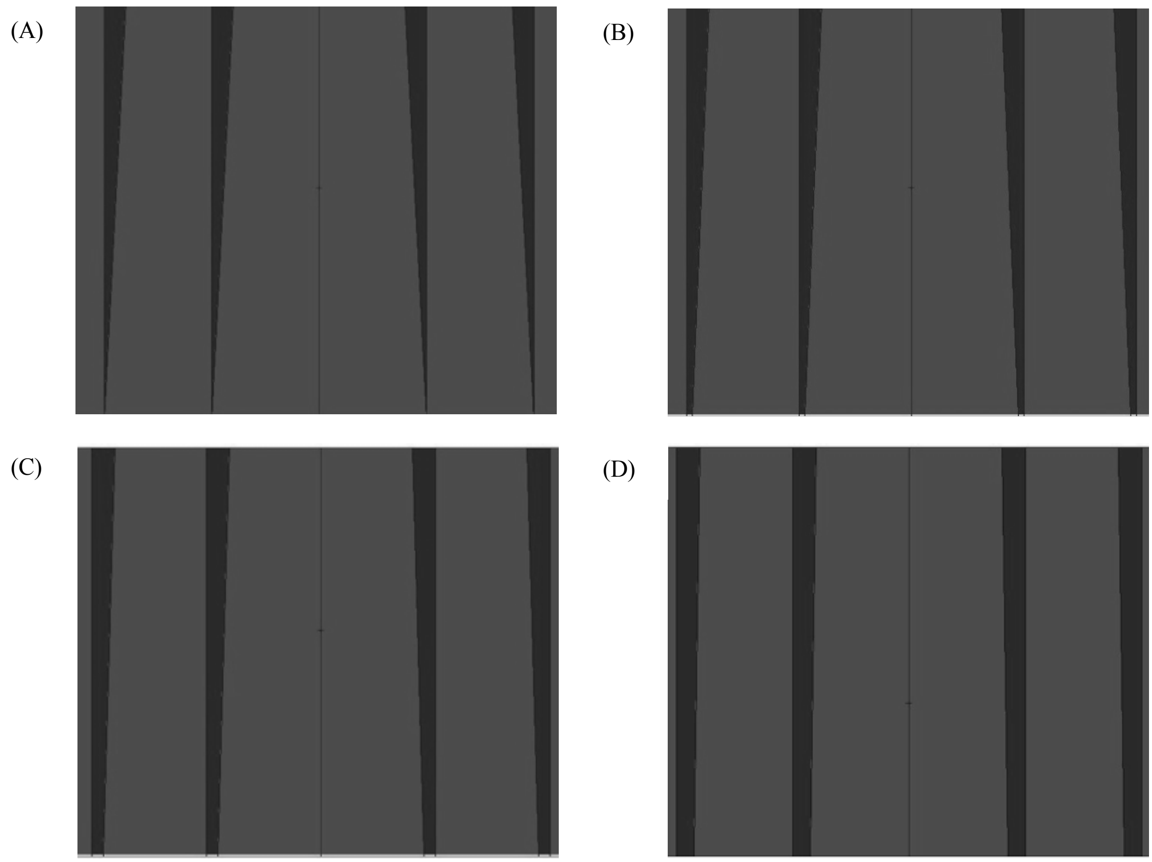

Fig. 1. Cross-sectional view of (A) type-A, (B) type-B, (C) type-C, and (D) type-D grid where the black part indicates shielding material (lead) and the gray part interspace material (PMMA).

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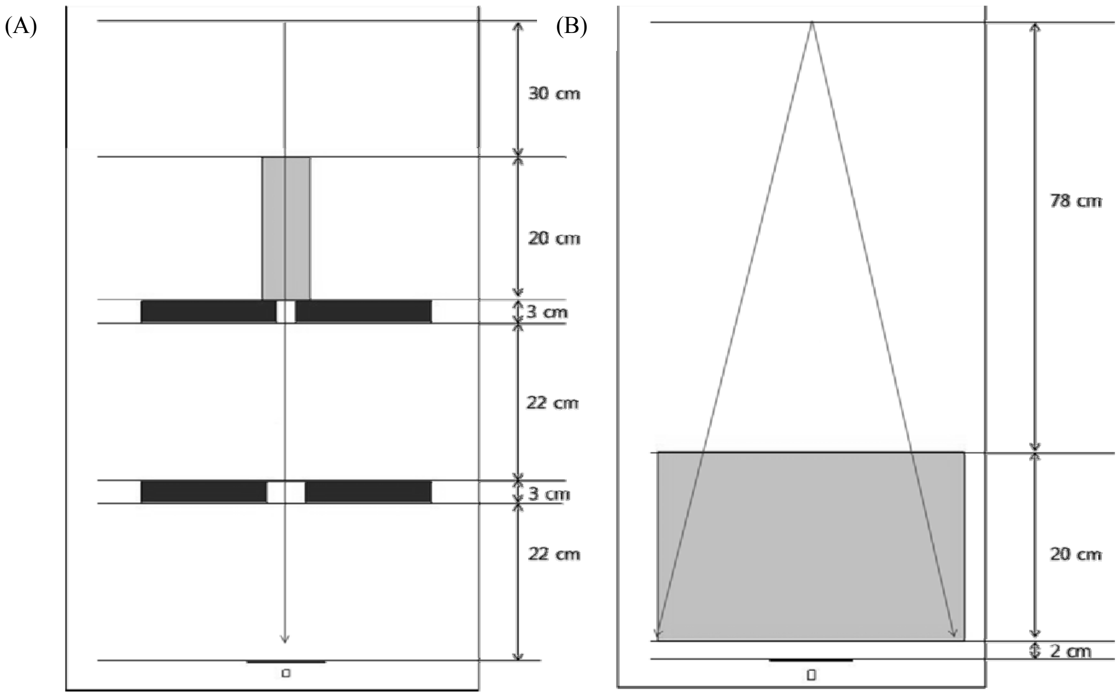

Fig. 2. (A) Overall geometry of simulation for primary photon transportation and (B) for total photon transportation.

the shielding material was inclined. The single side of shielding material was tapered while the other side was normal to the bottom of the grid. The shielding material was symmetry with respect to the x=0 and y=0 plane. As a result, the shielding material was looked like a focused grid. The shielding material (black part) consisted of pure lead which had density of 11.34 g·cm^{-3}. The shielding material was inclined. The interspace material (gray part) consisted of hydrogen, carbon and oxygen where their ratio was 8:5:2. It was assumed as Poly(methyl methacrylate), PMMA, and it had density of 1.18 g·cm^{-3}.

In order to investigate the effect of taper angle, four types of model are shown in Fig. 1. Fig. 1A shows a cross-sectional view of type-A. The type-A is a thoroughly tapered model where there is no shielding material at bottom of the grid. Fig. 1B, C, and D shows cross-sectional view of type-B, type-C and type-D. Type-B, Type-C and Type-D are partly tapered models where shielding material at bottom has thickness of 1/4, 1/2 and 3/4 of thickness of top each.

To estimate performance of the grid, there are three variables; thickness of shielding material, thickness of interspace material and grid ratio. The thickness of shielding material at top of the grid was fixed as 20 μm. The thickness of interspace material or a distance between the shielding walls was set as 80 and 100 μm. Height of the grid is very important because the height determines the grid ratio of grid. Grid ratio was defined as h/d. The height was changed by the value of grid ratio. In this study, grid ratio was set as 6, 8, 10, 12 and 14.

Parallel type of grid which had same variables was also simulated for comparison.

2.2 Simulation design

Whole simulation in this paper was conducted by MCNPX 2.7.0 which is included in the MCNP6 code package [7]. MCNP is the particle transport tool that is widely used in nuclear core design and radiation protection. It is based on Monte-Carlo method. It can be used from 1 keV to 100 GeV in the case of photon.

The whole simulation geometry was based on IEC 60627 [8]. IEC 60627 is an international standard for diagnostic X-ray imaging equipment-Characteristics of general purpose and mammographic anti-scatter grids. It includes standard method of experimental test for general purpose and mammographic anti-scatter grid and parameters for performance of the grid.

Figure 2 shows diagram of whole simulation. Fig. 2A shows the diagram for primary photon transport, and Fig. 2B is the diagram for total photon. The gray part is a scatterer which consists of 1.00 g·cm^{-3} water, and the black part is a lead block which consists of 11.34 g·cm^{-3} pure lead of natural isotope composition.

The arrows indicate direction of photon. For primary photon transportation, the photons had very narrow angle of which cosine value was 0.99995 (about 0.573°). For total photon transportation, the photons had relatively wide angle of which cosine value was 0.98894 (about 8.53°) to obtain both scattered photons and primary photons. The thick line which locates almost bottom of the figure indicates grid. The detailed design of grid will be described in next section. The square at bottom of the figure indicates detector. It was cylinder which has height of 1 cm and radius of 3 mm.

2.3 Method of analysis

Indicators of performance of girds are selectivity, contrast improvement factor and Bucky factor. Acquired data in the simulation was the photon flux in the detector. The flux of photon was tallied with DF option, where the option 'DF' can convert the unit of the output value as micro-Sievert per hour from # cm^{-2} s^{-1} with consideration of energy dependence. The flux was obtained with grid condition and without grid condition. The transmission ratio of primary photon (T_p) and total photon (T_t) was calculated as a ratio of the data acquired from with grid and without grid condition. Contrast improvement factor, CIF, is a ratio of T_p to T_t. where it implies how many primary photons enter to detector relative to the total photons. High CIF means that the fraction of primary photons is high rather than scattered photons. The Bucky factor can be expressed as $1/T_t$ which represents the loss of photon data in the system. The Bucky factor correlates to the patient dose because the lost data should be filled by increasing exposure. In this study, the transmission of scattered photon was not considered because the contrast improvement factor and Bucky factor was considered to compare the performance of the grid.

For Bucky factor versus CIF graph, the higher performative grid has two characteristics: (1) high slope (2) relatively leftward shift. High slope and relatively leftward shift implies high CIF for same Bucky factor.

3. RESULTS AND DISCUSSION

Figure 3 shows the result of simulation. The data were figured as Bucky factor versus CIF. All data were appeared linear. It implies that grid ratio has no dependency of grid performance where the grid performance has meaning of both reduction of patient dose and improvement of image quality. Grid ratio can affect the CIF very dominantly, but it is hard to say the increasing of grid performance because Bucky factor is also increased severely.

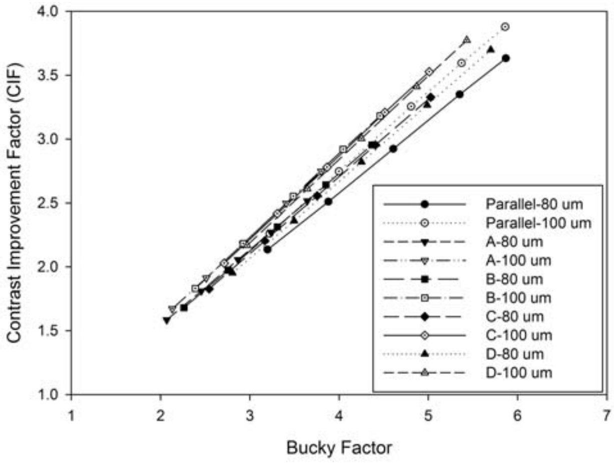

Fig. 3. Result data for simulation. Black symbols are data of interspace material width of 80 μm and white symbols of 100μm.

In general, the interspace material width of 100 μm cases had better performance than 80 μm cases. At Bucky factor of 5.35, 100 μm cases had higher CIF value about 0.1. Slope of the graphs were similar for each type. All four types have similar slope but A-type has slightly bigger slope.

The best performance was shown at 100 μm A-type case. But absolute value of CIF was relatively low. It had 2.7482 of CIF and Bucky factor of 3.7983 when its grid ratio was 14. The lowest Bucky factor was shown at 80 μm A-type for grid ratio of 6 (2.0681). The highest CIF was shown at 100 μm D-type for grid ratio of 14 except for the parallel type (3.7737). These results could be summarized by two ways; the first one was that A-type (thoroughly tapered type) showed best performance and the other one was that increment of the thickness of shielding material at the bottom resulted in increment of the absolute CIF.

The X-ray irradiates with angle to the grid, the grid with inclined shielding material has benefit to transmit the primary photons but it has sufficient thickness to block the scattered photons. It is thought that at the bottom part of grid, scattered photons are already lose their energy, therefore thin layer of shielding material is effective. It can be simple explanation how the inclined type has relatively higher performance than the parallel one and shielding material thickness of bottom had very low effect on the grid performance.

The performance test of focused type grid was not conducted in this study. It is thought that the suggested type of grid (inclined type) may have performance between focused and parallel type grid. However, inclined type has benefits of fabricating process. To fabricate the focused type grid, it is needed to carve the grid line one by one because of angular distribution. Or special mask for lithography is required. For this type, more efficient sawing system can be applied.

The inclined type has relatively higher CIF than the parallel type for same Bucky factor. It implies that the inclined type has higher performance than parallel type. Or choice of inclined type can reduce the patient dose. But, absolute CIF is lower for same grid ratio. If higher aspect ratio is hard to fabricate but grid requires absolutely higher CIF, the parallel type would be better choice. However, to reduce the patient's dose, inclined type would be better.

4. CONCLUSION

The performance of the X-ray anti-scattering grid of the inclined type was tested by MCNP simulation. The X-ray anti-scattering grid of the inclined type had higher performance than that of the parallel one in the aspect of Bucky factor and Contrast improvement factor. It implied the hybrid type could give two benefits relative to parallel one, the reduction of patient dose and the improvement of image quality. The extension was thought to be needed to the performance test of focused type grid and method of fabrication.

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