MCNP4C-based Monte Carlo study of grid performance in diagnostic radiology

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Abstract

The MCNP Monte Carlo radiation transport code was used for calculation of scatter distribution and scatter-to-primary ratio (SPR) for different tube voltages, phantom thicknesses and field size in diagnostic radiology. Subsequently, the effect of grid's design parameters such as strip density, grid ratio, interspace material and lead-to-interspace ratio on scatter rejection was investigated by calculation of bucky factor (BF) and contrast improvement factor (CIF) in more than 120 linear parallel grids under standard conditions proposed by the International Electrotechnical Commission (IEC). The accuracy of simulation of x-ray spectra and photon transport in grids with different design parameters was validated through comparison with measured results demonstrating good agreement, thus increasing the reliability of the results presented in this work.

1 Introduction

The corruption of diagnostic radiology images with scattered photons effectively decreases image quality and low contrast detectability. The amount of scattered radiation in diagnostic radiology examinations strongly depends on the object under study and exposure settings. The most common technique to reduce the detection of scattered radiation is the use of a linear grid, introduced in the beginning of the 20th century by Bucky and modified later on by Potter. Detailed knowledge of scatter distribution is, however, necessary for optimization of grid design.

In this study The MCNP4C Monte Carlo computer code was used for the calculation of scatter distribution and scatter-to-primary ratio (SPR) as function of tube voltage, phantom thickness and field size. Subsequently, the effect of grid design parameters on its performance was investigated by calculation of transmittance of total (T_t), primary (T_p) and scattered radiation (T_s), bucky factor (BF) and contrast improvement factor (CIF). The experimental measurements published by Fewell *et al* [1] and Chan *et al* [2] were used as benchmark for validation of simulated data.

2 Material and Methods

In this work, MCNP4C running on Pentium-based PC was used to fully transport the electrons and photons into the anode, filter, phantom and grid. The code was run in photon and electron mode using default values for PHYS:P and PHYS:E cards to enable full electron and photon transport including secondary electrons, bremsstrahlung photons and characteristic x-rays production. The measured spectra published in the Handbook of Computed Tomography x-ray spectra [1] was used for validation of simulated spectra in the exit window of the x-ray tube and after the phantoms for various materials and thicknesses. In addition, the experimental measurements published by Chan *et al* [2] for different grid parameters were used for validation of photon transport into the grid and water phantom. It should be emphasized that the accuracy of MCNP4C code for the simulation of x-ray spectra is well established [3]. Following validation of Monte Carlo simulations, the standard conditions proposed by IEC 60627 [4] were used for investigation of grid performance for strip density varying between 20 and 60 lines/cm, grid ratio from 6 to 15 and lead-to-interspace ratio from 1/9 to 1/2 for both aluminium and cotton fibre as interspace material.

3 Results

Table 1 compares simulated and measured results for different combinations of grid parameters. A pair of Kodak Lanex Regular screens (Gd_2O_2S:Tb, 70 mg/cm^2 per screen) was employed as the x-ray recording system. The pollution of transmitted photons with scattered radiation was investigated quantitatively by calculation of SPR as function of phantom thickness, tube voltage and field size. The variation of SPR is shown in Table 2, where the effect of nominated parameters was calculated individually.

Table 1. Comparison of measured and simulated grid performance parameters for various imaging conditions.

kV/H_2O thickness	Grid identification	Measured/Simulated			
		T_t	T_p	BF	CIF
70 kV/ 25 cm	40/6/50	0.195/0.209	0.678/0.685	5.13/4.80	3.48/3.28
	40/8/50	0.154/0.156	0.658/0.654	6.49/6.42	4.27/4.20
	40/10/50	0.127/0.120	0.621/0.630	7.87/8.35	4.89/5.26
	40/12/50	0.112/0.105	0.601/0.613	8.93/9.52	5.37/5.84
80kV/ 20 cm	33/5/50	0.257/0.263	0.682/0.707	3.89/3.80	2.56/2.69
	33/8/50	0.210/0.200	0.649/0.672	4.76/5.00	3.09/3.36
	33/10/50	0.181/0.171	0.595/0.621	5.52/5.85	3.29/3.63
	33/12/50	0.159/0.142	0.581/0.599	6.29/7.04	3.65/4.22
	33/15/50	0.140/0.122	0.544/0.565	7.14/8.20	3.89/4.63
120kV/ 15 cm	40/6/50	0.355/0.358	0.728/0.723	2.82/2.79	2.05/2.02
	40/8/50	0.301/0.285	0.699/0.699	3.32/3.51	2.32/2.45
	40/10/50	0.264/0.254	0.682/0.676	3.79/4.08	2.58/2.76
	40/12/50	0.241/0.218	0.663/0.654	4.15/4.59	2.75/3.00

Table 2. Variation of SPR as function of water thickness, field size and tube voltage

kV	Parameter (Variation)	Variation of SPR
80	Water thickness (3 - 40 cm)	0.168 – 13.059
120	Water thickness (3 - 40 cm)	0.157 – 13.804
80	Field size (5×5 - 30×30 cm^2)	0.111 – 1.788
120	Field size (5×5 - 30×30 cm^2)	0.096 – 1.660
-	Tube voltage (40 - 150 kV)	2.379 – 2.798

Figure 1 illustrates the bucky factor for constant lead-to-interspace ratio as a function of grid ratio for grids with different strip density. It can be seen that when grids with the same lead-to-interspace ratio and different strip density are considered, the bucky factor increases with grid ratio owing to the decrease in the transmittance of total radiation. This behaviour is much more evident for grids with low strip density.

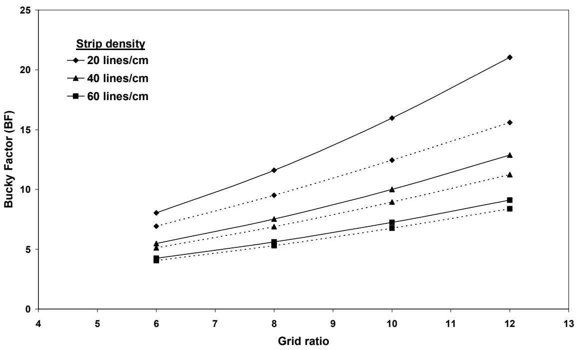

Fig. 1 Plot of Bucky factor vs grid ratio for different strip density with lead-to-interspace ratio of 1/4. Solid line: aluminium interspace; dashed line: cotton fibre interspace.

The relationship between different grid design parameters is further illustrated in Figure 2 where the CIF is plotted versus BF for constant strip density and different grid ratios. It can be seen that for a constant grid ratio, both CIF and BF increase with increasing strip thickness. The same behaviour is observed for a constant thickness of strip when grid ratio increases, which is the result of the decrease of scattered and primary transmittance when increasing grid ratio and strip thickness.

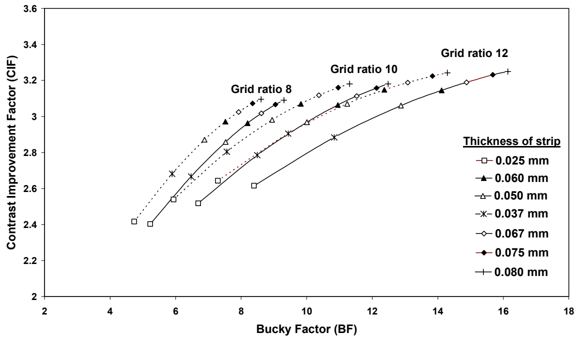

Fig. 2 Plot of CIF against BF for grids with strip density of 40 lines/cm. Solid line: aluminium interspace; dashed line: cotton fibre interspace.

4 Conclusion

A Monte Carlo-based assessment of the performance of antiscatter grids was performed. It has been shown that in grids with the same strip density, both CIF and BF increase with increasing grid ratio. The same behaviour was observed for grids with similar grid ratio when decreasing the strip density. The investigation of the effect of interspace material showed that grids with cotton fibre have higher CIF and lower BF than aluminium, resulting in higher image quality and lower patient dose. In conclusion, grids with cotton fibre show better performance compared to aluminium grids interspace with the same grid parameters especially in low strip density and high grid ratio. Likewise, grids with high strip density and high grid ratio perform better than low strip density grids.

Acknowledgements

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5 Literature

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