Quantitative analysis for digital radiography system with various grid ratio using image quality indicators in terms of ALARA principle

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INTRODUCTION

The anti-scatter grid has been used as one of the components in a radiography system for decades and it is known to be a common method for radiation scatter correction. The main specifications of the grid are strip frequency and ratio. The method of determining the strip frequency has long been proposed and used by grid manufacturers. But there are has been little research for effect of ratio. Here, we show how we should determine the ratio of the grid to achieve ALARA principle by image quality measurement.

AIM

The objective of this study is to analyze how the grid ratio affect image quality by measuring Modulation of Transfer Function (MTF), Scatter Fraction (SF), Noise Power Spectrum (NPS), effective Detective Quantum Efficiency (eDQE) and effective Noise Equivalent Quanta (eNEQ). And we show how the grid ratio can be related to patient dose.

METHOD

Experiment Setup

- Grid interspaced material : Aluminum
- Grid specification : Grid 100 $strips/cm$ with grid ratio (6~15)
- Radiation condition : 100 kV, 3 exposure (mAs) conditions for each phantom and grid setup (Table.1)
- Detector : consist of 140 μm $pixel$, CsI scintillator and a-Si TFT
- Phantom : MTF edge (Tungsten), beam stoppers for SF (Lead) and PMMA phantom (surface size : $30 \times 30\ cm^2$)

Image Acquisition

- NPS : 10 images for a given exposure and phantom setup
- MTF : 3 images for a given exposure and phantom setup
- SF (Scatter Fraction) : 10 images for a phantom setup

Definition and Meaning

- $eDQE(mf) = \frac{MTF^2 \cdot (1-SF)^2}{NNPS \cdot \frac{1}{m^2} \cdot \phi \cdot m^2}$, where $\phi = k_a SNR_{in}^2$
- $eNEQ(mf) = eDQE(mf) \cdot \phi \cdot m^2$

- Effective DQE describes the efficiency of an imaging system including detector, phantom, grid, and magnification at the image plane, defined as top of the phantom.
- Effective NEQ means the number of effective photons that contribute to making the image. It indicates actual image quality depending on exposure (or dose).

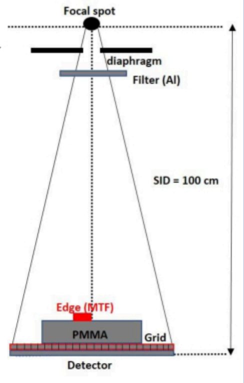

Figure 1. Geometry for MTF image acquisition

RESULTS

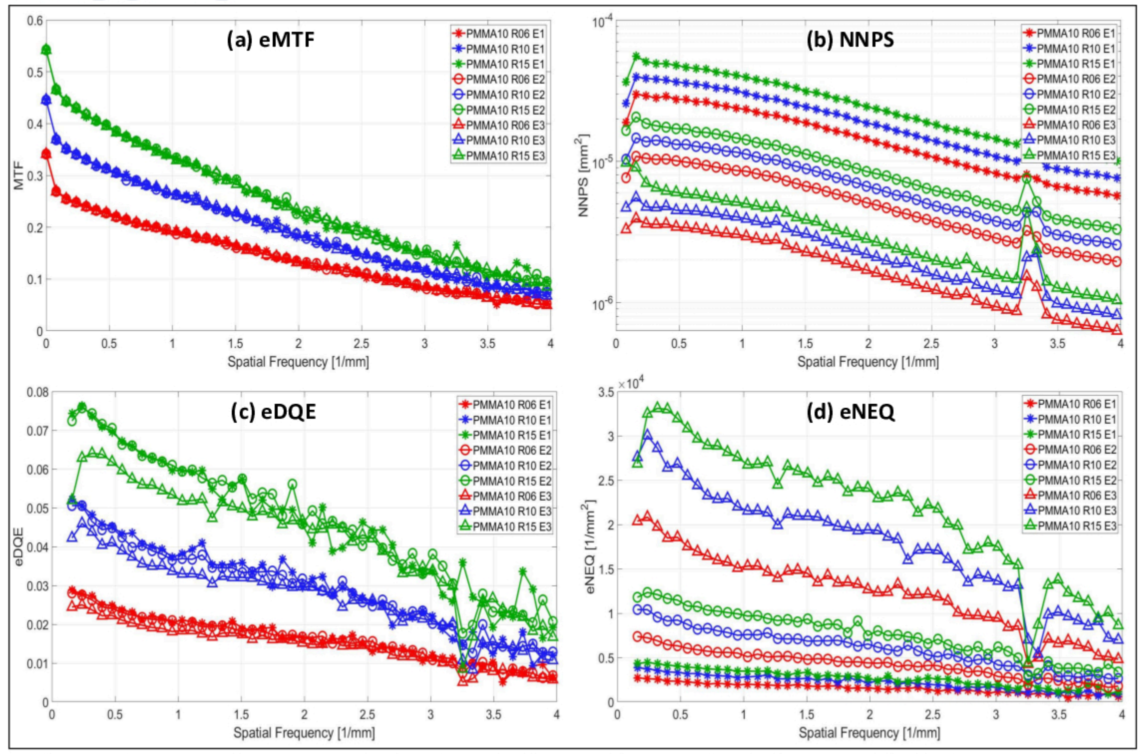

Figure 2. Image quality results for Grid 100 $strips/cm$ with 3 types of ratio, 10 cm of PMMA phantom and three exposure conditions (a) eMTF = MTF(1-SF) (b) NNPS (c) eDQE (d) eNEQ. The line colors represent different ratio type of the grid and the markers represent different exposure condition. In the legend for each plot, measurement conditions are expressed by 'PMMA' for phantom thickness [cm], 'R' for grid ratio and 'E' for exposure setup (**Table.1**).

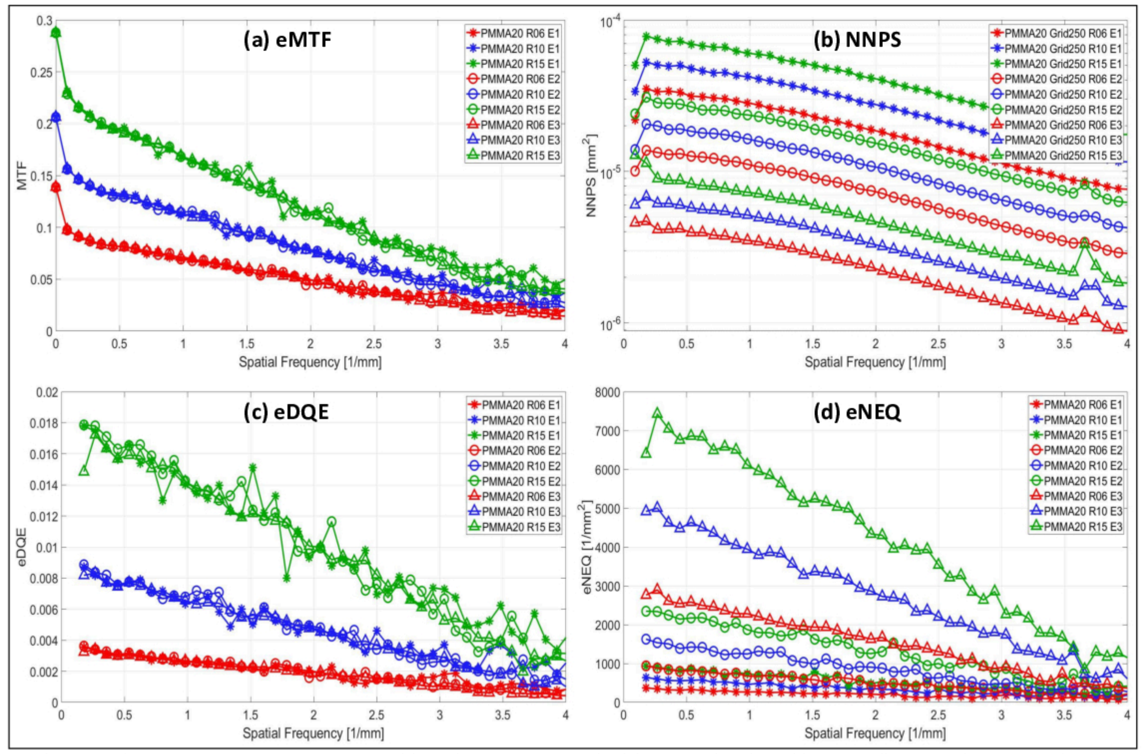

Figure 3. Image quality results for Grid 100 $strips/cm$ with 3 types of ratio, 20 cm of PMMA phantom and three exposure conditions (a) eMTF = MTF(1-SF) (b) NNPS (c) eDQE (d) eNEQ. The line colors represent different ratio type of the grid and the markers represent different exposure condition. In the legend for each plot, measurement conditions are expressed by 'PMMA' for phantom thickness [cm], 'R' for grid ratio and 'E' for exposure setup (**Table.1**).

Analysis

eMTF results are proportionally increased as grid total heights (h_{grid}), which is given by grid cover thickness and ratio. Setting the ratio value of 6 as a default, the image resolution is improved by 35% and 79% as grid ratio is controlled 10 and 15, respectively, with 10cm PMMA phantom. Higher ratio has tendency to be more effective with thicker object, such as 20cm PMMA phantom. However, eMTF is independent with exposure and the low frequency drop ($< 0.1/mm$) is attributed to scattering effect of the phantom.

$$h_{grid} = 2t_{cover} + ratio \times t_{interspace}\ (t_{cover} = 0.2\ mm,\ t_{interspace} = 0.075\ mm)$$

NNPS is approximately proportional to the inverse of the photon fluence (or mAs) due to dominant quantum noise when thick object, such as 20cm PMMA phantom is used. However, when PMMA phantom is set at 10 cm, other noise sources (detector and grid) has more impact on NNPS structure comparison to 20cm PMMA phantom, but the quantum noise is still dominant. That shows it is possible to control NNPS by adjusting the grid ratio instead of exposure.

eDQE results show that the image system efficiency is improved by raising of grid ratio. The exposure dependency of NNPS is almost balanced out with normalization factor ϕ so that DQE is mainly determined by eMTF except for high exposure conditions (e.g. E3). The exception is caused by the contribution of grid noise at low-frequency range (< 1.5/mm) becoming large as higher exposure and lower thickness of phantom are implemented.

eNEQ is proportional to the exposure conditions, as we can see the definition. Also, it can be improved by a high grid ratio from the results. For PMMA 10 cm, eNEQ(0.5/mm) of ratio 6 is increased as 43% and 72% by ratio 10 and 15 respectively. For PMMA 20 cm, it is increased as 75% and 160%, respectively. These results indicate that the effect for the image resolution improvement is greater than the effect for dose reduction caused by the increase in grid ratio.

Exposure/ Phantom	E1 [mAs]	E2 [mAs]	E3 [mAs]
PMMA 0 cm	0.1	0.28	0.9
PMMA 5 cm	0.18	0.5	1.6
PMMA 10 cm	0.36	1.0	3.2
PMMA 15 cm	0.7	2.0	6.4
PMMA 20 cm	1.6	4.0	12.8

Table 1. Experiment setup table for exposure and phantom. The exposure conditions were chosen by considering the detector saturation range and the generator control range.

CONCLUSIONS

This study shows how the image qualities can be affected by grid ratio at various conditions with exposure and phantom thickness. The image resolution of the system, corresponding to eMTF, is improved by increasing the grid ratio regardless of exposure conditions. The noise characteristics of the system strongly depend on the photon fluence at the detector, which can be determined by exposure, phantom thickness, and the anti-scatter grid. As the results of eMTF and NPS, both eDQE and eNEQ can be improved by increasing the grid ratio.

What we should point out is the patient dose can be reduced by a change of grid ratio without loss of image quality, because detectability for a specific object in a clinical region can be determined by eNEQ values. As you can see in the case of 20 cm PMMA of eNEQ, the image quality of ratio 15 with exposure 2 (4 mAs) can be comparable with that of ratio 6 with exposure 3 (12.8 mAs). That means we can turn down the mAs value 3 times lesser by changing ratio from 6 to 15 in 20 cm PMMA case. This is why the proper choice of grid ratio can be consistent with ALARA principle.

ACKNOWLEDGEMENTS

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