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Effects of Anti-Scatter Grid on Noise Power Spectrum at Different Dose Levels in Digital Mammography

Dijital Mamografi Sistemlerinde Farklı Doz Seviyelerinde Saçılma Önleyici Gridin Gürültü Güç Spektrumu Üzerindeki Etkisi

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Abstract

Aim: The noise power spectrum (NPS) is an important quality control parameter used to characterize the noise in a digital image in the frequency domain. The NPS is divided by the square of the mean value of the pixels in the region of interest (ROI), and this ratio is referred to as the normalized noise power spectrum (NNPS) and is used for noise analysis. This study aims to determine the effect of using an anti-scatter grid on the NNPS measurement.

Methods: The NNPS measurements are performed on five Fujifilm Amulet Innovality full-field digital mammography (FFDM) systems with and without a scatter reduction grid for different dose levels ranging from 8 µGy to 400 µGy. The set of three images of the uniform detector is acquired with and without a grid at each dose level for evaluation. All the preprocessed (raw) images are analyzed using the ImageJ software-COQ plug-in. The relative difference is preferred to determine the changes in the NNPS.

Results: The maximum relative difference between the grid and non-grid images is found to be 2.63 at 0.5 mm-1 spatial frequency for a 20.31 µGy dose level.

Conclusion: The results show that NNPS fell with rising doses, whereas NNPS increased due to the decrease in the average number of x-ray photons reaching the detector when the grid is used.

Keywords: digital mammography, noise power spectrum, anti-scatter grid, noise.

Öz

Amaç: Gürültü güç spektrumu (NPS), dijital bir görüntüdeki gürültüyü frekans uzayında karakterize etmek için kullanılan önemli bir kalite kontrol parametresidir. NPS'nin ilgi alanı içerisindeki (ROI) ortalama piksel değerlerinin karesine bölünmesiyle normalize NPS (NNPS) hesaplanır ve NNPS medikal bir görüntüdeki gürültü analizi için kullanılmaktadır. Bu çalışmanın amacı, NNPS analizinde saçılma önleyici grid kullanımının NNPS'e etkisini belirlemektir.

Yöntemler: NNPS ölçümleri, 8 µGy ile 400 µGy arasında değişen farklı doz seviyeleri için beş Fujifilm Amulet Innovality tüm-alan dijital mamografi (FFDM) sisteminde gridli ve gridsiz olarak gerçekleştirildi. Belirlenen her bir doz seviyesi için üç farklı homojen dedektör görüntüsü alındı. Elde edilen tüm ham dedektör görüntüleri ImageJ yazılımı COQ eklentisi kullanılarak değerlendirilmiştir. NNPS'deki değişimleri belirlemek için bağıl fark tercih edilmiştir.

Sonuçlar: Gridli ve gridsiz elde edilen görüntüler arasındaki maksimum bağıl fark 20.31 µGy doz seviyesi için 0.5 mm-1 uzaysal frekansta 2.63 olarak bulunmuştur.

Tartışma: Sonuçlar, artan doz seviyesi ile NNPS'nin azaldığını, grid kullanıldığında ise dedektöre ulaşan ortalama x-ışını foton sayısındaki azalma nedeniyle NNPS'nin arttığını göstermiştir.

Anahtar Kelimeler: dijital mamografi, gürültü güç spektrumu, grid, gürültü.

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1. Introduction

In digital radiography systems, noise is a crucial parameter that affects the visibility of low-contrast and small-diameter objects (1). In digital imaging systems, noise in the image is analyzed from measurements of the variance of the signal in the spatial domain and from the noise power spectra (NPS) in the frequency domain. Hence, NPS is an important parameter for characterizing the performance of a digital detector because it relates to the appearance of noise in the image. Many factors can affect the measured NPS, such as image processing, anti-aliasing filters, defective pixels, air kerma, and detector technology, but careful and accurate analysis of the NPS gives insight into the detector's performance (2). The NPS may increase or decrease in the same beam conditions for several reasons, and knowledge of the test processes is essential to derive useful information from these measurements. In literature, NPS is generally divided by the square of the mean pixel value (MPV), and the normalized noise power spectrum (NNPS) is obtained as Equation (3).

$$\text{NNPS } (\text{mm}^2) = \text{NPS}/\text{MPV}^2 \quad (1)$$

The NNPS is also equivalent to the square of the signal-to-noise (SNR) (4). In particular, normalization is carried out to eliminate the direct effect of signal variations between images or regions of interest (ROIs) used for NPS. The NNPS is also used to determine detective quantum efficiency (DQE), which is the relationship between the x-ray photons and the image from the digital detector and is determined from the combination of the modulation transfer function (MTF), NNPS, and SNR (5). In a nutshell, the terms "NPS" and "NNPS" are often used interchangeably to refer to the NNPS in the literature (6).

As known, scattering radiation refers to the x-rays losing their original linearity due to the interaction with the object when they pass through it (7). The scattered radiation would reduce the quality of the radiographic image, and anti-scatter grids between the patient and the image receptor in radiographic imaging systems are used to remove scatter radiation in diagnostic radiology (8). Mammography systems generally have "grid in" and "grid out" options because the grid not only attenuates scattered radiation but also primary radiation (9). In quality control protocols such as those of the International Electrotechnical Commission (IEC, 2007) (10), European Guidelines for Quality Assurance in Mammography Screening (EUREF, 2013) (11), and the Institute of Physics and Engineering in Medicine (IPEM, 2010) (12), the NNPS measurement is recommended without an anti-scatter grid. Many publications in the literature evaluate noise in the frequency domain for radiography systems, but the results were generally obtained without an anti-scatter grid in these publications (1,3,6,13,14).

However, some scientific publications do not specify whether or not the anti-scatter grid was in place during the NNPS measurement. On the other hand, it is crucial to know the exact test geometry, especially when comparing imaging systems with each other, as measurement results will depend on beam quality and evaluation methods. It should be remembered that NNPS measurements have many uses, such as quality control, comparison of detectors, and analysis of noise sources. In addition, measurement conditions are important, as NNPS will affect the DQE result. This study aims to determine the effect of using the scatter reduction grid on the NNPS measurement.

3. Methods

Five identical Fujifilm Amulet Innovality full-field digital mammography (FFDM) systems, using amorphous selenium (a-Se) direct conversion detector technology, were tested (from this point on, the tested systems were named S1–S5). RaysafeXi multimeter was used for the detector air kerma (µGy) measurements (RaySafe Xi, Billdal, Sweeden). The NNPS test was carried out as described by the IEC (2007) [10] and IPEM (2010) [12]. Measurements were performed at 29 kV, W/Rh (tungsten/rhodium) anode/filter combination, and different dose levels were obtained by changing mAs (milliampere-seconds). Before acquiring detector images (flat-field images) for NNPS analysis, a 2.0 mm uniform aluminum (Al) filter was placed on the x-ray tube output (exit side of the collimator), as 2.0 mm Al is as close as possible to the absorption characteristics of the relevant body part. Then, flat-field images were obtained at the selected dose levels. NNPSs were determined at three air kerma levels, most commonly used clinically, ranging from 8 µGy to 400 µGy, and three images were acquired for each dose level. In only S5, NNPS analysis was performed at two different dose levels.

A series of three images were opened with the software ImageJ COQ Plug-in, freely available on the website http://www.medphys.it/down_dqe.htm, that determines

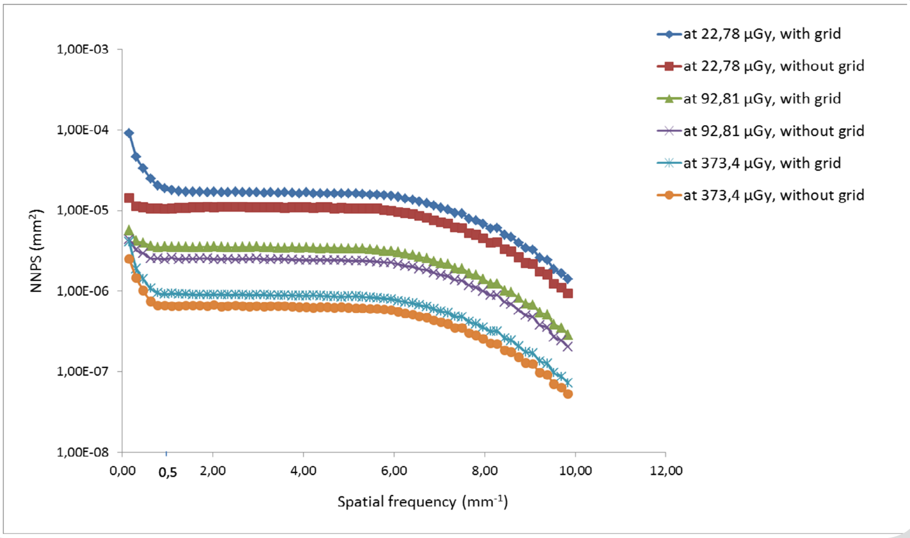

Figure 1. Radially averaged NNPS curves for S1 at three dose levels with and without the anti-scatter grid

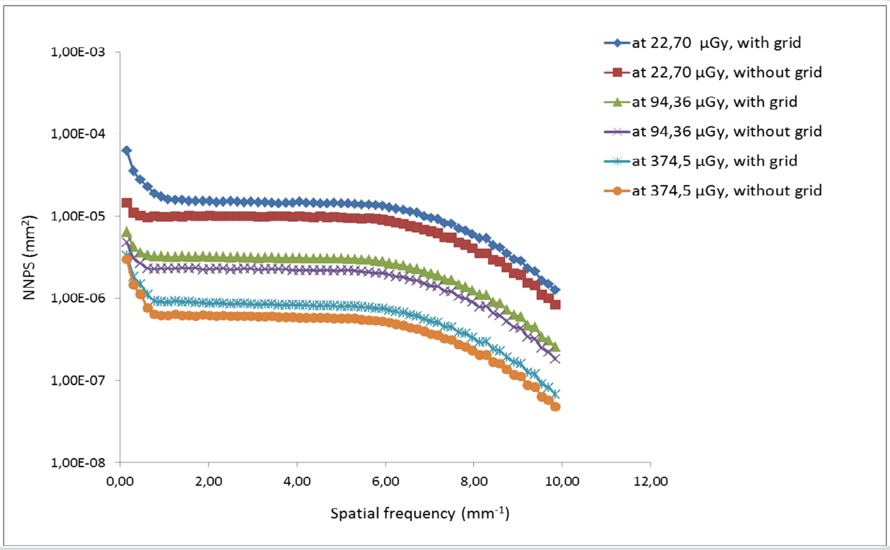

Figure 2. Radially averaged NNPS curves for S2 at three dose levels with and without the anti-scatter grid

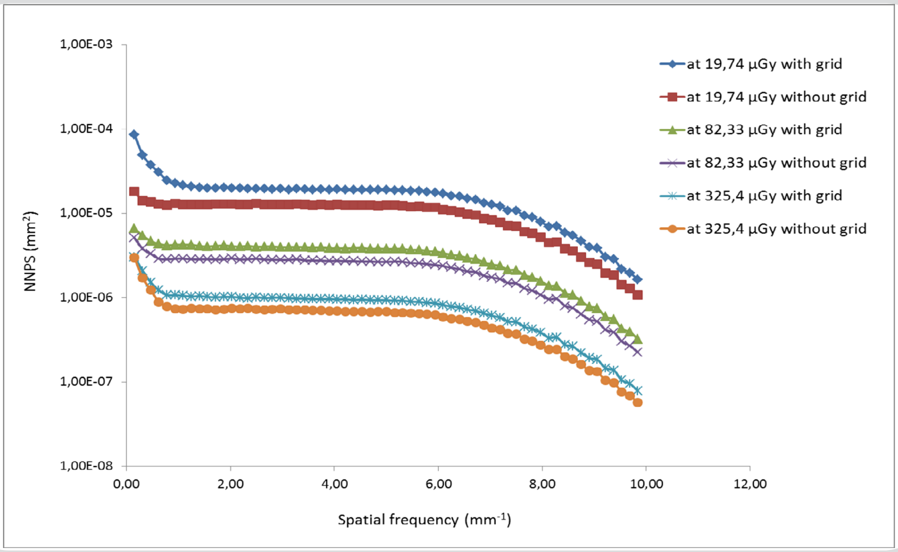

Figure 3. Radially averaged NNPS curves for S3 at three dose levels with and without the anti-scatter grid

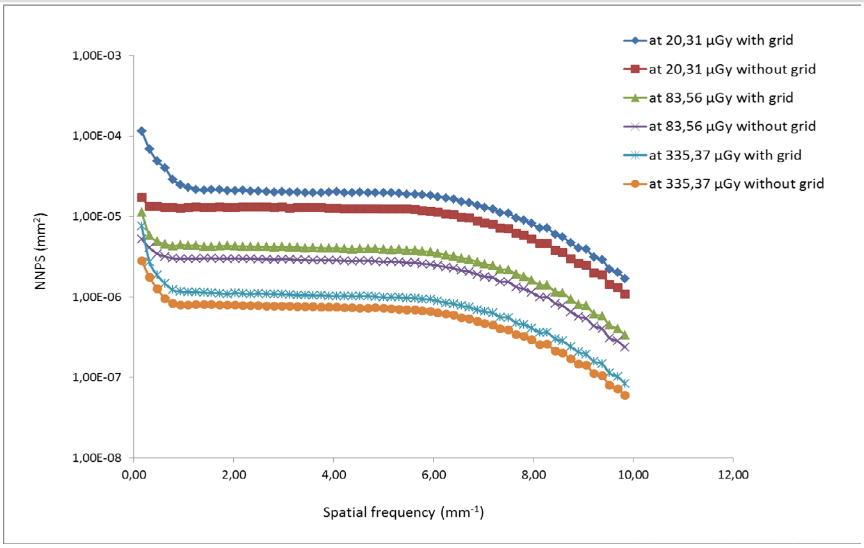

Figure 4. Radially averaged NNPS curves for S4 at three dose levels with and without the anti-scatter grid

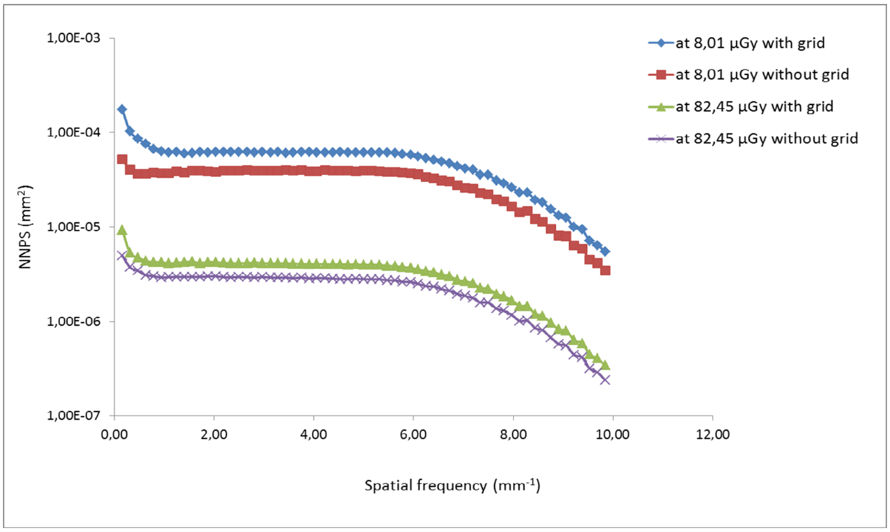

Figure 5. Radially averaged NNPS curves for S5 at two dose levels with and without the anti-scatter grid

Table 1. The relative differences in selected frequencies for S1

Frequency (mm^{-1})	Relative difference for 22.78 µGy	Relative difference for 92.81 µGy	Relative difference for 373.4 µGy
0.5	2.04	0.35	0.38
1.0	0.67	0.37	0.42
2.0	0.55	0.45	0.34
4.0	0.54	0.43	0.39
6.0	0.52	0.42	0.37
8.0	0.51	0.41	0.38

Table 2. The relative differences in selected frequencies for S2

Frequency (mm^{-1})	Relative difference for 22.70 µGy	Relative difference for 94.36 µGy	Relative difference for 374.5 µGy
0.5	1.73	0.35	0.32
1.0	0.63	0.39	0.44
2.0	0.50	0.41	0.40
4.0	0.51	0.42	0.43
6.0	0.47	0.39	0.43
8.0	0.48	0.37	0.44

Table 3. The relative differences in selected frequencies for S3

Frequency (mm^{-1})	Relative difference for 19.74 µGy	Relative difference for 82.33 µGy	Relative difference for 325.4 µGy
0.5	1.75	0.43	0.24
1.0	0.69	0.46	0.45
2.0	0.53	0.39	0.37
4.0	0.53	0.41	0.37
6.0	0.54	0.42	0.39
8.0	0.54	0.45	0.41

Table 4. The relative differences in selected frequencies for S4

Frequency (mm^{-1})	Relative difference for 20.31 µGy	Relative difference for 83.56 µGy	Relative difference for 335.37 µGy
0.5	2.63	0.43	0.48
1.0	0.77	0.45	0.44
2.0	0.62	0.42	0.42
4.0	0.60	0.41	0.37
6.0	0.56	0.43	0.41
8.0	0.56	0.42	0.41

Table 5. The relative differences in selected frequencies for S5

Frequency (mm^{-1})	Relative difference for 8.01 μGy	Relative difference for 82.45 μGy
0.5	1.35	0.38
1.0	0.64	0.40
2.0	0.64	0.40
4.0	0.59	0.41
6.0	0.55	0.41
8.0	0.59	0.43

1D NNPS by averaging 2D NNPS radially, vertically, and horizontally (15). Generally, the information of NNPS is displayed in graphical form, and in this study, the NNPSs are determined for the radial direction. Zero frequency is excluded from the analysis because it is difficult to measure accurately (6). The relative difference (RD) between two NNPS values is calculated to compare NNPS results with and without an anti-scatter grid at 0.5 mm-1, 1.0 mm-1, 2.0 mm-1, 4.0 mm-1, 6.0 mm-1, and 8.0 mm-1 spatial frequencies as shown in Equation 2 (16). The relative difference is preferred for comparison because it gives more significant results in small changes.

$$RD = \sum_{i=1}^{n} |NNPS_1(i) - NNPS_2(i)| / NNPS_2(i) \quad (2)$$

4. Results

Figures 1– 5 show the NNPS curves at three dose levels—with and without a grid for five Fujifilm Amulet mammography systems (S1– S5). Tables 1– 5 also show the relative differences, calculated according to Equation (2), for selected spatial frequencies. The NNPS curves are plotted for all five tested systems to show the variability of the results, and the results show almost identical performance in the radial direction for all tested mammographies. As seen from the results, NNPS curves are almost uniform over a wide spatial frequency range, and the maximum relative differences between the NNPS of the grid and non-grid images are 2.04, 1.73, 1.75, 2.63, and 1.35 at 0.5 mm^{-1} spatial frequency for S1-S5, respectively. The maximum differences are also observed at the lowest dose levels. The results of the NNPS analysis clearly show that when the anti-scatter grid is used, the NNPS is higher.

5. Discussion and Conclusion

Five Fujifilm Amulet Innovality mammography systems have been tested to investigate differences observed in NNPS results with and without an anti-scatter grid. Since only one manufacturer's five mammography systems are examined in this study, systems with the same grid ratio (6:1) and line frequency (41 lines/cm) can be compared. Therefore, this study is limited to one type of mammography system, and the results are evaluated based on this.

The anti-scatter grid is known to cause structural noise (fixed pattern noise), which is one of the sources of noise in the image (17). It should be noted that the NNPS is sensitive to changes in structure noise. Therefore, using an anti-scatter grid can change the noise conditions due to structure noise. Moreover, the lower the number of photons absorbed in the detector, the higher the quantum noise, which is the main noise source in a digital image. This probably means using an anti-scatter grid will also affect the DQE result.

Furthermore, graphs show that NNPS declines with increasing dose, indicating that noise falls. It must be noted, however, that the magnitude of the noise will increase with the dose, but the noise relative to the signal will decrease with the increasing dose.

A qualified imaging system is expected to have high X-ray photon absorption, low structural noise, and low NNPS at low spatial frequencies. The NNPS curves obtained without an anti-scatter grid are compared with the NHS report 1601, and the curves are almost identical (18). Also, when comparing the results with the literature, almost similar results were observed for digital detectors (7). In conclusion, the NNPS was higher when using the anti-scatter grid because the grid reduced the radiation dose to the detector and increased structural noise in the image. Since using the grid affects the NNPS result, performing the NNPS test without an anti-scatter grid is more appropriate, as recommended in the protocols (10,11,12). In summary, NNPS is an effective parameter for determining an imaging system's image quality and is highly sensitive to changes in the digital detector.

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