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Limitations of anti-scatter grids when used with high resolution image detectors

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Abstract

Anti-scatter grids are used in fluoroscopic systems to improve image quality by absorbing scattered radiation. A stationary Smit Rontgen X-ray grid (line density: 70 lines/cm, grid ratio: 13:1) was used with a flat panel detector (FPD) of pixel size 194 micron and a high-resolution CMOS detector, the Dexela 1207 with pixel size of 75 microns. To investigate the effectiveness of the grid, a simulated artery block was placed in a modified uniform frontal head phantom and imaged with both the FPD and the Dexela for an approximately 15×15 cm field of view (FOV).

The contrast improved for both detectors with the grid. The contrast-to-noise ratio (CNR) does not increase as much in the case of the Dexela as it improves in the case of the FPD. Since the total noise in a single frame increases substantially for the Dexela compared to the FPD when the grid is used, the CNR is degraded. The increase in the quantum noise per frame would be similar for both detectors when the grid is used due to the attenuation of radiation, but the fixed pattern noise caused by the grid was substantially higher for the Dexela compared to the FPD and hence caused a severe reduction of CNR.

Without further corrective methods this grid should not be used with high-resolution fluoroscopic detectors because the CNR does not improve significantly and the visibility of low contrast details may be reduced. Either an anti-scatter grid of different design or an additional image processing step when using a similar grid would be required to deal with the problem of scatter for high resolution detectors and the structured noise of the grid pattern.

Keywords

CNR; scatter; image quality; anti-scatter grid; high-resolution detector

1. INTRODUCTION

In digital radiographic imaging, scatter is inevitably produced when the primary beam passes through an object, degrading the image quality. Air-gap techniques¹, scanning beams², moving grids³ and stationary grids may be used to control the amount of scatter. Out of all these methods the stationary anti-scatter grid has usually proved to be the most practical choice for fluoroscopy due to its compact design and simplicity compared to

scanning-beams or moving grids which have additional implementation complexity in real-time imaging. Also the static grid enables adequate control of scatter without increasing geometric un-sharpness as in the case of air-gap techniques and hence they are widely used in projection x-ray radiography to reduce scattered radiation and improve image contrast. Unfortunately, stationary anti-scatter grids can leave grid-line shadows (grid-line artifact) and moiré patterns⁴ on the image, depending upon line density of the grid and the sampling frequency of the x-ray detector, which may still degrade the image quality and mask the small details in the image.

Besides cutting down the scattered radiation, the grid also attenuates the primary radiation and this causes an increase in the noise which also could decrease the contrast to noise ratio (CNR) and consequently could impair the visibility of low contrast objects. Therefore, the effectiveness of an anti-scatter grid demands that there be an increase in both the image contrast and the CNR. This implies that the increase in both the quantum and the structured noise level due to introduction of the grid should be such that the overall CNR will nevertheless improve.

2. METHODS AND MATERIALS

The study was done by analyzing images of the simulated artery block phantom (Nuclear Associates, Stenosis/Aneurysm Artery Block 76-705) taken with the frontal head equivalent phantom^{5, 6} used as the scattering source. The artery phantom was an acrylic block ($15 \times 45 \times 2.5$ cm thick) that contained three iodine-filled simulated arteries whose widths were 1, 2 and 4 mm in one half of the block while the other half has no features (see Fig. 1a). Each artery included stenoses and aneurysms that are one-fourth, one-half and three-fourths of the artery's width. The iodine concentration is 15mg/ml. The slot located in the middle of the frontal head equivalent phantom (see Fig. 1b) allows the artery block to slide into the phantom when the artery features are to be evaluated (see Fig. 1c and 1d).

A Toshiba Infinix C-arm imaging system was used to image the phantom for a field of view (FOV) of approximately ($15 \text{ cm} \times 15 \text{ cm}$) at the detector plane with a high-resolution detector, Dexela 1207 CMOS X-ray detector (pixel size 75μ and sensitive area $11.5 \text{ cm} \times 6.5 \text{ cm}$), and the flat panel detector (FPD), Paxscan 2020 (pixel size 194μ and sensitive area $19.8 \text{ cm} \times 19.8 \text{ cm}$), without (w/o) and with a grid. The Dexela was placed almost in the center of the FOV to simulate a high-resolution detector with a large sensitive area. In this way even though this specific Dexela detector could not image the full $15 \times 15 \text{ cm}$ FOV, a future detector with the same high resolution as this detector but with a larger FOV and exhibiting the scatter of such a larger FOV could be simulated.

The Smit Roentgen X-ray grid (Smit Roentgen, Best, Netherlands) used was the same one normally used with the FPD system. Table 1 shows the relevant specifications.

The experimental set-up is shown in the Fig. 2. The detector and the grid respectively are 6.7 cm and 3.7 cm above the top end of the whole phantom (frontal head equivalent phantom with artery block in the slot).

The images of the artery block were taken with the table at 84 kVp in angiography mode without (w/o) the grid ('object w/o grid') and with the grid ('object with grid'). Scatter-free images of the table w/o the grid ('table w/o grid') and with the grid ('table with grid') and the flat-fields of the detectors were taken with the featureless part of the artery block in the slot (to keep the filtration of the x-ray beam the same) while keeping the whole phantom far from the detector and close to the source. In this study, wherever an average is mentioned it is the average of 65 single frames. All the images were flat-field and offset corrected for both detectors.

Image Corrections

The 'object w/o grid' images were divided by the average (65 frames) of the 'table w/o grid' to eliminate the blotches due to the table in the images (table correction) and shown in Fig.3. To correct for the effect of scatter, an estimate of the scatter component was obtained by taking the difference in the mean value of a selected region between the average frame of the 'object w/o grid' and the 'table w/o grid' and this was subtracted from the 'object w/o grid' images; the result was then divided by the average of the 'table w/o grid' to correct for table structure noise (scatter and table correction). The average of the 'object w/o grid' images corrected both for the scatter and the table is shown in the Fig. 4. Similarly, the difference in the mean value of the same region in the average frame of both the 'object with grid' and the 'table with grid' was subtracted from the 'object with grid' images and then divided by the average of the 'table w/o grid' and the average of these is shown in the Fig. 5.

Contrast Calculation

The images shown in Fig. 4a and 5a were used to calculate contrast w/o and with the grid for the FPD and images shown in Fig 4b and 5b were used for the Dexela for the contrast calculation. An area was selected in the 4 mm thick artery to serve as signal and the same size area is selected in the background in the central part of the image. The images shown in Fig. 4a and 5a were used to calculate contrast w/o and with the grid for the FPD and images shown in Fig 4b and 5b were used for the Dexela for the contrast calculation. An area was selected in the 4 mm thick artery to serve as signal and the same size area is selected in the background in the central part of the image. These selected regions are shown respectively as red box and green box in the Fig. 4a in the case of the FPD. In the case of the Dexela, the size of the each box was 51×51 pixels which is equivalent to almost 20×20 pixels for the FPD to represent the same area. The difference in the average pixel intensity value of the background and the signal was normalized with the average pixel intensity value of the background to determine the contrast (refer to Table 2).

Noise Calculation

In order to characterize noise in a single frame for the images 'object w/o grid' and 'object with grid' following the scatter and table correction, a blue box (twice the size of green box) was selected in a single frame as shown in Fig.6b in the case of the Dexela. In the case of Dexela the size of the blue box was 101×101 pixels which is equivalent to almost 40×40 pixels for the FPD to represent the same area. This blue box was further divided into 36 smaller overlapping sub-regions of 51×51 pixels in the case of Dexela and 25 smaller overlapping sub-regions of 20×20 pixels in the case of FPD. The noise of a sub-region is

defined as the ratio of the standard deviation of the pixel intensity by the average pixel intensity value of the sub-region. The noise in a sub-region of the blue box varies a lot with sub-region for the 'object with grid' images due to formation of moiré patterns and grid-line artifacts which are clearly visible in the average frames (Fig. 5a and 5b); therefore, the averaging over all the sub-regions in the blue box was done to calculate noise in the blue box. It was found that the noise in the blue box varies also with frame so it was averaged further over ten different frames and taken as noise in a single frame (refer Table 3).

CNR Calculation

The ratio of the contrast in the averaged image to the noise in the single frame was defined as the contrast-to-noise ratio (CNR) (refer to Table 2). The noise in the average frame in Table 3 refers to the noise in the blue box of the average frame.

3. RESULTS

Figures 3, 4, 5 and 6 show images of arteries of width 4 mm and 1 mm obtained with the Dexela and FPD under various conditions. Fig. 3 shows images obtained after only the table correction was applied and the residual blotches in the images are due to structure in the table which could not be removed properly in the phantom images by just the table correction because the image of the table alone used for the correction was scatter free while the image of the object with the table included scatter. The scatter adds a constant to the pixel values in the image for the same attenuation of the beam for the given filtration and the effect cannot be eliminated by dividing it by the image obtained w/o scatter. This kind of image with residual blotches was not suitable for doing contrast and noise analysis and could skew the results and conclusions; therefore, the removal of the blotches was essential to this analysis. To do this, an estimate of the added scatter was subtracted from the image. The mean value of a selected region in the average frame of the 'object w/o grid' was higher than the mean value of the same region in the average frame of the 'table w/o grid' which was due to the addition of scatter. The blotches are removed when the difference of the mean value was first subtracted from the 'object w/o grid' images and then divided by the average of the 'table w/o grid' (scatter and table correction) (see Fig. 4). Similarly, this exercise was repeated with the 'object with grid' to remove the blotches and increase the visibility of grid artifacts and moiré pattern (see Fig. 5).

Table 2 shows that the contrast improves for both detectors when the grid is introduced but improvement in the CNR is much higher in case of the FPD compared to the Dexela. Table 3 shows that the total noise level for a single frame increases after introducing the grid for both detectors but the increase is higher for the Dexela (14.1 %) compared to the FPD (3.5 %). There are two factors responsible for the increase in the total noise after introducing the grid: the first is the increase in the quantum noise due to attenuation of radiation reaching the detector plane and the second is the line artifacts caused by the grid (fixed pattern noise). The combined effect is much worse in the case of Dexela which is evident from the fact that the visibility of the artery of width 1 mm is clearer both in the single and the average frame in the case of the FPD compared to the Dexela (Fig 5 and 6). The increase in quantum noise due to introduction of the grid should be the same, therefore, the increase in the fixed pattern

noise (grid line artifacts) in the case of the Dexela is much more compared to the FPD. Table 3 also shows in the average frame, for which the quantum noise would be minimum, that the increase in the total noise after introducing the grid, is very high in the case of the Dexela (145 %) compared to the FPD (27.8 %). This rise in the total noise level is the reason that improvement in the CNR is not very significant in the case of the Dexela compared to the FPD.

4. DISCUSSION

The removal of blotches was important to characterize the contrast and the noise more accurately. The idea that was used to remove the blotches from the images could also be used to get rid of line artifacts from the 'object with grid' images. In order to achieve this, the difference in the mean value between the same uniform region in the average frame of the 'object with grid' and the 'table with grid' was subtracted from the 'object with grid' images and then divided by the average of the 'table with grid' instead of 'table w/o grid'. The average frame of the 'object with grid' without grid artifacts is compared to the same average frame with grid artifacts in the case of the FPD only in Fig 7 (Fig. 5a and 7a are identical). The visibility of the stenoses (white small circles) in the 1 mm thick artery improves. The contrast and the CNR both improve very significantly as shown in Table 4. This is a simple way compared to other more complex methods that rely on image processing to get rid of grid line artifacts^{7, 8} and might be used in the case of a high resolution detector where the problem is more severe as artifacts are more likely to be visible even in a single frame; however, for the current study this was not implemented pending the creation of an improved rigid support for the grid.

In reality, scatter is not a constant throughout the field but it is a very low spatial frequency distribution so it was able to be represented by a constant number as a good approximation here. In the case of the FPD, we selected a region in the central part of the image, where the scatter was maximum, to apply this technique. This appeared to work well for the whole image (Fig 7b). This technique could be implemented with a method for scatter to primary ratio estimation.

5. CONCLUSIONS

The limitations of an anti-scatter grid of a design commonly used for FPD fluoroscopic systems are investigated when applied to high resolution x-ray imaging detectors which are important for neurovascular imaging procedures. We observe that the contrast improves when the grid is used with the high resolution Dexela detector but the increase in the CNR is not so significant compared to the case of the FPD. Assuming the quantum noise increases similarly for both detectors when the grid is used (due to reduced photon fluence), it is the substantial increase in the visualization of the grid's fixed pattern noise in the case of the Dexela which degrades the CNR. It may be possible to ameliorate this problem either with a grid of improved design or with additional image processing corrections to minimize the structured grid-line artifacts. The latter was demonstrated for the FPD.

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Figure 1.

Pictures of head phantom used in study a) artery block insert, b) side view of head phantom with artery block inserted through center, c) top view of head phantom with uniform section of artery block inserted, d) top view of head phantom with vascular section of artery inserted.

Figure 2.
The experimental setup to study the effect of the grid

Figure 3.
Average image for a) FPD and b) Dexela w/ o grid after table correction

Figure 4.
Average image for a) FPD and b) Dexela w/o grid after scatter and table correction

Figure 5.
Average image for a) FPD and b) Dexela with grid after scatter and table correction

Figure 6.
Single frame image for a) FPD and b) Dexela with grid after scatter and table correction

Figure 7.
Average image a) with FPD with grid after (scatter + table) correction compared to b)
average image of FPD with grid after (scatter + table + grid) correction

Table 1

Grid specifications

Type number	989601061091
Focus	100 cm
Line rate	70 lines/cm
Grid ratio	13 : 1
Septa	Lead, 27.5 μm
Interspace material	Fiber

Table 2

Contrast and CNR comparison of Dexela to FPD

Condition	Contrast (%)		CNR		Effect of grid on	
	w/o grid	with grid	w/o grid	with grid	Contrast increase	CNR increase
FPD	3.0	4.08	1.06	1.40	36.0 %	32.1 %
Dexela	3.2	4.01	0.81	0.89	25.3 %	9.8 %

Table 3

Noise comparison of Dexela to FPD

TOTAL NOISE						
Frames	Single (%)		Increase in noise	Average of 65 (%)		Increase in noise
Condition	w/o grid	with grid		w/o grid	with grid	
FPD	2.82	2.92	3.5 %	0.61	0.78	27.8 %
Dexela	3.97	4.53	14.1 %	0.75	1.84	145 %

Table 4

Effect of image correction on contrast, noise and CNR for the FPD

	Contrast (%)		Total Noise (%)		CNR	
Image correction	Table only	Table + grid	Table only	Table + grid	Table only	Table + grid
FPD	4.08	4.27	2.92	2.86	1.40	1.50