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Scatter reduction for high resolution image detectors with a region of interest attenuator

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Abstract

Compton scatter is the main interaction of x-rays with objects undergoing radiographic and fluoroscopic imaging procedures. Such scatter is responsible for reducing image signal to noise ratio which can negatively impact object detection especially for low contrast objects. To reduce scatter, possible methods are smaller fields-of-view, larger air gaps and the use of an anti-scatter grid. Smaller fields of view may not be acceptable and scanned-beam radiography is not practical for real-time imaging. Air gaps can increase geometric unsharpness and thus degrade image resolution. Deployment of an anti-scatter grid is not well suited for high resolution imagers due to the unavailability of high line density grids needed to prevent grid-line artifacts. However, region of interest (ROI) imaging can be used not only for dose reduction but also for scatter reduction in the ROI. The ROI region receives unattenuated x-rays while the peripheral region receives x-rays reduced in intensity by an ROI attenuator. The scatter within the ROI part of the image originates from both the unattenuated ROI and the attenuated peripheral region. The scatter contribution from the periphery is reduced in intensity because of the reduced primary x-rays in that region and the scatter fraction in the ROI is thus reduced. In this study, the scatter fraction for various kVp's, air-gaps and field sizes was measured for a uniform head equivalent phantom. The scatter fraction in the ROI was calculated using a derived scatter fraction formula, which was validated with experimental measurements. It is shown that use of a ROI attenuator can be an effective way to reduce both scatter and patient dose while maintaining the superior image quality of high resolution detectors.

Keywords

Region of Interest; Scatter; ROI Attenuator; Digital Imaging

1. INTRODUCTION

When x-rays pass through a patient's body, Compton interactions produce scattered radiation. This scattered radiation is a major factor that can degrade image signal to noise ratio (SNR). SNR degradation due to scatter may be a severe problem especially in the case of low contrast object detection. To reduce the scattered radiation, possible methods are smaller fields-of-view (FOV), larger air gap between object and detector, and the use of an anti-scatter grid. Large air gaps may give rise to geometrical un-sharpness, which must be

kept minimal for high-resolution detectors. Deployment of an anti-scatter grid is an effective method to reduce scattered radiation but grids specifically designed for small pixel or high resolution detectors are unavailable. The use of conventional grids with these detectors can result in increased structure noise due to the finite thickness of grid lines. [1] Use of a smaller field of view is another option but this limits the usefulness of large field of view detectors and scanned beams are not practical for real-time imaging.

2. METHOD AND MATERIALS

Use of a large FOV, high-resolution detector with a ROI [2] attenuator is an alternative that can be used for scatter reduction without total FOV reduction. ROI imaging is used to decrease integral dose to the patient by reducing the entrance x-ray fluence with an attenuator in a region peripheral to the ROI. The reduction in exposure outside the ROI due to the ROI attenuator will also result in substantial reduction of scatter into the ROI.

X-rays are attenuated by a ROI attenuator outside the ROI (Figure 1), and then further attenuated by the phantom (Figure 2) before reaching the image receptor. For the experiment, we used AAPM uniform head equivalent phantom (6 inch PMMA and 3.2 mm Al). The scatter fraction in the ROI part of the image can be calculated if the ratio of primary x-rays in the ROI and outside the ROI is known (Figure 3).

In figure 3, area A is the ROI area and area B is the total area. Area A receives fluence attenuated by the phantom, while the fluence in the area outside A is attenuated by a ROI attenuator and the phantom. Knowing the attenuation by the ROI attenuator and the phantom, X (the primary fluence in the ROI area A) and Y (the primary fluence outside the ROI area) can be related. If Y is a fraction, f, of X, then,

$$Y = f * X$$

The primary x-ray fluence can be considered to be the sum of two separate exposures as indicated in Figure 4.

The following expression describes the scatter fraction in the ROI A:

$$\text{Scatter Fraction} = \frac{\text{Total Scatter}}{(\text{Total Primary} + \text{Total Scatter})} \quad \text{Scatter Fraction} = \frac{[Sa(1 - Sb) + f(Sb - Sa)]}{[(1 - Sb) + f(Sb - Sa)]}$$

where Sa is the scatter fraction for area A and Sb is the scatter fraction for area B.

The scatter fraction was measured using a uniform head equivalent phantom with the following conditions:

Air-Gap	3 cm, 6 cm, 9 cm and 12 cm
Area (Measured in the object plane)	9 cm ² , 25cm ² , 49 cm ² , 81cm ² , and 121 cm ²

X-ray kVp	Various kVp's between 60 and 100
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The area was measured in the object plane at the phantom entrance and the area was square in shape. The measured scatter fraction data was plotted in a 3D plot of scatter fraction vs. air gap and area. A 3D surface (3rd order polynomial) was fitted to the experimental data and the fitted polynomial function was used to estimate the scatter fraction for any given area and air gap. The scatter fraction with and without the ROI attenuator was also measured using the standard lead beam stop technique and the results were compared with the theoretical calculations of scatter fractions using the above equation.

3. RESULTS

In this section, all the results are summarized. Figures 5 and 6 show the measured scatter fractions for different areas (9 cm^2 , 25 cm^2 , 49 cm^2 , 81 cm^2 , and 121 cm^2) and air-gaps (3 cm, 6 cm, 9 cm and 12 cm) for 90 kVp. The scatter fraction increases with increasing area and decreases with increasing air-gaps. Figures 7 and 8 show the scatter fraction vs. air-gap (area) for different kVps. The scatter fraction is seen to be quite independent of the kVp.

The scatter fractions for various combinations of air-gaps and area are plotted on a 3D graph in figure 9 for 90 kVp. Figure 9 also shows the third order polynomial fit along with the experimental points. This fitted function was used to estimate the scatter fraction for any given combination of the air-gap and area. Table 1 shows the compiled results for the calculated scatter fraction and the measured scatter fraction for the ROI. For the verification of our calculation, we chose three different cases. For a 100 cm^2 area with no ROI attenuator, the measured scatter fraction was 0.60 while the calculated one was 0.61. For the confirmation for the calculated scatter fraction, we chose two ROI areas (21.9 cm^2 and 10.2 cm^2) with 1 mm thick Cu as the ROI attenuator. For 90 kVp, 1 mm thick Cu provides about 80% attenuation of the primary exposure reaching the detector. The results for the calculated scatter fraction are very close to the measured ones (0.43 compared to 0.44 and 0.37 compared to 0.38).

4. CONCLUSION

This work presents a novel use of the ROI imaging concept for scatter reduction when using high resolution detectors where current conventional grids may be inappropriate, while maintaining the image of the full FOV at reduced dose. In this study, we have developed a formulation for calculating the scatter fraction in the ROI and demonstrated that a ROI attenuator can be used as an efficient way to manage the scatter problem. We also demonstrated the validation of our formulation by obtaining very close agreement between experimental and calculated findings. The use of a ROI attenuator results in significant scatter and patient dose reduction.

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Figure 1.
Concept of ROI imaging

Figure 2.
Experimental setup

Figure 3.
Description of ROI and total area

Figure 4.

The primary x-ray fluence outside the ROI and within the ROI area is shown as the sum of two components.

Figure 5.

Scatter fraction vs. air gap for different beam sizes (9 cm², 25 cm², 49 cm², 81 cm², and 121 cm²) for 90 kVp.

Figure 6. Scatter fraction vs. beam area for different air gaps (3 cm, 6 cm, 9 cm and 12 cm) for 90 kVp.

Figure 7.
Scatter fraction vs. air gap for different kVp's

Figure 8.
Scatter fraction vs. area for different kVp's

Figure 9.
Scatter fraction vs. air gap and area for 90 kVp

Table 1

kVp	AreaB (cm ²) Total Area	Area A (cm ²) ROI Area	ROI- Attenuator	ROI Attenuator (% Attenuation)	Calculated Scatter Fraction	Measured Scatter Fraction
90	100	0	No	0	0.61	0.60
90	100	21.9	1 mm Cu	80	0.43	0.44
90	100	10.2	1 mm Cu	80	0.37	0.38