Original Article/นิพนธ์ต้นฉบับ

Impact of Dual Energy Window Scatter Correction on Image Quality in Tomographic Iodine 131

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Abstract

Background: The major limitation factors in single photon emission computed tomography (SPECT) detectability is the presence of scattered photons within the main photopeak.

Objective: To evaluate the impact of dual-energy window (DEW) scatter correction from Xeleris processing workstation (GE Healthcare) on the image quality including image contrast, background noise and contrast-to-noise ratio (CNR).

Methods: A NEMA/IEC phantom with a set of fillable spheres was used in this study. The phantom with hot lesion to warm background ratio of 10:1 were acquired with different acquisition times 20, 30, 40, and 90 seconds per frame. All projections were reconstructed with no scatter correction (NSC) and scatter correction (SC) using Xeleris vendor-supplied software.

Results: Image contrast decreased as the acquisition time increased and the larger sphere showed the greater contrast as expected. Interestingly, the contrast dropped more than half when applied SC compared with NSC. For noise, the SC resulted in an increased of image noises for all sphere sizes and acquisition times when compared with NSC. To reveal the impact of scatter on contrast and noise, the CNR was investigated, our results found that the CNR for SC was higher than NSC when acquired 30, 40, and 90 seconds per frame for small spheres (0.52 mL, 1.15 mL, and 2.57 mL), whereas in large sphere (26.52 mL and 11.49 mL), the CNRs were varied when SC or NSC applied.

Conclusions: Our results showed that the implementation of DEW scatter correction could be degraded image quality in an iodine 131 (^{131}I) SPECT when compared with uncorrected image.

Keywords: Scatter correction, DEW, SPECT, Iodine 131, Image quality

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Introduction

Image degradation in an iodine 131 (^{131}I) single photon emission computed tomography (SPECT) images results from the significant scatter in the patient or collimator-detector system due to the high energy of the 364 keV photons and the presence of significant numbers of high-energy photons (637 keV and 723 keV for 7.2% and 1.8%).[1, 2] One important cause is the presence of scattered higher-energy photons within the main photopeak window (364 keV).[2] This effect leads to lower rate of lesion detectability from poor image contrast, relatively high background noise and low contrast-to-noise ratio (CNR).[2] Scatter correction is a method to resolve the scatter and improve the quality of the SPECT images.

In clinical nuclear medicine, scatter correction is an important process in image reconstruction. There are several scatter correction methods such as dual-energy window (DEW) method, triple-energy window (TEW) method and dual-photopeak window (DPW) method that are including in the commercial processing software of nuclear medicine imaging system.[1, 3-5]

This study aims to evaluate the impact of scatter correction on the image quality parameters including image contrast, relative background noise and CNR ratio using the DEW scatter-corrected option from the commercial nuclear medicine image processing workstation.

Methods

Phantom Preparation

The NEMA/IEC (National Electrical Manufacturers Association/International Electrotechnical Commission) body phantom (Data Spectrum Corp, Chapel Hill, NC) with a set of fillable hollow spheres was used in this study. The hot lesion with warm background ratio of 10:1 was designed to represent the tumour condition in clinical radioiodine image. The ^{131}I-sodium iodide solution with activity concentration of 740 kBq/mL was filled in the hollow spheres.[6, 7] The volume specifications of the fillable hollow spheres were 26.52 mL, 11.49 mL, 5.58 mL, 2.57 mL, 1.15 mL, and 0.52 mL. However, the 5.58 mL sphere was excluded from the experiment due to a defect of phantom.

Image Acquisition

All SPECT images were acquired using a dual-head Infinia Hawkeye-4 (GE Medical Systems, Milwaukee, WI, USA) equipped with a high-energy general purpose (HEGP) collimator and crystal thickness of 25.4 mm. Sixty projections (matrix size 128 × 128, main photopeak at 364 keV with 20% energy window) are acquired in orbit mode for 360° camera rotation with different acquisition times per frame of 20, 30, 40, and 90 second per frame (s/f). Additional computed tomography (CT) images were also acquired for attenuation correction and localization of the hot spheres.

Scatter Correction and Image Reconstruction

The projection data was performed scatter correction as a pre-correction. The two data sets of the image were reconstructed with scatter correction (SC) and no scatter correction (NSC). The pulse height analyzer (PHA) is adjusted to collect photopeak events and a 20% energy window for ^{131}I at 364 keV has ranges from 327.6 keV to 400.4 keV and scatter window was set at 297 keV ± 20 % energy windows (scatter window 267.3 - 326.7 keV). More exactly, DEW scatter correction was performed using the following equation (Eq. 1).

$$Scatter\ corrected\ data = C_p - k.\frac{C_s}{W_s}.W_p \quad \text{Eq. 1}$$

Where, the counts measured within the main photopeak are defined by C_p, the counts in the scatter window by C_s, and the sizes of the windows by W_p, W_s respectively. The k is the subtraction weighting factor. It is common to use a value of 0.5 which initially proposed by Jaszczak et al.[8] The k factor also set at 0.5 in our study.

Chang's method attenuation correction was used with vendor recommended settings. Then, the post-correction SPECT data were reconstructed with the Xeleris processing workstation version 2.1753 (GE Healthcare, Milwaukee, WI, USA). Image reconstruction were used FBP with a Hann filter at 0.7 of cutoff frequency and an ordered-subset

expectation maximization (OSEM) reconstructions with 2 iterations and 12 subsets.

Image Quality Evaluation

The image quality was evaluated using image contrast (Eq. 2) and CNR (Eq. 3).[7, 9]

$$Contrast = \frac{|C - C_B|}{C_B} \quad \text{Eq. 2}$$

$$CNR = \frac{|C - C_B|}{\sigma_B} \quad \text{Eq. 3}$$

Where C is the mean pixel value in the sphere region of interest (ROI), C_B is the mean voxel value in the background ROI, and σ_B is the standard deviation (SD) in the background ROI. A measure relative noise of the background using the percentage coefficient of variation (%CV) was also calculated using following equation (Eq. 4).[10]

$$\%CV = \frac{\sigma_B}{C_B} \times 100 \quad \text{Eq. 4}$$

Sphere ROIs were drawn with the size about 50% of each sphere on the co-registered CT image (Figure 1). The background ROI was delineated at the center of the phantom.

To eliminate inconsistency, the ROIs were repeatedly drawn on three separate occasions in order to obtain the mean and standard deviation of each value.

Ethics

This study was approved by the Committee on Human Rights Related to Research Involving Human Subjects Faculty of Medicine Ramathibodi Hospital, Mahidol University, No. MURA 2016/554 on August 30, 2016.

Results

This study evaluated the impact of scatter correction on the image quality using the NEMA/IEC body phantom with hot lesion to warm background ratio of 10:1. The image contrast based on sphere size of phantom and acquisition time per frame were illustrated in Figure 2 for NSC group and in Figure 3 for SC group.

As seen from Figure 3 and 4, the image contrast decreased as the acquisition time increased. Additionally, the larger sphere showed the greater contrast, as expected. Interestingly, the overall image contrasts for SC were poorer than those images that NSC. For example, the contrast for largest sphere (26.52 mL) was above 2 for all acquisition times whereas the contrast dropped more than 50% when applied scatter correction.

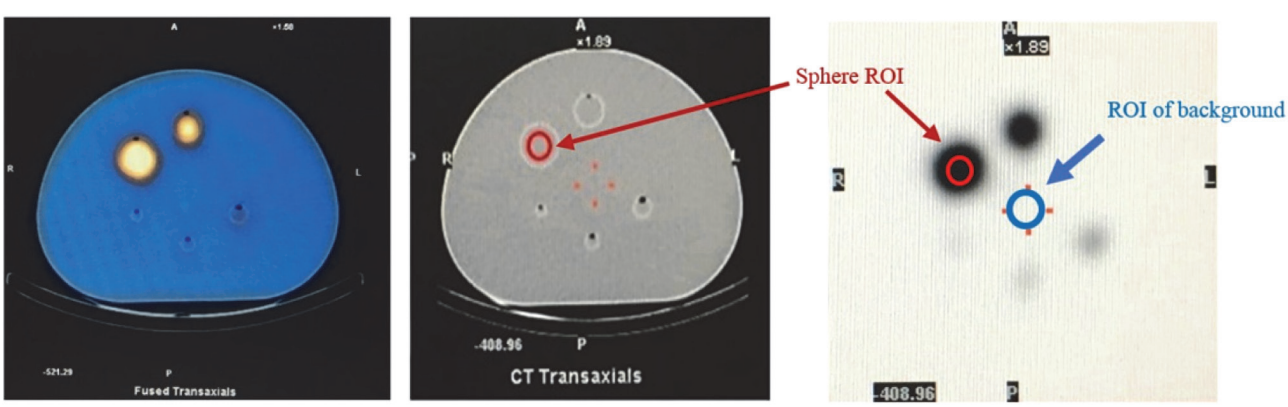


Figure 1 *^{131}I SPECT/CT Trans-Axial Images of NEMA/IEC Body Phantom*
(left) Fused SPECT/CT with lesion to warm background ratio of 10:1 (centre) CT image was used to draw ROI with size about 50% of each sphere (right) SPECT image illustrated the sphere ROI and background ROI.

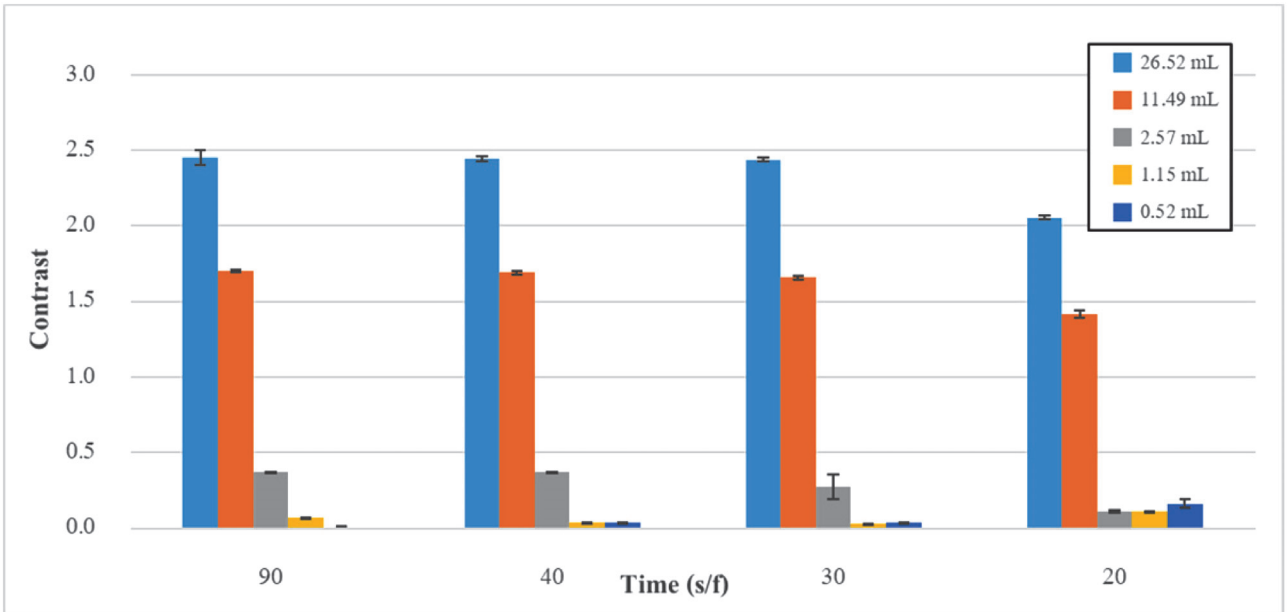


Figure 2 *Image Contrast Using the Five Sphere Sizes for Various Acquisition Time per Frame in NSC*

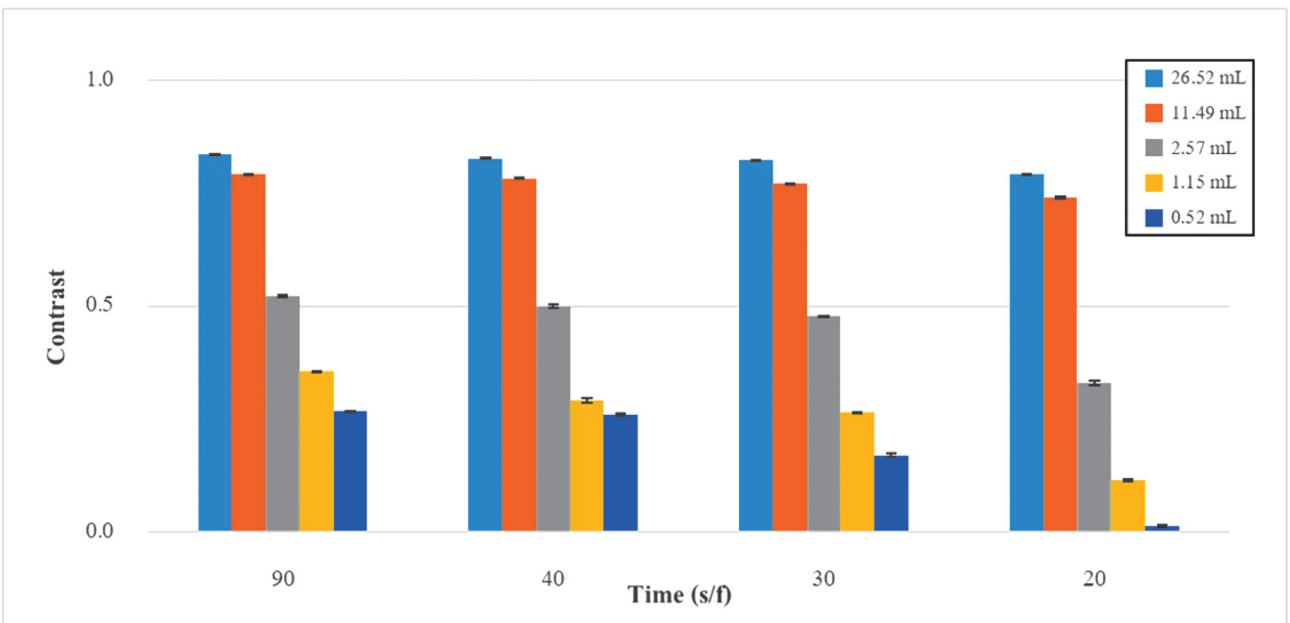


Figure 3 *Image Contrast Using the Five Sphere Sizes for Various Acquisition Time per Frame in SC*

The relative noise of the background expressed as %CV of each sphere and acquisition time for NSC and SC shown in Figure 4 and 5.

Based on the plots, the overall results also indicated that the %CV of background noise was elevated in larger object and shorter acquisition time for both NSC and SC. Remarkably, the SC with DEW method resulted in an increased of overall image noises for all sphere sizes and acquisition times with compared with NSC.

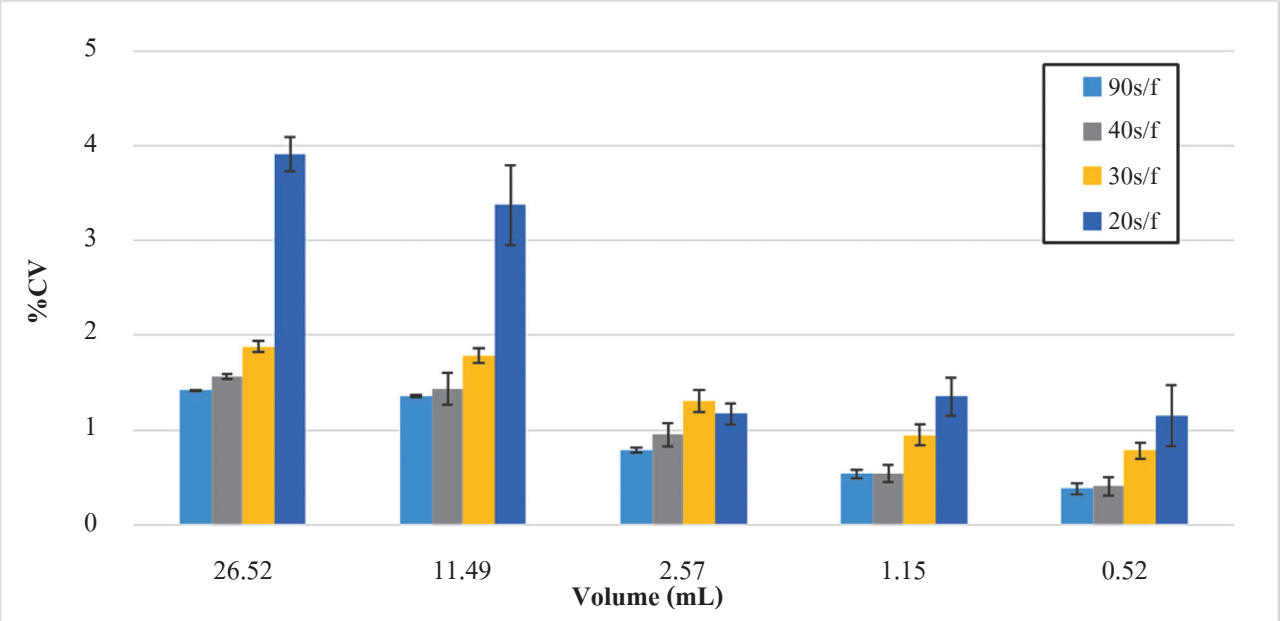


Figure 4 *Relative Noise of the Background Expressed as %CV (± SD) Plot With Sphere Size of 26.52, 11.49, 2.57, 1.15, and 0.52 mL, and Acquisition Time of 20, 30, 40, and 90 s/f for NSC*

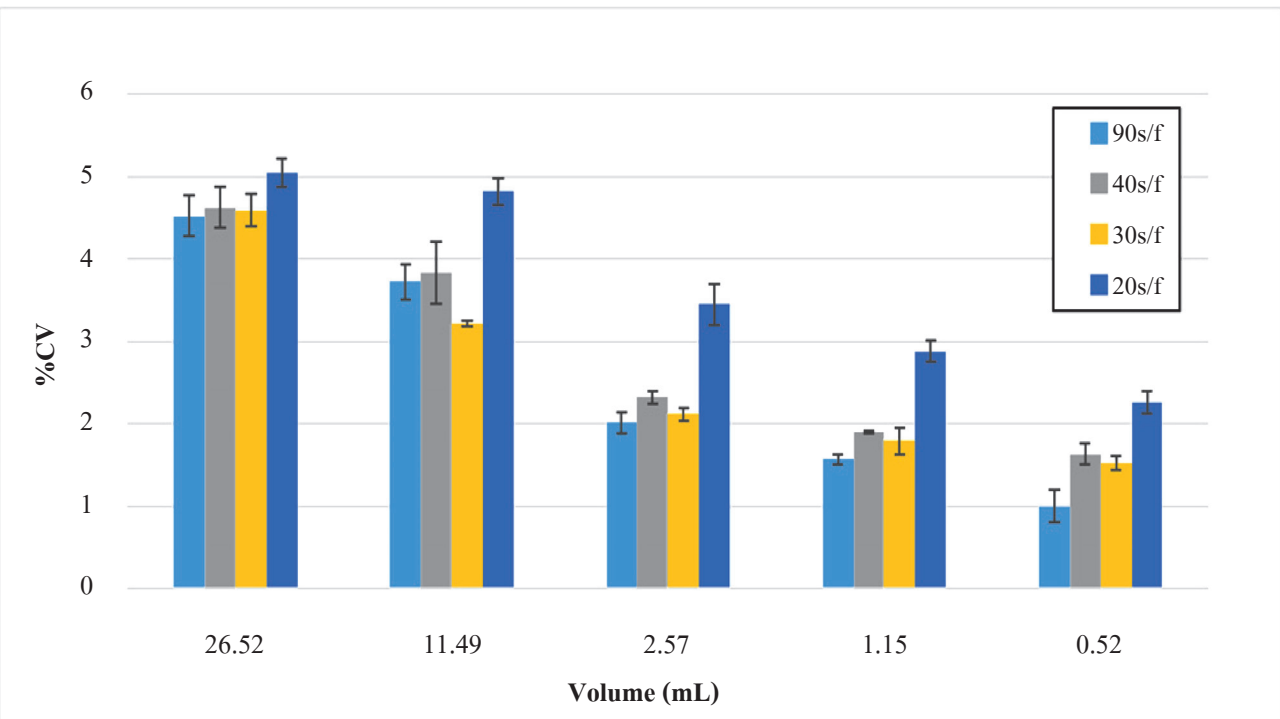


Figure 5 *Relative Noise of the Background Expressed as %CV (± SD) Plot With Sphere Size of 26.52, 11.49, 2.57, 1.15, and 0.52 mL, and Acquisition Time of 20, 30, 40, and 90 s/f for SC*

To reveal the impact of scatter on contrast and noise, the CNR was investigated as this factor can associate between those contrasts and noises. Accordingly, the comparison of CNR between NSC and SC are shown in Figure 6.

In NSC, CNR was high when using large sphere size and it was rapid drop in small sphere size. SC improved CNR in sphere with smaller size but it decreased CNR when larger sphere was applied. This effect was obviously presented when the acquisition time per frame was increased.

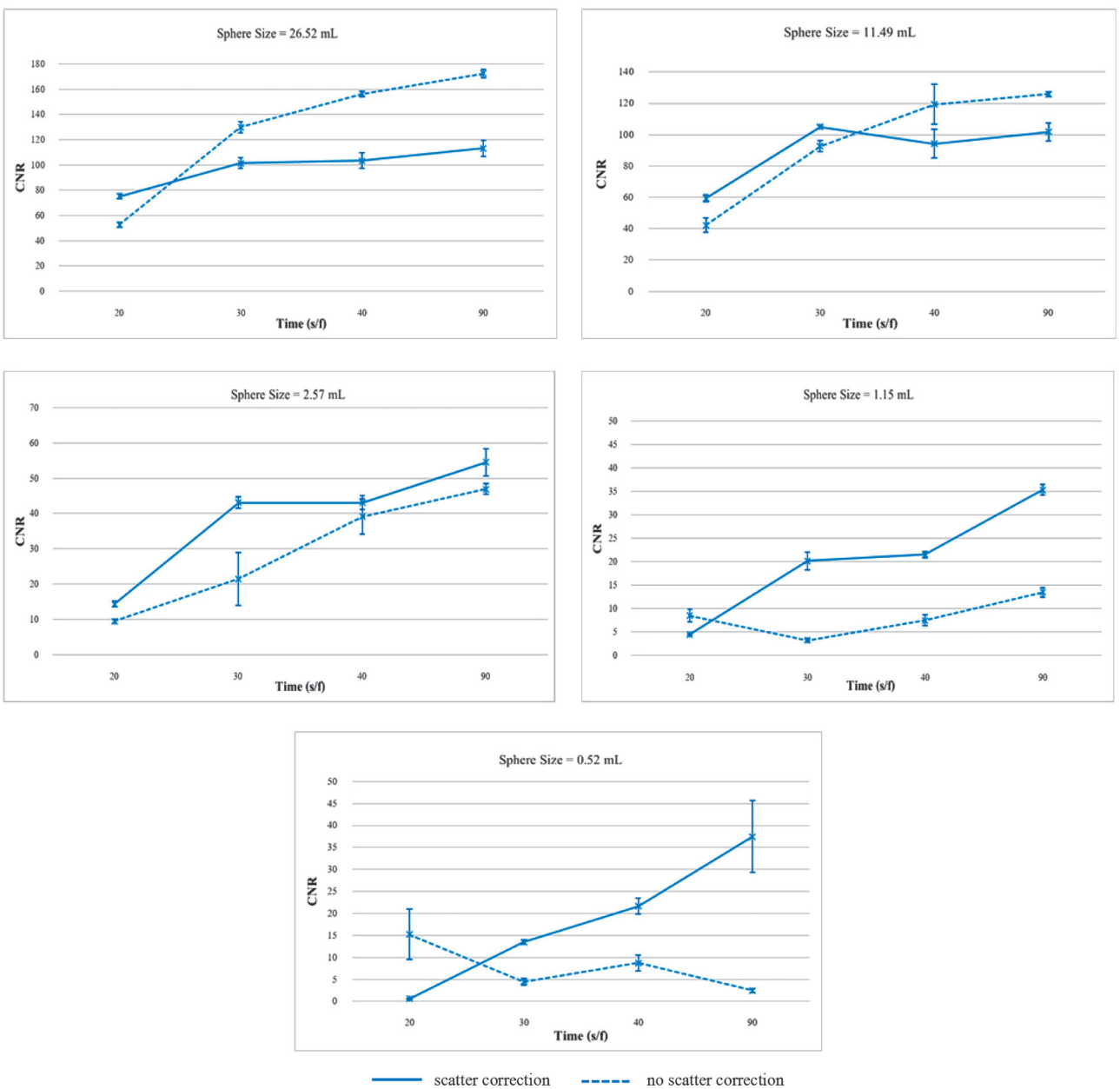


Figure 6 *Comparison of CNR Between NSC (Dashed Line) and SC (Solid Line) With Acquisition Time of 20, 30, 40, and 90 s/f Using Different Sphere Size*

Discussion

The scattered photon is altered the image quality, especially in tomographic imaging. In most nuclear medicine commercial software, the simplicity scatter correction approach is employed in the clinical routine for example DEW or TEW. In our institute, the DEW scatter correction approach is implemented in the Xeleris workstation. The principle of the DEW method is well known as the scattered window located below the photopeak window is additionally acquired. Then, the scattered counts are multiplied with a vendor specific *k* factor and subtracted from the counts in the main photopeak. However, the impact of scatter correction on image quality is not explicitly explored. In this work, we studied the impact of scatter correction in tomographic ^{131}I using the image contrast, background noise and CNR.

For image contrast, our results showed that the image contrast dropped when applied the scatter correction. This might be related to number of counts. Many studies proposed that the results of the DEW method strongly depend on the *k* factor, which set at 0.5 in our system.[1, 4, 5] The *k* factor commonly depends on the shape of the object, nonuniform attenuation in object/background and acquisition geometry. Hence, the use of the DEW scatter correction can lead to either under- or over-correction of counts and then effect the image contrast according to Eq. 2.

According to Figure 4 and 5, the %CV for SC increased in all sphere sizes compared with NSC, reflecting the increase in noise with scatter correction. As mentioned earlier, the scatter correction is a subtraction process of the scattered counts in projection data prior to reconstruction (pre-correction process). Hence, the SC alters the Poisson nature of the noise and so effect the performance of iterative reconstruction algorithm. Previous report confirmed that SC using DEW potentially increased noise in the image and our findings were inconsistent with their results.[3, 11]

To connect image contrast and noise, the CNR includes both parameters and it can represent the practical quantitative parameter. SC improved CNR in spheres with smaller size (2.57 mL, 1.15 mL, and 0.52 mL) but it degraded CNR in spheres with larger size (26.52 mL and 11.49 mL). These were resulted from the elevated relative background noise in large spheres when applied SC (Figure 4 and 5). The previous work on using DEW scatter correction proposed that removing scattered photons could be resulted the higher noise and declining the image contrast at the same time especially in non-uniform high counts (large sphere).[5]

To compare with other scatter correction methods, study of Asl et al[3] evaluated six scatter correction approaches in SPECT using the computer simulation. Their results indicated that DEW increases the image noise and image contrast, while, the TEW improve the image quality parameters including higher contrast, higher signal-to-noise ratio (SNR) and lower image noise. Many works confirmed that the TEW approach is the most proper scatter correction method due to their straightforwardness, uniform performance and good enhancement image contrast and SNR. In addition, The Medical Internal Radiation Dose (MIRD) pamphlet no.24*: Guidelines for quantitative ^{131}I SPECT in dosimetry applications* recommended that TEW is well appropriated for ^{131}I because the subtraction of scattered counts above the photopeak could reduce the down scatter from high energy penetration of 637 keV and 723 keV photons.[2]

Conclusions

Our results showed that the implementation of DEW scatter correction could be degraded image quality in ^{131}I SPECT including reduce contrast, elevated relative background noise and decreased CNR especially in large size spheres when compared with uncorrected image. This study was showed that the vendor supplied scatter correction could be additional investigated prior to use especially in ^{131}I SPECT. As this scatter correction could improve image quality only in some, but might not work in all clinical situations.

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Original Article/นิพนธ์ต้นฉบับ

การศึกษาผลของการแก้รังสีกระเจิงด้วยวิธี Double Energy Window กับคุณภาพของภาพตัดขวางไอโอดีนรังสี-131

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บทคัดย่อ

บทนำ: รังสีกระเจิงเป็นปัจจัยสำคัญที่ทำให้คุณภาพภาพตัดขวางทางเวชศาสตร์นิวเคลียร์มีคุณภาพลดลง โดยทั่วไปโปรแกรมที่ใช้ในการประมวลผลภาพทางคลินิกจะมีอัลกอริทึมช่วยในการแก้รังสีกระเจิงดังกล่าว

วัตถุประสงค์: เพื่อศึกษาและเปรียบเทียบคุณภาพของภาพตัดขวางไอโอดีน-131 ที่แก้รังสีกระเจิงด้วยวิธีการ Double energy window (DEW) และไม่แก้รังสีกระเจิง

วิธีการศึกษา: การวิจัยทำในหุ่นจำลอง NEMA/IEC ที่ภายในประกอบด้วยลูกทรงกลมขนาดต่างๆ ที่สามารถบรรจุไอโอดีนรังสี-131 โดยกำหนดค่าความเข้มข้นของสารไอโอดีนรังสีในทรงกลมให้มีอัตราส่วน 10:1 เมื่อเทียบกับบริเวณข้างเคียง (Background) หลังจากนั้นนำหุ่นจำลองมาถ่ายภาพด้วยเครื่อง SPECT/CT โดยใช้เวลาการเก็บข้อมูลในแต่ละมุมที่ 20, 30, 40 และ 90 วินาที และนำมาสร้างภาพตัดขวางโดยการแก้รังสีกระเจิงด้วยวิธี DEW และไม่แก้รังสีกระเจิงโดยใช้โปรแกรมประมวลผลภาพ Xeleris (ของบริษัท GE Healthcare) และประเมินคุณภาพของภาพโดยการใช้ค่าการเปรียบต่าง ค่าสัญญาณรบกวน และอัตราส่วนของค่าการเปรียบต่างและสัญญาณรบกวน

ผลการศึกษา: ค่าการเปรียบต่างมากขึ้นเมื่อเก็บข้อมูลนานขึ้นและทรงกลมมีขนาดใหญ่ขึ้น อย่างไรก็ตาม การแก้รังสีกระเจิงด้วยวิธี DEW ทำให้ค่าการเปรียบต่างลดลง และค่าสัญญาณรบกวนในภาพมากขึ้นเมื่อเปรียบเทียบกับภาพที่ไม่ได้แก้รังสีกระเจิง

สรุป: การแก้รังสีกระเจิงด้วยวิธี DEW ในโปรแกรมประมวลผลภาพที่ติดตั้งมาพร้อมกับเครื่อง SPECT/CT ทำให้คุณภาพของภาพตัดขวางไอโอดีนรังสี-131 มีคุณภาพแย่ลง

คำสำคัญ: การแก้รังสีกระเจิง วิธี Double energy window ภาพตัดขวาง ไอโอดีนรังสี-131 คุณภาพของภาพ

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