Iranian Journal of Medical Physics
ijmp.mums.ac.ir

Energy Window Optimization Using Triple Energy Window Scatter Correction Method for In-111 SPECT Imaging: A SIMIND Monte Carlo Study

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ARTICLE INFO

Article type:
Original Paper

Article history:
Received: Feb 25, 2020
Accepted: Aug 10, 2020

Keywords:
SPECT
Contrast
In-111
SIMIND Program

ABSTRACT

Introduction: Detecting scattered photons in the photo peak window degrades the image contrast and quantitative accuracy of single-photon emission computed tomography (SPECT) imaging. This study aimed to determine optimal main- and sub-energy windows for Triple Energy Window (TEW) in In-111.

Material and Methods: We used the simulating medical imaging nuclear detectors (SIMIND) program to simulate the Siemens SYMBIA gamma camera equipped with a medium energy (ME) collimator. We also used the SIMIND Monte Carlo program to generate theIn-111SPECT projection data of the Jaszczak phantom. The phantom consisting of six spheres with different diameters (9.5, 12.7, 19.1, 15.9, 25.4, and 31.8 mm) was used to evaluate the image contrast. Geometric, scatter, and penetration fraction, point spread functions, and contrast curves were drawn and compared.

Results: The results showed that the 171keVphotopeak compared to the 245keVphotopeak yielded the best results with an ME collimator when the TEW scatter correction method was applied. The reason can be the large amount of scatter and penetration from the photo peak and the collimator for the 245keVphotopeak window.

Conclusion: With the TEW scatter correction method, it is better to use a 171keVphotopeak window because of its better spatial resolution and image contrast.

► *Please cite this article as:*
Asmi H, Bentayeb F, Bouzekraoui Y, Bonutti F. Energy Window Optimization Using Triple Energy Window Scatter Correction Method for In-111 SPECT Imaging: A SIMIND Monte Carlo Study. Iran J Med Phys 2021; 18: 300-305. 10.22038/IJMP.2020.46778.1735.

Introduction

The Monte Carlo simulation program develops scatter correction reconstruction algorithms and imaging parameters. The Monte Carlo simulation program, SIMIND, simulates a single-photon emission computed tomography (SPECT) gamma camera and can easily classify scattered and un scattered photons.

In radionuclide imaging with a gamma camera, the presence of scatter in the photo peak energy window reduces resolution and image contrast and introduces significant uncertainty in quantifying the underlying activity distribution. Therefore, scattered counts should be eliminated from the total image to obtain the best image quality. The counts of scattered photons can be reduced in the radioisotope SPECT study [1-9]. In In-111 SPECT images, the scatter correction improves contrast yielding clinically useful accuracy of activity quantification. These activity values can be used as an input for absorbed dose calculations in targeted radiotherapy. For the triple energy window (TEW) method, scatter estimation in the total image is acquired in energy windows below and above the main window. The scatter fraction in the photo peak window is estimated from counts acquired in two adjacent narrow windows and is subtracted from the scatter fraction inthe main window. TEW has proved effective by improving image contrast and quantification. In-111 emits gamma rays at energies of 171 and 245 keV, with nearly equal emission probabilities, and has a half-life (67.9 h)[10]; it can be imaged with standard gamma cameras using a medium energy (ME) collimator.In-111 is quantified using Monte Carlo simulation to subtract scattered counts from the total image. Previous studies [11, 12] have assessed TEW scatter correction for In-111 SPECT imaging. However, the determination of optimal main- and sub-energy windows was different in each study. The present study attempted to determine optimal main- and sub-energy windows for the TEW method in In-111 using a SIMIND simulation.

Materials and Methods

This study used the SIMIND Monte Carlo simulation program [13] to simulate the Siemens SYMBIA gamma camera. The dimension of the detector surface was 59.1×44.5 cm^2 with 2.54 cm NaI (Tl) crystal thickness.

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Table 1. The collimator data

Collimator	Geometry of the hole	Length of the hole(mm)	Septal thickness(mm)	Diameter of the hole(mm)	Collimator type
ME	Hexagonal	4.064	0.114	0.294	Parallel hole

Table 2. Main radiation emission rays of In-111

Energy (keV)	22.98	23.17	26.15	26.68	150.81	171.28	245.35
Abundance	0.24	0.44	0.12	0.02	0.00	0.91	0.94

A water-filled cylindrical phantom with the dimension 16×22×22 $cm^3$was placed at 15cm from the detector surface. We used a planar acquisition of the In-111 point source with a 0.05 cm diameter located in the center of the cylinder phantom to evaluate the resolution. Moreover, we used the Jaszak phantom consisting of six hot spheres ranging from 9.5 mm to 31.8 mm in diameter to evaluate the image contrast. In this simulation, we used an ME collimator, as shown in Table1, Table 2 shows the main radiation emission data. The SIMIND program consisted of two programs: CHANGE that defined parameters and SIMIND that performed the actual simulation. Also, CHANGE contained menus that prompted the user to input specific parameters [13,14].The photon count generated for each simulation was 50million. The counts were acquired in the two 20% windows centered on 171 and 245 keV. The projections were generated in matrices of 128 × 128 pixels with a0.39 cm pixel size. We imported each binary image created by SIMIND to Image J software [15]. Figure 1 shows the geometry used during the simulation.

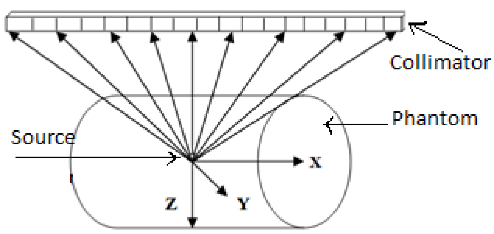


Figure 1. Simulation geometry

Triple energy window (TEW) method

The TEW method estimates scattered counts in the photo peak window with the secondary energy window for each pixel. This study used two 20% main-energy windows centered on 171and 245keVwith3keV sub-energy windows. The counts of scattered and primary photons were calculated using the following equation [1-3]:

$$C_{sca} = \left(\frac{C_{left}}{W_s} + \frac{C_{right}}{W_s}\right) \times \frac{W_m}{2} \quad (1)$$

$$C_p = C_{tot} - C_{sca} \quad (2)$$

Where

C_{left}: counts in the lower sub-energy window; C_{right}: counts in the upper sub-energy window;

W_s: the width of the sub-energy window; W_m: the width of the main window;

C_{tot}: counts in the main window; C_{sca}: scatter counts, and C_p: primary counts.

We evaluated the point spread functions (PSFs) and image contrast assessment to quantify the In-111 SPECT images. The contrast was calculated using Equation (1):

$$\text{Contrast} = \frac{C_{S-}C_b}{C_{S+}C_b} \quad (3)$$

Where C_s and C_b are the mean pixel values of the spheres activity and the background activity as noise, respectively.

Results

The decomposition of the simulated energy spectrum is shown in Figure 2 , Figure 3 shows the total, scatter, and corrected images of the In-111 point source (with both 171kev and 245keV)obtained from the simulation. The PSFs of the projection data from each acquisition are shown in Figure 4.We compared counts provided by the Monte Carlo simulation and those obtained by TEW. The TEW-corrected PSF was closer to the primary PSF than to the total PSF but was still significantly different due to the finite spatial resolution of the gamma camera for both 171keV and 245keV.The contribution of the geometric (photons detected without interaction inside the collimator),penetration(photons penetrating the collimator septa that did not scatter in the collimator or the object), and scattering (photons scattered in the collimator or the object) fraction in the parallel-hole collimator (ME) for each emission peak for the point source using Monte Carlo simulation is given in Figure5. As shown in the figure, the geometric fraction value for the 171 keV and 245 keV photo peak windows was 93% and 84%, respectively. The geometric fraction using the171keVphotopeak window was more important than that using the245keV photo peak. Photons with high energy increased penetration and scatter acquired in the photo peak window. In nuclear medicine imaging, image contrast refers to differences in intensity in parts of the image corresponding to different levels of radioactive uptake in the object. The primary factor affecting contrast is added background counting rates. Hence, an image of high contrast has a significant role in accurate activity estimation.

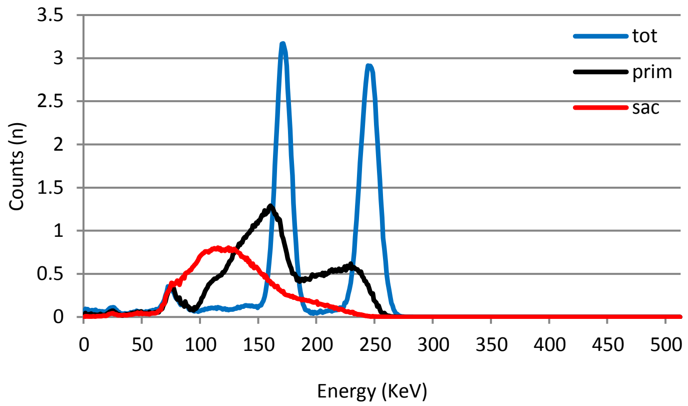


Figure 2. Simulated separated energy spectra for a point source in water

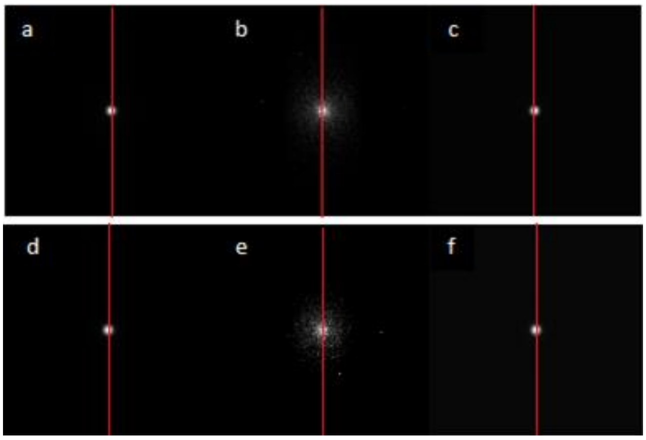


Figure 3. Point source images: with 171keV: total image (a). Scatter image (b) and corrected image with TEW(c); with 245keV: total image (d). Scatter image (e) and corrected image with TEW (f).

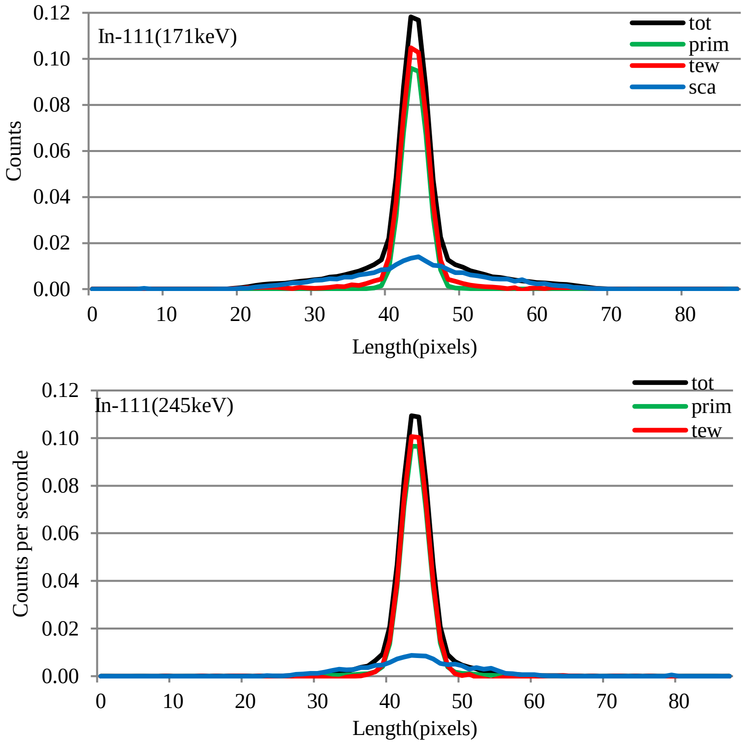


Figure 4. Comparison of the point spread functions of the projection data for true primary photons and the projection data for primary photons estimated using the TEW scatter correction method for In-111(171keV) and In-111(245keV)

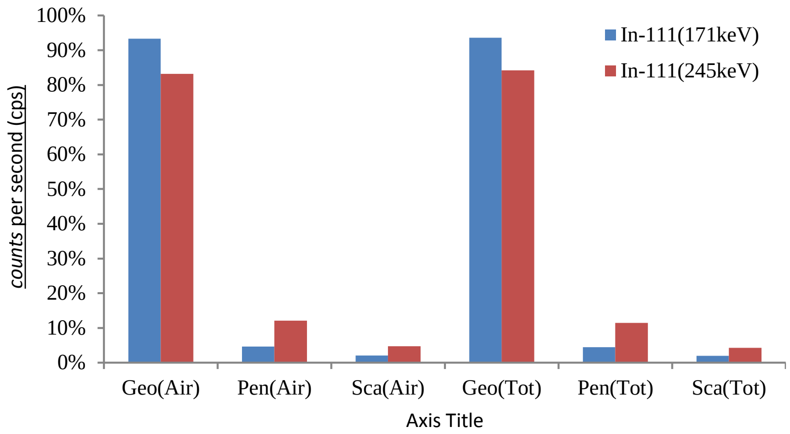


Figure 5. History of photons reaching the detector (with a scattering medium) for In-111 with a ME collimator. Penetration (Pen) photons are photons passing through septa without attenuation. Scatter (Sca) photons are photons scattered in the collimator. Finally, geometric (Geo) photons are photons passing through a collimator hole.

Table 3. Contrast of the six hot spheres of a Jaszcak phantom with and without the TEW method

		S_1	S_2	S_3	S_4	S_5	S_6
In-111(171keV)	Without TEW	0.93	0.87	0.74	0.65	0.37	0.19
	With TEW	0.98	0.97	0.92	0.89	0.77	0.63
In-111(245keV)	Without TEW	0.97	0.93	0.86	0.80	0.61	0.38
	With TEW	0.86	0.75	0.58	0.49	0.32	0.16

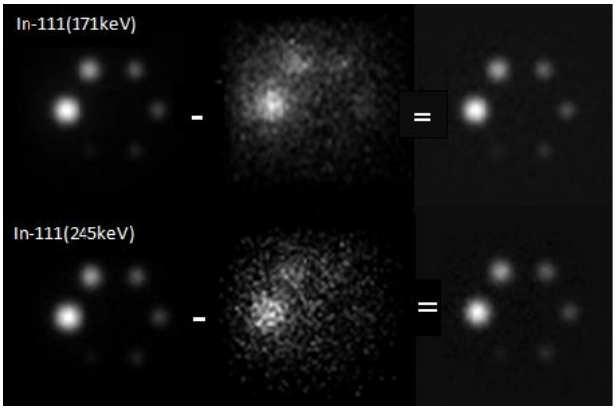
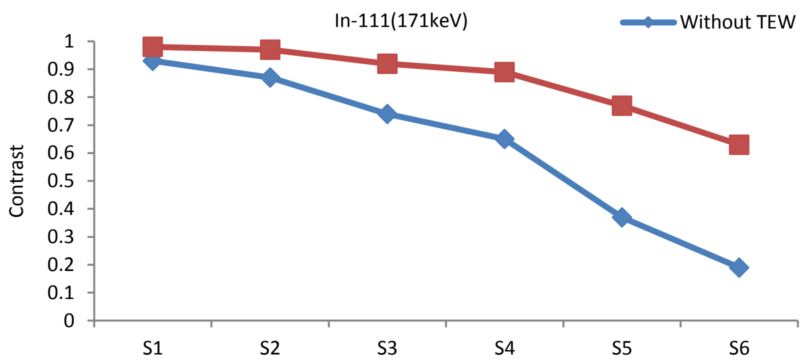


Figure 6. The reconstructed images of the simulated Jaszak phantom SPECT for comparing the image contrast of the six hot spheres with different diameters: 9.5., 12.7., 19.1., 15.9., 25.4, and 31.8 mm before and after the TEW method. In-111 SPECT imageswere generated using a simulated phantom study.



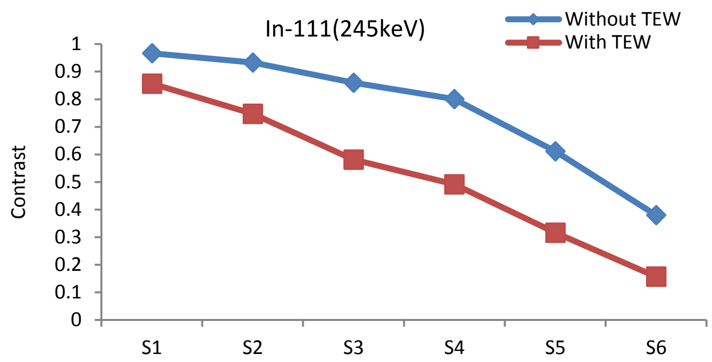


Figure 7. Contrast of the six hot spheres obtained without and with the TEW method

Table 3 shows the effects of the TEW method for In-111 SPECT imaging with the parallel-hole collimator on the image contrast of the hot spheres. Reconstructed images used for the contrast study are shown in Figure 6. In comparison to the 245keV photopeak window, the171keVphotopeak window increased the image contrast of all the spheres. Hence, the image contrast of the 171 keV main-energy widow with 3 keV sub-energy windows with TEW was significantly better when the TEW method was applied, as compared to the 245 keV window (Figure 7).

Discussion

In SPECT, resolution and image contrast are affected by collimator penetration and scatter. Many studies have investigatedIn-111 quantification [11-12]. This study used the TEW method to optimize main and secondary energy windows for In-111 to subtract scattered counts from the total image, which lost contrast and resolution. We obtained the best contrast for all the spheres with the 171 keV window using the TEW method. We can easily implement TEW in experimental studies and determine scattered photons in images in all situations.

Conclusion

With the TEW method, it is better to use an ME collimator with a20 % (171keV) main-energy window with 3keV sub-energy windows because of its better spatial resolution and image contrast. The TEW method will be helpful in studies with a single radionuclide and multiple photo peaks, such as In-111.

Acknowledgment

The authors are grateful to the International Atomic Energy Agency (IAEA) for their sincere cooperation.

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