Energy Window and Collimator Optimization in Lutetium-177 Single-photon Emission Computed Tomography Imaging using Monte Carlo Simulation

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Abstract

Introduction: In lutetium-177 (Lu-177) single-photon emission computed tomography (SPECT) imaging, the accuracy of activity quantification is degraded by penetrated and scattered photons. We assessed the scattered photon fractions in order to determine the optimal situation and development of correction method. This study proposes to compare the image quality that can be achieved by three collimators. **Materials and Methods:** Siemens Medical System Symbia fitted with high-energy (HE), medium-energy (ME), and low-energy high-resolution collimators was simulated using the SIMIND Monte Carlo code simulation code. Counts were collected in three different main-energy window widths (20%, 15%, and 10%) for Lu-177 point source. Primary and scattered point spread functions and also geometric, penetration, scattering were drawn and analyzed. **Results:** In Lu-177 imaging, a 20% of main-energy window and ME collimator were found to be optimal. HE collimator can be used when the resolution is not required. **Conclusion:** These results provide the optimal energy window and collimator in Lu-177 SPECT imaging and will help the quantification of Lu-177.

Keywords: *Energy window, lutetium-177 imaging, penetration, primary, scatter, SIMIND*

Introduction

In recent years, lutetium-177 (Lu-177) isotope is a promising radionuclide for the treatment of neuroendocrine tumors and prostate cancer.[1-6] Lu-177 has a therapeutic beta-energy of 0.5 MeV and two main gamma-energies of 113 and 208 keV (6.1% and 10.3% yield) used for imaging to evaluate the radiotracer biodistribution. We used only the higher energy peak because of downscatter from the 208 keV peak into the 113 keV window. Previous studies were investigated experimentally 20% energy window with medium-energy (ME) collimator for the 208 keV.[7-9] Gamma camera cannot classify the image-forming photons into primary and scattered photons. Knowledge of scatter distribution is essential for the optimization of imaging parameters and development of correction method. In this work, we evaluated three collimators high-energy (HE), Medium -energy (ME) and low-energy high resolution (LEHR) and 20%, 15%, and 10% energy windows around the 208 keV using the SIMIND Monte Carlo code .[10,11]

Materials and Methods

In experimental study, it was not easy to calculate the scattered photon fraction accurately. Using a Monte Carlo simulation, it was possible to track the photons and hence calculate the fractions of primary, scattered, and collimator-penetrated photons. Since high scatter and penetration fraction have deteriorated the image quality, their characterizations give insight into the effectiveness of the chosen collimator and energy window. In this work, we used Monte Carlo simulation code to simulate a planar acquisition of the Lu-177 point source having 0.05 cm diameter and located in the center of the cylinder phantom. The dimension of crystal surface was 59.1 × 44.5 and had 2.54 cm NaI (Tl) crystal thickness. A water-flled cylindricaphantom of dimension 16 cm × 22 cm × 22 cm was placed at 15 cm from the detector surface. Three parallel-hole collimators have been used during the simulation: HE, ME, and LEHR. The collimators data used during the simulation are given in Table 1. Lutetium-177 radiation emission rays are

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Received: 28-06 -2019,
Revised: 24-07-2019,
Accepted: 28-07-2019,
Published: 31-12-2019.

Access this article online
Website: www.ijnm.in
DOI: 10.4103/ijnm.IJNM_121_19
Quick Response Code:

How to cite this article: Asmi H, Bentayeb F, Bouzekraoui Y, Bonutti F, Douama S. Energy window and collimator optimization in lutetium-177 single-photon emission computed tomography imaging using Monte Carlo simulation. Indian J Nucl Med 2020;35:36-9.

shown in Table 2. The. The Figure 1 shows the geometric used during the simulation. The projections were generated in matrices of 128 ×128 pixels, 0.39 cm pixel size. We imported the images created by SIMIND in ImageJ software Institutes of Health and the Laboratory for Optical and Computational Instrumentation, University of Wisconsin (Bethesda, Maryland, USA).[12] The authors of the SIMIND have used the delta-scattering methods to sample the photon interaction through the collimators.[13] Therefore, with SIMIND Monte Carlo program, it is possible to calculate the fractions of geometrical, penetrating, and scattered photons inside the photopeak.

Results and Discussion

Figure 2 shows the simulated total energy spectrum of a Lu-177 point source in water placed at 15 cm away from detector surface. The spectrum characteristics will help explaining the choice of collimator type of imaging. Spatial resolution is an important system property and was obtained using the point spread function (PSF). In this study, we evaluated the primary and scattered PSFs for Lu-177 single-photon emission computed tomography (SPECT) imaging. It varies in shape and magnitude with collimators, as illustrated in Figure 3. It clear that, when using the ME and LEHR, we obtained a large and similar primary components, while a small components of this one for HE collimator.

In Lu-177 SPECT, image quality and quantification accuracy are degraded by scatter and penetration in the collimator. In this study, we evaluated the geometric, penetration, and scatter component in parallel-hole collimators (HE, ME, and LEHR) for 20%, 15%, and 10% energy windows, respectively, using Monte Carlo simulation. Figure 3 shows the variation of geometric, penetration, and scatter component with energy window width in HE, ME, and LEHR collimators, respectively. Spatial resolution was obtained using full-width half maximum (FWHM) and full-width tenth maximum (FWTM) of the PSF curve. Results for both FWHM and FWTM are shown in Figure 4. It shows that the use of a LEHR collimator would be better for good spatial resolution. The spatial resolution observed for HE and ME in comparison to LEHR collimator may be due to the combined effect of larger diameter of the holes (diameter = 0.506 cm for HE and diameter = 0.294 cm for ME) and increased septa thickness.

As shown in Figure 5, It is clear that the geometric component is large and remains constant with increase in energy window width collimator produces a weak component of geometric for the three windows. It suffers from a lot of penetration and scattering from the main emission peak. Collimators are made mostly of lead materials with a high density and have holes that allow only those photons traveling along the desired paths to pass through and will determine the geometrical field of view. It also essentially determines the sensitivity and

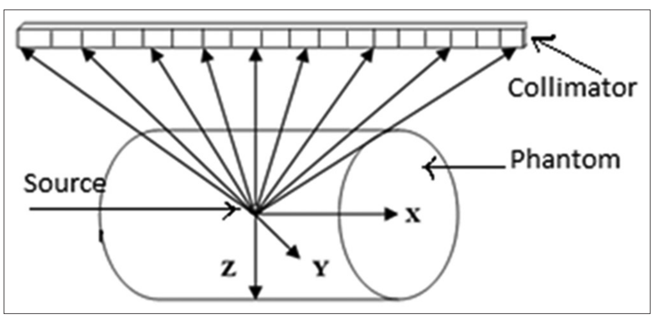

Figure 1: Geometry of simulation

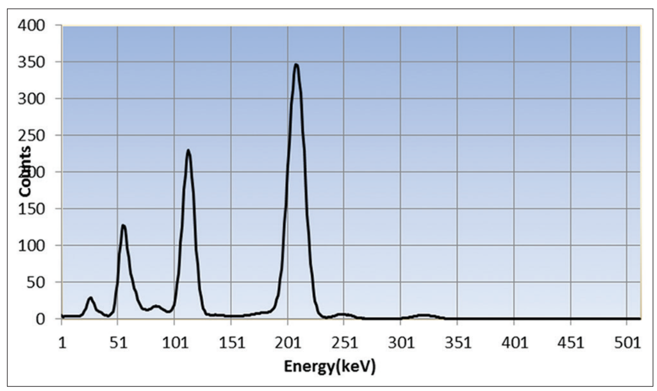

Figure 2: The simulated energy spectrum for lutetium-177

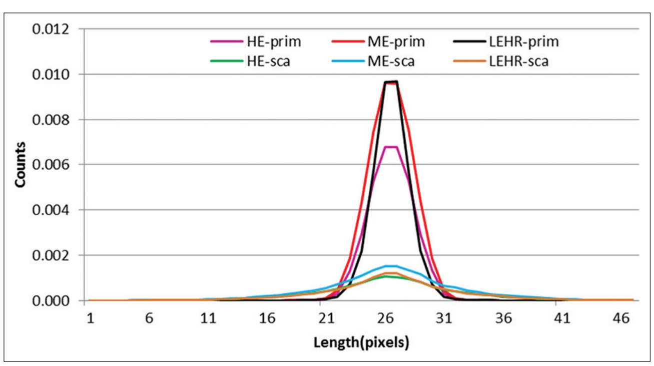

Figure 3: Primary and scattered point spread functions for high-energy, medium-energy, and low-energy high-resolution collimators

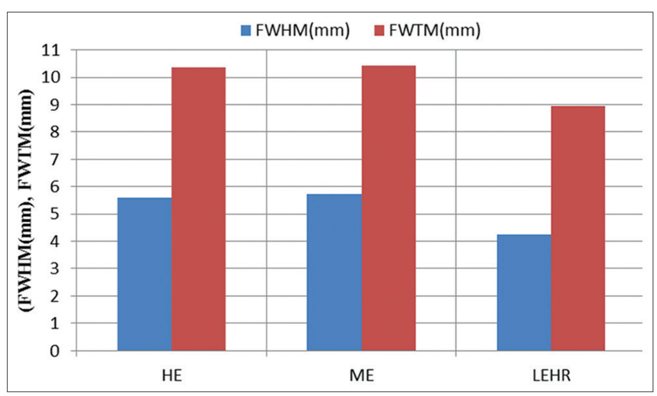

Figure 4: Full-width half maximum and full-width tenth maximum of the point source images with high-energy, medium-energy, and low-energy high-resolution collimators

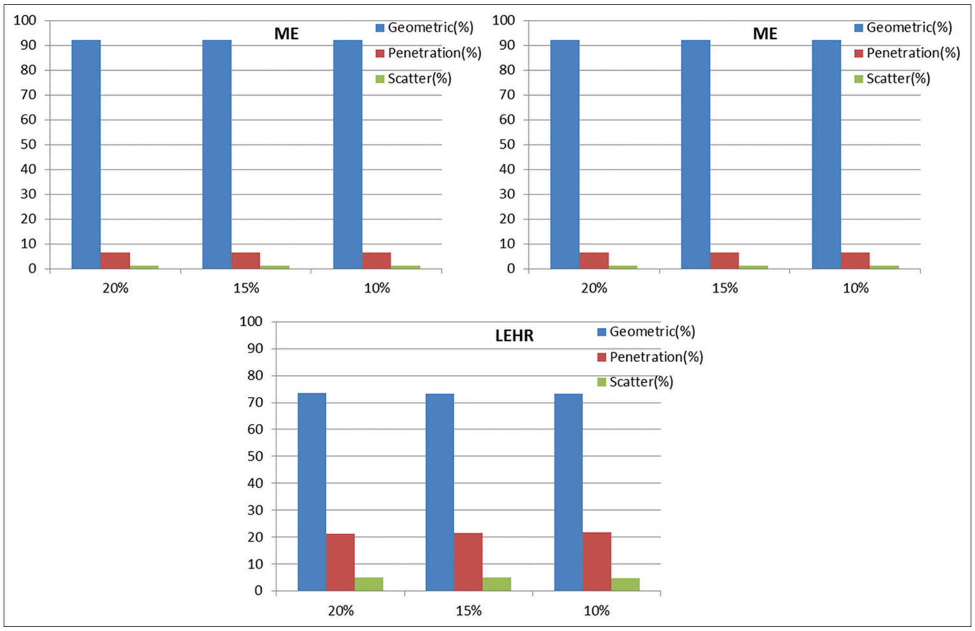

Figure 5: The variation of geometric, penetration, and scatter component with energy window width for high-energy, medium-energy, and low-energy high-resolution collimators

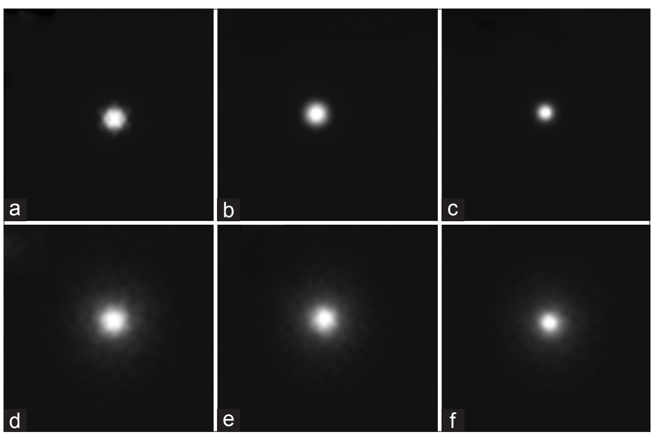

Figure 6: Total images obtained with high-energy (a), medium-energy (b), and low-energy high-resolution (c) collimators. Scatter images with high-energy (d), medium-energy (e), and low-energy high-resolution (f) collimators

resolution of the system. Collimator sensitivity refers to the percentage of incident photons that pass through the collimator. Therefore, only a small fraction of emitted photons pass through the holes and are detected, which seriously limit sensitivity. The sensitivities were determined by the ratio of the detected counts in the energy window per second per unit activity (cps/MBq). In this study, we presented the impact of HE, ME, and LEHR collimators on sensitivity as it affects the image quality in Lu-177 SPECT imaging, as illustrated in Table 3. The sensitivity decreases when the energy window width decreases. The better sensitivity is recorded by ME collimator with 20% window. Figure 6 shows total and scatter images of point source obtained as a result of the simulation.

Table 1: Design parameters of high-energy, medium-energy and Low-energy high resolution collimators

Collimators	HE	ME	LEHR
Hole diameter (cm)	0.506	0.294	0.111
Hole length (cm)	5.970	4.064	2.405
Septal thickness (cm)	0.2	0.114	0.016
Hole shape	Hexagonal	Hexagonal	Hexagonal
Type of collimation	PA	PA	PA

HE: High energy, ME: Medium energy, LEHR: Low-energy high resolution, PA: Parallel hole

Table 2: Energies and intensities of gamma rays emitted from Lu-177

Energy (keV)	Abundance (%)
54.61	0.016
55.79	0.027
62.99	0.003
63.24	0.005
64.94	0.002
71.64	0.001
112.95	0.061
208.37	0.103
249.67	0.002
321.32	0.002

The sixfold symmetry of tails is related with the hexagonal-hole shape of the collimator used in the simulation. As shown in Figure 6, the foggiest image has the highest value of collimator penetration and scatter.

Conclusion

From this study, we believe it should be evident that solely

Table 3: Sensitivity (Cps/MBq) as function of energy windows for high-energy, medium-energy, and low-energy high-resolution collimators

Energy windows, *n* (%)	HE	ME	LEHR
20	5.75	8.21	6.26
15	5.20	7.42	5.69
10	4.26	6.08	4.68

HE: High energy, ME: Medium energy, LEHR: Low-energy high resolution

using ME collimator and 20% energy window is enough to improve Lu-177 SPECT image to its fullest extent. The result provides the optimal collimator and energy window for Lu-177 SPECT imaging and will help the quantification of Lu-177.

Financial support and sponsorship

Nil.

Conflicts of interest

There are no conflicts of interest.

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