Investigation of Image Quality for Quantitative Lu-177 in SPECT imaging: A Phantom Study

I A S Mu’minah1, N R Hidayati2, P Widodo2, R Shintawati3, D S Soejoko1

1 Department of Physics, Faculty of Mathematics and Natural Sciences, Universitas Indonesia, Depok, 16424, Indonesia
2 National Nuclear Energy Agency of Indonesia, Jakarta, 12440 Indonesia
3 Department of Nuclear Medicine, Dr. Hasan Sadikin General Hospital, Bandung, 40161 Indonesia

Email: intan.apriliani@sci.ui.ac.id

Abstract. A lutetium 177 (177Lu) radiopharmaceutical has been used for a theragnostic agent in molecular radiotherapies. This study aimed to investigate the image quality of SPECT image from 177Lu from Jaszczak Cylindrical Phantom based on tomographic uniformity, local-sphere uniformity, and signal-to-noise ratio (SNR). Data acquisitions were conducted using a SPECT/CT unit. For contrast measurement, six hollow sphere inserts with diameters of 9.9, 12.4, 15.6, 19.7, 24.8, and 31.2 mm were filled by 177Lu with radioactivity concentration 10 times higher than the warm background. Images were reconstructed using three different iterative reconstruction algorithms, including Flash3D, OSEM2D, and Wallis. All reconstructions were carried out with the same iteration number of 4, subset number of 4, and Gaussian Filter. Results for tomographic uniformity measurement were (112.47±8.40%), (114.30±9.59%), and (105.94±17.49%) counts for Flash3D, OSEM2D, and Wallis algorithms, respectively. Flash3D algorithm provided better tomographic uniformity than others, while Wallis algorithm yielded the highest noisy image with low SNR. Local-sphere uniformity and SNR tended to significantly increase for sphere diameters larger than 19.70 mm. It was concluded that the reconstruction method significantly affects the image quality in 177Lu quantification. Then, it seems that Flash3D is the best reconstruction method for 177Lu SPECT image acquisition.

1. Introduction

The radionuclide Lutetium 177 (177Lu) has been proven useful in many applications for tumour treatment by radionuclide therapies. Due to its favourable decay characteristics which have not only β- particle emissions with the maximum energy of 498.3 keV, but also associated with two peak of γ-ray emission with the energies of 112.9 (6.17%) and 208.4 keV (10.36%), 177Lu has been widely used as the theragnostic agent to provide the diagnostic and therapy procedures in radionuclide therapy [1].

The guideline for the quantitative 177Lu SPECT for dosimetry and radiopharmaceutical therapy has published by MIRD Report No. 26 [1]. The estimation of absorbed dose for 177Lu quantification can be carried out by the imaging system either performed by a planar or a tomographic gamma camera imaging. Compared with planar imaging, the tomographic imaging by SPECT provides more accurate image quantification as well as for absorbed dose estimation [2,3]. However, SPECT image quantification could be significantly impacted by an image quality of a system. This research
investigated the image quality at different image reconstruction and filter compensation methods in \(^{177}\)Lu SPECT image quantifications carried out by a phantom study.

2. Material and Method

2.1. Phantom measurement

The Jaszczak Cylindrical Phantom was used for the measurement. This phantom was a circular cylinder, as the larger background compartment with the volume of 6000 mL, consisting six fillable spheres with varying diameters of 9.9, 12.4, 15.6, 19.7, 24.8 and 31.2 mm, as displayed in Figure 1. The larger background compartment was filled by \(^{177}\)Lu solution with 13 µCi/mL of radioactivity concentration. Then, each sphere was filled with a radioactivity concentration 10 times higher than the background, resulting in the sphere-to-background ratio (SBR) of 10:1.

2.2. SPECT/CT imaging protocol

Phantom was scanned to acquire the SPECT and CT images by Siemens Symbia SPECT/CT unit (Siemens Healthineers) at Dr. Hasan Sadikin General Hospital as shown in Figure 2. The SPECT image acquisition was concluded by a circular step-and-shoot acquisition orbit with 20 number of frame projections in rotation and 20 s per projections. Projection data were performed using a parallel-hole MEGP (medium energy general purpose) collimator, and the energy window was selected at peak lower 208 keV with the lower and upper limit at 188.10 keV and 229.90 keV, respectively.

![Cylindrical phantom](image1.png)  ![Fillable sphere inserts](image2.png)

**Figure 1.** The Jaszczak Cylindrical Phantom (Biodex).
Figure 2. The SPECT/CT acquisition for the phantom measurement.

(a) Flash3D/Gaussian                      (b) Wallis/Gaussian                       (c) OSEM2D/Gaussian

Figure 3. Results for tomographic uniformity evaluation at three different iterative methods as (a) Flash3D, (b) Wallis, and (c) OSEM2D. Top: A slice of the reconstructed image. Bottom: The Tomographic profiles of these reconstructed images.

The SPECT images were reconstructed with three different iterative reconstruction algorithms including Flash3D, OSEM2D, and Wallis reconstruction algorithms. All reconstructions were carried out with 4 iteration numbers, 4 subset numbers, and Gaussian post-processing filter with 6.00 mm FWHM. Then, SPECT images displayed with 128 × 128 matrix size (pixel size of 4.795 × 4.795 mm).
The reconstruction methods used in this work were implemented into the reconstruction engine of a commercially available reconstruction package, Symbia T6 version 8.5.11.10 SP4 (Siemens SwfSyngo).

For the CT scanning, CT tube voltage of 130 kVp with 24 mAs was used based on the clinical protocol for CT image acquisition. CT data were reconstructed to 512 × 512 matrix size with 0.977 mm pixel size and 2.5 mm slice thickness. The CT reconstruction was AC AbdRoutine 5.0 80s, the kernel’s smoother kernel (B08s) for attenuation correction and scatter correction.

2.3. Image evaluation

Images were quantified by ImageJ™ software to extract pixel values. The image quality was evaluated in the terms of tomographic uniformity, local-sphere uniformity, and signal-to-noise ratio (SNR), respectively calculated by these following equations:

$$ Uniformity = \frac{PV_{\text{us}}}{\delta_{\text{bkg}}} $$

(1)

$$ Local\text{-}sphere\text{-}uniformity = \frac{PV_{\text{sphere}}}{\delta_{\text{sphere}}} $$

(2)

Figure 4. Results for fillable sphere inserts of the reconstructed by a different method: (a) Flash3D/Gaussian, (b) Wallis/Gaussian, and (c) OSEM2D/Gaussian.

| No. | Sphere diameter (mm) | Flash3D/Gaussian Mean PV ± STDev (%) | Wallis/Gaussian Mean PV ± STDev (%) | OSEM2D/Gaussian Mean PV ± STDev (%) |
|-----|----------------------|-------------------------------------|-----------------------------------|------------------------------------|
| 1   | 9.90                 | 95.50 ± 7.38                        | 149.25 ± 4.22                     | 80.50 ± 4.81                      |
| 2   | 12.40                | 116.50 ± 10.26                      | 201.00 ± 7.81                     | 151.75 ± 6.66                     |
| 3   | 15.60                | 168.75 ± 7.38                       | 292.75 ± 5.32                     | 251.50 ± 10.18                    |
| 4   | 19.70                | 408.75 ± 7.11                       | 373.00 ± 2.93                     | 356.00 ± 6.11                     |
| 5   | 24.80                | 1027.75 ± 8.94                      | 790.75 ± 4.65                     | 870.75 ± 10.04                    |
| 6   | 31.20                | 1721.75 ± 5.88                      | 1404.50 ± 1.83                    | 1664.50 ± 4.20                    |

$$ SNR = \frac{(PV_{\text{sphere}} - PV_{\text{bkg}})}{\delta_{\text{bkg}}} $$

(3)
with $\overline{PV}_{sphere}$ and $\delta_{sphere}$ are the mean pixel value and deviation standard of the sphere, as well as $\overline{PV}_{bkg}$ and $\delta_{bkg}$ are the mean pixel value and deviation standard of the background, respectively.

3. Results and Discussions
Reconstructed images for tomographic uniformity are shown in Figure 3. For tomographic uniformity evaluation, the mean pixel values at a specific image reconstruction were $(112.47 \pm 8.40\%)$, $(114.30 \pm 9.59\%)$, and $(105.94 \pm 17.49\%)$ counts for Flash3D, OSEM2D, and Wallis algorithms, respectively. To evaluate the image quality at the size-specific object, the local-sphere uniformity and signal-noise-to-ratio (SNR) were evaluated based on the reconstructed sphere images as presented in Figure 4. By evaluating the pixel intensity at the sphere objects, the local-sphere uniformity is given in Figure 5 and summarized in Table 1. While the SNR describes in Figure 6 and summarized in Table 2.

Image evaluation for the sphere object presents a size-dependent image quality both in the terms of the local-sphere uniformity and SNR. The local-sphere uniformity and SNR tended to significantly increase for sphere diameters larger than 19.70 mm. These results confirmed the consequence of partial volume effect (PVE) at small lesion size as like the objects which have diameters smaller than 19.7 mm for this phantom study. PVE is significantly caused an overestimation of FWHM by spilling out the pixel intensity at the object, particularly for the object size less than three times of the spatial

| No. | Sphere diameter (mm) | Flash3D/Gaussian | Wallis/Gaussian | OSEM2D/Gaussian |
|-----|----------------------|------------------|----------------|-----------------|
| 1   | 9.90                 | 8.47             | 16.21          | 40.50           |
| 2   | 12.40                | 24.13            | 22.85          | 88.00           |
| 3   | 15.60                | 46.35            | 34.63          | 154.50          |
| 4   | 19.70                | 106.62           | 44.94          | 224.17          |
| 5   | 24.80                | 207.97           | 98.57          | 567.33          |
| 6   | 31.20                | 321.79           | 177.37         | 1096.50         |

**Table 2.** Signal-to-noise ratio (SNR) of each sphere object at different reconstruction methods.
resolution of a scanner. PVE also depends on image acquisition methods. Kinds of research have described sphere-based recovery coefficient in compensating the size-dependent quantification [1,4,5].

Generally, both Flash3D and OSEM2D reconstruction method give smoother images as visually shows in Figure 3 and 4. Flash3D algorithm provided better tomographic uniformity than others, while Wallis algorithm yielded the highest noisy image with low SNR. In general, 3DOSEM given the highest pixel value than those of Wallis and 2DOSEM. Tran-Gia et al reported the noise build-up for Flash3D algorithm is independent to the number of subsets [4]. Flash3D is OSEM 3D-reconstruction method. The ordered-subsets expectation maximization (OSEM) algorithm is typically used and recommended [6]. These results should be noted for a clinical patient-specific quantification particularly for $^{177}$Lu radionuclide therapy.

4. Conclusion
The reconstruction method significantly affects the image quality in $^{177}$Lu quantification. Supporting from results for three image quality parameters as the terms of tomographic uniformity, local-sphere uniformity, and signal-to-noise ratio, it seems that Flash3D is the best reconstruction method for $^{177}$Lu SPECT image acquisition.

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