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Pakistan Journal of Nuclear Medicine is the official journal of Pakistan Society of Nuclear Medicine

# The impact of varying number of OSEM iterations on standardized uptake value and image quality of PET/CT scan

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## ABSTRACT

**Background:** In positron emission tomography (PET) scan reporting, both quantitative and qualitative interpretations are used. Qualitative and quantitative interpretations depend upon PET/CT image quality that, along with many biological factors, strongly depends upon image reconstruction parameters. This study intends to evaluate one of the key reconstruction parameters, i.e., the number of reconstruction iterations on standardized uptake value (SUV) and the image quality of PET/CT scan.

**Methods:** Images of National Electrical Manufacturers Association International Electrotechnical Commission Image Quality Phantom (with a tumor to background ratio of 4:1 and 2-Fluoro-2-Deoxy-Gulucose as a radiotracer) were acquired on Discovery STE PET/CT scanner for acquisition time of 5 minutes. Acquired data were reconstructed using 2-7, 10, 15, and 20 ordered subset expectation maximization (OSEM) iterations of iterative reconstruction.

**Results:** Quantitative measure SUV and qualitative measure hot and cold lesion contrast, image's spatial resolution and background variability showed an increasing trend with OSEM iterations. A maximum increase in 20.25%, 16.33%, 9.79%, and 6.88% was observed in SUV for 10, 13, 17, and 22 mm lesions for OSEM iterations varying from 2 to 3. Percentage of hot lesion contrast showed a rapid increase as the number of iterations changed from 2 to 7 and increased slowly afterward. The percentage background variability showed an increasing trend for each lesion with OSEM iterations.

**Conclusion:** Optimized number of OSEM iterations is 3 with an image matrix size of 128 × 128 with filters full width at half maximum (FWHM) of 6 mm. High-resolution studies require three iterations with an image matrix size of 256 × 256 with filters FWHM of 6 mm. The extended reconstruction time limits the use of a higher number of iterations.

**Keywords:** SUV, PET/CT, hot lesion contrast, cold lesion contrast, OSEM, iterations, FDG, background variability.

Received: 15 September 2020

Revised: 14 March 2021

Accepted: 14 March 20210

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## Introduction

Several imaging modalities, including nuclear medicine, are used in cancer diagnosis and staging [1]. Nuclear medicine imaging is divided into two broad classes: single photon emission tomography (SPECT) and positron emission tomography (PET) [2]. In PET, imaging is carried out using positron-emitting radionuclide [3]. PET has revolutionized nuclear medicine, not only because of its superior performance than SPECT, but also because of its impact as the fastest growing diagnostic imaging modality. PET has become a robust metabolic imaging procedure possibly utilizing the best radiopharmaceutical 2-Fluoro-2-Deoxy-Gulucose (<sup>18</sup>F-FDG) ever used. PET using <sup>18</sup>F-FDG has appeared as a well-proven and extremely sensitive modality to deliver fast, inclusive, and consistent information [4,5]. PET, in combination with CT, has proved to be a better modality in cancer diagnostic, staging, tumor localization, tumor volume definition, morphological and physiological

imaging, and in differentiating the malignant from benign tumors. PET/CT has modernized many diagnostic imaging fields, as it provides precise anatomic localization and physiological information. In disease detection, response monitoring, and staging, the standardized uptake value (SUV) provides the lesion's pathologic relevance. PET/CT has become a standard practice in disease diagnostic, treatment planning, treatment evaluation, and response monitoring for cancer [6-8]. Regardless of the popularity of SUV, their consistency is fairly debatable. SUV is subjected to many variability sources such as acquisition protocols, recovery coefficients, and patient-dependent variables [9]. It is necessary to address factors affecting SUV quantification before its clinical implication. Before using PET images for diagnostic, therapy, treatment evaluation, or response monitoring studies, it is essential to optimize the effect of PET image reconstruction parameters on the quantification

of PET data. PET image reconstruction using the iterative reconstruction method is also quite lengthy, and it is necessary to optimize the number of OSEM iterations. As clinical decisions depend upon the SUV and image contrast, it is essential to optimize the number of iterations that give proper quantification of activity uptake and image contrast. The effect of changing the number of iteration (1-5, 10, 20, and 40) on SUVs was studied by Jaskowiak et al. [8] on a data set of 50 human tumors. Their results showed that  $SUV_{avg}$  and  $SUV_{max}$  tend to increase with the number of iterations.  $SUV_{avg}$  showed a significant increase only for early iterations, while the change in  $SUV_{max}$  was substantial over a range of iterations. Jaskowiak et al. [8] concluded that the ordered subset expectation maximization (OSEM) method converges early for  $SUV_{avg}$ . Wiyaporn et al. [7] investigated the effect of iterative updates on SUV quantification in  $^{18}F$ -FDG PET imaging. The tumor to background ratio of 5:1 was used to study the impact of a varying number of iterative updates (from 8 to 168). This study showed that  $SUV_{avg}$  and  $SUV_{max}$  increased as the number of iterative updates increased to 48 and slightly increased afterward. Wiyaporn et al. [7] concluded that a higher number of iterative updates result in increased image noise, leading to higher SUV. This study's objective was optimization and evaluation of the impact of a varying number of OSEM iteration on the image quality of PET/CT scans on discovery STE PET/CT scanner at the Institute of Nuclear Medicine and Oncology (INMOL), Lahore, Pakistan. Although many studies have already been carried out on this topic by many authors worldwide, this study is fairly unique because the number of iterations used for this study ranges from two iterations to 20 iterations. No such research is carried out in Pakistan as PET/CT is emerging as a new advanced imaging modality in Pakistan. The public sector of Pakistan is in the adopting phase of this modality. This study will give an insight into the matter for institutions starting PET/CT imaging. This study is different from previous studies as it includes both qualitative and quantitative aspects of imaging. SUV is used as a quantitative measure of reconstructed images, while image quality is assessed in terms of lesion contrast and background variability.

## Materials and Methods

National Electrical Manufacturers Association International Electrotechnical Commission image quality phantom was prepared to obtain a tumor to background ratio of 4:1. Non-radioactive water was used to fill two larger lesions/spheres (28.0 and 37.0 mm diameters). Larger spheres filled with non-radioactive water simulates cold lesion. Four small spheres were filled with high activity four times for the background. At the time of the acquisition, activity concentration in the hot sphere was 17.42 kBq/ml, while background activity concentration was 4.354 kBq/ml. IEC image quality phantom was acquired on GE Discovery-STE PET/CT scanner for 5 minutes in list mode and VIP

reply ON. The data set representing a 5-minute acquisition time was reconstructed using 2-7, 10, 15, 20 OSEM iterations; however, all other reconstruction protocols were kept to standard clinical practice. The transverse image was selected by viewing each slice for every reconstruction image set and image with the highest cold and hot lesion contrast. The same slice was used for all spheres and all image sets representing a different number of iterations. SUV measurement was carried out using circular regions of interest (ROI) with diameters approximately the same as the inner diameter of spheres drawn on each hot sphere, as shown in Figure 1.

The mathematical form of SUV and underestimation of SUV calculation is given in the following equations:

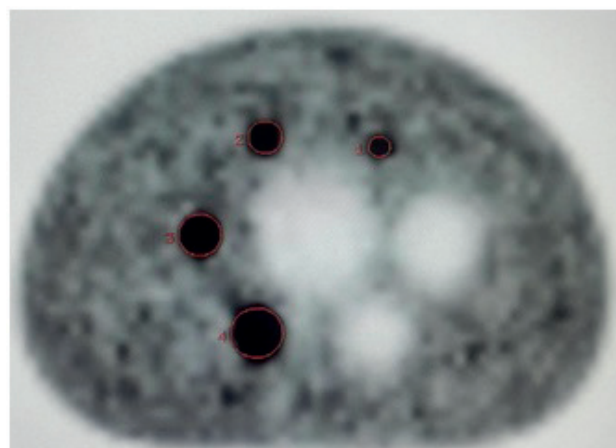
$$S_T \left( \frac{g}{ml} \right) = \left\{ \frac{A_L}{A_I} \right\} \times m_b$$

$$S_U (\%) = \frac{S_T - S_M}{S_T} \times 100$$

where  $S_T$  is the true SUV,  $A_L$  is the lesion activity,  $A_I$  is the injected activity,  $S_M$  is the measured SUV,  $S_U$  is the underestimated SUV, and  $m_b$  is the body mass.

The same transverse slice was used for image quality analysis and the same slice was used for all spheres and all image sets representing a different number of iterations. Twelve 37-mm diameter background ROIs were drawn on the same slice, as shown in Figure 2. Percentage of hot and cold lesion contrasts were calculated to evaluate hot and cold lesion contrasts in cold background. The percentage hot sphere contrast  $Q_{h,j}$  is calculated in the following equation:

$$Q_{h,j} = \frac{(C_{h,j} - C_{b,j}) / C_{b,j}}{(a_h - a_b) / a_b} \times 100$$



**Figure 1.** Circular ROIs are drawn on 10, 13, 17, and 22 mm hot spheres for the SUV measurement on a slice reconstructed using two iterations.

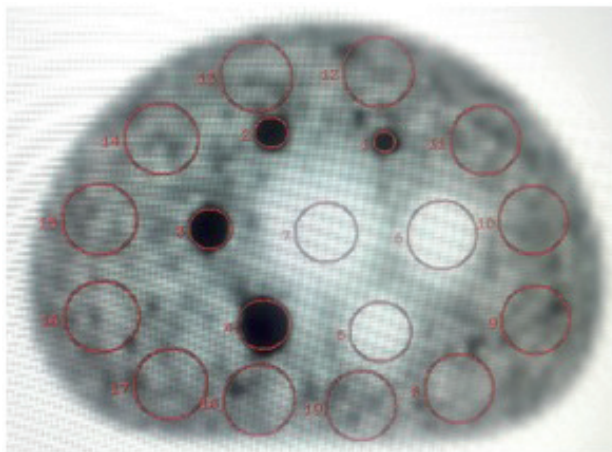
$C_{h,j}$  is the average number of counts in ROI of the sphere  $j$ ,  $C_{b,j}$  is the average background counts of sphere  $j$ ,  $a_h$  is the activity concentration in hot spheres, and  $a_b$  is activity concentration in the background. The percent cold sphere contrast  $Q_{c,j}$  is calculated by the following equation:

$$Q_{c,j} = \left\{ \frac{C_{b,j} - C_{c,j}}{C_{b,j}} \right\} \times 100$$

where  $C_{c,j}$  is the average counts in ROI of cold sphere  $j$  and  $C_{b,j}$  is the average counts in 12 background ROIs. The percent of background variability  $M_j$  for sphere  $j$  is calculated using the following equation:

$$M_j = \left\{ \frac{\sqrt{\frac{1}{k-1} \sum_{k=1}^k (C_{b,j,k} - C_{b,j})^2}}{C_{b,j}} \right\} \times 100$$

where  $k = 12$  numbers of background ROIs. The percent of background variability is used as a measure of image noise.



**Figure 2.** An image slice reconstructed with OSEMs with two iterations and 28 subsets, corresponding to an acquisition time of 5 minutes per frame. Circular ROIs are drawn on all hot and cold lesions, lung insert, and 12 background ROIs are also drawn to measure the number of counts.

## Results and Discussion

SUV is reported in two ways:  $SUV_{mean}$  and  $SUV_{max}$ .  $SUV_{mean}$  is relatively less sensitive to image noise as it includes information from a relatively large number of voxels. However, measured  $SUV_{mean}$  is subjected to variance depending upon the selection of voxel in ROI definition.  $SUV_{max}$  gives the highest voxel value in ROI.  $SUV_{max}$  is independent of ROI definition and the most commonly used measure of uptake due to its observer independence and reproducibility [9]. Because of its current acceptance in clinical studies and less inter-observer variability,  $SUV_{max}$  is used as a quantitative measure of radio tracer uptake in this study. The effect of a varying number of iterations on maximum SUV is given in Table 1.

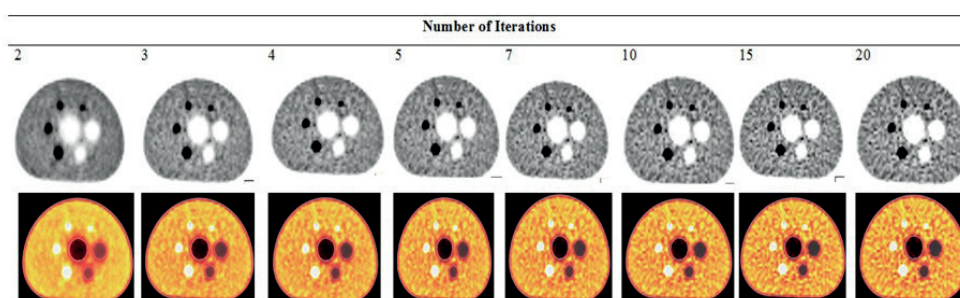
In this study, to observe the effect of a varying number of iterations on SUV and image quality, iteration number was first increased linearly from 2 to 5 because for the earlier iteration the SUV was changing rapidly, but after five iterations no remarkable change was observed in SUV. This is the reason why after five iterations the selection of the number of iteration was not linear. The higher number of iterations was selected as 20 because SUV is not changing after 10 iterations for all lesion sizes. The results showed that SUV increased with the increasing number of iteration; this is because the small number of iteration images has lower spatial resolution and underestimates the SUV. Lower iterations yield lower spatial resolution and low noise, but a higher number of iterations produce a better spatial resolution with increased noise [9]. High-frequency features are fully recovered with the increasing number of iterations, explaining a systematic increase in SUV. Percentage change in SUV over the range of iterations groups is maximum (30.32%) for the smallest sphere 10 mm in diameter than three spheres larger in diameters. The same effect was observed by Mejía et al. [10], who reported that a higher percentage increment of 13.3% in RC for a 10-mm diameter lesion was compared to the lower percentage increment of 2.9% in RC, a 28-mm diameter lesion. Mejía et al. [10] also reported a more significant increase in RC values for earlier iterations (1-5), and RC showed convergence to stable values at higher iterations (5-12). Our results also showed the same trend as reported by Mejía et al. [10]. The

**Table 1.** SUV as a function of the number of iterations and percentage change in SUV between successive iteration groups.

Number of OSEM iterations	SUV(g/ml)				Percentage change in SUV in the successive iterations (%)			
	10 mm	13 mm	17 mm	22 mm	10 mm	13 mm	17 mm	22 mm
02	2.43	3.01	4.40	4.92	-	-	-	-
03	2.92	3.51	4.83	5.26	20.25	16.33	9.79	6.88
04	3.04	3.60	4.95	5.29	4.21	2.63	2.55	0.58
05	3.11	3.63	4.95	5.32	2.02	0.85	0.00	0.58
07	3.14	3.66	5.01	5.32	0.99	0.85	1.24	0.00
10	3.17	3.69	5.07	5.32	0.98	0.84	1.23	0.00
15	3.17	3.69	5.11	5.32	0.00	0.00	0.61	0.00
20	3.17	3.69	5.11	5.32	0.00	0.00	0.00	0.00

**Table 2.** Percentage underestimation for hot lesions at varying number of iterations.

Number of iterations	Percentage SUV underestimation from true SUV			
	10 mm lesion	13 mm lesion	17 mm lesion	22 mm lesion
02	54.67	43.77	17.95	8.20
03	45.49	34.59	9.92	1.88
04	43.20	32.87	7.62	1.31
05	42.05	32.29	7.62	0.74
07	41.47	31.72	6.47	0.74
10	40.90	31.15	5.33	0.74
15	40.90	31.15	4.75	0.74
20	40.90	31.15	4.75	0.74



**Figure 3.** Image from a data set corresponding to 5 minutes acquisition time per bed position reconstructed using the varying number of iterations.

convergence of the SUV to stable value can be explained by the nature of the iterative reconstruction method. The iterative reconstruction method system starts with an initial guess of the image and computes projection views from this initial guess. These computed projection views are compared with the measured projections, and correction slices are generated using the ratio of the two projection views to update the initial guess [2]. In an earlier iteration, the initial guess is far away from the actual image, but as the number of iterations increases, the computed guess image is reached closest to the object’s actual measured image. That is why the SUV increased with an increase in the number of iterations. The observed increase in SUV is more rapid for the earlier iteration and convergence to static values at higher iterations. Ivanovic et al. [11] also studied the effect of a varying number of reconstruction iteration in the OSEM algorithm. Ivanovic et al. [11] reported a change of 6%-70% as the number of iterations increased from 2 to 10. Jaskowiak et al. [8] have reported an increase in SUV due to increased noise pixel value or reduced partial volume effect. Wiyaporn et al. [7] reported an increase in SUV with a number of iterative updates due to increased image noise. The lower value of SUV for smaller lesions may be explained based on the partial volume effect [10,12]. The smaller the lesion the more significant the partial volume effect [13]. The partial volume effect reduces the intensity values in the image from actual values. Counts from the small lesion spill out of the actual source and reduce the actual source image’s intensity and counts. This is one reason for drawing the background ROIs not smaller

than 15 mm lesion. This effect decreased with an increase in lesion size and the measured SUV values approach the true SUV for the larger sphere. The percentage underestimation in SUV is calculated for all four hot lesions. True SUV is calculated using the SUV equation, which is 5.36 g/ml. Percentage underestimation of SUV as a function of the number of iterations is given in Table 2.

Percentage underestimation shows a decreasing trend with lesion diameter and number of iterations. Maximum underestimation in SUV for all lesion diameters is observed at two iterations. Smallest and the largest diameter lesions showed maximum underestimations of 54.67% and 8.20% at two iterations, respectively. With the increase in the number of iterations, the underestimation value decreased for all hot lesions. It is also observed with the increasing number of iterations, the SUV underestimation is reduced for all hot lesions and so is the partial volume effect. The larger the sphere volume the smaller the SUV underestimation [13]. The higher value of underestimation for small lesions is due to the partial volume effect that increased with a decrease in lesion diameter and decreased with an increase in the number of iterations [7]. Figure 3 shows that with an increase in the number of iterations, spatial resolution is enhanced at the expense of increased image noise [7,10]. It can be seen that smaller diameter hot lesions are more blurred when compared to larger diameter hot lesions. This is due to the PET system’s spatial resolution limitation that depends upon the detector design and reconstruction process. Image blurring is due to count spillover between background and

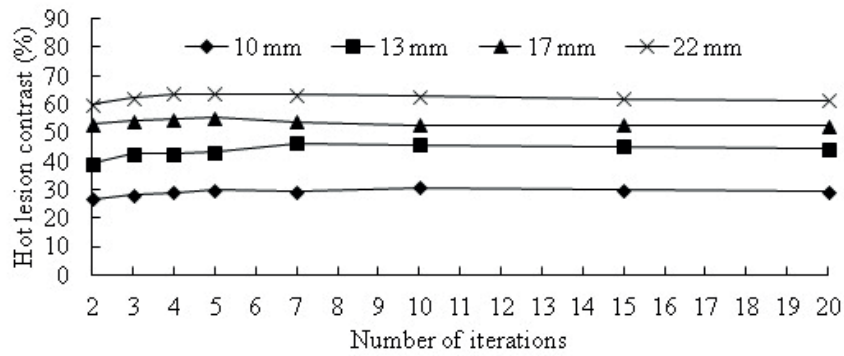


Figure 4. Hot lesion contrast for four hot lesions as a function of the number of iterations and lesion size.

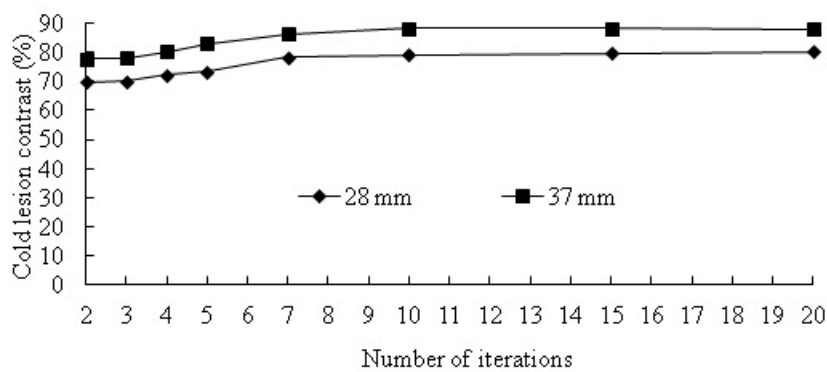


Figure 5. Cold lesion contrast for 28 and 37 mm cold lesion as a function of the number of iterations.

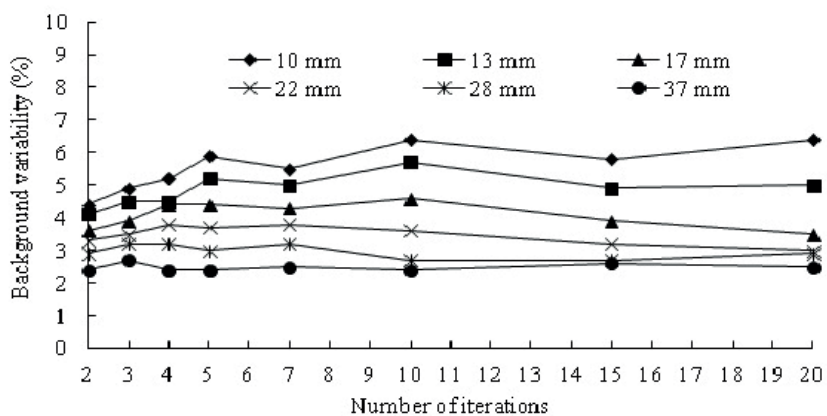


Figure 6. Background variability as a function of the number of iterations for four hot lesions and two cold lesions.

lesion [10,12] due to partial volume effect. Due to the partial volume effect, small sources appeared to be relatively larger in reconstructed images with less intensity [9,10]. Percentage of hot and cold lesion contrast as a function of the number of iterations for each lesion is shown in Figures 4 and 5. Percentage of hot lesion contrast for 10 mm lesion varies from 26.6% to 31.4% for a number of iterations from 2 to 20. Similarly, for 13, 17, and 22 mm lesions, hot lesion contrast varies from 39% to 46.3%, 52.6% to 56.8%, and 60% to 65.4%, respectively. The results show that the overall percentage of hot lesion contrast

is different for all lesions. Percentage of hot lesion contrast showed a rapid increase as the number of iterations changed from 2 to 7 and increased slowly afterward. 10 and 22 mm showed the lowest and highest hot contrasts, respectively. Percentage of cold lesion contrast for 28 mm sphere varies from 69.8% to 80.3% and for 37 mm sphere from 77% to 88.4% with a number of iterations from 2 to 20. Cold lesion contrast also showed a rapid increase up to seven iterations and increased slowly at higher iterations, as shown in Figure 5. Hot lesion contrast has the lowest value for the smallest lesion in all iterations, but

it showed an increasing trend with increasing iterations. The increase in hot lesion contrast with lesion size is also apparent because it is easy to detect larger lesions than smaller ones. This can also be explained based on the partial volume effect that is more enhanced for the smallest lesion but decreases with increasing iterations.

Background variability (%age) for all six lesions (four hot spheres and two cold spheres) as a function of a number of iterations is shown in Figure 6. Background variability ranges from 4.4% to 6.4%, 4.1% to 5.7%, 3.6% to 4.6%, 3% to 3.8%, 2.7% to 3.2%, and 2.4% to 2.7% for 10.0, 13.0, 17.0, 22.0, 28.0, and 37.0 mm spheres, respectively. The behavior shown by background variability with the number of iterations is due to the OSEM method's nature. As described by Jaskowiak et al. [8], high-frequency features tend to increase at higher iteration, and high-frequency noise also increases with the number of iterations [9,14]. Background variability depends on background counts and background noise increased with the number of iterations.

## Conclusion

Results from the phantom study showed two iterations result in a maximum underestimation of SUVs and SUV converge to a stable value at 5 to 7 iterations for all hot lesions. With a higher number of iterations, the time required for reconstruction also increases, which appeared to be a problem in very busy clinical settings. The maximum change in SUV is observed between two and three iterations. Although image noise is increased at three iterations due to better spatial resolution, increased lesion contrast and better SUV quantification, and not too much extended reconstruction time, three iterations can be used as an optimized number of iterations.

## Limitation of study and future recommendations

As this phantom study was carried out in a very busy PET/CT center, this study's results were not applied and verified using patient data. This study can be extended using list mode patient data to obtain actual clinical outcomes of this research.

## List of Abbreviations

<sup>18</sup> F-FDG	2-Fluoro-2-deoxy-gulucose
OSEM	Ordered subset expectation maximization
PET	Positron emission tomography
SPECT	Single photon emission tomography
SUV	Standardized uptake value

## Conflict of interest

There is no conflict of interest regarding the publication of this article.

## Funding

None.

## Consent to participate

This article does not contain any studies with human participants carried out by any of the authors.

## Ethical approval

This research work was offered by Department of Medical Physics (INMOL, Lahore) via reference no. INMOL-27 dated 26/12/2016.

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