Factors affecting standardized uptake value of $^{99m}$Tc-MDP bone SPECT/CT: A phantom study

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Abstract. Currently, state-of-the-art SPECT/CT with 3D reconstruction allows for quantitative data that can be represented as standardized uptake value (SUV). However, there are a number of factors that affect the value. The goal of this study was to investigate the factors affecting SUV of $^{99m}$Tc-MDP bone SPECT/CT. A NEMA phantom with $^{99m}$Tc-MDP background activity concentration of 18 kBq/ml and tumor to background ratio of 4:1 were studied. The data were acquired based on clinical bone SPECT/CT imaging protocol and OS-EM algorithm with compensation for attenuation, scatter and resolution recovery was applied using 10 subsets and varying iterative numbers from 1 to 5. SUVs ($SUV_{\text{mean}}$ and $SUV_{\text{max}}$) were measured for each sphere using Q.Metrix software. Moreover, three cut-off frequencies of Butterworth filter including 0.35, 0.48 and 0.65 cycle/cm with order of 10 were investigated at 20 iterative updates. The percentage of difference of both SUVs for each sphere was calculated. Both SUVs tended to increase when the iterative update of the OS-EM and cut-off frequency of Butterworth filter were increased. Measurement of SUVs from SPECT/CT is feasible. However, the iterative update, cut-off frequency and sphere size can affect both SUVs.

1. Introduction

Recently, state-of-the-art SPECT/CT system can provide quantitative data in a manner similar to quantitative PET. The quantitative data can be obtained by applying advance 3-dimensional (3D) iterative reconstruction with accurate compensations for image degrading factors (including attenuation, scatter, and collimator-detector response). Thus, the counts in image voxel can be converted to unit of radioactivity per volume (i.e., kBq/ml) which is called tissue concentration using a calibration factor. With quantitative data, the tissue concentration can be normalised by injected radioactivity and patient body weight resulting in standardized uptake value (SUV) [1].

Quantitative parameter SUV derived from $^{99m}$Tc-MDP bone SPECT/CT has been applied for normal spines, joint disorders, degenerative changes and bone metastases [1-3]. Clinical utility of SUV appears to be suitable for bone SPECT/CT study in the evaluation of bone disorders, however, there are several factors may affect the accuracy of quantitative data such as reconstruction algorithm, reconstruction parameter, compensation method for image degrading factors and parameter of post-reconstruction filter [4-6].

For this reason, the goal of this work was to study factors affecting SUV derived from $^{99m}$Tc-MDP bone SPECT/CT. Several factors including iterative update of the OS-EM algorithm, cut-off frequency...
of post-reconstruction Butterworth filter and tumor size were investigated by measuring maximum SUV (SUV$_{\text{max}}$) and mean SUV (SUV$_{\text{mean}}$).

2. Materials and methods

2.1. Phantom preparation
A NEMA body phantom which consists of six spheres with different inner diameters including 10, 13, 17, 22, 28 and 37 mm was used as shown in figure 1. The phantom mimics the shape of an upper human body and the total volume of this phantom is 10012 ml. The phantom was filled with $^{99m}$Tc instead of $^{99m}$Tc-MDP and activity concentration of the background was 18 kBq/ml which was obtained from cancer patients who underwent $^{99m}$Tc-MDP bone SPECT/CT imaging [7]. To simulate hot tumor, the $^{99m}$Tc solution was filled in each of six spheres with tumor to background ratio (TBR) of 4:1 which is commonly used for image quality test [8].

![Figure 1. A NEMA Body phantom (a) and the circular cover with six spheres attached (b).](image)

2.2. Data acquisition
GE Discovery NM/CT 670 Pro SPECT/CT system with dual-head detectors was used to acquire the data. The phantom was placed in the center of field of view (FOV) of SPECT/CT system and imaging was performed based on clinical $^{99m}$Tc-MDP bone SPECT/CT imaging protocol at Division of Nuclear Medicine, Siriraj hospital. Firstly, the emission data were acquired using LEHR collimator, step and shoot mode with 60 projections over 360-degree, 15 seconds per step, 6-degree angular step, non-circular orbit and matrix size of 128 × 128. The energy window setting for photopeak and scatter was 140 keV with 20% window width and 120 keV with 10% window width, respectively. After that, CT acquisition was then performed using tube voltage of 120 kVp, tube current of 40 mA, slice thickness of 3.75 mm and matrix size of 512x512.

2.3. Image reconstruction and post-reconstruction filtering
The emission data were reconstructed by using 3D OS-EM reconstruction algorithms with CT-based attenuation correction, dual-energy window scatter correction and resolution recovery. In this study, the effect of iterative update was investigated by varying the number of iterations from 1 to 5 with 10 subsets without post-reconstruction filtering. After that, SPECT images were post-filtered by using Butterworth filter. To investigate the effect of cut-off frequency, the iterative update of 20 was selected according to the manufacturer recommendation for clinical protocol and three different cut-off frequencies including 0.35, 0.48 and 0.65 cycle/cm with order of 10 were applied.

2.4. SUV measurement
Commercially available Q.Metrix software package was used to measure SUVs (SUV$_{\text{max}}$ and SUV$_{\text{mean}}$). Firstly, transaxial slices of SPECT and CT images were read into the software. In the software, planar system sensitivity of 4.32 cpm/kBq was used according to the camera acceptance test. After that,
information of the phantom including height and weight, and information of radioactivity including half-life, pre-injection activity and time, injection time, post-injection activity and time, were entered into the software. For each sphere, the volume-of-interest (VOI) was drawn semi-automatically based on the low-dose CT images covering the entire volume of the sphere (fig. 2) and SUVs were then measured.

![CT and SPECT images](image)

**Figure 2.** First and second rows are CT images and SPECT images, respectively. Spherical VOI was drawn on each sphere based on CT images to cover the entire sphere volume.

3. Data analysis
The measured SUVs ($SUV_{\text{measured}}$) of each sphere were compared with true SUV ($SUV_{\text{true}}$) and the percentage of difference ($\%\text{Difference}$) was calculated as:

$$\%\text{Difference} = \frac{SUV_{\text{measured}} - SUV_{\text{true}}}{SUV_{\text{true}}} \times 100 \quad (1)$$

The $SUV_{\text{true}}$ was given by:

$$SUV_{\text{true}} = \frac{\text{Activity concentration in sphere (kBq/ml)}}{\text{Injected activity (kBq)/Total weight (g)}} \quad (2)$$

In this study, the activity concentration in the sphere of NEMA phantom was 73.46 kBq/ml. The total injected activity was 183,879 kBq and total weight of the phantom was 10,100 g. Therefore, the $SUV_{\text{true}}$ for each sphere was 4.04 g/ml.

4. Results and discussion
The results of this phantom study showed that two hot spheres with diameter of 10 and 13 mm were not visible for all reconstruction conditions. Similarly, Nakahara et al. [7] found that a 10 mm hot sphere was undetected for all four SPECT/CT system under all reconstruction conditions and a 13 mm sphere was barely discernible in most of the reconstructed images. In this study, the hot sphere at least 17 mm was clearly observed in the reconstructed images and SUVs were measured.
The iteration number of the OS-EM algorithm that was varied from 1 to 5 with 10 subsets was investigated and plots of SUV\textsubscript{max} and SUV\textsubscript{mean} as a function of iteration number for each sphere size are shown in figure 3 and 4, respectively. When comparing with SUV\textsubscript{true}, %difference of SUV\textsubscript{max} and SUV\textsubscript{mean} of each sphere for each iteration is shown in table 1. For the effect of iterative update, both SUVs increased gradually when the iteration number increased from 1 to 5. In addition, the results showed that SUV\textsubscript{max} provided underestimation for all 4 spheres at first iteration and overestimation for three larger spheres (22, 28, and 37 mm) at higher iteration number. However, the sphere size of 17 mm gave underestimated SUV\textsubscript{max} for all iterations. For SUV\textsubscript{mean}, all sphere sizes provided underestimation when comparing with SUV\textsubscript{true}.

![Figure 3. SUV\textsubscript{max} plotted as a function of iteration number for each sphere size.](image1)

![Figure 4. SUV\textsubscript{mean} plotted as a function of iteration number for each sphere size.](image2)

**Table 1.** The percentage of difference (%difference) of SUV\textsubscript{max} and SUV\textsubscript{mean} comparing with SUV\textsubscript{true} of each sphere for each iteration.

| Iteration Number | %Difference of SUV\textsubscript{max} | %Difference of SUV\textsubscript{mean} |
|------------------|---------------------------------------|---------------------------------------|
|                  | 37 mm | 28 mm | 22 mm | 17 mm | 37 mm | 28 mm | 22 mm | 17 mm |
| 1                | -15.99 | -22.93 | -36.31 | -55.89 | -43.99 | -49.94 | -54.40 | -63.07 |
| 2                | 16.724 | 12.51 | -9.29 | -41.27 | -30.86 | -39.03 | -43.25 | -56.14 |
| 3                | 30.35 | 34.81 | 11.02 | -26.89 | -25.90 | -34.33 | -36.81 | -50.93 |
| 4                | 36.55 | 50.18 | 26.64 | -14.25 | -23.92 | -31.35 | -33.83 | -44.24 |
| 5                | 43.24 | 61.33 | 38.28 | -3.10 | -22.68 | -29.87 | -31.35 | -43.74 |

In this study, the effect of cut-off frequency of Butterworth filter was also investigated. The iterative update of 20 was selected according to the manufacturer recommendation for clinical protocol and three cut-off frequencies of Butterworth filter including 0.35, 0.48 and 0.65 cycle/cm with order of 10 were studied. Plots of SUV\textsubscript{max} and SUV\textsubscript{mean} as a function of cut-off frequency for each sphere size are shown in figure 5 and 6, respectively, and %difference of SUVs is shown in table 2. The results showed that both SUVs increased when the cut-off frequency increased from 0.35 to 0.65 cycle/cm. For %difference of SUV\textsubscript{max}, overestimated values were found for the largest sphere size, whereas, underestimated values were observed for smaller sizes for all cut-off frequencies. In addition, the underestimation of SUV\textsubscript{mean} was observed for all spheres and cut-off frequencies. The larger the sphere size, the less %difference of both SUVs for each cut-off frequency.
As demonstrated in the results of this study, the %difference of SUVs increased in smaller spheres than larger spheres and the greatest underestimated SUVs was found in the sphere diameter of 17 mm. The reason of this effect is due to partial volume effect (PVE) that arises from the finite spatial resolution of the imaging system. The PVE strongly depends on tumor size and make the SUVs differ from what they should be [9]. Moreover, this study showed that both SUVs increased when increasing the iterative updates and this result is similar to several studies [10, 11]. It is known that when increasing the number of iterative updates of the OS-EM, the image resolution improved. However, the image noise also increased with iterative update and this results in higher SUVs.

In addition, the system sensitivity used in this study was obtained by using a Petri dish as recommended by vendor and this may result in the overestimation of SUV max. Collarino et al. [11] reported that overestimation of the activity concentration in both background and spheres resulted from camera sensitivity using Petri dish. Moreover, a phantom study reported by An et al. [12] showed that inaccuracy of measured activity was larger when the camera sensitivity was applied using Petri dish compared to the system volume sensitivity using a uniform phantom.

Our study found that the %difference between true SUV and measured SUVs was high. To obtain accurate quantitative value, appropriate PVE correction that does not apply in this study must be used and the commonly used method is recovery coefficient (RC) [11, 13]. Koral et al. [14] investigated the activity recovery of I-131 SPECT and RC-based correction was applied in a simulated patient with spherical tumors. They found that %error in SPECT estimate of tumor activity before and after RC-based correction was reduced and suggested that a full set of RC with different tumor volumes might improve the quantitative accuracy in patient study. In addition, perturbation-based partial volume correction was introduced and also yielded good quantitative results for Tc-99m [15] and I-131 imaging [16]. Thus, applying RC-based correction need to be investigated in the future.
5. Conclusion

Two spheres with small size of 10 and 13 mm were not visible in the reconstructed SPECT images at TBR of 4:1 and hot sphere at least 17 mm was clearly seen and used to measure \( \text{SUV}_{\text{max}} \) and \( \text{SUV}_{\text{mean}} \). The variations of both SUVs were observed when changing the number of iterative update for the OS-EM algorithm and also the cut-off frequency of Butterworth filter. When increasing the number of iterative update and cut-off frequency, both SUVs also increased significantly. The overestimation of \( \text{SUV}_{\text{max}} \) was found for large spheres and \( \text{SUV}_{\text{mean}} \) provided underestimation for all sphere sizes. The smaller sphere size, the higher %difference of SUVs. As shown in this study, the measurement of SUVs from quantitative SPECT/CT is feasible, however, it should be aware the influence of quantitative value due to decreasing object size and changing parameters of reconstruction algorithm and post-reconstruction filter.

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