Intra-vendor clinical SPECT/CT system activity validation of $^{99m}$Tc in phantom studies

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Abstract. This study was to establish various conversion factors and its impact on the quantitative accuracy of an absolute activity in phantom between 2 variant clinical SPECT/CT system from the same vendors in different centre. Multiple series of uniform phantom scans were performed with 370 MBq filled activity in the uniform phantom using different isotropic voxel sizes (64×64×64, 128×128×128, and 256×256×256). For activity validation purpose, single anthropomorphic phantom scan with different activities ratios for different organs (0:0:1:10, lung: spine: background: liver), matrix sizes and iterations were performed. Various conversion factor (in cps/Bq or Bq(cps) estimated from various matrix sizes ($CF_{64}, CF_{128}$, and $CF_{256}$) were applied to generate the activity concentration of distribution in SPECT/CT images. The measured activities for background and liver were then compared to an absolute activity distribution and reported as a percentage difference, while for lung and spine region were reported as activity relative errors percentage. The identical methods were replicated in the other system and the differences between the system were evaluated. Both systems produced an identical trend of CF curves over the different iterations number and voxel sizes. Both systems were capable to estimate the activity distribution within 10% and 15% of error for the liver and background respectively using 256×256×256 voxel sizes. Furthermore, the relative error percentage was within 10 to 15% of error. Different variant of SPECT/CT system from the same vendor could be able to estimate an accurate activity distribution in phantom according to an identical procedure of CF establishment.

1. Introduction

The quantitative assessment for physiological changes human is the use state of the art of hybrid single photon emission computed tomography (SPECT) with computed tomography (CT). However, if we envison using the SPECT system to assess biological variability in a patient over time, or to compare a pool of patient populations with the same disease or to perform internal dosimetry estimations, one needs to have a reference standard that has small variability and allows for reliable measurement of absolute activity distribution in-vivo. Therefore, one important benefit of using absolute quantification is standardization and consistency [1]. Standardization of the techniques is essential to be able to generate quantitative functional images that are consistent among institutions and SPECT systems. This limitation is attributed to a lack of standardized procedures in the reconstruction software offered by vendors, particularly in terms of correctly attenuating, scatter and resolution, and parameters related to acquisition protocols and patients (e.g. respiratory, involuntary motion, and tracer kinetics) [2-6].

Recent studies presented the clinical application of quantitative SPECT/CT in multi-center and intra-vendors systems on the relative performance. In 2002, O’Connor et al. [7] performed a multicenter study using a standardized phantom to investigate the performance of eight attenuation correction techniques and ultimately discovered considerable variability in performance between them. Knoll et al. [8] reported an improvement of up to roughly 30% in resolution for the three aforementioned vendors’ advanced algorithms relative to their standard ordered subsets expectation maximization (OSEM)-based algorithms without corrections; however, no conclusions were made regarding the

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relative performance between these systems. Zeintl et al. [9] reported that the advanced SPECT/CT technology facilitated quantitative $^{99m}$Tc SPECT imaging with excellent accuracy in both the phantom (error $< 3.6\%$) and patient studies (error $< 1.1\%$) [10]. In 2012, Seret et al. [11] investigated the performance of the four state-of-the-art SPECT/CT systems in quantitative assessment using 3D-OSEM with attenuation and scatter corrections and resolution recovery. Quantitative errors of the four SPECT/CT systems were less than 10% if the targets were several times larger than the spatial resolution of these SPECT devices. Hughes et al. [12] also conducted a phantom study in order to compare the images obtained with three different SPECT/CT systems. Their study showed no significant differences in image quality when using their own algorithm, whereas image quality was different between images reconstructed with the vendors’ reconstruction software. These results seem to raise a problem regarding the standardization of SPECT/CT quantitation among different nuclear medicine institutions.

The aim of this study was to compare the quantitative performance of the two SPECT/CT imaging systems that available at Institut Perubatan dan Pergigian Ternajiu (IPPT) and Hospital Universiti Sains Malaysia (USM) using uniform phantom and an anthropomorphic phantom. Our investigation focuses on the establishing an optimum CF value and its impact on the absolute activity difference and relative error of the reconstructed images using the same variant clinical SPECT/CT system.

2. Materials and Method

2.1. SPECT/CT System

Two hybrid SPECT/CT system from the same vendor but a different variant was involved in this study. Both systems were separately located, namely IPPT and HUSM. The first center equipped Discovery NM/CT 670 SPECT/CT systems while the second center was equipped with Discovery NM/CT 670 Pro (GE Healthcare, Milwaukee, USA). Low-energy high-resolution (LEHR) collimator was used for this study.

2.2. Phantom preparation

This study consists of two parts, i.e. the establishment of conversion factors (CF) and activity validation in phantom setup. The first part of the study used a Jaszczak cylindrical homogenous phantom (Data Spectrum Corporation, Hillsborough, NC, USA) with the total volume of 6900 mL and filled with 370 MBq of $^{99m}$Tc activity and resulting of $\approx 53.6$ kBq/mL of $^{99m}$Tc concentration. The second phantom study was performed using an anthropomorphic torso phantom (Data Spectrum Corporation, Hillsborough, NC, USA) consist of different inserts for the lungs, spine, and liver. The $^{99m}$Tc concentrations ratio between organs was 0:0:1:10 (lung: spine: background: liver). A total of $\approx 100$ kBq/mL and $\approx 10$ kBq/mL of $^{99m}$Tc concentration in the liver and background compartment respectively. The measurement of absolute activity concentration for both centers was performed using annually calibrated dose calibrator by Malaysian Nuclear Agency.

2.3. Image acquisition

For the establishment of CF using uniform phantom, the emission data were acquired based on 120 projections over 360° with 20 second of acquisition time per projection. Next, the acquisition process was followed by CT transmission acquisition (with 80 mAs, 120 kV$_p$) which was used to derive an attenuation map and for image registration. For activity validation purpose using an anthropomorphic phantom, the emission data were acquired based on 60 projections over 360° with 30 seconds of acquisition time per projection. All scanning parameters were identical for both centers. Both phantoms were acquired using an isotropic voxel size of $64\times 64\times 64$, $128\times 128\times 128$, and $256\times 256\times 256$.

2.4. Image reconstruction

SPECT/CT data processing was carried out on a dedicated workstation equipped with Xeleris (GE Healthcare, Milwaukee, USA), version 3.8 for IPPT and version 4.0 for HUSM respectively. The acquired SPECT emission data was reconstructed using 3D-OSEM algorithm that incorporating
attenuation, scatter and resolution correction. For both parts of the study, multiple iteration numbers was used with a fixed subset of 10 and incrementing iteration number from 1 until 10 resulting in the 10, 20, 30, 40, 50, 60, 70, 80, 90 and 100 iterations. 2 mm Gaussian post-reconstruction filters were used for both phantoms study.

2.5. Image analysis
For uniform phantom, five spheres volume of interest (VOIs) with the diameter of 30 mm each were placed one in the center while four others on the peripheral region of the center axis slice of the uniform phantom as in figure 1. As in anthropomorphic phantom, twelves VOIs sphere with a diameter of 30 mm each was placed in the background region distributed over the whole background region as in figure 2. In addition, the VOIs for the lungs and liver region were generated based on thresholding method covering the whole regions based on CT images. A cylindrical VOIs with the 25 mm diameter and 160 mm of length was placed to cover the whole spine region.

The mean counts were generated from each sphere were used in determining the CF that later can be used for converting counts into the activity concentration in the activity validation study. The formula to determine the CF or system volume sensitivity as follows;

\[
CF = \frac{R}{V_{\text{VOI}}} \div \frac{C_A}{C_A}
\]

where \(V_{\text{VOI}}\) is the volume of the drawn VOI, and \(C_A\) is the actual activity concentration in the phantom. The unit of the system volume sensitivity is counts per second (cps)/Bq or Bq/cps. There are two types of CF values that were generated which is the average over multiple iteration values (named as CF\textsubscript{fixed}) (iteration 30 to 100) and individual value (consist of 10 individual CFs, named CF\textsubscript{curved}). The mean counts from each VOIs in the anthropomorphic phantom were divided by CF\textsubscript{fixed} or CF\textsubscript{curved} to generate the activity concentration in kBq/mL. Decay correction were applied for each data 64, 128, and 256) from different acquisition time. For activity validation purposes, two parameters were used i.e. absolute percentage difference \([\frac{C_{\text{SPECT}} - C_{\text{Absolute}}}{C_{\text{SPECT}}} \times 100]\) and relative errors percentage \([\frac{C_{\text{SPECT}}}{C_{\text{Absolute}}} - 100]\).

**Figure 1.** a) Transaxial b) Coronal and c) Sagittal plane of uniform phantom shows different VOIs in SPECT images overlay on CT images.

**Figure 2.** a) Transaxial b) Coronal and c) Sagittal plane of anthropomorphic phantom shows different VOIs in SPECT images overlay on CT images.
3. Results

Figure 3. CF value versus iteration number corresponds to different centres; IPPT (●) and HUSM (■) for a) 64 b) 128 and c) 256 voxel sizes.

Figure 3 shows the CF values in different iterations for different centers, and for different voxel sizes. Inconsistent CF value for both centres for 64×64×64 voxel size. The CF values were converged after 30 iterations and above for 128×128×128 and 256×256×256 voxel size. Figure 4 shows an absolute activity differences percentage between the activity concentration generated from SPECT both using one fixed value or multiple values corresponding to the iteration numbers. For the liver region, the absolute different percentage shows an overestimation of activity within 15% for HUSM centre, both with fixed or curved CFs values while underestimation within 5% for IPPT centre both for fixed and curved CF values. Note that the reduction of absolute difference was found after 30 iterations and above. In addition, less than 10% difference for background regions for both centres. The 64×64×64 voxel sizes shown the worst absolute difference percentage since the inconsistent of CF value that resulting in a large difference between the SPECT and absolute activity concentration. Figure 5 shows a relative error percentage, for the regions without any activity. Using one average CF value (fixed) could resulting in a reduction of relative error for lung regions for both centres. The spine region shows greater relative error compare to the lung regions.

4. Discussion
This study consists of two part; 1) establishing and optimizing the volume sensitivity in generating CF values and 2) validating the quantitative accuracy of the two variant of clinical SPECT/CT system from the same vendor. The results showed the CF value needs to be estimated accurately. From this study, the CF value from reconstructed SPECT emission shown a variation depending on the different parameters used such as voxel sizes and iteration numbers. Depending on the counts statistics, the operator needs to choose the suitable voxel size to be used in estimating the counts and thus in establishing CF value as in our study [13]. For 64 voxel sizes, the CF value showed inconsistent due to over accumulation of counts resulting from high statistics counts. On the other hand, 128 and 256 voxel sizes proved to produce a consistent CF value over different iteration number. After 30 iterations, the CF value remain constant both for 128 and 256 voxel size. Our data shows that the accuracy of counts estimation within the uniform phantom achieved a convergence and it could represent the estimated counts distribution for certain amount of an absolute activity, in both centres.

In our study, we are pointing out the different way in generating CF values, i.e. the mean over multiple iteration (fixed) and for individual iteration number (curved). Activity concentration estimation in SPECT/CT using one fixed mean value of CF could reduce the absolute different percentage by 2-3% compare to individual CF value (curved) as in higher count region (liver), and not contributing any impact on the lower count region as in the background (figure 4a and 4b). The fixed mean CF value could be less cumbersome compare to the curved methods as it is very dependent on each individual CF that corresponding to the iteration number. In term of relative error, using fixed CF value could reduce
the error in less density region as in lung compare to individual CF value (curved). No difference of relative error in high density region as in spine.

Figure 4. An absolute activity difference between SPECT relatives to dose calibrator for a) liver and b) background region for fixed and curved CF values.

Figure 5. Relative error percentage of the different region a) lung and b) spine over different iteration number for fixed and curved CF values.

The quantitative accuracy of activity estimation in SPECT/CT system for both centres show an absolute difference within ±15% with application of 3D-OSEM reconstruction with compensation for physical degrading factors such as attenuation, scatter and resolution. The differences between the same SPECT/CT system from different centres may be originated from activity preparation error and dose calibrator calibration error. From our study, it was shown that the system sensitivity difference that lead to error of activity estimation and this might lead to inaccurate semi quantitative evaluation such as standardize uptake value (SUV) as in more established quantitative emission system in positron emission tomography (PET) [14].

5. Conclusion
Our study found out that the quantitative accuracy of SPECT/CT system from the same variant and vendor located in different centre could provide an accuracy of absolute activity within ±15%. In term of establishing the CF value, each centre needs to utilise a minimum requirement of the following factor; at least 128×128×128 voxel sizes, iterative reconstruction process need to include attenuation, scatter and resolution compensation with 30 iterations an above to achieve the highest accuracy of activity estimation.
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