Original Article

Does Single Computed Tomography Attenuation Correction able to Surrogate Serial Computed Tomography Attenuation Correction in Single-Photon Emission Computed Therapy Imaging for Peptide Receptor Radionuclide Therapy Dosimetry Result?

Mohamad Aminudin Bin Said, Hairil Rashmizal Abdul Razak[1], Marianie Bnti Musarudin[2]

Department of Nuclear Medicine, Institut Kanser Negara, Putrajaya, [1]Centre for Diagnostic Nuclear Imaging, Universiti Putra Malaysia, Serdang, Selangor, [2]School of Health Sciences, Health Campus, Universiti Sains Malaysia, Kelantan, Malaysia

Abstract

Peptide Receptor Radionuclide Therapy (PRRT) is the administration of a radionuclide, such as the Lu-177 label, along with a pharmaceutical agent to destroy the lesion cell. The first cycle of Lu-177 DOTA-TATE is an excellent way to estimate radionuclide uptake for organs at risk. To estimate the absorbed dose for a kidney, serial SPECT-CT imaging with up to five sets is required. In general, serial CT on patients would result in additional external exposure and extra time consuming, especially for low dose CT such as cone beam CT technology. However, by introducing a new method, such as optimized single CT (24 h) to perform with serial SPECT attenuation correction, additional external exposure from serial CT exposure could be reduced. **Aims:** The purpose of this study is to assess the agreement between single CT scanning as CT attenuation Correction with serial CT scanning for serial SPECT imaging as well as estimated absorbed dose to the organ at risk. **Settings and Design:** During the first cycle of Lu177-DOTA-TATE, all patients should undergo internal dosimetry technique using SPECT-CT imaging with a PHILIP Brightview XCT gamma camera. The quantifications of SPECT images are being used to measure the uptake activity to the organ. In this investigation, Partik's categorical grading criteria are being used to convert the numeric value of Lin's concordance coefficient into an ordinal scale. **Method:** Total of 9 patients at our institution was administered with Lu177-DOTA-TATE enroll in this study. SPECT-CT data were acquired using automatic body contouring with a total of 48 angular views at steps of 6° (15 s/projections). The pixel size is 4.66 x 4.66 x 4.66 mm, the images size set to one, and SPECT data has been acquired for three-bed positions extending from the abdomen to the thorax region. Low-dose CT imaging performed at an X-ray tube voltage of 120 kVp. **Results:** Our current result demonstrated by single CT scanning for SPECT attenuation shown the excellent agreement with standard serial CT imaging for organs at risk such as kidney 0.999, spleen 0.9951, liver 0.9951 and bladder 0.9972. **Conclusions:** When compared to the previous method, patients benefit significantly more from this study, such as lower CT exposure.

Keywords: Dosimetry, Lu-177, single-photon emission computed therapy

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Introduction

Single-photon emission computed therapy with computed tomography (SPECT-CT) is an imaging technique that can observe the distribution of SPECT radiopharmaceuticals within the target organ. SPECT-CT is the ideal nuclear medicine imaging system in peptide receptor radionuclide therapy (PRRT) to investigate abnormal organ uptake in

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Address for correspondence: Mr. Mohamad Aminudin Bin Said, Department of Nuclear Medicine, Institut Kanser Negara, Putrajaya, Malaysia.
E-mail: aminhpj@gmail.com

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patients.[1,2] For PRRT procedure, internal dosimetry technique is useful to estimate the absorbed dose (AD) to the organ at risk. The kidneys are the most important organ for this therapy, and the total AD should be less than 23 Gy and as high as 40 Gy for the biologically effective dose (BED) to be approached.[3-6] The unique property of Lu-177, which emits low-gamma energy and generates medium beta particles, makes it the ideal choice for nuclear medicine theranostic imaging.[7] The 7.4 GBq of Lu-177-DOTA-TATE is administrated to the patients each therapy cycle as standard practice.[4,5] Radionuclide dosimetry technique for Lu-177-DOTA-TATE therapy suitable to be carried out at the first cycle. To estimate the AD for a kidney, five sets of serial SPECT-CT imaging are necessary.[8] Serial CT to the patients would, in general, expose the patients to more radiation and take longer, even with low-dose CT such as cone-beam CT technology. However, offering a novel approach, such as an optimized single CT (24 h) to be used in conjunction with serial SPECT attenuation correction, could help to reduce additional external exposure from serial CT exposure. The time it takes to acquire a CT scan would also be greatly decreased. The goal of this study is to assess the AD agreement for organs at risk between a single attenuation CT with serial CT as a reference (gold standard).

Methods

A total of nine patients at our institution was administered with Lu-177-DOTA-TATE enrolled in this study. During the first cycle of Lu-177-DOTA-TATE, all patients must undergo internal dosimetry procedure with SPECT-CT imaging using a Philips BrightView XCT gamma camera. SPECT-CT data were acquired using automatic body contouring with a total of 48 angular views at steps of 6° (15 s/projections). The pixel size is 4.66 mm × 4.66 mm × 4.66 mm, the size of the image is set to one, and SPECT data has been acquired for three-bed positions extending from the abdomen to the thorax region. The SPECT image quantifications are used to measure the organ's uptake activity. The SPECT activity calibration procedure had explained in previous publications.[9,10] CT images reconstructed with Iterative Iteration algorithm 8 Iteration with 16 Subset with scatter correction as recommended by the manufacturer.

Applied used for attenuation correction. Low-dose CT imaging was performed at an X-ray tube voltage of 120 kVp. The X-ray tube current is set to 20 mA for all imaging time points. The same CT image was also used for the SPECT attenuation correction and as well for image registration of different time points. CT data reconstructed with iterative method algorithm with pixel size 2.00 mm × 2.00 mm and a slice thickness of 2.75 mm. Data from nine procedures with complete sets of uptake measurements 2, 4, 24, 48, and 72 h after intravenous administration of 7.4 GBq was used to estimate AD for kidneys, spleen, liver, and bladder. To determine the agreement between two sets, the reconstruction of SPECT images was classified into two groups.

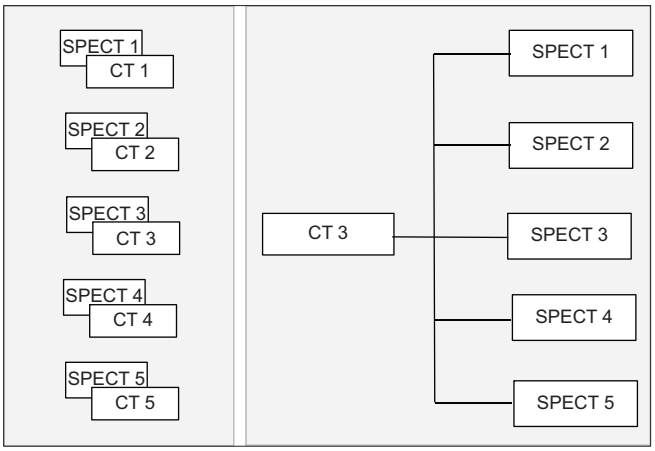

Figure 1: Left is SET A and right is SET B

SET A belongs to the serial CT used for serial SPECT attenuation correction and SET B refers to the single CT (24 h) used for serial SPECT attenuation correction, as shown in Figure 1. All the registrations between the CT and the subsequent SPECTs were done semiautomatically in Philips Extended BrightView Workstations. Image analysis for time disintegration was performed using the MIM software version. 9.4.6 Encore Module. Internal dosimetry software was used to estimate the AD to the targeted organ for both sets. The flowchart in Figure 2 summarizes the steps to reach an agreement between SET A and B.

Statistical methods

Lin's concordance was used to analyze the AD agreement between two groups to the kidneys, liver, spleen, and bladder. Lin's concordance correlation coefficient is a measure of how well a set of bivariate data (Y) compares to a "gold standard" measurement or test (X) as referring to Figures 1 and 2,[11] for example,[12] suggests the following guidelines for interpreting Lin's concordance correlation coefficient <0.90: poor, 0.90–0.95: moderate, 0.95–0.99: substantial, and >0.99: almost perfect.

Results

The administered activity of Lu177-DOTA-TATE was 7.489 ± 0.259 GBq. The absorbed dose to the organ address in Gy/GBq, the study based on the number of disintegrations occurring in a source organ such as kidney, liver, spleen and bladder. Figure 3 illustrates an excellent agreement between Set A and B, especially kidney 0.999, spleen 0.9951, liver 0.9951, and bladder 0.9972.

Discussion

The CT component attached with the gamma camera is very critical to perform attenuation correction for SPECT images. CT imaging also leads to highly accurate anatomic localization of SPECT imaging. This hybrid modality performed within the same couch with imaging artifacts induced by patient movements easily reduced by using MIM Encore software. The

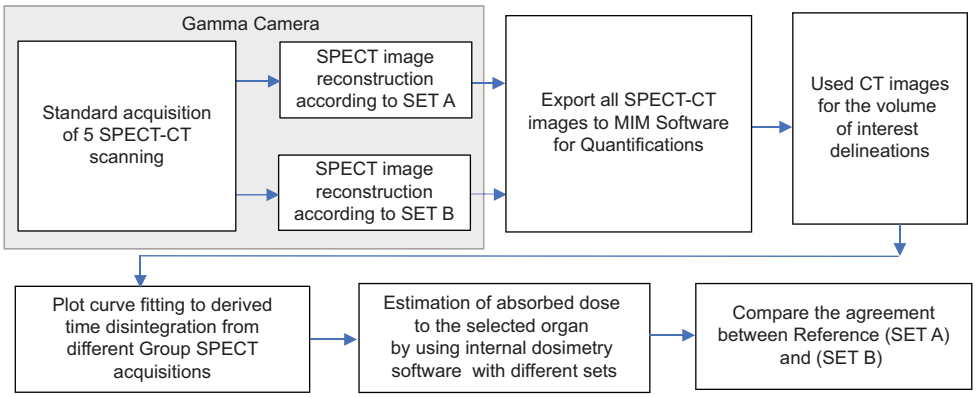

Figure 2: The summary of the steps performed to determine the agreements between data set

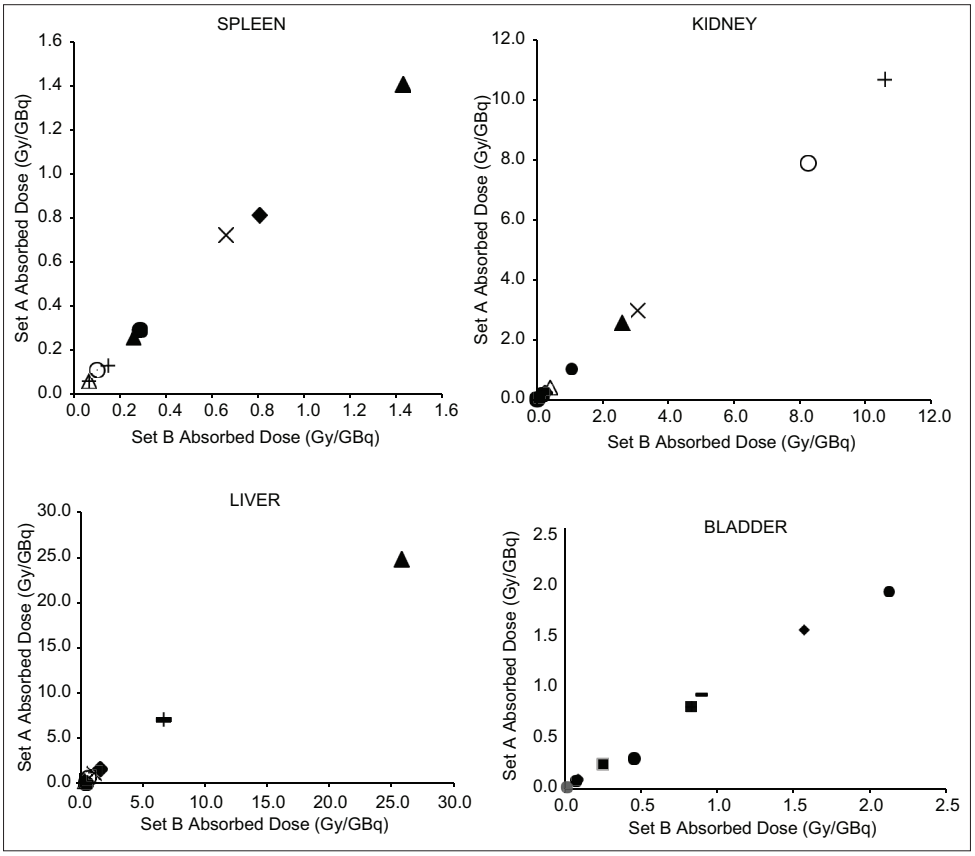

Figure 3: The absorbed dose agreement between SET A and SET B for nine patients

current results show AD for the critical organ done by single CT attenuation and serial CT attenuation shown a good agreement. It should be noted that previous studies have indicated that kidney AD is between 5.30% ± 6.20%, respectively.[9] They use the semiautomated SPECT-based segmentation method to get a good agreement result. According to Figure 3, the almost perfect agreement between both sets leads to the new ideas that benefit the single CT imaging in serial SPECT imaging. Our institutional clinical protocol required 24 h SPECT-CT acquisition to verify the radionuclide uptake to the organ. In line with our institutional clinical protocol, the optimization of 24-h CT attenuation correction is beneficial to optimize the single CT imaging to determine AD. Based on our initial null hypothesis, there was no difference in the method of CT attenuation technique of the patients between the two sets of protocols. The agreement between the two data set is nearly perfect, particularly for kidney 0.999, spleen 0.9951, liver 0.9951, and bladder 0.9972. The accuracy of this result is dependent on several factors such as the type of software used to analyze the images, camera calibration efficiency, CT attenuation capability, and accurate dosimetry software package.[10,12-14]

Although Philips BrightView gamma camera used low-dose CT, the SPECT images corrected with the iterative reconstructed

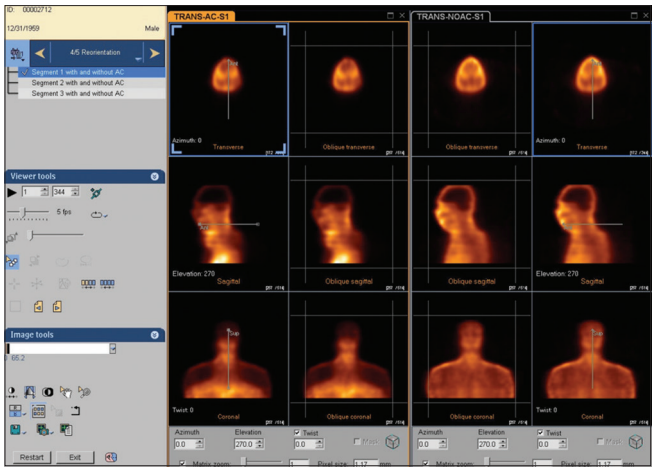

Figure 4: Astonish reconstruction systems

technique give a consistent result. Astonish reconstruction systems software had introduced by Philips is an image restoration process to enhance the image resolution for SPECT images as shown in Figure 4. This technique by using the blind deconvolution technique is currently the most widely used iterative reconstruction technique and provides better image quality and consistent value. The organ volume segmentation from CT images will be transferred and fused with serial SPECT images.[15,16] The SPECT imaging protocol was similar to another center in which no scatters correction was applied but produced acceptable results.

The accuracy of the result from the number of disintegrations occurring in a source organ is very crucial to estimate the accurate result, as shown in Equation 1. The SPECT segmentation method is less accurate than with positron emission tomography radiopharmaceutical due to its physical properties.[17-19] The AD to whole organs, tissue subregions, voxelated tissue structures, and individual cellular compartments from internally deposited radionuclides define below.

$$\bar{D}_{[Gy]}(r_t) = \sum_{r_s} \tilde{A}_{r_s} * S_{[Gy]}(r_t \leftarrow r_s) \quad (1)$$

Where $\bar{D}$ referred to AD at the target organ, r_t and r_s refer to target and source organ, $\tilde{A}_{rs}$ refer to cumulated activity at target organ and $S_{[Gy]}(r_t \leftarrow r_s)$ is the mean AD per cumulated activity form r_s to r_t. $\tilde{A}_{rs}$ is very critical to estimate the dose to the critical organ. In this study, the cumulated activity $\tilde{A}_{rs}$ derived directly by the area under the time-activity curve that plots the effective disappearance of activity in an organ, or the integral may be approximate by standard methods such as the trapezoidal rule.

Our current result [Figure 3] showed that SET A (Reference) had an excellent agreement with SET B. The low CT imaging was very challenging to delineate organ volume segmentation, especially at the spleen organ due to the density of the spleen density. The CT forms high dose will help to delineate the accurate segmentation easily but give a higher dose to the organ as pointed out before.[20,21] Different patient positioning (e.g., SPECT imaged with arms stretched upward, and whole-body imaged with arms next to the body) may have led to an internal shift of organs and lesions as reported before.[21] That issue can be reduced by using a patient vacuum bag during SPECT acquisitions. The vacuum bag to use immobilization of patients during serial SPECT acquisition to avoid mispositioning organs and lesions. The CT-based segmentation resulted in an almost perfect agreement of the organ definitions with a similar renal dose by using MIM box-based assisted alignment features. As we understand, the protocol of Lu-177-DOTA-TATE dosimetry takes about 3 to 4 days to complete, this option is useful when the CT system had a failure during the procedure. From the standpoint of CT radiation exposure, this option allows for a reduction of up to 80% in nontherapeutic patient exposure, and radiation workers would be able to conduct more patients. Consistent with other findings, single CT exposure radiation would be lower when compared to the serial set of CT imaging used in PRRT dosimetry for CT over the abdomen.[22]

Conclusions

Single CT imaging for SPECT attenuation is the best alternative option to estimate AD to the organ at risk for dosimetry technique. This option also will ensure the patient is more comfortable by an optimized single CT imaging procedure. Hybrid imaging approaches combining SPECT-CT provide a compromise between accuracy and user-friendliness. Further, prospective studies are warranted to assess the benefits of Lu-177-DOTA-TATE postdosimetry for the individual patient and the patient outcome.

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Nil.

Conflicts of interest

There are no conflicts of interest.

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