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To cite this article: T Thareeboonchai et al 2019 J. Phys.: Conf. Ser. 1248 012013

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IOP Conf. Series: Journal of Physics: Conf. Series 1248 (2019) 012013 doi:10.1088/1742-6596/1248/1/012013

Impact of acquisition time on image quality and visibility of Yttrium-90 Positron Emission Tomography: A phantom study

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Abstract. ⁹⁰Y has internal pair production which enables the imaging of this isotope with positron emission tomography (PET). The acquisition time is a crucial factor which strongly influence the image quality due to very small decay branch of this isotope. Hence, the aim of this study was to evaluate the impact of acquisition time on image quality and visibility of ⁹⁰Y PET. A NEMA IEC body phantom with set of fillable spheres were filled with ⁹⁰Y to generate a hot lesion to background ratio of 8:1. PET image was acquired by Philips Gemini TF PET/CT scanner with acquisition time per bed varied from 15, 30, 60 and 120 minutes. Image quality was assessed by percentage hot contrast (HC), image noise (CV), signal-to-noise (SNR) ratio and visibility (VS). From a result, hot spheres and their edges were more defined as acquisition time increased. Additionally, SNR and visibility were increased with acquisition time and sphere size as expected but percentage hot contrast was decreased. Thus, this can be explained by the growing of noise at shorter acquisition times and smaller spheres. In conclusion, ⁹⁰Y PET imaging was feasible but the imaging protocol should be carefully considered particularly in small object.

1. Introduction

Selective internal radiation therapy (SIRT) is alternative treatment option for liver cancer that is not able to remove with surgery [1]. Specifically, SIRT is a technique that direct delivery radioactive beads to target lesions by hepatic angiography. Among the radionuclides used for SIRT, Yttrium-90 (⁹⁰Y) has become popular due to it physical properties of high pure energetic beta with no primary gamma emission. After trans-arterial SIRT, post-delivery imaging of ⁹⁰Y by either bremsstrahlung SPECT (Single photon emission computed tomography) or PET (Positron emission tomography) may use to localize tumor coverage, extrahepatic deposition and dosimetric consideration of the treatment. For SPECT imaging, ⁹⁰Y bremsstrahlung suffers from several limitations for example low spatial resolution, broad photon spectrum as well as scatter and collimator penetration [2]. Besides, ⁹⁰Y PET might offer better image quality and further increases quantitative accuracy after the treatment [3]. Hence, the aim of this study was to evaluate the feasibility of imaging ⁹⁰Y with PET. In addition, this study also aims

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to examine the impact of acquisition time on image quality and visibility of 90 Y PET due to very low positron fraction of 90 Y.

2. Materials and methods

2.1. PET/CT scanner

The Gemini TF PET/CT scanner (Philips Medical Systems, Cleveland, OH, USA) at Division of Nuclear Medicine, Department of Radiology, Ramathibodi Hospital was used in this study. This PET system combines a LYSO detector with a fully 3D Time-of-Flight (TOF) technology and a 64-slice Brilliance CT scanner [4].

2.2. Phantom preparation

NEMA IEC Body PET with set of six hollow spheres (inner diameters of 37, 28, 22, 17, 13 and 10 mm) and a cylindrical lung insert was used in this study. The phantom was filled with ⁹⁰Y solution in chloride form. In this work, the sphere to background ratio of 8:1 was examined. This ratio was based on the work of Bhangoo et al from retrospective clinical data [5]. The activity concentration of ⁹⁰Y in sphere was set to 1 MBq/mL and 0.125 MBq/mL for background based on the study of Carlier [6].

2.3. Acquisition and reconstruction

All PET data were acquired in frame mode by varying the acquisition times (15, 30, 60 and 120 minutes) to study the impact of this parameter on hot contrast (HC), image noise (CV), signal to noise ratio (SNR) and visibility (VS). Then data were reconstructed using a fully 3D iterative OSEM (Ordered subset expectation maximization) TOF algorithm. This reconstruction algorithm was included the normalization, deadtime, attenuation and scatter correction.

2.4. Image analysis

Circular hot sphere region of interest (ROI) was manually drawn on each sphere with diameter close to the inner diameter of the sphere using CT as a guide. The background ROIs were defined at the location following NEMA standards publication NU 2-2001 with a total of 60 background throughout the five axial slides ± 1 cm and ± 2 cm (as illustrated in figure 1) [7].



Figure 1. Defined ROIs of hot spheres and background ROIs in trans-axial images of NEMA IEC Body PET phantom. (figure 1A) fused SPECT-CT image (figure 1B) PET image (figure 1C) CT image showing hot spheres.

Additionally, the ROIs were repeatedly drawn in 3 separate occasions. The mean of measurement and standard deviation (SD) were calculated and plotted (mean \pm SD) in order to estimate inconsistency of defining the ROI.

Percentage hot contrast (HC) was calculated using following parameters; C_H is the mean counts in the hot sphere, C_B is the mean counts of background and R is the sphere to background ratio.

$$HC = \frac{c_{H/c_B} - 1}{R - 1} \times 100\%$$
(1)

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Image noise was evaluated by the coefficient of variation (CV) using equation (2). In this equation, STDVB is the standard deviation measured from 60 background ROIs.

Image Noise (CV) =
$$\frac{STDVB}{C_B} \times 100\%$$
 (2)

Signal to noise ratio (SNR) was calculated using equation (3). Where, CV is the noise.

$$SNR = \frac{C_H - C_B}{CV} \tag{3}$$

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Visibility (VS) was calculated based on Rose's formula where A is the number of pixels of hot sphere. VS relates the ability of human vision to image quality parameter which include the size of object [8].

$$VS = SNR\sqrt{A} \tag{4}$$

3. Results

Trans-axial image slice centering on the middle of hot spheres was selected for the analysis. Based on visually inspecting of the trans-axial image, the hot spheres and their edges were more defined as acquisition time increased. All hot spheres were seen with acquisition time per bed of 60 and 120 minutes, whereas at acquisition time of 15 and 30 minutes, the small spheres of 10 and 22 mm were not seen as shown in figure 2.



Figure 2. Trans-axial image of NEMA IEC Body PET phantom on the middle of hot spheres of ⁹⁰Y-PET/CT images (A) Acquisition time 15 minutes, (B) 30 minutes, (C) 60 minutes, (D) 120 minutes per bed.

Visual inspection was confirmed by quantitative analysis of percentage hot contrast, image noise, signal to noise ratio and visibility. Consequently, hot contrast for each hot sphere as function of acquisition time is plotted in figure 3. Hot contrast increased when the diameter of sphere increased as expected. Interestingly, hot contrast was decreased when prolonged acquisition time. This finding will later discuss in the next section.

Graph in figure 4 displays image noise as function of acquisition time. Image noise tended to decrease with longer acquisition time. For smallest sphere (diameter of 10 mm), image noise was as high as 51.76 % when acquired with 15 minutes, then increasing acquisition time, image noise was dropped to 39.78 %, 32.20 % and 20.76 % when acquired with 30, 60 and 120 minutes per bed, respectively. Consequently, this also confirmed in figure 5 which is plotted between SNR and acquisition time. Increasing acquisition time of 15 to 30 minutes, SNR slightly increased, whereas, increasing acquisition time from 30 to 120 minutes showed an exponential improvement in the SNR for all spheres.

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Figure 3. Percentage hot contrast graph was plotted between HC and acquisition time (minute) per bed.

Figure 4. Noise graph was plotted between noise and sphere size (mm).



and acquisition time (minutes).

Figure 5. SNR graph was plotted between SNR Figure 6. Visibility graph was plotted between VS and acquisition time (minutes).

For visualization, the visibility was increased for larger spheres. Additionally, the visibility of the hot spheres elevated when the acquisitions become longer similar trend as we founded for SNR.

4. Discussion

Based on our work, one interesting result is the percentage hot contrast decreased when acquisition time become longer. However, this similar finding was also found by Van Elmbt et al which explained that contrast could be greater than the genuine value because of the noise amplification at shorter acquisition time [8]. This assumption was also confirmed in figure 4, short acquisition times had a greater noise. Especially, the greater noise was observed in smaller spheres. This is the reason why the error bars in

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figure 3, 5 and 6 are larger for short acquisition times and smaller spheres [8, 9]. It is also important to note that the contamination of natural radioactivity from LYSO (Lutetium-yttrium oxyorthosilicate) crystal used in the Gemini TF PET/CT might elevate the random fraction and background in the image as well. This finding was reported by many publications [6, 8, 10].

For SNR and visibility, our results clearly demonstrate a great impact of acquisition time. Thereby, increasing the acquisition time leads to a substantial improvement of SNR and visibility. This factor is dominant for smaller objects. Therefore, the small object or lesion requires longer acquisition time to obtain similar visibility condition. This also confirmed by many studies [8, 10, 11].

5. Conclusion

This study demonstrated that the imaging of ⁹⁰Y with PET was feasible. The shorter acquisition times may result the higher noise which can further exaggerate the actual contrast especially in smaller objects. Subsequently, the image quality was better at longer acquisition due to the low positron yield of this isotope. However, this is restrictive in clinical setting due to patient discomfort, scanner availability and the increased chance of motion. Consequently, improving image quality using post-processing filter or reconstruction technique for ⁹⁰Y PET should be further studied.

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