Evaluation of nuclear medicine planar images based on partial volume effects and recovery coefficients at different activity levels of radionuclides and matrix sizes

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Abstract. The partial volume effect evaluations had been effectively used as method for the evaluation of SPECT images in nuclear medicine. The study focused on the use of partial volume effect method and the evaluation of recovery coefficient in the 2D planar images in nuclear medicine. The planar images were obtained by using a modified Jaszczak phantom that contains radionuclide volume of different diameter sizes and three activity levels. The planar images were also taken at three different matrix sizes of gamma camera set up at 128 x 128, 256 x 256 and 512 x 512. The results showed that the contrast values increased exponentially at larger diameter sizes of radionuclide. The contrast also significantly increased when higher matrix sizes were used. The recovery coefficient evaluation of the planar images were significantly decreased when larger matrix sizes were used. There were no significant differences between the recovery coefficients between planar images obtained with and without background counts. The overall results indicated the suitability of using the partial volume effect method to evaluate the planar images of nuclear medicine.

1. Introduction
The performances parameters of gamma camera play major role in describing the radionuclide distribution [1-3]. The important performances parameters in gamma camera system are spatial resolution and sensitivity. Besides, uniformity and high counting performances are also considered. So that, the performances of gamma camera system are defined as the sharpness and detail of the image produced, efficiency of detecting the incident radiation, ability to measure the energy of incident radiation and counting rate it can handle without significant dead time losses [1].

The performances characteristic of the gamma camera system is related to the partial volume effect (PVE). The PVE is important in qualitative and quantitative of the image [4]. It is commonly occurred at the object with small size that near to the resolution limits of the imaging device. It appears to contain smaller activity and concentration then the actual value [5]. It is also known as spill out and spill in effect. Spill out is defined as the activity inside the region of interest (ROI) distributed over the border, hence, spill in effect is referred as the activity outside the ROI integrated into the ROI due to the limited spatial resolution [4]. Thus, the spatial resolution degraded caused the activity concentration inside the ROI to be either underestimated or overestimated. The ratio between the apparent activity concentrations to the true activity concentration is known as recovery coefficient
(RC). Besides RC, image contrast also plays important roles in both qualitative and quantitative of the image quality. Image contrast is an important indicator of how well a system is performing with respect to detection of small lesion. Image contrast here is defined as the ratio of signal change of an object interest to the signal level in surrounding part of the images [6].

This study focused on the evaluation of the gamma camera performance for planar imaging in nuclear medicine based on the PVE. The contrast and of the planar images were evaluated at different matrix sizes of the gamma camera and different activity levels.

2. Methodology

2.1. Simulation of Radionuclide with Different Sizes
A modified phantom from the readily available Jaszczak was used to simulate radionuclide of different sizes as shown in Figure 1(a) [7-9]. A set of cylindrical vials with internal diameters between 1.3 and 3.5 cm was used to contain radionuclide as shown in Figure 1(b). The set of vials were placed into the Jaszczak phantom filled with water to simulate the density of human soft tissue. The vials were filled with $^{99m}$Tc of three different activity levels of 3, 10 and 18 µCi while the Jaszczak phantom was filled with water and an amount of $^{99m}$Tc with activity ratio of 1:12 to the activity used in the vials [7].

![Figure 1](image)

**Figure 1.** (a) The Jaszczak phantom used in the study and (b) the cylindrical vials of different diameters used in this study

2.2. Measurement of contrast and recovery coefficient
The prepared phantom was scanned by using gamma camera model NM/CT 670 Pro at planar imaging mode. The phantom containing radionuclides with three activity levels were scanned each at three different matrix sizes of $128 \times 128$, $256 \times 256$ and $512 \times 512$. The contrast of SPECT/CT image was evaluated based on the volume of interest (VOI) on each of vials and the around the background region. The contrast of SPECT/CT image was calculated based on the equation:

$$contrast = \frac{c_{vial} - c_{background}}{c_{background}}$$  \hspace{1cm} (1)

where $c_{vial}$ is count per pixel of vial and $c_{background}$ is the count per pixel in background region. The contrast values at different activity level and matrix sizes were analysed. The recovery coefficient was calculated based on the equation:

$$Recovery\ coefficient = \frac{A_a}{A_t}$$  \hspace{1cm} (2)

where $A_a$ is apparent activity of radionuclide concentration radionuclide and $A_t$ is actual activity of concentration radionuclide [1]. The apparent activity concentration of radionuclide was calculated by using equation:

$$Apparent\ activity, A_a = \frac{R_{roi}}{S_{vol}} \times \frac{VS}{T_{acq}}$$  \hspace{1cm} (3)
where $R_{vol}$ is count per pixel of volume of interest vial, $S_{vol}$ is volume sensitivity, $VS$ is voxel size and $T_{acq}$ is total time of scanning [9][10]. The count per pixel for each vial was measured by manually drawn the VOI at each vial based on the CT image using the Volumetric MI Evaluation software on the Xeleris workstation. The value of volume sensitivity is 2.667 cps/µCi. While the value voxel size for matrix size 128 x 128 is 4.42 x 4.42 x 4.42 mm$^3$ was based from the department's recent quality assurance for the gamma camera [7]. The actual activity concentration of radionuclide was calculated by using the equation:

$$A_{t} = A_{0} e^{-\lambda t} \tag{4}$$

where $A_{t}$ is actual activity concentration of radionuclide, $A_{0}$ is initial activity concentration of radionuclide source ($^{99m}$Tc), $\lambda$ is decay constant of radionuclide and the $t$ is time elapsed from the initial activity. The value of the decay constant of radionuclide source was 2.5 x 10$^{-5}$ s$^{-1}$.

3. Results and discussion
The planar images taken at different activity levels and matrix sizes are shown in Figure 2 to Figure 4. The results showed that all the images of the radionuclide at different sizes and activity levels are clearly visualised at all matrix sizes. However, the images taken by using smaller matrix size appeared to be brighter and sharper compared to higher matrix sizes.

![Figure 2. Planar images of (a) 3 µCi (b) 10 µCi and (c) 18 µCi activity levels at 128 × 128 matrix size.](image)

![Figure 3. Planar images of (a) 3 µCi (b) 10 µCi and (c) 18 µCi activity levels at 256 × 256 matrix size.](image)

![Figure 4. Planar images of (a) 3 µCi (b) 10 µCi and (c) 18 µCi activity levels at 512 × 512 matrix size.](image)

The measured contrast values at 3 µCi, 10 µCi and 18 µCi activity levels at different matrix sizes are shown in Figure 5. The results showed that the contrast values increased at bigger sizes of
radionuclide at all activity levels and matrix sizes [4,7]. The results also showed that the contrast values increased when higher activity levels were used. At low activity level (3 µCi), higher matrix sizes provided the highest contrast values whereas at high activity level (18 µCi), the lower matrix sizes provided higher contrast values [7].

![Graphs showing contrast vs. diameter of cylinder for different matrix sizes.](image)

**Figure 5.** The contrast of planar images taken at (a) 3 (b) 10 and (c) 18 µCi by using different matrix sizes.

The correlation test between the sizes of radionuclide and matrix sizes is shown in Table 1. The correlation test showed positive relationship between diameter of cylinders and the image contrasts on different matrix sizes used indicated by the linear regression (R) values obtained from the test which were ranging from 0.971 to 0.993. The R values obtained that was close to the value of 1 indicated strong relationship between the sizes of the radionuclide and images contrast. This observation could be the result of count collected being higher at larger diameter of cylinder compared to smaller diameter of cylinder. The matrix sizes were also influenced the image [11]. The matrix size or voxel size give the significant effect on image quality and visibility of structures and object within the body. The choice of matrix size depends on several factors which are spatial resolution, smallest object of interest in image, time to perform the processing step and amount of storage available [12]. This result is in agreement with the previous work by Grotch and Erwin [13] that suggested that the ideal matrix size used should be less than 1/3 of expected full half width maximum (FWHM) resolution.
Table 1. Correlation test between contrast values at different activity levels and matrix sizes used.

| Activity (µCi) | Matrix size | Mean ± SD      | R value |
|---------------|-------------|----------------|---------|
| 3             | 128 × 128   | 13.21 ± 9.9    | 0.993   |
|               | 256 × 256   | 16.13 ± 11.9   | 0.988   |
|               | 512 × 512   | 19.23 ± 14.0   | 0.992   |
| 10            | 128 × 128   | 23.42 ± 18.9   | 0.972   |
|               | 256 × 256   | 21.36 ± 17.5   | 0.971   |
|               | 512 × 512   | 29.58 ± 24.60  | 0.971   |
| 18            | 128 × 128   | 32.86 ± 24.2   | 0.987   |
|               | 256 × 256   | 37.37 ± 27.78  | 0.988   |
|               | 512 × 512   | 30.14 ± 22.7   | 0.983   |

The recovery coefficients of the planar images at different activity levels and matrix sizes used are illustrated in Figure 6. The results showed that the activity levels and matrix sizes used in planar imaging did not significantly affect the RC pattern. In 128 × 128 matrix size, the effect of spill-over occurs when the diameter of the radionuclide exceeded 3.0 cm indicated by the RC value of more than 1. The RC in larger matrix sizes showed value of lower than 1 indicating close value between the actual and apparent activity of radionuclide [7,9].

Figure 6. The recovery coefficient at different activity levels and matrix sizes of (a) 128 × 128, (b) 256 × 256 and (c) 512 × 512.
4. Conclusion
The contrast in planar images in nuclear medicine is influenced by the matrix size used rather than the activity level of the radionuclide. When lower activity levels are used, the large matrix sizes are preferred as they provided larger pixel values. The recovery coefficients in planar images did not significantly influence by the activity levels of the radionuclide and matrix sizes.

5. References
[1] Cherry S R, Sorenson J A and Phelps M E 2012 Phys. in Nucl. Med. 4th ed. (Philadelphia: Saunders Elsevier).
[2] Erlandsson K, Buvat I, Pretorius P H, Thomas B A and Hutton B F 2012 A review of partial volume correction technique for emission tomography and their application in neurology Phys. Med. Biol. 57 119-159.
[3] Sjogreen K, Ljungberg M, and Strand S 2009 Parameter influencing volume and activity quantitation in SPECT. Acta Oncol., 35(3) 323-330.
[4] Ritt P, Vija H and Hornegger J 2011 Absolution quantification in SPECT. J. Nucl. Med. 38 69-77.
[5] Willowson K, Bailey L, and Baldoc, C 2008 Quantitative SPECT reconstruction using CT-derived corrections. Phys. Med. Biol., 53(12) 3099–3112
[6] Saad I E, Helal N, El-din H M, and Monem R A 2012 Evaluation of varying acquisition parameter on the image contrast in SPECT studies. IJRRAS 13(2) 485-491.
[7] Yusof M F M, Ghani U S A, Ghazali N A, Khaizul A T and Idris A W 2020 Evaluation of contrast and recovery coefficients as performance parameters in planar and SPECT imaging. IOP Conf. Series: Mater. Sci. Eng., 785 012046.
[8] Hamid P N K A, Yusof M F M, Tajuddin A A, Hashim R and Zainon R 2018 Design and evaluation of corn starch-bonded Rhizophora spp. particleboard phantoms for SPECT/CT imaging. IOP Conf. Series: Mater. Sci. Eng., 298 012041.
[9] Hamid P N K A, Yusof M F M, Tajuddin A A, Hashim R and Zainon R 2018 Evaluation of image quality and recovery coefficient of corn starch-bonded Rhizophora spp. Particleboards as phantom for SPECT/CT imaging. IOP Conf. Series: Mater. Sci. Eng. 555 012031.
[10] IAEA 2014 Quantitative nuclear medicine imaging concepts, requirements and methods Human Health Reports No. 9 (Vienna: International Atomic Energy Agency).
[11] Sprawls P 2014 Optimizing Medical Image Contrast, Detail and Noise in the Digital Era 2(1) 41-48.
[12] Madsen M T 1994 Computer acquisition of nuclear medicine images. J. Med. Technol. 22(1) 3–12.
[13] Groch M W and Erwin W D 2000 SPECT in the year 2000: basic principles. J. Nucl. Med. Technol. 28(4) 233–44.

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