KJNMT. 2023 November, 27(2)129-132
https://doi.org/10.12972/kjnmt.20230018

pISSN 1229-9901
eISSN 2982-8406

Original article

Study on the PET image quality according to various scintillation detectors based on the Monte Carlo simulation

Eunsoo Kim[1] · Chanrok Park[2]

[1]Radiology, Seoul Asan Medical Center, Seoul, South Korea

[2]Dept. of Radiological Science, Eulji University, Gyonggi, South Korea

*Corresponding Author : Chanrok Park, Department of Radiological Science, Eulji University, 553, Sanseong-daero, Sujeong-gu, Seongnamsi, Gyeonggi, 13135, South Korea, Tel :+82-31-740-7185, E-mail : tigeaglepcr@eulji.ac.kr

ABSTRACT

Purpose: Positron emisson tomography (PET) is a crucial medical imaging scanner for the detection of cancer lesions. In order to maintain the improved image quality, it is crucial to apply detectors of superior performance. Therefore, the purpose of this study was to compare PET image quality using Monte Carlo simulation based on the detector materials of BGO, LSO, and LuAP. **Materials and Methods:** The Geant4 Application for Tomographic Emission (GATE) was used to design the PET detector. Scintillations with BGO, LSO and LuAP were modelled, with a size of 3.95 × 5.3 mm2 (width × height) and 25.0 mm (thickness). The PET detector consisted of 34 blocks per ring and a total of 4 rings. A line source of 1 MBq was modelled and acquired with a radius of 1 mm and length of 20 mm for 20 seconds. The acquired image was reconstructed maximum likelihood expectation maximization with 2 iteration and 10 subsets. The count comparison was carried out. **Results and Discussion:** The highest true, random, and scatter counts were obtained from the BGO scintillation detector compared to LSO and LuAP. **Conclusion:** The BGO scintillation detector material indicated excellent performance in terms of detection of gamma rays from emitted PET phantom.

Key words: GATE simulation, Positron emission tomography, scintillation detector, Nuclear medicine, Quantitative analysis

INTRODUCTION

The nuclear medicine imaging, in particular, positron emission tomography (PET), plays an important role in the medical field for providing functional information by using appropriate radioisotopes [1]. The fundamental principle of PET image acquisition is based on the detection of two opposing gamma rays of 511 keV using scintillation detectors. The coincidence circuit divides detected counts into three categories: true counts, scatter counts and random counts. Subsequently, the counts, which are referred to as a sinogram, were sorted according to distance and angle and sinogram is reconstrued by applying the various reconstruction algorithms [2]. To improve the PET image quality, research was conducted on the development of algorithms and software. Lee at al. reported that the contrast to noise ratio and coefficient of variation values were 1.08, and 1.10 times higher than compared images when applying median modified Wiener filtering technique [3]. Furthermore, research for alternative detector material and hardware system, which is available for detection of accurate gamma rays and reduction of signal loss [4, 5]. Zhang et al. developed the 2 meter long total body PET system, and improved the limited axial field of view [5]. In particular, the density is crucial parameter when detecting the 511 keV gamma rays. Because high density material is consisted with high effective atomic number. Therefore, detector material considering the density and effective atomic number is determined for improvement of detection efficiency in PET signal.

Received August 21, 2023 **Revised** August 30, 2023 **Accepted** September 12, 2023

The Geant4 Application for Tomographic Emission (GATE) simulation toolkit is widely used for performance evaluation of image quality in nuclear medicine [6-7]. The GATE simulation toolkit is optimized for simulation in nuclear physics, instruments of nulcear medicine. Based on the GATE simulation toolkit, Park et al. suggested the TlBr material is possible for alternative new detector material for gamma ray detection due to its excellent performance [8].

Therefore, the purpose of this study was to compare the PET image quality obtained by BGO, LSO, and LuAP scintillation detector based on the GATE simulation.

MATERIALS AND METHODS

In this study, the PET simulation was modeled by GATE simulation toolkit. The Fig.1 illustrates the simplified schematic of PET simulation. The BGO, LuAP, and BGO scintillation detectors were designed with $3.95 \times 5.3 \times 25$ mm^3 (width × height × thickness). The number of crystals per block and ring were 144 and 34, respectively. Additionally, the axial filed of view was 200 mm and the bore size was 744 mm. The simulated images were obtained during 20 seconds with 1 MBq by simulating cylinder phantom with the 1 mm of diameter and 20 mm height. To reconstruct acquired gamma ray distribution as the sinogram, the maximum likelihood expectation maximization algorithm with 2 iteration and 10 subsets was used with $128 \times 128 \times 64$ dimension and $3 \times 3 \times 3$ mm^3 of voxel size.

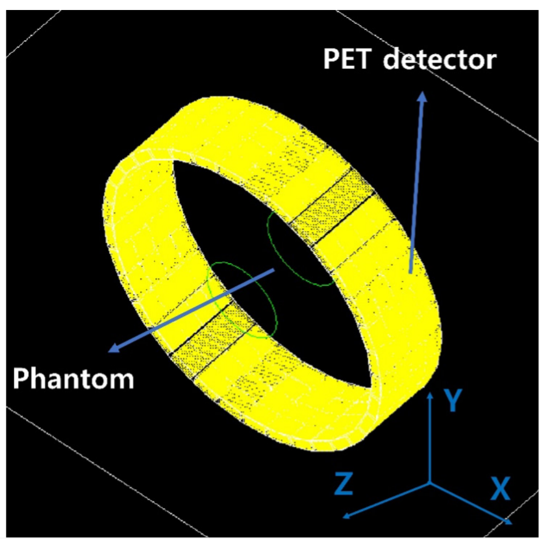

Fig. 1. The PET detector and phantom simulation model were designed using the GATE simulation toolkit.

RESULTS AND DISCUSSION

The Fig. 2 showed the acquired images according to axial, coronal, and sagittal views, respectively.

According to results, the true counts, scatter counts and random counts were 364334, 184661, and 6778 for BGO material; 307641, 156708, and 6009 counts for LSO material, and 329985, 166871; 6324 counts for LuAP material, respectively. When comparing with BGO events due to highest total event in this study, the true count for BGO material was 1.1 and 1.2 times than LuAP and LSO materials, and scatter counts were higher 1.1 and 1.2 times than LuAP and LSO materials, and random count was higher 1.1 times than LuAP and LSO materials. Based on the event results, the BGO material was the best performance in terms of count rate due to high stopping power among conditions.

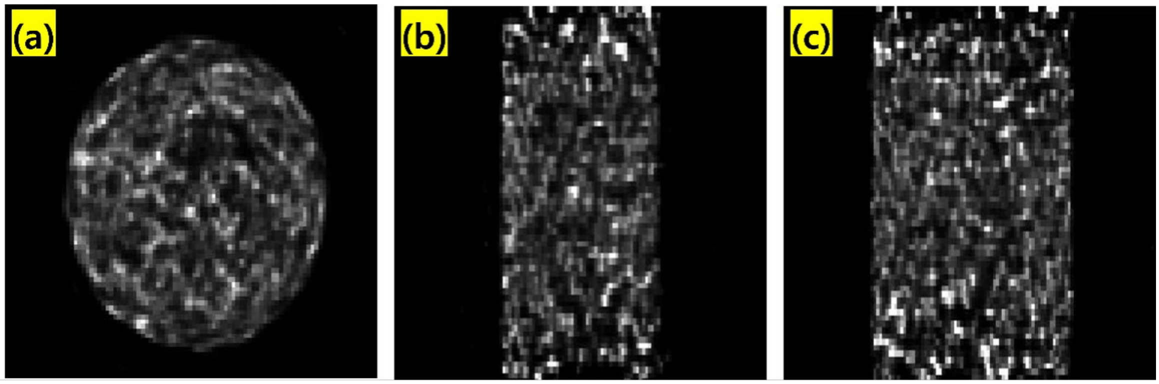

Fig. 2. The axial (a) and coronal (b) images based on the MLEM reconstruction algorithm were acquired.

In the future study, we are planning to calculate noise equivalent count rate, which is representative performance parameter for evaluation of image quality and scanner condition, based on the acquired results in this study.

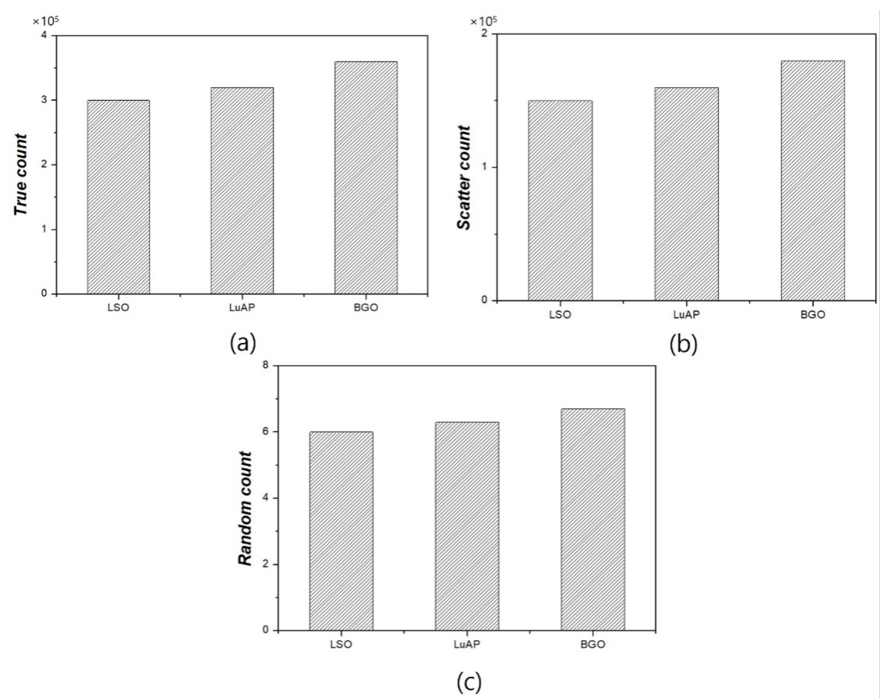

Fig. 3. The result bar graphs with (a) true count, (b) scatter count and (c) random count were indicated according to various PET scintillation detector materials.

CONCULSION

We simulated the PET scanner and phantom using the GATE simulation toolkit, which is one of the Monte Carlo simulation models. In addition, acquired PET images according to various detector materials based on the sinogram data with MLEM reconstruction algorithm were analyzed by count event rates such as true, scatter, and random counts. Consequently, BGO material was excellent performance in terms of count detection of 511 keV gamma rays.

REFERENCES

1. Madsen MT, Recent adavances in SPECT imaging. J Nucl Med. 2007;48:661-673
2. Tarantola G, Zito F, Gerundini P, PET Instrumentation and Reconstruction Algorithms in Whole-Body Applications. J Nucl Med. 2003;48(5):756-769.
3. Lee S, Lee y, Performance evaluation of median-modified Wiener filter algorithm in high-resolution complementary metal-oxide-semiconductor radio-magnetic X-ray imaging system: An experimental study. Nucl Instrum Methods Phys Res, A. 2021;1010:165509.
4. Mikiko I, Hong SJ, Lee JS, Positron emission tomography(PET) detectors with depth-of-interaction(DOI) capability. Biomed Eng Lett. 2011;1:70-81.
5. Zhang X, Zhou J, Simon RC, Badawi RD, Qi J, Quantitative image reconstruction for total-body PET imaging using the 2-meter long EXPLORER scanner. Phys. Med. Biol. 2017;62(6):2465.
6. Schmidtlein CR, Kirov AS, Nehmeh SA, Erdi YE, Humm JL, Amols HI, Bidaut LM, Ganin A, Stearns CW, McDaniel DL, Hamacher KA, Validation of GATE Monte Carlo simulations of the GE Advance/Discovery LS PET scanners. Med. Phys. 2006;33(1):198-208.
7. Buvat I, Castigilioni I, Monte Carlo simulations in PET and SPECT. Q J Nucl Med Mol. 2002;46:48-61.
8. Park C, Lee Y, Evaluation of TlBr semiconductor detector in gamma camera imaging: Monte Carlo simulation study. Nucl Eng Technol. 2022;54:4652-4659.