Detector selection reference for prompt gamma ray imaging during boron neutron capture therapy: A Monte Carlo simulation

Moo-Sub Kim, Han-Back Shin, Joo-Young Jung, Sunmi Kim, Hye Jeong Yang, Min-Young Lee, Do-Kun Yoon, Tae Suk Suh**

Department of Biomedical Engineering and Research Institute of Biomedical Engineering, College of Medicine, Catholic University of Korea, Seoul 505, Korea, and mskim0726@catholic.ac.kr, hashin07@catholic.ac.kr, modeljjy@catholic.ac.kr, sunmikim@catholic.ac.kr, yangbling@catholic.ac.kr, pearlmyl@catholic.ac.kr, dbsehrns@catholic.ac.kr, suhsanta@catholic.ac.kr

The purpose of this study was to investigate the optimal detector material for prompt gamma ray imaging during boron neutron capture therapy (BNCT). For this investigation, the sixteen detector materials were simulated using the Monte Carlo simulation codes. Because several times of the detector materials changing is essential in this study, the simulation operation was used as the strategy to deduct results. Information of the sixteen detector materials used for radiation detection was collected from previous experimental data to make simulation codes. Physical specifications such as the energy resolution and detection efficiency of materials were investigated. Prompt gamma ray images during BNCT simulation were acquired using only some detectors with excellent performance. From the simulation, the superiority of detector materials was determined. We could acquire prompt gamma ray image using six high ranked detector materials and lutetium yttrium oxyorthosilicate (LYSO). Each detector material has intrinsic specifications including strong points and weak points. In this study, we provided a strategy to select detection material for prompt gamma ray imaging during BNCT.

I. INTRODUCTION

Boron neutron capture therapy (BNCT) is one of effective treatment techniques in a radiotherapy field. The 10B(n, α)7Li reaction is a main atomic principle used to treat tumor.[1] After an injection of a boronate compound to a patient, this compound including boron can be stacked in the tumor region. In addition, the feasibility of imaging guided technique for the BNCT has been raised through the discovery of emission of 478 keV prompt gamma ray after boron neutron capture reaction.[2] Because this 478 keV prompt gamma ray is a single photon, when this gamma ray is detected by a nuclear medicine instrument such as a single photon emission computed tomography (SPECT) or a positron emission tomography (PET) during BNCT, the original reaction point can be identified through the image.[3] In our previous study, we have tried to reduce the reconstruction time using graphic processing unit (GPU) and developed a specific reconstruction algorithm for prompt gamma ray SPECT system.[4] In order to find the optimal detector material, we searched and collected specifications of sixteen detector materials mainly used for radiation detection[5]. Although we can select detector material for prompt gamma ray imaging during BNCT only using these specification data, H our ultimate goal is to find the best detector material through comparison based on quantitative results. Therefore, the objective of this study was to determine the optimal detector material for prompt gamma ray imaging during BNCT using Monte Carlo simulation. Because using all sixteen detector materials for the SPECT scanner is almost impossible in realistic experimental conditions, results of this study completely came from the simulation works.

II. METHODS AND RESULTS

A. Prompt gamma ray imaging and data analysis

When the full width at half maximum (FWHM) value was divided by the applied peak energy value, the divided value could be changed to energy resolution value by presenting 100% ratio. The energy resolution value from the prompt gamma ray energy spectrum for each detector material was then calculated. This simulation was also repeated 10 times to analyze statistical error. By using home-made MATLAB (R2012a, Mathworks Inc., MI, USA) code, energy resolution values at 478 keV were calculated from each energy spectrum acquired by operating Monte Carlo simulation.

The detection efficiency was calculated by using projection data through Monte Carlo simulation. In order to compose projection data of SPECT scanning during neutron irradiation in the simulation, effective events within an energy window of 10% at 478 keV prompt gamma ray peak were selected from P-trac record. These effective events were then arranged at the projection domain according to the original deposit position to deduct the sinogram. In the case of the detection efficiency, we counted the number of these effective events regarding each detector material simulation. Each ratio of detector efficiency was determined. In order to calculate statistical error of the detection efficiency, ten simulations according to each detector material were conducted with different random numbers. In a previous study, we developed fast image reconstruction algorithm for prompt gamma ray. To accelerate the image reconstruction process, we applied graphics processing unit (GPU) for the reconstruction algorithm with a compute unified device architecture (CUDA). To compare performance according to detector materials, the same reconstruction conditions as used in a previous simulation study such as GPU, CUDA setting, and reconstruction algorithm were used. Acquired projection data using information of seven detector materials were applied to the reconstruction algorithm. Projection data involved 32 projection frames with each scanner head at rotation of 11.25°. After the acquisition of reconstructed images, images were analyzed to acquire value of signal to noise ratio (SNR) and FWHM for each BUR.

A diagram summarizing entire simulation procedure is shown in Figure 1.

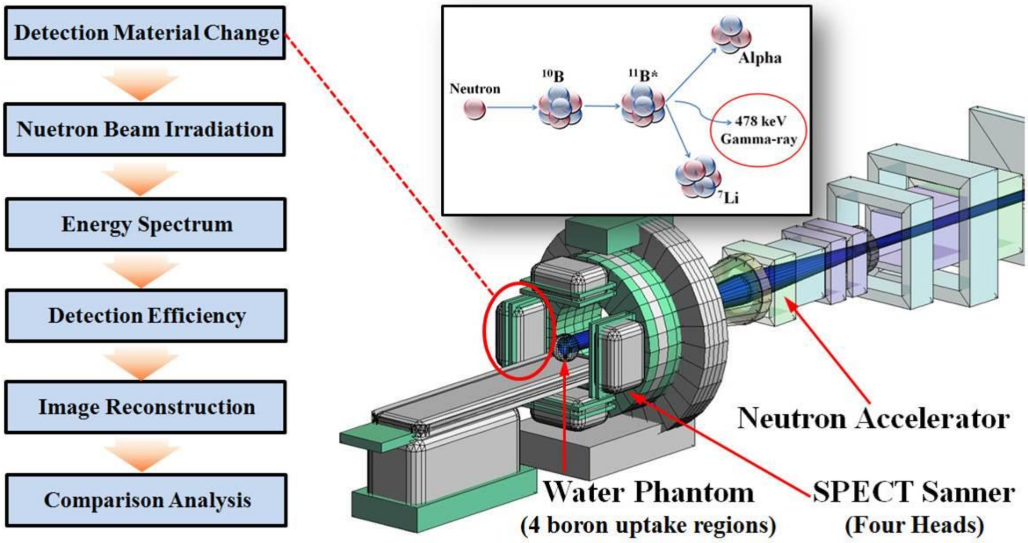

FIG.1. Diagram Summarizing the simulation procedure and simulation configuration. After changing the detection material, detection efficiency and energy resolution were determined for the detection materials based on simulation results. The prompt gamma ray image was reconstructed using simulation information of seven detection materials.

III. CONCLUSION

This study investigated the optimal detector material for prompt gamma ray imaging when BNCT was performed. For this investigation, basic performances of sixteen detector materials were evaluated using Monte Carlo simulation codes. And we reconstructed prompt gamma ray images by using simulation cases about best three performances regarding both the detection efficiency and the energy resolution, respectively. Although specifications according to the detection materials were different from each other, we could provide a strategy to select the optimum detection material for prompt gamma ray imaging during BNCT.

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