New approach to real-time measurement of the number of $^{10}$B(n, α)$^{7}$Li reactions using Gaseous Electron-Tracking Compton Camera (ETCC) system in boron neutron capture therapy

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1. Introduction

In boron neutron capture therapy (BNCT), dose with high LET by $^{10}$B(n, α)$^{7}$Li reaction is deposited in tumors. Transition probability of 478 keV gamma-ray emitted from $^{7}$Li$^+$ excited state in the $^{10}$B(n, α)$^{7}$Li is 93.7%. A lot of studies have been challenging to perform in-vivo real-time dosimetry during the BNCT1, 2. However, these studies have not succeeded in the dosimetry. This study is a feasibility test for evaluating the number of $^{10}$B(n, α)$^{7}$Li reactions by counting the 478 keV gamma-rays emitted from the region of interest with a typical compton camera system to measure the in-vivo real-time dosimetry during the BNCT.

2. Materials and Methods

National Cancer Center (NCC), Tokyo, Japan, has been installing an accelerator-based BNCT system. In order to evaluate the number of the neutron capture reactions in the patient body, we are going to use a Gaseous Electron-Tracking Compton Camera (ETCC) system which consists of a gaseous chamber and a GSO scintillator array. Although commonly compton camera systems determine emission angles of gamma-rays by measuring position and energy of recoil electron and energy of scattered gamma-rays by a semiconductor detector, the ETCC provides direction of recoil electrons in addition by the gaseous tracker. Therefore, energy, direction and position of initial gamma-ray are determined with high precision. Moreover, the background gamma-rays which have much lower energies than 478 keV can be effectively eliminated using the ETCC. Imaging of $^{199}$Au (411 keV) and $^{18}$F (511 keV) which were measured with the ETCC system succeeded3. The modeling of the BNCT system in NCC was performed with a Monte Carlo simulation package, Particle and Heavy Ion Transport code System (PHITS, version 2.64). The schematic diagram of the treatment room on PHITS is shown in Figure 1.

The schematic diagram of the setup for these simulations is shown in Figure 2. Simulations with the PHITS are performed for estimation of an energy spectrum of the initial gamma-rays emitted by irradiation of ~800 keV neutron to a water phantom of 30 $\times$ 30 $\times$ 20 cm$^3$ (Blue in Fig. 2). Beam aperture is placed on top of the water phantom. The central axis of the water phantom corresponds to the beam central axis. To simulate the target region with high concentration of $^{10}$B, $^{10}$B was placed in the target region of a 3 $\times$ 3 $\times$ 3 cm$^3$ in the water phantom (Purple in Fig. 2). $^{10}$B density used were 25 ppm, 250 ppm, and 2500 ppm, respectively. For these simulations, the number of neutrons was always $6.3 \times 10^7$. The energy distribution of the neutron was evaluated with another independent simulation which were performed with the BNCT system of NCC. The initial gamma-rays are counted at a distance of 12 cm from the target region after penetrating the sensitive area. In this study, the number of 478 keV gamma-rays was extracted by interesting the counts of gamma-rays whose energies lie between 460 keV and 480 keV. The cut-off energy of the neutron was $1 \times 10^{-4}$ eV, and that of the photon was $1 \times 10^3$ eV.

3. Results

The relationship between the number of 478 keV gamma-ray and the density of $^{10}$B is shown in Figure 3. The number of 478 keV gamma-rays is almost proportional to the density of the $^{10}$B. When the density of the $^{10}$B is 300 ppm, the number of the measured gamma-rays between 400 keV and 2.5 MeV is $1.1 \times 10^4$, and that of the 478 keV gamma-rays is $2.9 \times 10^3$. When the noise signal is defined as what the $^{10}$B-density of tumor is 0 ppm, the signal-to-noise ratio (SNR) is shown Table 1.

4. Discussion

The ETCC system can sustain a data acquisition rate of a few kcps. If the distance between the tumor and the detector is 300 cm, the number of the 478 keV gamma-ray rate is $6.2 \times 10^6$s. Therefore, with limiting of the detection area or with using the shield material, this study showed that the ETCC system would be applicable to BNCT. In the future, we make improvements to the ETCC system with using these simulation data, and we investigate the detection efficiency of the ETCC system.

5. Conclusion

This study shows the possibility of the in-vivo real-time dosimetry during the BNCT with using the ETCC system. Even if the saturate of the detector happens under the condition of the BNCT beam, this problem is solved by limiting of the measurement region or by using shield material.

Comparing with the common compton camera, the ETCC system has the typical feature that detects the electron tracking. Therefore, the in-vivo real-time dosimetry can be performed with high precision.

References


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