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Feasibility Study for Proton Radiography Using Two Double-sided Silicon Strip Detectors and NaI(Tl) Scintillation Detector

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1. Introduction

Because the proton beam has a unique energy deposition characteristic, so-called Bragg peak, the radiation therapy using the proton can locally deliver the planned dose to a tumor volume while minimizing the dose to healthy tissue or critical organs surrounding the tumor volume. For this advantage, the number of proton therapy facilities and treated patients has rapidly increased in the past decade [1]. However, the quality assurance and control (QA/QC) tools and/or procedures for the proton therapy are not fully established. Proton radiography has gained interest as a potential tool for the QA/QC technique to precisely deliver the dose in proton therapy by correcting patient positioning and determining optimal beam directions [2,3]. In the present study, a proton radiography system has been designed and simulated to estimate its performance using Geant4 Monte Carlo simulation toolkit [4].

2. Methods

In the proton radiography system under development, two identical position-sensitive semiconductor detectors, i.e., double-sided silicon strip detectors (DSSDs), were used to measure the entrance and exit position of the proton before and after passing through the phantom. The DSSDs are 5 × 5 × 0.15 cm^3 in size. In the present study, two different systems were tested; that is, 16 × 16 strip DSSD radiography system and 50 × 50 strip DSSD radiography system maintaining its size, which means that the pixel size of the image is 3 × 3 mm^2 and 1 × 1 mm^2, respectively. It also means that one could produce 256 pixel image, and the other could produce 2,500 pixel image. The subsequent scintillation detector, NaI(Tl) scintillator, was used to measure the residual energy of the proton, from which the range and range uncertainty information could be obtained. To completely absorb the residual energy of a proton and fully cover the area of the DSSD, the cylindrical NaI(Tl) scintillator which has dimensions of 3 in. (D) × 3 in. (L) was used.

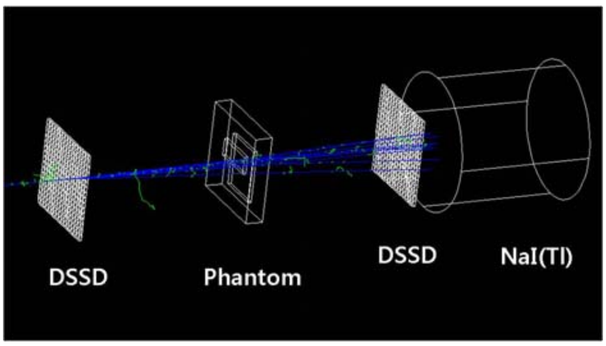

Fig. 1. Proton radiography system using two double-sided silicon strip detectors (DSSDs) and a NaI(Tl) scintillation detector. The phantom used in this simulation study is shown between the DSSDs.

The images were produced using the range information and range uncertainty information, which is the mean residual energy and the standard deviation of the mean residual energy as a function of proton position, respectively. The phantom, which has two plates made of bone at different depth in the water box, was placed between the DSSDs. The thickness of water box and bone plate is 1 cm and 0.1 cm, respectively. Figure 1 shows the proton radiography system with phantom. The broad parallel beam covering whole radiography system was employed as the proton source with the energy of 50 MeV.

3. Results and Discussion

3.1 Imaging Results Using Range Information

Figure 2 shows the spectra of the mean residual energies of the pixels (= pixel values) for the 50 × 50 strip DSSD radiography system. There are three peaks at 22.5 MeV, 24 MeV, and 25.5 MeV. The lowest mean residual energy is deposited in the NaI(Tl) scintillator when the proton passes through both of the bone plates

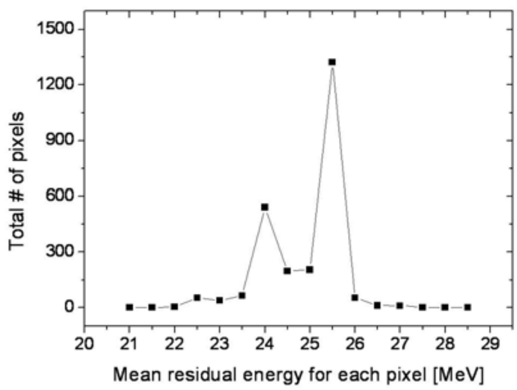

Fig. 2. Spectra of the mean residual energies of the pixels (= pixel values) for 50 × 50 strip DSSD radiography system.

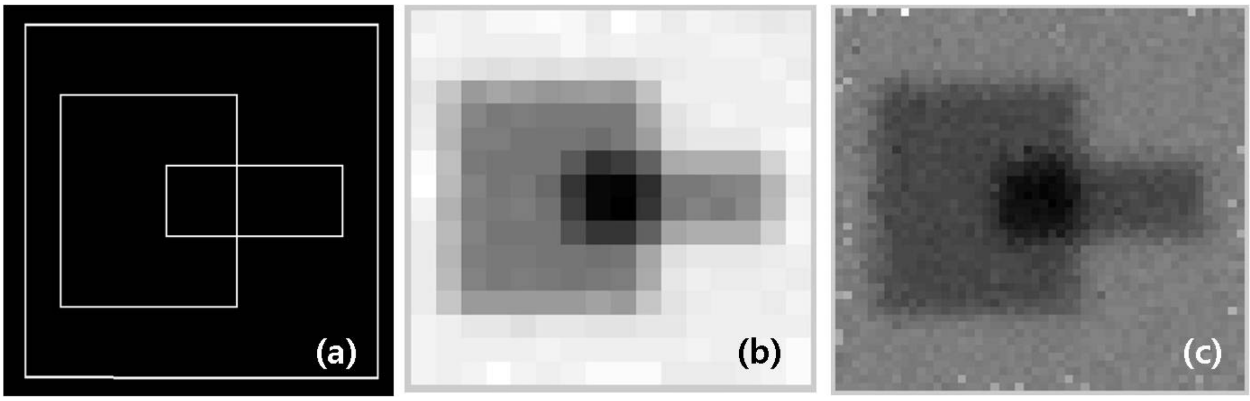

Fig. 3. (a) Phantom composed of two bone plates inside the water box, (b) image produced with range information for the 16 × 16, and (c) 50 × 50 strip DSSD radiography system.

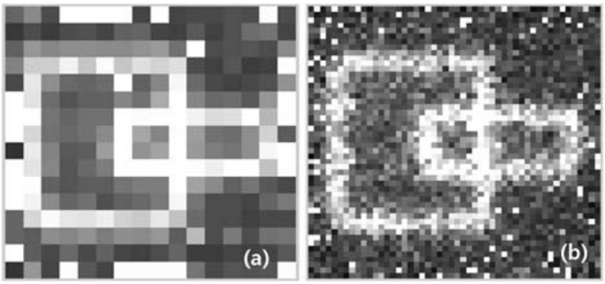

Fig. 4. Images produced with range uncertainty information for the (a) 16 × 16 and (b) 50 × 50 strip DSSD radiography system.

inside the water box, i.e., the central region of the phantom. The highest mean residual energy is deposited in the NaI(Tl) scintillator when the proton passes through only the water box, i.e., the outer region of the phantom. The images produced with range information using the 16 × 16 and 50 × 50 strip DSSD radiography systems are shown in Fig. 3. The average deposit energy inside the first and second DSSD was 3.53 ± 0.17 MeV and 5.45 ± 0.30 MeV, respectively.

3.2 Imaging Results Using Range Uncertainty Information

Due to multiple Coulomb scattering of the proton with the Coulomb field of the nuclei in medium, the uncertainty of the proton range is increased; consequently, it limits the spatial resolution of the proton radiography. When the proton traverses the interface of the different materials, the range uncertainty increases and one cannot precisely predict the dose distribution inside the body for proton therapy. To determine optimal beam directions, it is important to obtain the range uncertainty information. The images produced with range uncertainty information using both radiography systems are shown in Fig. 4. It clearly shows the interface of the different materials. In other words, the interface has larger uncertainty in proton range.

4. Conclusions

In the present study, the proton radiography system has been designed and simulated to estimate its performance using Geant4 Monte Carlo simulation toolkit. In the near future, a prototype proton radiography system will be constructed based on the simulation studies in the present study.

Acknowledgments

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