Measurements of Relative Depth Doses in Induced by High-Energy Proton Beam Using Multi-Dimensional Fiber-Optic Radiation Sensor

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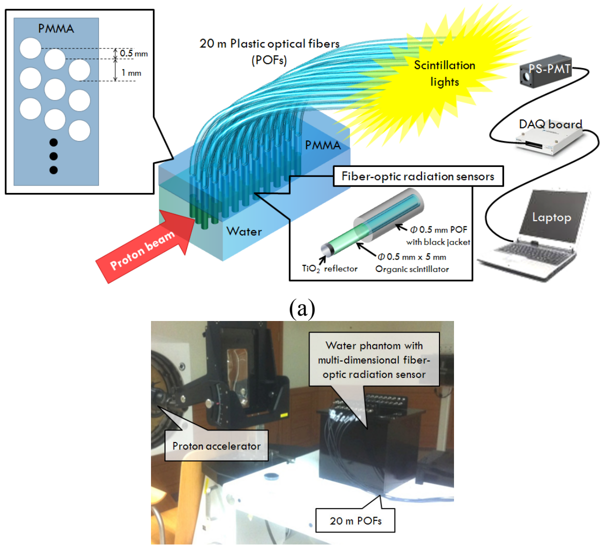
1. Introduction

Proton therapy makes it possible to remove a tumor effectively relative to conventional photon or electron therapy. The distal fall-off in depth dose distribution of the proton beam assures little irradiation damage on normal tissues except for the tumor. In addition, the high energy deposition in the Bragg-peak area is possible to concentrate more doses on a tumor. However, the misposition of the Bragg-peak could cause critical damage to normal tissues and give rise to serious problem to cancer patients. Therefore, the quality assurance (QA) to get the position accuracy of the proton beam using a dosimeter is very important process in proton therapy. Especially, in ocular proton beam therapy, comparably low energies and relatively short ranges (1 ~ 4 cm) of the proton beams are required, and the depth dose distributions of proton beams have to be measured with a high resolution dosimeter in a real-time. In proton therapy, it is not easy to measure the depth dose distribution using a conventional ionization chamber in a real-time with a high spatial resolution because it has a relatively large volume and consists of non-water equivalent material. On the other hand, a fiber-optic radiation sensor (FORS) uses an organic scintillator as a sensing material, the diameter of which is usually less than 1.0 mm. Organic scintillators are water equivalent and can be used for an exact dose measurement without complicated calibration processes due to temperature and pressure variations [1,2].

In this study, we fabricated a multi-dimensional FORS which consists of organic scintillators, plastic optical fibers (POFs) and a water phantom with polymethyl methacrylate (PMMA) for the ocular proton therapy dosimetry. In addition, the relative depth dose of 109 MeV proton beam was measured by using of a multi-dimensional FORS which has 10 × 3 sensor array with a 0.5 mm interval.

2. Materials and Methods

The organic scintillator (BCF-12, Saint-Gobain Co., OH, USA) which is chosen in this experiment is synthesized with polystyrene (PS) and wavelength-shifting fluors and is used as the sensor-tip of the FORS. The organic scintillator has a cylindrical shape and a core/cladding structure, just like an optical fiber. The materials of the core and the cladding are PS and PMMA, respectively. The refractive indices of the core and the cladding are 1.680 and 1.490, respectively, and the numerical aperture (NA) is 0.580. The emission color of this scintillator is blue and the peak wavelength is 435 nm. The number of emitted photons per 1 MeV of energy deposited in this scintillator is about 8000. This scintillator is a cylinder with diameter of 0.5 mm and length of 5.0 mm. The POF chosen for this study is a step-index multi-mode fiber (SH-2001, Mitsubishi Rayon Co., Ltd., Japan). The outer diameter is 0.5 mm and the cladding thickness is 7 μm. The refractive indices of the core and the cladding are 1.492 and 1.402, respectively and NA is about 0.510. The materials of the core and the cladding are PMMA and fluorinated polymer, respectively, and the jacket was made of polyethylene (PE). As a scintillating light measuring device, we used a position-sensitive photomultiplier tube (PS-PMT: H7546, Hamamatsu Photonics Inc., Japan) whose measurable wavelength is in the range between 300 nm to 650 nm, and the peak wavelength is about 420 nm. Ion Beam Applications (IBA) PROTEUS 235 proton therapy machine (Chemin du Cyclotron, Louvain-La-Neuve, Belgium) in the national cancer center (NCC) was used for generating the proton beam.



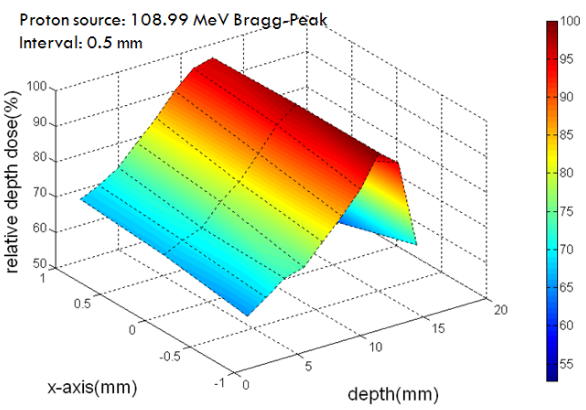
(b)

Fig. 1. Experimental setup and construction of a multi-dimensional FORS ((a) construction of a multi-dimensional FORS, (b) experimental setup)

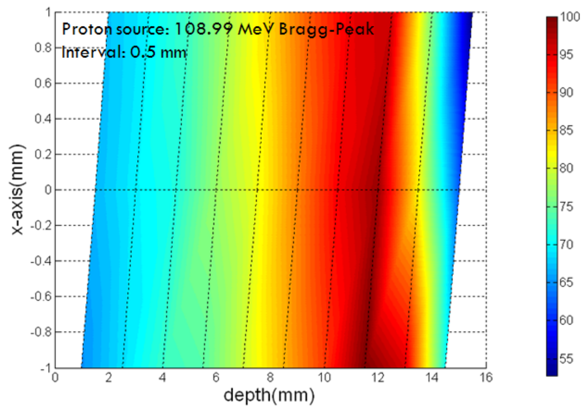
Fig. 1 shows the experimental setup and construction of a multi-dimensional FORS to measure ocular therapeutic proton beams. The FORSs consist of organic scintillators with TiO_2 reflectors and plastic optical fibers. Each sensor is embedded in a PMMA block, and sensor probes – scintillators with TiO_2 reflectors – are submerged in the water. The FORSs can be arrayed minimally with a 0.5 mm interval using the phantom as shown in the figure. When the proton beam irradiates the sensor probes, light signals from scintillators are transmitted to a PS-PMT via 20 m-length of POFs. Then, the amplified electric signals from the PS-PMT are measured with a DAQ board and displayed by the LabVIEW program.

3. Experimental Results

Fig. 2(a) shows two-dimensional distribution of the relative depth dose of 109 MeV proton beam by using of a multi-dimensional FORS which has 10 × 3 sensor array with a 0.5 mm interval. In this result, the Bragg-peak was measured near the depth of 12 mm. And we could find that planar dose distributions at the same depths are almost uniform as shown in Fig. 2(b).



(a)



(b)

Fig. 2. Measurements of the relative depth dose of 109 MeV proton beam using a multi-dimensional FORS ((a) 3-D display of relative depth dose, (b) planar display of relative depth dose)

One-dimensional distribution of the relative depth dose also can be obtained using a multi-dimensional FORS as shown in Fig. 3. This result shows that a multi-dimensional FORS can measure depth dose distributions of therapeutic proton beam with a 0.5 mm resolution. The depth dose distribution of 109 MeV proton beam increased gradually till the Bragg-peak at the depth of 11.5 mm and then decreased with a steep gradient.

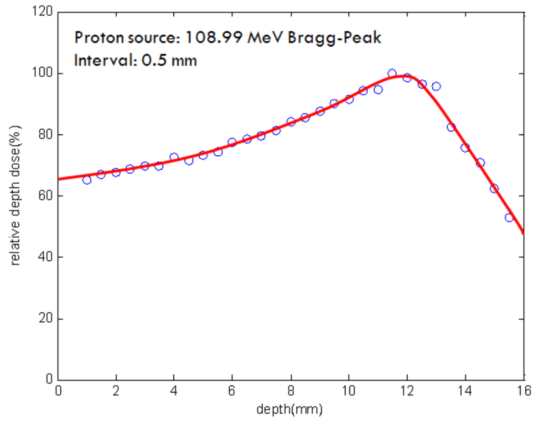


Fig. 3. 1-D display of the relative depth dose of 109 MeV proton beam using a multi-dimensional FORS

3. Conclusions

A multi-dimensional FORS which consists of organic scintillators, POFs and a water phantom for the ocular proton therapy dosimetry was fabricated through this study. And the Bragg-peak of 109 MeV proton beam was measured at the depth of 11.5 mm of a phantom by using of a multi-dimensional FORS which has 10 × 3 sensor array with a 0.5 mm interval.

The multi-dimensional FORS can be employed as a dosimeter of proton beam therapy due to its favorable characteristics such as high-resolution measurement in real-time, water-equivalence, and no corrections for temperature, pressure and humidity. Further study will be carried out for the measurement of the spread-out Bragg-peak (SOBP) using a multi-dimensional FORS.

ACKNOWLEDGEMENT

This work was supported by Nuclear R&D program through the National Research Foundation of Korea funded by the Ministry of Education, Science and Technology. (grant code: M 2009-0078227)

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