35th Annual International Conference of the IEEE EMBS
Osaka, Japan, 3 - 7 July, 2013

Feasibility Study on Development of Cerenkov Fiber-Optic Dosimeter for Radiotherapy Application*

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Abstract— **To obtain real-time dose information in photon-beam therapy using a clinical linear accelerator, we fabricated a novel Cerenkov fiber-optic dosimeter using two plastic optical fibers without employing a scintillator. In this study, the light intensity and spectrum of Cerenkov radiation induced by a high-energy photon beam were measured as functions of the irradiation angle and the length difference between the two plastic optical fibers in the dosimeter probe. Also, we obtained a percentage depth dose curve for a 6 MV photon beam with a field size of 10 x 10 cm^2 according to the depth of the solid water phantom. Based on the results of this study, it is anticipated that the proposed Cerenkov fiber-optic dosimeter can be developed as a useful dosimeter to accurately obtain dose information prior to conducting radiotherapy.**

I. Introduction

As an alternative to conventional dosimeters, different types of scintillating fiber-optic dosimeters (SFODs) using various organic scintillators have been developed [1-4]. For radiotherapy dosimetry, the SFODs offer a number of advantages, including small sensitivity volume, substantial flexibility, tissue or water equivalence, remote and real-time sensing, and immunity to electromagnetic interference (EMI), because they use optical fibers to guide light signal containing dose information. Although SFODs have many desirable qualities, they accompany the drawback of unwanted light signal such as Cerenkov radiation which can be produced by the direct action of the radiation in the optical fiber. To obtain pure scintillating light signal, a variety of studies on removal technique of the Cerenkov radiation generated from the SFOD have been reported [5-7]. However, the Cerenkov radiation is of utility value for measuring absorbed dose because it is one of the signals produced in the dosimeter probe of the SFOD by radiation interactions [8]. In this study, we fabricated a novel Cerenkov fiber-optic dosimeter (CFOD) based on a Cerenkov counting technique to measure a percentage depth dose (PDD) for a 6 MV therapeutic photon beam. Also, the light intensity and spectrum of Cerenkov radiation induced by a high-energy photon beam were measured as functions of the irradiation angle and the length difference between the two plastic optical fibers (POFs) to evaluate the performance of the CFOD.

*This work was supported by the National Research Foundation of Korea (NRF) grant funded by the Korea government (MEST) (No. 20120004876, No. 2012045539, and No. 2012029724).

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II. Materials and Methods

A. CFOD System

In developing the CFOD system, we used the step-index multimode POFs (GH4001, Mitsubishi Rayon) to produce and transmit the Cerenkov radiation induced by a therapeutic photon beam. Diameters of the POF were 0.98 ± 0.06 mm for the core only and 1.0 ± 0.06 mm including the cladding. The transparent material of the core was polymethylmethacrylate (PMMA) resin and the thin cladding layer was made of fluorinated polymer. The refractive indices of the core and the cladding were 1.49 and 1.402, respectively, and thereby the numerical aperture (NA), which denotes the light-gathering power, was about 0.5. In the previous report, the PMMA was regarded as a water-equivalent material in radiotherapy dosimetry applications because the electron density (i.e., number of electrons per cubic centimeter) of PMMA was adequately close to that of water [9]. The CFOD which is made of the POFs accordingly has a desirable quality for the dose measurement without complicated calibration processes.

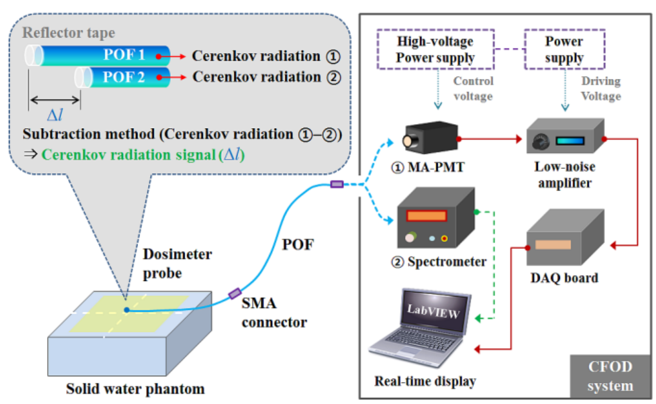

Figure 1. Structure of the dosimeter probe and the schematic diagram of the CFOD system

Fig. 1 shows the structure of the dosimeter probe and the schematic diagram of the CFOD system. For applying a subtraction method, the dosimeter probe was composed of two POFs with different lengths (Δl). To increase the light collection efficiency of Cerenkov radiation, the distal end of the probe was coated with a reflector tape (BC-642, Saint-Gobain Ceramic & Plastics) based on polytetrafluoroethylene (PTFE, Teflon®) with a thickness of 0.08 mm. The length of the transmitting POF as a light guide was determined to be 25 m, which was a sufficient distance to prevent radiation damage and noise in the light-measuring device due to scattered radiations. Two subminiature-type A (SMA) connectors were installed on the both sides of the transmitting POF to enable connection with the proximal end of the probe and a light-measuring device. A multi-anode photomultiplier tube (MA-PMT) module (R7600U-03-M4, Hamamatsu Photonics) was used as a main light-measuring device to measure the light intensity of Cerenkov radiation. The measurable wavelength range of the MA-PMT was from 185 to 650 nm and the peak wavelength was about 420 nm. In addition, to obtain the light spectrum of Cerenkov radiation, an optical spectrometer (Avaspec-HS 1024x122TEC, Avantes) having a charge-coupled device (CCD) image sensor with 1,024 x 122 pixels was also used.

B. Experimental Setup

The experimental setup for measuring Cerenkov radiation generated from the POF in the probe is illustrated in Fig. 2. The characteristic analysis of the proposed CFOD system was evaluated using a clinical linear accelerator (CLINAC® 21EX, Varian Medical Systems). The energy of therapeutic photon beam and the field size were 6 MV and 10 x 10 cm^2, respectively, and the source-to-surface distance (SSD) was set to 100 cm as the condition for calibrating the CLINAC. The dose rate of the 6 MV photon beam was 600 MU/min and the irradiation time was 30 sec. Generally, monitor unit (MU) is a number that is set on a CLINAC and 1 MU gives an absorbed dose of 1 cGy at a depth of maximum dose for a field size of 10 x 10 cm^2 and a SSD of 100 cm.

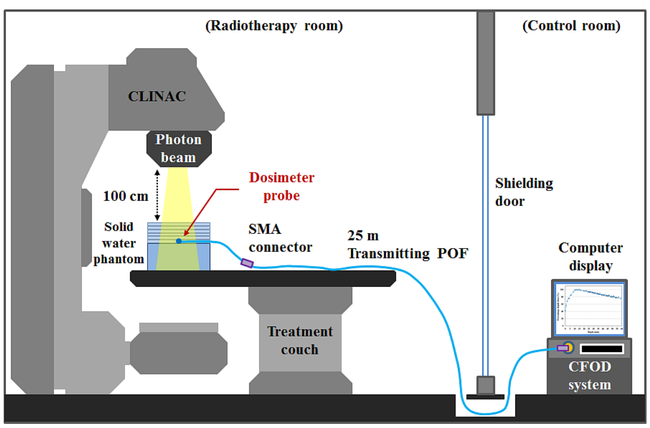

Figure 2. Experimental setup for measuring Cerenkov radiation using the CFOD system

III. Experimental Results

In this study, we measured the intensity difference (Δi_c) of the two Cerenkov radiations (i.e., intensity of Cerenkov radiation generated from the limited length of POF in the dosimeter probe) using the proposed CFOD system without employing a scintillator for the dose measurement of a photon beam. Using the CCD spectrometer, first, we measured the spectrum of Cerenkov radiation to obtain angular dependence of Cerenkov radiation generated in the POF. Fig. 3 shows the light spectrum of the Cerenkov radiation according to the incident angle of the photon beam. This spectrum was measured by integrating the output counts during 30 sec of a photon beam irradiation. The Cerenkov radiation measured by the CCD spectrometer had a wide spectral range in visible light. As the irradiation angle increased by 10° increments from 40° to 90°, the intensity of Cerenkov radiation decreased.

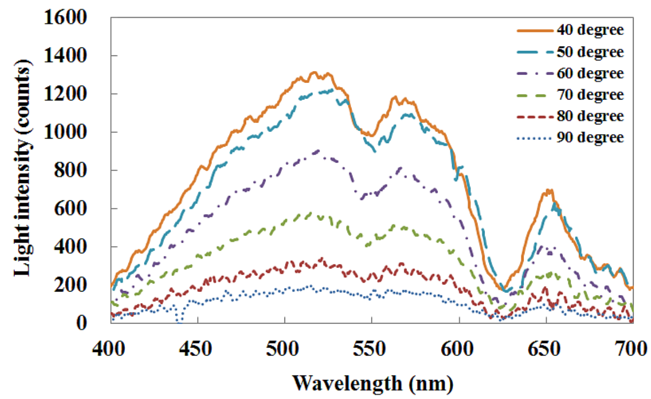

Figure 3. Spectrum of Cerenkov radiation generated in POF according to the irradiation angle

Fig. 4 shows the angular dependence of the Cerenkov radiation generated in the POF. By integrating the intensity measured over the wavelength range from 400 to 700 nm, the amount of Cerenkov radiation was obtained as a function of the irradiation angle and the peak value was measured at the angle around 40°, as shown in Fig. 4.

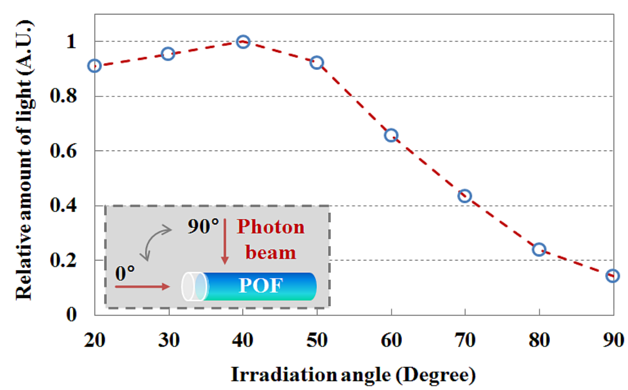

Figure 4. Angular dependence of Cerenkov radiation generated in POF

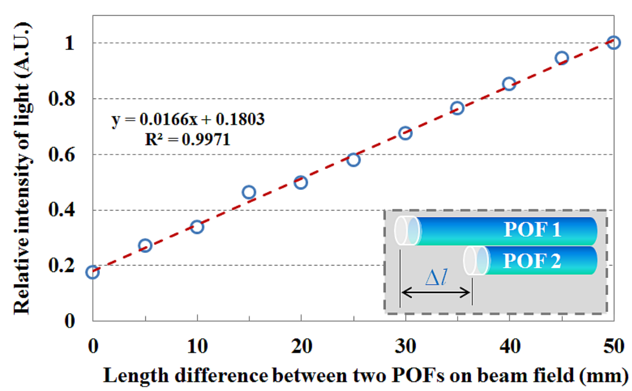

Figure 5. Relative intensity of Cerenkov radiation according to the length difference between the two POFs in the dosimeter probe

Next, by using the MA-PMT, the light intensity of Cerenkov radiation was measured according to the length difference between the two POFs in the dosimeter probe as shown in Fig. 5. As the length difference increased from 0 to 50 mm, the intensity difference of the two Cerenkov radiations linearly increased because the generation rate of Cerenkov radiation was proportional to the volume of irradiated medium. To provide a high-spatial resolution for dose measurements, we determined the length difference between POFs in the probe of the CFOD is 10 mm in this experiment.

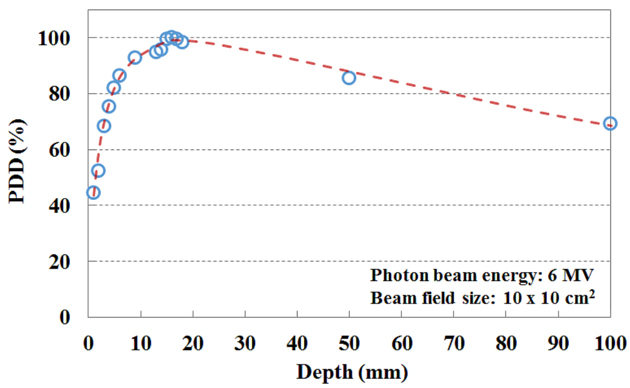

Figure 6. Measured PDD curve for 6 MV photon beam with a field size of 10 x 10 cm^2 using the CFOD

Fig. 6 shows the measured PDD curve for a 6 MV photon beam. The PDD values were normalized as the percentage of the maximum dose for the fixed 10 x 10 cm^2 field and they were measured using the fabricated CFOD. In the build-up region, the maximum PDD value was found to be at depth of about 15 mm for 6 MV photon beam and this result was consistent with well-known results using other dosimeters [10,11]. Therefore, we demonstrated that the proposed CFOD can measure the dose distribution of a therapeutic photon beam using the intensity difference of the two Cerenkov radiations generated in the dosimeter probe.

IV. Conclusion

In this study, we carried out the feasibility study on the development of a novel CFOD that integrates a Cerenkov counting technique and a fiber-optic radiation sensor without employing a scintillator. For the characteristic analysis on the Cerenkov radiation produced in a POF by irradiating high energy photon beam, the light intensity and spectrum were measured as functions of the irradiation angle and the length difference between the two POFs. According to the depth of the solid water phantom, a PDD curve for a 6 MV photon beam was also measured using the fabricated CFOD. Based on this fundamental study, it is anticipated that the proposed CFOD can be effectively used to obtain real-time dose information in radiotherapy.

Acknowledgment

This work was supported by the National Research Foundation of Korea (NRF) grant funded by the Korea government (MEST) (No. 20120004876, No. 2012045539, and No. 2012029724).

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