OPTICAL REVIEW Vol. 14, No. 5 (2007) 351–354

Development of One-dimensional Fiber-Optic Radiation Sensor for Measuring Dose Distributions of High Energy Photon Beams

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(Received January 25, 2007; Revised June 22, 2007; Accepted July 18, 2007)

The purpose of this study was to develop a method for measuring the one-dimensional dose distribution of a high-energy photon beam using a miniaturized high-resolution fiber-optic radiation sensor array. The measurements were made by thin plastic optical fibers with organic scintillating fiber sensor probes that emit the visible wavelength of light. The scintillating light is guided to a silicon photodiode array by plastic optical fibers in order to convert light output to an electrical signal. The one-dimensional spatial dependence of photon beam is measured by a one-dimensional fiber-optic sensor array in a poly(methyl methacrylate) (PMMA) phantom. It is shown that this fiber-optic radiation sensor has better spatial resolution than a conventional ionization chamber and much less time is required to measure one-dimensional dose distribution in the high radiation fields. The real-time and the high spatial resolution measurements due to the small detector volume make this system suitable for dosimetry in radiation therapy.

Key words: plastic optical fiber, organic scintillator, radiation sensor, one-dimensional dose distribution

1. Introduction

The success of radiotherapy treatments such as intensity modulated radiation therapy (IMRT) or brachytherapy depends on the precision with which the prescribed dose is delivered to the prescribed site and, therefore, on the faculty to control it.[1)] For this purpose, small sized dosimeters for radiotherapy such as ionization chambers, silicon photodiodes, diamond detectors, and a liquid ionization chamber have been developed and used for dose measurements.[2–5)] However, there are some problems as a rather large sensitive volume, dose rate dependence, and complicated construction with these sensors.[6)] And it is difficult to measure depth dose curve and beam profile with conventional detectors due to the loss of lateral electronic equilibrium and volume averaging.[7)] In recent years, a miniature fiber-optic radiation sensor based on an organic scintillator was developed.[8,9)] Organic scintillators can be used as dosimeters because they emit visible light proportional to the absorbed electron and gamma dose rate;[10)] and the sensor using this scintillator can minimize dose distribution perturbation in a plastic phantom or water because the sensitive volume of the sensor is very small and nearly water-equivalent. Especially, the material properties of a radiation sensor used as a dosimeter should be well matched to the medium in which the absorbed dose is to be measured. Therefore, the sensing volume should absorb and scatter radiation the same way water or human tissue does. It is well known that polystyrene is the best water or tissue-equivalent phantom material available at present.[11)] Typically, fiber-optic radiation sensors for radiotherapy dosimetry applications use an organic scintillator probe, optical fiber, and light-measuring devices.[12,13)]

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An optical fiber is usually made of plastic or glass, which is used to guide the light signal from a scintillator probe to light measuring devices such as a photomultiplier tube (PMT), photodiode, and optical power-meter. As a light pipe, plastic optical fiber has many advantages such as good flexibility, ease of processing, long lengths, and lack of interference with electro magnetic fields.[14)] However, to use for measuring depth dose, profile, and dose rate of a high-energy treatment beam such as a photon or electron, the fiber-optic sensors should be embedded and arrayed in a plastic or water phantom.

In this study, a fiber-optic radiation sensor with an organic scintillator is fabricated to measure high-energy photon beam from a clinical linear accelerator (CLINAC), and a fiber-optic sensor array was also fabricated to measure one-dimensional (1D), high-resolution, and real-time dose distributions. The scintillating lights generated from each organic sensor probe embedded and arrayed in poly(methyl methacrylate) (PMMA) phantoms are guided by 10 m plastic optical fiber to the light-measuring device. 1D photon beam distributions in a PMMA phantom are measured with different energies and field sizes of photon beam. Also, 1D percent depth dose curves for 6 and 15 MV photon beams are obtained. Usually, photon beams generated from CLINAC are heterogeneous in energy and designated by megavolts (MV), as if the beam were produced by applying that voltage across an X-ray tube of CLINAC.

2. Materials and Experimental Setup

The optical fibers chosen for this study were commercial-grade plastic multimode fibers (CK-40) manufactured by Mitsubishi (Japan). The outer diameter of these fibers is 1.0 mm, and the cladding thickness is 0.02 mm. The refractive indices of the core and the cladding are 1.49 and

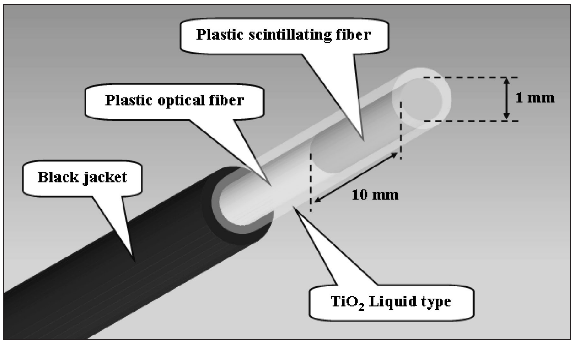

Fig. 1. Fiber-optic radiation sensor using an organic scintillator probe and a plastic optical fiber.

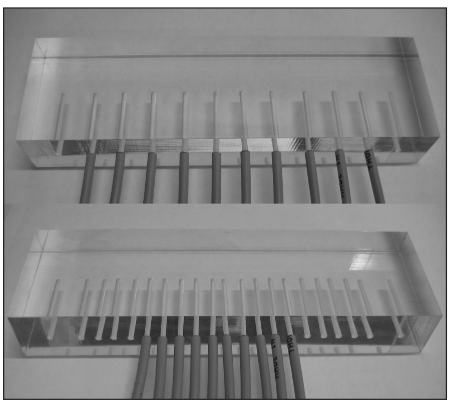

Fig. 2. One-dimensional fiber-optic radiation sensor arrays.

1.402, respectively, and the numerical aperture (NA) is 0.504. An organic scintillator made out of a polyvinyltoluene (PVT) base with wavelength-shifting fluors is used as a fiber-optic sensor probe. It is commercially available (BCF-20, Bicron) and has a cylindrical shape. The emission color and peak of this organic scintillator is green and 492 nm, respectively. And about 8000 photons are emitted when 1 MeV ionizing particle interacts with it. An organic scintillator of 1 mm diameter and 10 mm length is glued to the 10 m length plastic optical fiber. Both surfaces of the scintillator and plastic optical fiber are polished with various kinds of polishing pads in a regular sequence from coarse to fine.

Figure 1 shows a fiber-optic radiation sensor probe using an organic scintillator and a general plastic optical fiber. The surface of the sensor probe is surrounded by reflective paint based titanium oxide (TiO_2) to increase scintillating light collection efficiency and to intercept the light noise from outside. 1D fiber-optic radiation sensor arrays with gaps of 1 cm and 0.5 cm using PMMA phantoms are shown in Fig. 2.

Figure 3 shows the experimental setup to measure a 1D dose distribution of photon beams from a CLINAC. Throughout this study, photon beams were provided with a Varian Clinac 2100CD and two kinds of photon beam energies, 6 and 15 MV, were used. Field sizes of the photon

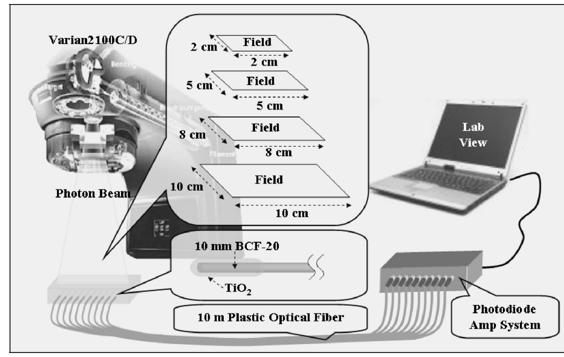

Fig. 3. Experimental setup.

beam are 2×2, 5×5, 8×8, and $10 \times 10\,cm^2$. The scintillating light measurements were made with 10 channel photodiodes (S1336-18BK, Hamamatsu) amplification system.

3. Experimental Results

Figure 4 shows the measured scintillating light signals from a 1D fiber-optic sensor array with different photon energies. The fiber-optic sensors are embedded in a PMMA phantom at 1 cm and arrayed with the same gap of 1 cm. The measured light signals show almost the same values and are distributed uniformly in a field size of $10 \times 10\,cm^2$ for two different photon beam energies. The scintillating light signals induced by the 6 MV photon beam are higher than those by the 15 MV photon beam because the maximum depth dose of the 6 and 15 MV photon beam occurs at about 1.5 and 3 cm in water, respectively.[15)]

Almost the same results are shown in Fig. 5 with a different field size of photon beam. The field size used in this experiment is $8 \times 8\,cm^2$, and thus the first and tenth fiber-optic sensors are unable to detect any signal due to the reduced field size.

Figure 6 also shows the 1D dose distribution of photon beams with different energies. The fiber-optic sensors are placed at 1 cm depth of a PMMA phantom and the gaps between sensors are the same 0.5 cm. The photon beam field

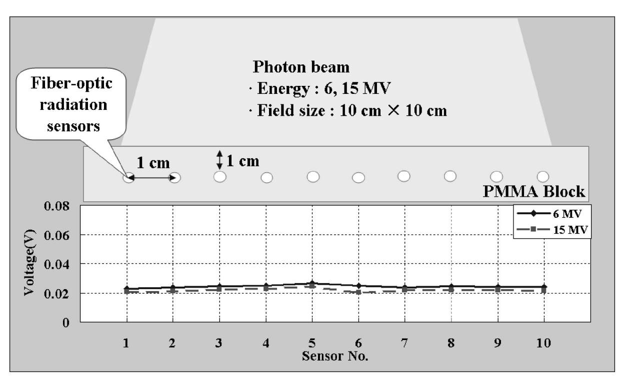

Fig. 4. Measurements of scintillating lights in one-dimensional fiber-optic radiation sensor whose gap is 1 cm for $10 \times 10\,cm^2$ field size of photon beams.

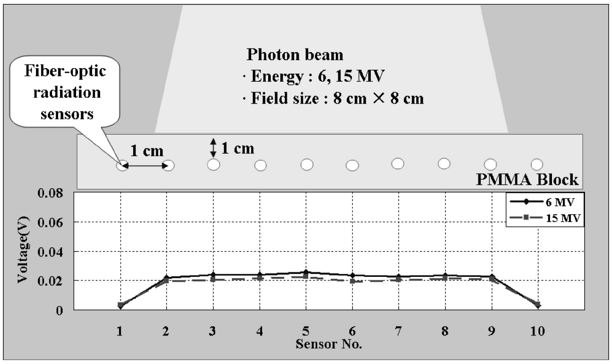

Fig. 5. Measurements of scintillating lights in one-dimensional fiber-optic radiation sensor whose gap is 1 cm for $8 \times 8\,\mathrm{cm}^2$ field size of photon beams.

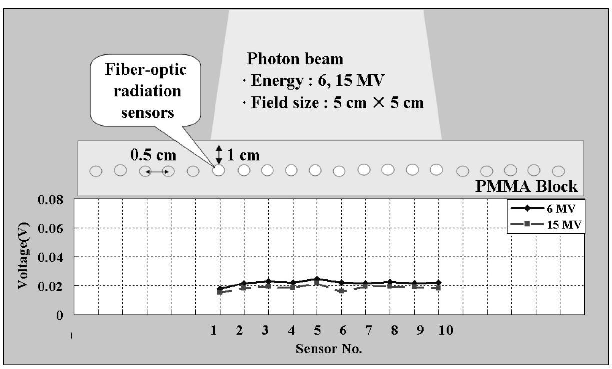

Fig. 6. Measurements of scintillating lights in one-dimensional fiber-optic radiation sensor whose gap is 0.5 cm for $5 \times 5\,\mathrm{cm}^2$ field size of photon beams.

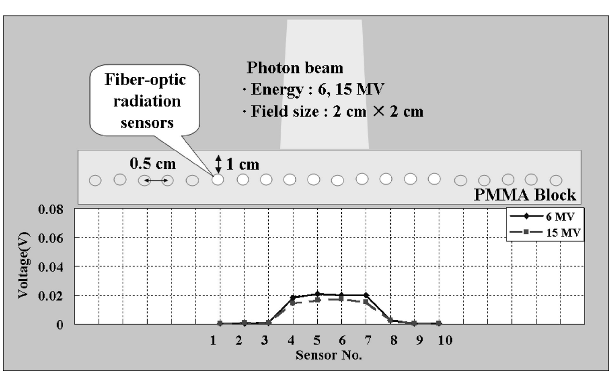

Fig. 7. Measurements of scintillating lights in one-dimensional fiber-optic radiation sensor whose gap is 0.5 cm for $2 \times 2\,\mathrm{cm}^2$ field size of photon beams.

size is $5 \times 5\,\mathrm{cm}^2$, and every light signal is detected uniformly in this beam. It is expected that the spatial resolution of this 1D sensor array is less than 0.5 cm.

Figure 7 shows scintillating lights in a 1D fiber-optic radiation sensor whose gap is 0.5 cm for the $2 \times 2\,\mathrm{cm}^2$ field size of a photon beam. This result also shows that its spatial resolution is less than 0.5 cm and it is possible to measure the signal in a field $0.5 \times 0.5\,\mathrm{cm}^2$ or less. It is difficult to measure the signal with an ionization chamber in the field of a photon beam less than $0.5 \times 0.5\,\mathrm{cm}^2$ because of its rather large size.[16]

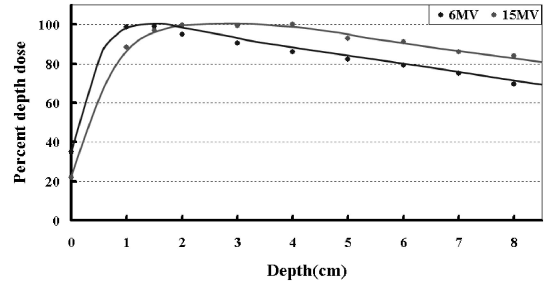

Fig. 8. Measurements of percent depth doses using a one-dimensional fiber-optic radiation sensor.

Measured percent depth dose curves using a 1D fiber-optic sensor array for 6 and 15 MV photon beams are shown in Fig. 8. These curves show that the percent depth doses for 6 and 15 MV photon beams are maximized at about a 1.5 and 3 cm depth of a PMMA phantom, respectively. These are consistent with previous results obtained using an ion chamber.[15]

4. Conclusions

In this study, we fabricated a fiber-optic radiation sensor with an organic scintillator and a 1D sensor array to measure high-energy photon beam distributions from a CLINAC. 1D, high resolution, and real-time dose measurements are possible using this fiber-optic sensor array. 1D photon beam distributions in a PMMA phantom are measured with different energies and field sizes of beam. Also, 1D percent depth dose curves for 6 and 15 MV photon beams were obtained. Further studies will be carried out to measure the limited spatial resolution of a 1D fiber-optic sensor array and to fabricate a two-dimensional (2D) fiber-optic sensor array.

Acknowledgment

This work was supported by Konkuk University.

References

1) A.-M. Frelin, J.-M. Fontbonne, G. Ban, J. Colin, M. Lavalme, A. Batalla, A. Isambert, A. Vela, and T. Leroux: Med. Phys. **32** (2005) 3000.
2) F. Sánchez-Doblado, R. Capote, J. V. Roselló, A. Leal, J. I. Lagares, R. Arráns, and G. H. Hartmann: Radiotherapy Oncol. **75** (2005) 342.
3) R. L. Dixon and K. E. Ekstrand: Int. J. Appl. Radiat. Isotopes **33** (1982) 1171.
4) B. Planskoy: Phys. Med. Biol. **25** (1980) 519.
5) K. Eberle, J. Engler, G. Hartmann, R. Hofmann, and J. R. Horandel: Phys. Med. Biol. **48** (2003) 3555.
6) T. Aoyama, S. Koyama, and H. Maekoshi: 6th Int. Conf. Medical Physics, 1999, p. 117.
7) D. Letourneau, J. Pouliot, and R. Roy: Med. Phys. **26** (1999)

2555.
8) A. S. Beddar, T. R. Mackie, and F. H. Attix: Phys. Med. Biol. **37** (1992) 1883.
9) A. S. Beddar, T. R. Mackie, and F. H. Attix: Phys. Med. Biol. **37** (1992) 1901.
10) K.-H. Becks, J. Drees, K. Goldmann, I. M. Gregor, and M. Heintz: Nucl. Instrum. Methods Phys. Res., Sect. A **454** (2000) 147.
11) A. S. Beddar: Radiat. Protection Dosimetry **120** (2006) 1.
12) B. M. Rogina and B. Vojnovic: Radiat. Meas. **26** (1996) 599.
13) E. Takada, A. Kimura, Y. Hosono, H. Takahashi, and M. Nakazawa: J. Nucl. Sci. Technol. **36** (1999) 641.
14) B. Lee, W. Y. Choi, and J. K. Walker: Polym. Eng. Sci. **40** (2000) 1996.
15) F. M. Khan: *The Physics of Radiation Therapy* (Williams & Wilkins, Baltimore, 1994) 2nd ed., p. 131.
16) A. S. Beddar, T. J. Kinsella, A. Ikhlef, and C. H. Sibata: IEEE Trans. Nucl. Sci. **48** (2001) 924.