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Experiment Study on the X-ray Attenuation by Tissue-Equivalent Matter

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1. Introduction

In radiation therapy, the dose distribution curve along the beam incident direction in the patient body is fundamental data which the formulation of irradiation planning is based on. The percent depth dose (PDD) curve is the standard dose distribution curve under conventional use [1]. In PDD curve, dose values are converted to the fractional quantity of the maximum dose d_{max}. The PDD curve for high-energy x-ray beam is characterized by the dose build-up at some depth in the beam direction inside the body.

The dose build-up with kilovoltage x-ray beam is not as clear as with the high-energy (~MeV) x-ray beam mainly because the depth of maximum dose is not that far from the body surface. The PDD curve formation with kilovoltage x-ray beam, therefore, requires better spatial resolution of dosimetric estimates to clarify the dose build-up at an immediate depth. There has been a study that compares different dosimeters in measuring percentage depth dose (PDD) for kilovoltage x-ray beams (Fletcher and Mills 2008). Among radiation dosimeters available, Gafchromic EBT film has advantages in energy dependence and spatial resolution.

In this study, we investigated the potential of Gafchromic EBT film dosimetry in profiling the PDD curve with kilovoltage x-ray beam. The PDD curve based on the experimental data was compared with one obtained from Monte Carlo simulation.

2. Methods

2.1 Film dosimetry

The radiation exposure was carried out in a hard x-ray irradiation facility run by the Radiation Bioengineering Laboratory (RadBioLab) in Department of Nuclear Engineering at Seoul National University. The main component of the x-ray facility is the YXLON model 450-D08 x-ray tube, which operates at maximum 450 kV.

The Gafchromic EBT film (International Specialty Products) was employed as radiation sensor. The film is almost water-equivalent with its effective atomic number Z_{eff} of 6.98 and physical density of 1.1 g/cm^3 (compare with Z_{eff} = 7.3 and ρ = 1.0 g/cm^3 for water). The change in optical density of films after radiation exposure was considered to directly relate to the absorbed dose to the films. The calibration curve of dose versus optical density, which was derived in the previous study at RadBioLab (Fig. 1), was referred to for assessing doses from various levels of optical density.

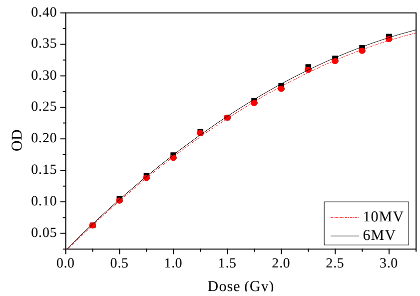

Fig. 1 Standard curves in terms of optical density (OD) versus dose for the response of Gafchromic EBT film to radiation exposure at doses ranging from 25 cGy to 300 cGy [3].

Regarding tissue-equivalent matter, PMMA (polymethyl methacrylate) was chosen out of several candidate matters considering the energy range of the x-ray beam source. The geometrical set-up of the phantom is a simple cylinder of 20 cm in diameter and 16 cm in height. To position the radiosensitive films at different depths, the phantom was sliced into five 2 cm-, five 1 cm-, and five 0.2 cm-thick pieces.

The spectral-energy x-ray beam was obtained by operating the YXLON beam tube at 150 kV, 250 kV or 350 kV. The beam irradiation time was arranged considering the sensitive dose range of EBT films, that is, 0.01 Gy to 3 Gy. In other words, we did not intend to have the same entrance dose at all three tube voltage settings but to have all dose readings within 0.01 Gy to 3 Gy.

Dose was measured at different depths from the phantom surface that faces the incoming radiation beam, which include 0.0 cm, 0.2 cm, 0.4 cm, 0.6 cm, 0.8 cm, 1.0 cm, 2.0 cm, 3.0 cm, 4.0 cm and 5.0 cm in depth. Two 4 cm x 4 cm pieces of EBT film were inserted between phantom slices at the corresponding depths. The water-equivalent EBT films were considered not to affect the dose to the phantom.

2.2 Monte Carlo simulation

The transport simulation for spectral-energy x-ray beam was carried out by using the MCNP5 Monte Carlo code. A point source was modeled to radiate multi-energy x-ray beam, which was then cut into 0.988π radian in solid angle from the phantom axis (Fig.2). The beam energy was selected in random from the energy spectrum of the bresstrahlung x-ray generated from the YXLON beam tube. The film was not modeled, but the dose detector was located in simulation at the position of the film inside the phantom.

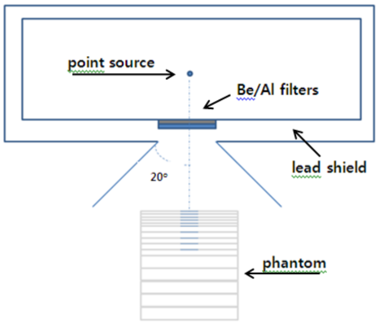

Fig. 2 Geometrical model for Monte Carlo simulation.

3. Results

The distribution of energy deposition in the body can be presented in terms of the percentage depth dose (PDD). Conventionally, the PDD curve is formed by dividing doses at different depths by the maximum value. Presented in Fig. 3 are (a) the PDD curves predicted by Monte Carlo simulation and (b) those measured by Gafchromic film dosimetry. Each experimental data point in Fig. 3(b) represents the mean value of eight readings from two film pieces. In both theoretical and experimental data, the maximum dose occurs not at the entrance but at some depth: at 0.6 cm depth from simulation and at 0.2 cm depth from experiment.

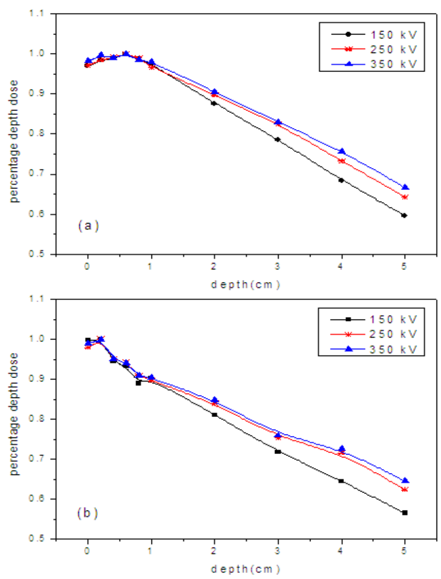

Fig. 3 Percentage depth dose curves formed with (a) the Monte Carlo simulation data and (b) experimental data using Gafchromic EBT films.

Since the energy of x-ray beam used in this study ranges below 350 keV, the attenuation of photon beam intensity is attributed to both photoelectric absorption and Compton scattering. The dose build-up inside the phantom implies that the charged particle equilibrium was settled at some depth from the phantom surface.

The PDD profiles from simulation and measurement do not fit each other as compared in Fig. 4. By film dosimetry, the maximum dose is located closer to the phamtom surface. Since the dose profile follows the photon attenuation past the maximum dose depth, the PDD value is less in measurement than in simulation at the following depths.

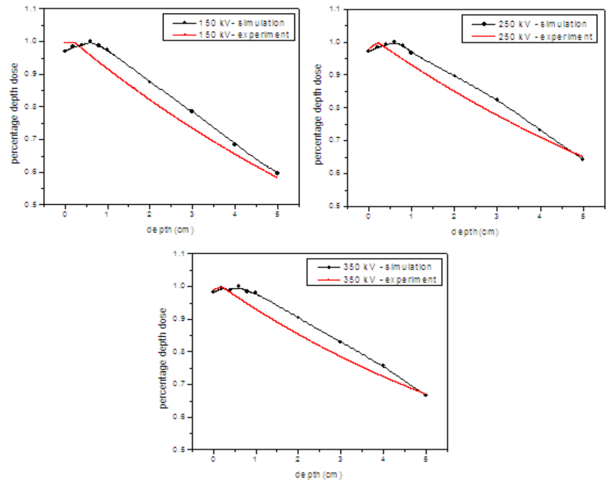

Fig. 4 Comparisons of percentage depth dose curves from simulation and measurement.

The early formation of charged particle equilibrium can be explained by the reduced loss of charged particles while coming from the surface to the sensor volume. In simulation, the film was not modeled so that the surrounding air filling at the film layer was not taken into consideration. In reality of measurement, charged particles produced upstream have less chance of scattering out of their moving track toward the sensor volume while traveling in the air surrounding of the film.

4. Conclusion

The percent depth dose curves have been drawn by measuring the optical densities of radiation-sensitive films. We have validated the Gafchromic EBT films as the sensor of kilovoltage x-ray beam for dosimetry. There remains a work to be done for correcting the shift of the maximum-dose depth toward the phantom surface in measurement with films.

References

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