Analysis on Dose Distribution in Heterogeneous Condition for Narrow 6 MV X-ray Beams

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1. Introduction

Advanced modality of high-precision radiotherapy fulfilled by a composition of large numbers of small field beams called "beamlets" can be achieved via non-uniform intensity fluencies [1]. In case of radiation measurements and calculations with narrow high-energy photon beams, however, an accurate two-dimensional dosimetry is a challenging task due to dosimetrically unfavorable phenomena such as dramatic changes of the dose at the field boundaries, dis-equilibrium of the electrons resulting from larger detector volume, and non-uniformity between the detector and the phantom materials [2-3].

Meanwhile, with the advantages of high spatial resolution and wide range of absorbed doses, there is a growing demand of GAFCHROMIC@EBT film to confirm delivered dose distribution [4]. Especially, the effects from the material differences between the phantom and the film can be minimized in the heterogeneous condition since the GAFCHROMIC@EBT film is composed of tissue-equivalent materials.

In the present study, therefore, the characteristic analysis on dose distribution in both homogeneous and heterogeneous environment for narrow 6 MV X-ray beams was performed by measuring the percentage depth doses (PDDs) using the GAFCHROMIC@EBT film. The result data were also compared with those of Monte Carlo (MC) calculations of BEAMnrc and PMCEPT codes which were validated for radiation transport.

2. Methods and Materials

In order to use the EBT films for absolute or relative dosimetry, it is necessary to establish a dose response relationship covering the range of doses that will be encountered during the exposure of the radiation. The response curve is a function of the sensitivity of the film as well as the characteristics of the digitization system [5]. This enables the decoded pixel value to be converted into the corresponding dose value. Thus, calibration process was independently performed ahead of the film measurements and analysis. At this time, the delivered doses were calculated using the beam data of the machine and daily output variation was corrected. The calibration curve using the GAFCHROMIC@EBT film (batch-number 47277-03I, International Specialty Products, Wayne, NJ) was then acquired with the pixel value ranged from 50417 to 19552 corresponding to the dose ranged from 0 cGy to 500 cGy.

For verifying the dose distributions in homogeneous and heterogeneous environment, experiments were performed in the homogeneous polystyrene phantom with inclusion of an air cavity and a high-density structure (Polytetrafluoroethylene, PTFE) with a dimension of 3 × 3 × 3 cm^3, 2 × 2 × 2 cm^3, and 1 × 1 × 1 cm^3 at the center as presented in Figure 1. The phantom was set with a source to surface distance (SSD) of 100 cm. 6 MV X-rays from a linear accelerator (Primus, Siemens Medical Systems, Concord, CA, USA) with two beams of 3 × 3 cm^2 and 9 × 9 cm^2 were irradiated to the homogeneous and heterogeneous phantoms composed of: (1) polystyrene only, (2) polystyrene with an air cavity, (3) polystyrene with a PTFE cubic block. The GAFCHROMIC@EBT film was then sandwiched between the phantom slabs parallel to the beam axis through the heterogeneous cube. The PDDs and lateral profiles on the film were read with an Epson Expression 1680 Pro scanner (Epson Seiko Corporation, Nagano, Japan) of a flat-bed type. The film analysis procedure including calibration, scan without dose distortion, and an image acquisition was in accordance with the process presented in the previous studies [6].

The result data from the experiments using the EBT films were then compared with MC calculation. Computations were performed with the BEAMnrc and PMCEPT MC codes and the phantom with a cell size of 0.1 × 0.1 × 0.1 cm^3 was used for the simulation.

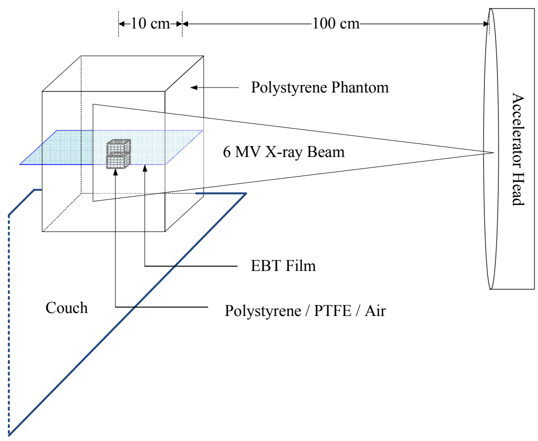

FIG. 1. Experimental Configuration for Percent Depth Dose Measurements

3. Results and Discussions

Figure 2 shows the PDDs for 3 × 3 cm^2 beam in a polystyrene phantom. Under the homogeneous condition, the differences of PDD and lateral profiles between the experiments and the calculations were less than about 2% as agreed well each other. With an air cavity in the phantom as shown in Figure 3, the PDDs gradually dropped from the proximal boundary of upper polystyrene layer and a lower PDD value than that in the polystyrene was observed in air region due to the low density. The PDDs were also agreed within 2%, but big fluctuations were observed in calculated value due to the poor convergence of MC calculation (maximum error of ~48%). In the case of the presence of PTFE in the phantom, the measured depth doses were higher than those of MC (see Figure 3). The behavior of PDDs on the boundaries between the PTFE cube and the polystyrene significantly differs to each other. Not only the overall PDDs value, but also doses on the boundaries of the PTFE cube were very different from the MC calculation.

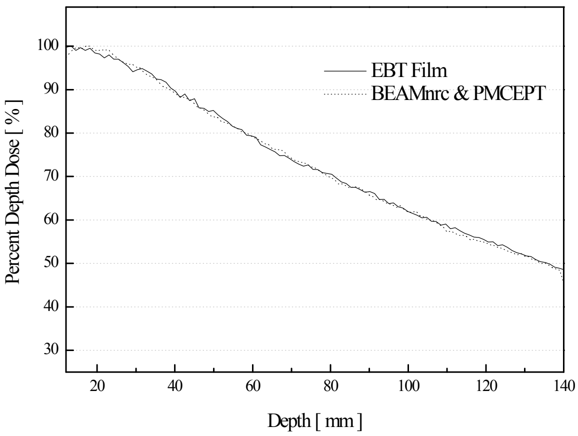

FIG. 2. Percent Depth Dose for 3×3 cm^2 Beam of 6 MV X-rays in Homogeneous Phantom Condition Composed of Polystyrene Only

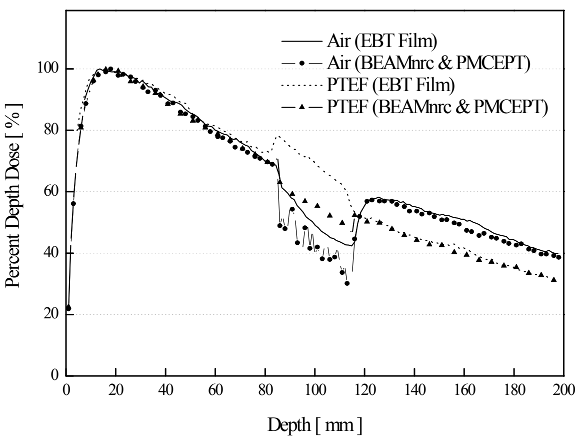

FIG. 3. Percent Depth Dose for 3×3 cm^2 Beam of 6 MV X-rays in Heterogeneous Phantom Conditions with 3×3×3 cm^3 Air Cube and PTFE

In the region inserted into PTFE, film data show increment of PDD while MC calculation under-estimate doses and predicted decrease of PDD. This observed behavior of the MC calculation poses a problem in simulating dose with a PMCEPT code. Therefore, correction methods which can be corrected by applying the total scatter factor on the calculation results are currently under investigation.

4. Conclusions

The dose distributions within and beyond heterogeneous cube in homogeneous condition were measured using the GAFCHROMIC$^{@}$EBT film and compared with those of MC calculations of BEAMnrc and PMCEPT codes. The PDDs and lateral profiles within homogeneous and air region inserted into the polystyrene phantom were agreed within 2% compared with the computation results. However, the significant difference was observed on the PDD curves in the high density/high atomic number material (PTFE) inserted in the homogeneous material (polystyrene). This behavior of the MC computation poses a problem in calculating dose with a PMCEPT code. Consequently, the observed results can be used as the data of reference study to validate the accuracy of the measurements and calculations on heterogeneous media for narrow high-energy X-ray beams which is a challenging task.

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