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MONTE CARLO CALCULATION OF LEAKAGE RADIATION THROUGH THE MULTI-LEAF COLLIMATOR

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Abstract

For the development of Monte Carlo (MC)-based dosimetric quality assurance (QA) tool for IMRT, multi-leaf collimator (MLC) model was constructed. Leakage radiation through the MLC leaves was simulated with this model as a preliminary step. Complicated structure of MLC leaves was developed for the Varian 80-leaf MLC using the Electron Gamma Shower version 4 (EGS4) MC program for 6 MV photon beam. This was then used to calculate dose profiles for an MLC fully blocked 10×10 cm^2 field at a depth of 5 cm in the water phantom. The energy spectra of incident photons were sampled from the published data of Sheikh-Bagheri *et al*. Obtained profiles had both of concavities and convexities. The intervals between adjacent peaks were from 0.9 to 1.1 cm, which agreed well to the actual thickness of 1 cm. The intensities of leakage radiations were not dependent on a location in a field. These results indicated the possibility that the MLC model developed in this study is valid.

1. Introduction

The goal of radiotherapy is to control the tumor by delivering high dose only to the target without injuring the surrounding normal tissues. Toward this goal, intensity-modulated radiotherapy (IMRT) was developed [1]. IMRT can produce the ideal dose distribution to effectively treat a cancer, which is determined by inverse treatment planning, by employing a computer-controlled multi-leaf collimator (MLC) and a medical linear accelerator. It is difficult to evaluate IMRT dose distribution accurately with commercial treatment planning systems used in clinics today. It is because that they do not take (1) issues derived from MLC design and (2) secondary electron disequilibrium into account.

MLC physical and mechanical properties cause specific delivery issues such as leakage radiation, rounded leaf tip effect and tongue-and-groove effect. It has been reported that the total MLC leakage can be larger than 10 % of the maximum in-field dose [2]. Most of the dose calculation algorithms used in commercial treatment planning systems cannot calculate accurate dose in electron disequilibrium regions such as IMRT field. Ma *et al.* [3] have reported that the discrepancy between the dose distributions calculated by a finite-size pencil beam (FSPB) algorithm and Monte Carlo (MC) simulation were more than 20 % in the critical structures of some IMRT patients. The effective treatment of cancers by radiotherapy needs an accuracy of about 5 % in the dose delivery [4]. MLC delivery issues and electron disequilibrium must be precisely considered to implement IMRT of sufficient quality.

These problems can be resolved with MC method by precisely modeling MLC structures. MC technique simulates transport of photons and electrons in the matter even in the electron disequilibrium region, hence, this can provide more reliable dose than any other algorithms. For the development of MC-based dosimetric quality assurance (QA) tool for IMRT, an MLC model was constructed and the leakage radiation through the leaves was simulated with this model as a preliminary step.

2. Materials and Methods

MC simulation was performed for the MLC mounted on the medical linear accelerator (Clinac 2300 C/D, Varian Medical Systems, Inc., Palo Alto, CA) used at Kyoto University Hospital. MC program modeling MLC leaves was developed, and this was then used to calculate dose profiles for an MLC fully blocked field. A schematic diagram of the MLC and phantom configuration in this study is shown in Figure 2.

1. MLC model

Complicated structure of the MLC (Figure 1) was modeled with the Electron Gamma Shower version 4 (EGS4) [5]. The MLC in this study consists of 40 pairs of leaves (80 leaves). MLC leaves are aligned so that all leaf edges are parallel to the beam ray generated from the radiation source (target), i.e., adjacent leaves were constructed with planes having different gradients to each other (Figure 1 (a)). The convex and concave structures, so-called *tongue* and *groove*, respectively, and small gap between adjacent leaves were taken into account. Rounded leaf tip structure (Figure 1 (b)) was simplified by making a sharp-edge geometry with two planes, because it is difficult to model a round geometry with EGS4.

2. Monte Carlo simulation

Dose profiles perpendicular to the direction of leaf motion at both sides of MLC (Figure 3) were calculated for an MLC fully blocked 10×10 cm^2 field at a depth of 5 cm in the water phantom at a source-to-surface distance of 95 cm. The energy spectra of incident photons were sampled from the published data by Sheikh-Bagheri *et al* [5]. They calculated the photon energy spectra of nine beams from three major manufacturers of commercial medical linear accelerators including Varian 6 MV Clinac in this work using the BEAM code [7]. These sampled photons impinge on the surface of MLC located 47.85 cm from the source.

3. Results and Discussion

Figure 4 shows the dose profiles perpendicular to the direction of leaf motion for an MLC fully blocked field at a depth of 5 cm in the water phantom at a source-to-surface distance of 95 cm. Doses are normalized so that the maximum dose equals unity. The profiles were not flat through the field because of the inter- and intra-leaf transmission radiation. Intervals between adjacent peaks derived from inter-leaf transmissions were from 0.9 to 1.1 cm, which agreed well to the leaf thickness of 1 cm at the distance of 100 cm from the source. The intensities of leakage radiations did not depend on the distance from the central axis and both sides of profiles agreed well. It was found that intensities of leakage radiations were not dependent on a location in a field. This is thought to be due to the MLC leaf alignment parallel to the beam ray as mentioned earlier. These results may indicate the validity of the EGS4 MLC model constructed in this study. This model can be developed to the QA tool for IMRT after being verified by measurement.

4. Conclusion

The Varian MLC model was constructed as a preliminary step to develop a MC-based dosimetric

QA tool for IMRT in this study. The possibility that the MLC model developed in this study is valid has been suggested. EGS4 MLC model can be useful to develop the QA tool.

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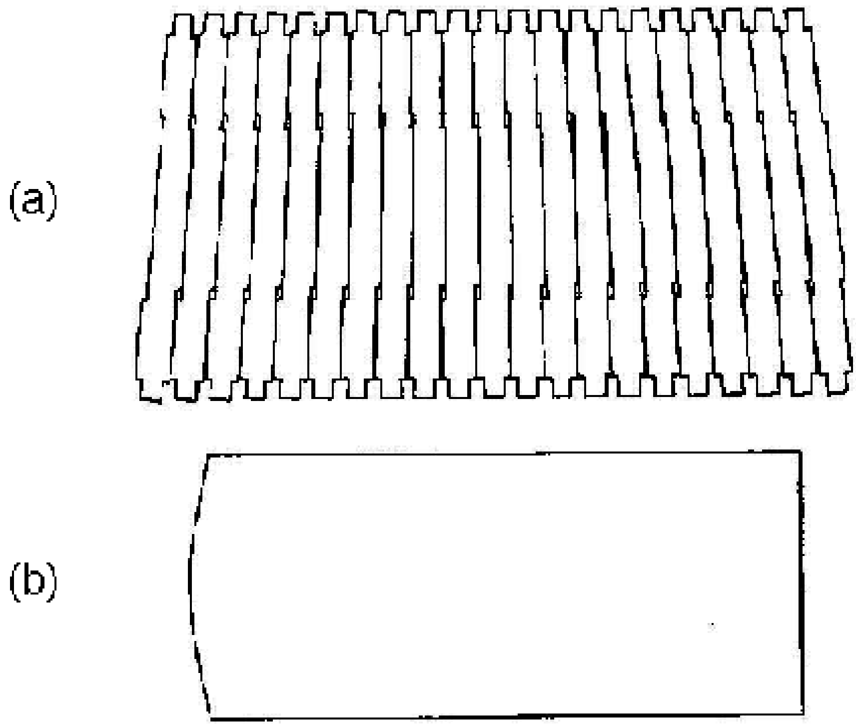

Figure 1. Cross sectional views of MLC leaves. (a) End view: Leaves have different gradients to each other so that all leaf edges are parallel to the beam ray generated from the source located 47.85 cm from the upper end of MLC. (b) Side view: Leaf end is rounded to produce constant penumbra for different displacements.

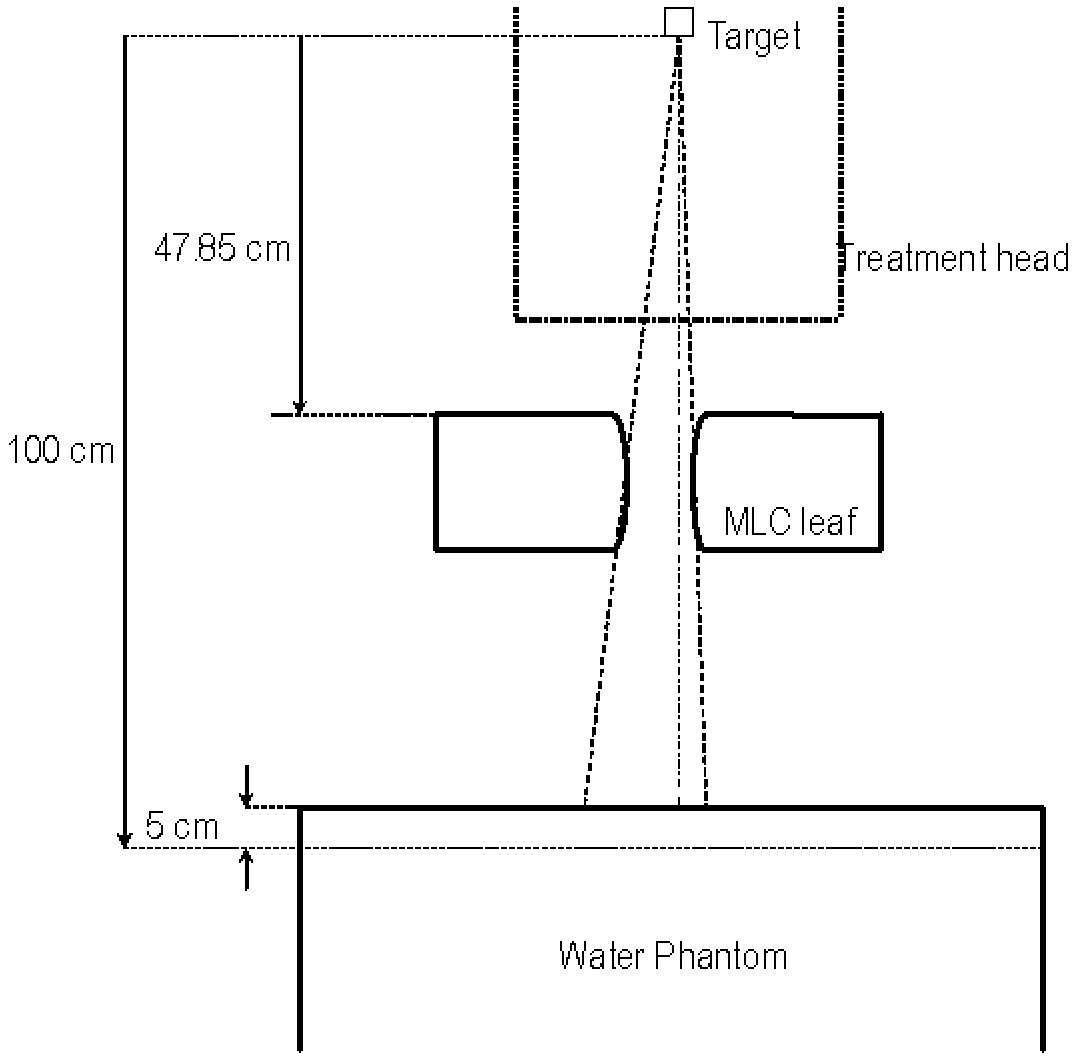

Figure 2. A schematic diagram of the MLC and water phantom configuration. MLC leaf is mounted on the treatment head of linear accelerator. The surface of water phantom is located 95 cm from the source and dose profiles were scored at the depth of 5 cm.

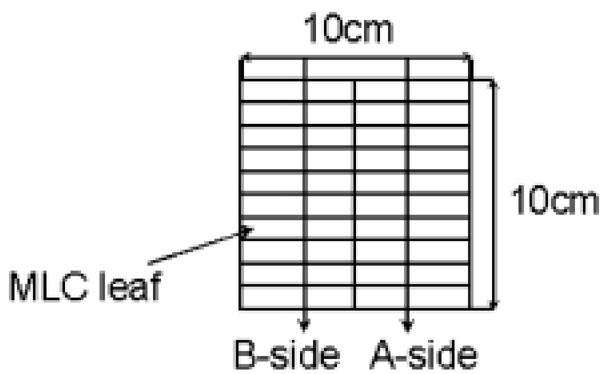

Figure 3. An MLC fully blocked 10×10 cm^2 field. Dose profiles were calculated for both of A- and B-side.

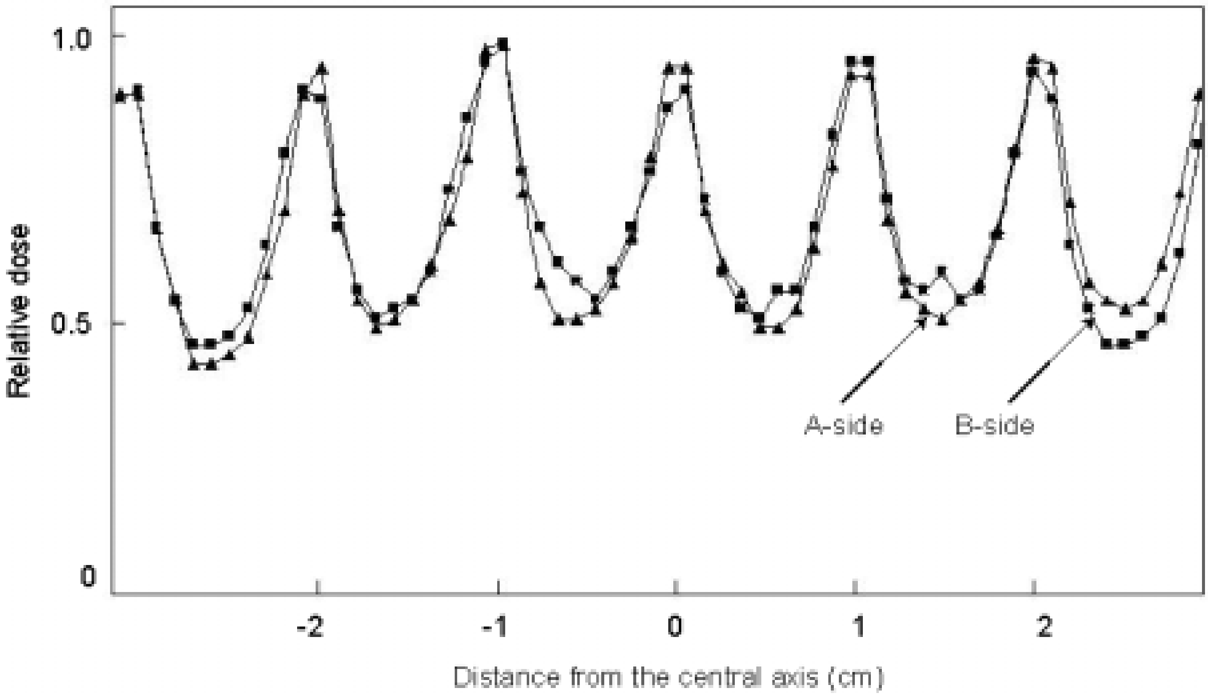

Figure 4. Dose profiles perpendicular to the direction of leaf motion for an MLC fully blocked 10×10 cm^2 field.