Photon Beam Commissioning for Monte Carlo Dose Calculation

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ABSTRACT

Recent advances in radiation transport algorithms, computer hardware performance, and parallel computing make the clinical use of Monte Carlo based dose calculations possible. Monte Carlo treatment planning requires accurate beam information as input to generate accurate dose distributions. The procedures to obtain this accurate beam information are called "commissioning", which includes accelerator head modeling. In this study, we would like to investigate how much accurately Monte Carlo based dose calculations can predict the measured beam data in various conditions. The Siemens 6MV photon beam and the BEAM Monte Carlo code were used. The comparisons including the percentage depth doses and off-axis profiles of open fields and wedges, output factors will be presented.

Keywords: Monte Carlo ,megavoltage photon beam, commissioning.

1. INTRODUCTION

Monte Carlo treatment planning requires accurate beam information as input to generate accurate dose distributions inside a patient to be treated. Accurate beam information requires accurate estimation of the energy and radial intensity distribution of electron beams incident on a target of medical linear accelerators. A recent study[1] proposed the in-air off-axis factor to estimate the radial intensity distribution of incident electron beams on a medical linear accelerator target and presented estimated values for nine photon beams from Varian, Elekta, and Siemens linacs. Using this data for a Siemens KD 6MV photon beam (the mean energy at 6.8 MeV with 14% of energy spread, 0.32 cm FWHM for radial distribution), we calculated the small-field output factor for our Siemens Primus 6MV photon beam, but found a large discrepancy between the calculated and the measured values. In the meanwhile, we replaced the x-ray target of our old Siemens MXE linac. It had a spot, as shown in Fig. 1, which produced by collisions with high-energy incident electrons, from which the radius of the incident electron beams could be roughly estimated to be less than 2mm diameter. The focal spot size of megavoltage photon beams has been investigated using the small-field output factor in air or in phantom. When the collimator setting becomes small enough to start blocking the x-ray source, the output factor drops sharply. This source-obscuration effect[2,3] can be utilized to estimate the radial intensity distribution of electron beams incident on a target. In the present paper, we develop a methodology using the small-field output factor as an estimator of the radial intensity distribution of the incident electron beams. With this estimated data, we would like to investigate how much accurately Monte Carlo based dose calculations can predict the measured beam data in various conditions. Siemens Primus 6MV photon beam and BEAM Monte Carlo code were used. The comparisons including the percentage depth doses and off-axis profiles of open fields and wedges, output factors were performed.

Fig. 1. X-ray target from a Siemens MXE machine after 7-years of use. The diameter of the spot was estimated to be less than 2mm.

2. MATERIALS AND METHODS

2.1 Small-field output factor

Small-field output factor of a Siemens Primus 6MV photon beam was measured at a depth of 10 cm, 90 cm SSD in water using a Scanditronix p-Si photon diode. The detector was aligned on the central axis of the beam by scanning the "in-plane" and "cross-plane" profiles. With these measured profiles, the positional accuracy of the overall field was always better than 1mm.

A linac model of a Siemens Primus 6MV photon beam was constructed using BEAM code[4] with the machine data including an exit window. While keeping the mean energy of incident electrons at 6.8 MeV with 14% of energy spread, which was taken from recent National Research Center of Canada (NRCC) data[1] , the radial distribution of incident electrons with Gaussian FWHM varying between 0.05, 0.1, 0.2, and 0.32 cm were simulated. The phase space files were collected with 10^8 initial electron histories for field sizes of 1×1 cm^2, 1.4×1.4 cm^2, 2x2cm^2, and 10×10m^2 with varied FWHMs. Once the phase-space output had been constructed, the output factor and the depth dose were calculated with the BEAM code's CHAMBER component module. The corresponding phase space files were recycled until the statistical uncertainty decreased to less than 1%.

2.2 Commissioning

To confirm the estimated FWHM of the incident radial distribution, we calculated a) the whole range of output factor, b) the depth dose curve and off-axis profiles of a 10×10 cm^2 field, and c) the depth dose curve and off-axis profiles of a 60° wedge.

3. RESULTS

3.1 Small-field output factor

Figure 2 presents the small-field output factors calculated at the isocenter, and at a 10 cm depth in water with a varied spread of radial distributions. The electron–beam radial distribution influences the small-field output factor to a great extent. The output factor of 1×1 cm^2 calculated with 0.32 cm FWHM was 32% lower than that calculated assuming 0.05 cm FWHM. The best estimated radial distribution FWHM of incident electrons for a Siemens Primus 6 MV photon beam was 0.12 cm as a result of comparison of the calculated and measured small-field output factor.

3.2 Commissioning

With an estimated FWHM of 0.12 cm for the incident electron beams, the calculated whole range of output factor, as shown by Fig. 3, was agreed with the measured values better than 1.6%. Output contributions caused by backscattered radiations into the monitor chamber from the collimator jaws were not taken into account. However, it is generally accepted this contribution is only about 2% or 3% relative to the maximum open field.[5] When normalized to a 10×10cm^2 field size, as was done in this study, this effect becomes around 1%. The calculated and measured depth dose values of a 10×10 cm^2 field with a usual measurement setup of SSD=100cm was matched within 1% of D_{max} beyond the depth of dose maximum. In addition, Fig. 4 presents the calculated and measured off-axis profiles of a 30x30 cm^2 field. To calculate the dose profile, we used the DOSXYZ code. The water phantom with dimensions of 40.5 cm by 40.5 cm by 40.5 cm was divided into 81×3×81 slices in the x, y, and z directions. The dimension of each Cartesian voxels containing the central x-z plane was 0.5×0.5×0.5 cm^3. Though the calculated dose profile suffered from an under-sampling problem, it well matched the measured values within the statistical uncertainty. Figure 5 shows 60° wedge profiles of the maximum field size, 30x20 cm^2.

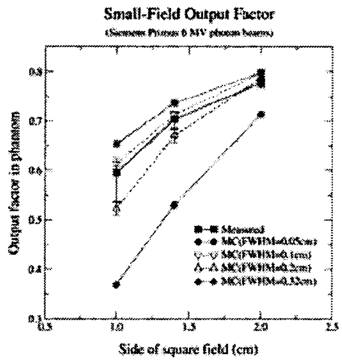

Fig. 2. Small-field output factor for a Siemens 6MV photon beam with four different FWHM of incident electrons

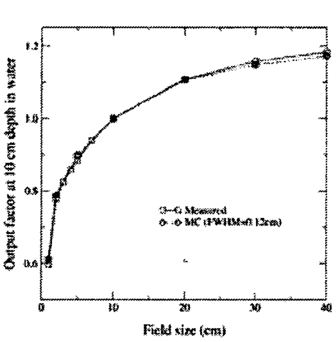

Fig. 3. Comparison of the calculated and measured utput factor for a Siemens 6MV photon beam with 0.12 cm FWHM of incident electrons

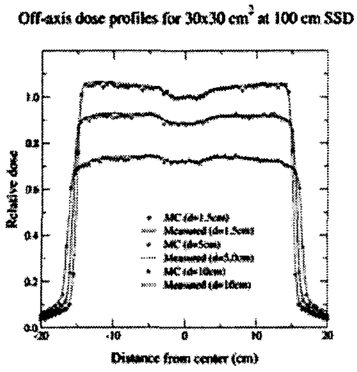

Fig. 4. Comparison of the calculated and measured off-axis profiles for a Siemens 6MV photon beam.

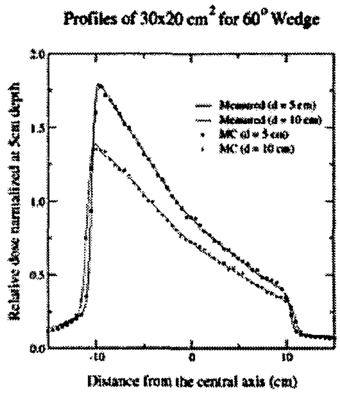

Fig. 5. Comparison of the calculated and measured off-axis profiles for 60° wedge

4. DISSCUSION AND CONCLUSION

Monte Carlo simulation for the Siemens Primus 6 MV photon beam was performed using BEAM code to predict the small-field output factor. We found that the small-field output is very sensitive to the radial intensity distribution of the incident electron beam, which is one of the "unknown" parameters for the BEAM simulation. Since the calculated output factor is very sensitive to the FWHM, the inaccuracy due to the measurement and collimator positions could be compensated. The best matching FWHM value was 0.12 cm while keeping the mean electron energy at 6.8 MeV with a 14% energy spread. With these parameters, we obtained good agreement across the whole range of output factors for the Siemens Primus 6MV photon beam with an accuracy of better than 1.6%, even disregarding the monitor backscatter effect. In addition, the calculated dose profiles well matched the measured values. In addition, the depth dose curve and off-axis profiles of open and wedged fields were agreed well within 1% of D_{max}. In conclusion, this study shows that the small-field output factor can be used as a sensitive estimator of the radial intensity distribution of an incident electron beam for megavoltage photon beam Monte Carlo simulation. This methodology can be successfully applied to clinical photon beam commissioning for Monte Carlo treatment planning.

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