Determination of primary electron beam parameters in a Siemens Primus Linac using Monte Carlo simulation

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ABSTRACT

The Monte Carlo method can be used to describe any technique that approximates solutions to quantitative problems through statistical sampling. This method is considered to be the most accurate method for dose calculation in radiotherapy. For complete modeling of a linear accelerator, it is required that the manufactured information covers all data, but some data such as primary electron energy must be indicated. The purpose of this study was to determine the best primary electron energy for 15 MV photon beam with varying the energy and FWHM. A Monte Carlo model for photon-beam output of a Siemens primus linear accelerator was validated by plotting the energy spectrum of photon beam and calculating the percentage depth dose (PDD) and beam profiles for 10×10 cm^2 field. Square 10×10 cm^2 field was validated by measurements in water by a farmer chamber. Linac head simulation was performed with BEAMnrc and dose calculation and 3D dose file were produced by DOSXYZnrc. The results were analyzed using MATLAB. It was found a good agreement between calculated PDD and beam profile for 15 MV photon beam using Monte Carlo simulation with primary electron energy of 11 MV and FWHM of 0.4 with maximum dose difference of 1.2% in PDD curves. In conclusion, using primary electron energy of 11 MV and FWHM of 0.4 has very good accuracy in calculating of dose distribution for 15 MV photon beam and it can be considered as a promising method for patient dose calculations.

Key words: BEAMnrc; Monte Carlo; Linac simulation; Beam Parameters; FWHM.

INTRODUCTION

Radiation therapy uses high-energy radiation to shrink tumors and kill cancer cells [1]. The main goal of radiation therapy is to deliver the highest dose to the tumor while maintaining minimum dose to the surrounding healthy tissues. To do so, the dose distribution must be computed and verified with an accurate method. Monte Carlo method is widely accepted as the most accurate method for modeling radiotherapy treatments [2-4] and has become more accessible due to technological advances in computer systems. To run Monte Carlo (MC) code for clinical applications, it is essential to define all the characteristics of photon beam such as: initial electron energy and full width of half maximum (FWHM) of the intensity distribution of these primary electrons that stimulate the target of linac. The accelerated primary electron beam starts from the flight tube dominating an angular and spatial distribution, subsequently. This electron beam punches the high-*Z* metal target resulting to production of bremsstrahlung photons. It is notable that in Monte Carlo simulation of clinical linacs, usually no electron beam modeling is performed preceding to exiting the flight tube; so numerous works have been performed on determination of primary electron

energy in radiotherapy accelerators [5-8]. Simulating the linac head with Monte Carlo codes is the most accurate and detailed method to obtain the influence of different parameters on dose distribution [9]. The purpose of this work was to compute the best primary electron energy for 15 MV photon beam linac (Siemens primus, USA) varying the energy and FWHM using Monte Carlo method. The BEAMnrc and DOSXYZnrc codes were used to model 15 MV Primus linac head and measure the PDD and beam profile in the modeled water phantom. The data were validated by measurements in water phantom using a farmer chamber.

MATERIALS AND METHODS

In this study, we explored full width at half maximum (FWHM) of the intensity distribution of primary electrons from the target of Siemens Primus linac stimulated by BEAMnrc and DOSXYZnrc. Both programs are based on electron gamma shower user code (EGSnrc) that come as a package under license of the National Research Council of Canada (NRC) [10]. All the materials and the dimensions for the Linear accelerator head were built based on manufacturer's specification datasheet provided from Siemens Healthcare Company, USA.

The primus accelerator components are shown in Figure 1, including the exit window, target, primary collimator, flattening filter, monitor chamber, Y jaws and MLC. PEGS4 (EGS preprocessor) cross-section data for the specific materials in the accelerator were from 700 ICRU PEGS4data file.

In simulation of radiation transport using MC methods, the history of a particle is specified as a sequence of tracks where each track ends with an interaction event where the particle can change its direction and lose energy. The history ends when it leaves the region of interest or when its energy is lower than the predefined cutoff energy [11]. In this study, the number of histories for Monte Carlo calculations was 5×10^8 particles, resulting from 10^8 particles in a phase space after the primus linac head. This was done to ensure reliable statistics in the phase space file generated by the BEAMnrc simulation [12]. The number of the primary electrons that strike the target on top of the linac head is similar to the number of history. The global cut-off energies used in the simulations were 700 KeV for electron cutoff energy (ECUT) and 10 KeV for photon global cutoff (PCUT) [13]. Monte Carlo simulations were performed for monoenergetic beams ranging from 11 to 15 MeV and FWHM varied from 0.3 cm to 0.4 cm for 15 MV beam.

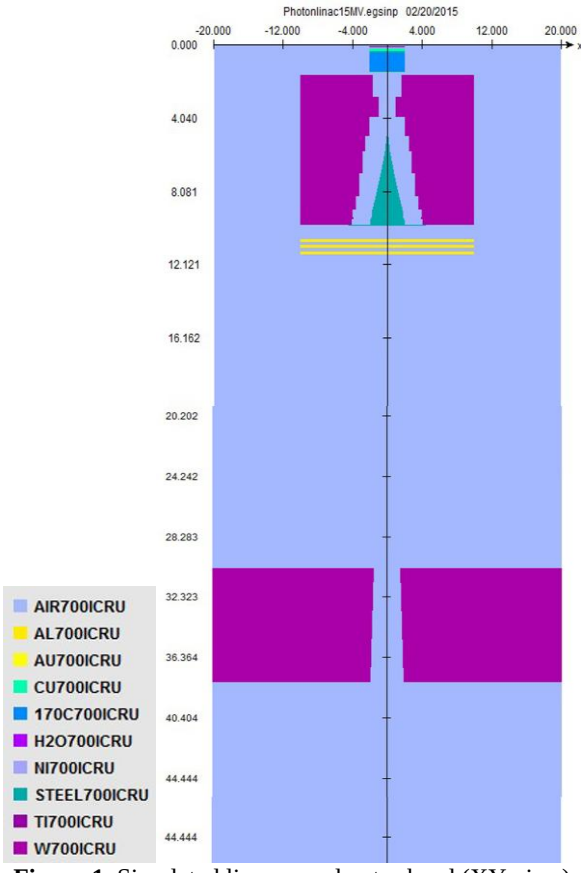

Figure 1. Simulated linear accelerator head (XY view)

The primary output of the BEAMnrc simulation for the head of linac is a file called phase space. The phase space contains information such as energy, position, direction, etc. of millions of particles (photons, electrons, positrons). From this space, beam quality factors including photon and electron spectra and two-dimensional energy distribution was obtained to analyze beam production mechanism. This phase space was scored in a plane upright to the beam axis at 100 cm distance from the target.

For PDD and dose profiles measurements at the maximum dose depth in square fields, farmer chamber was used in the water tank for 15 MV X-ray beam.

The water phantom was created using DOSXYZnrc code with voxel size of 0.5×0.5×0.2 cm^3 at source to surface distance (SSD) of 100 cm. The simulated PDD and beam profile were compared with that obtained by the farmer chamber. The primary electron parameters such as energy and FWHM were changed to reduce difference between calculated and measured values to less than 2%.

RESULTS

We evaluated four different modes to achieve the accurate PDD values and profiles. All PDD and profiles were calculated at different conditions (including energy and FWHM) using Monte Carlo method and were compared to experimental values using ion chamber. Figure 2 shows the PDD obtained from simulation for the field size of 10×10 cm^2 in 15 MV beam. The solid line shows the PDD obtained from Monte Carlo simulation and the dots represent the measured data points using ion chamber. Figure 2(a, b and d) illustrate the discrepancy between the calculated and measured values.

To reduce this discrepancy, the initial energy of the primary electron beam was decreased and finally after several probations, the value at which the simulation and measurements matched was 11 MeV (Figure 2(c)).

The agreement between calculated results by Monte Carlo modeling and direct measurement was obtained to be 1.2%.

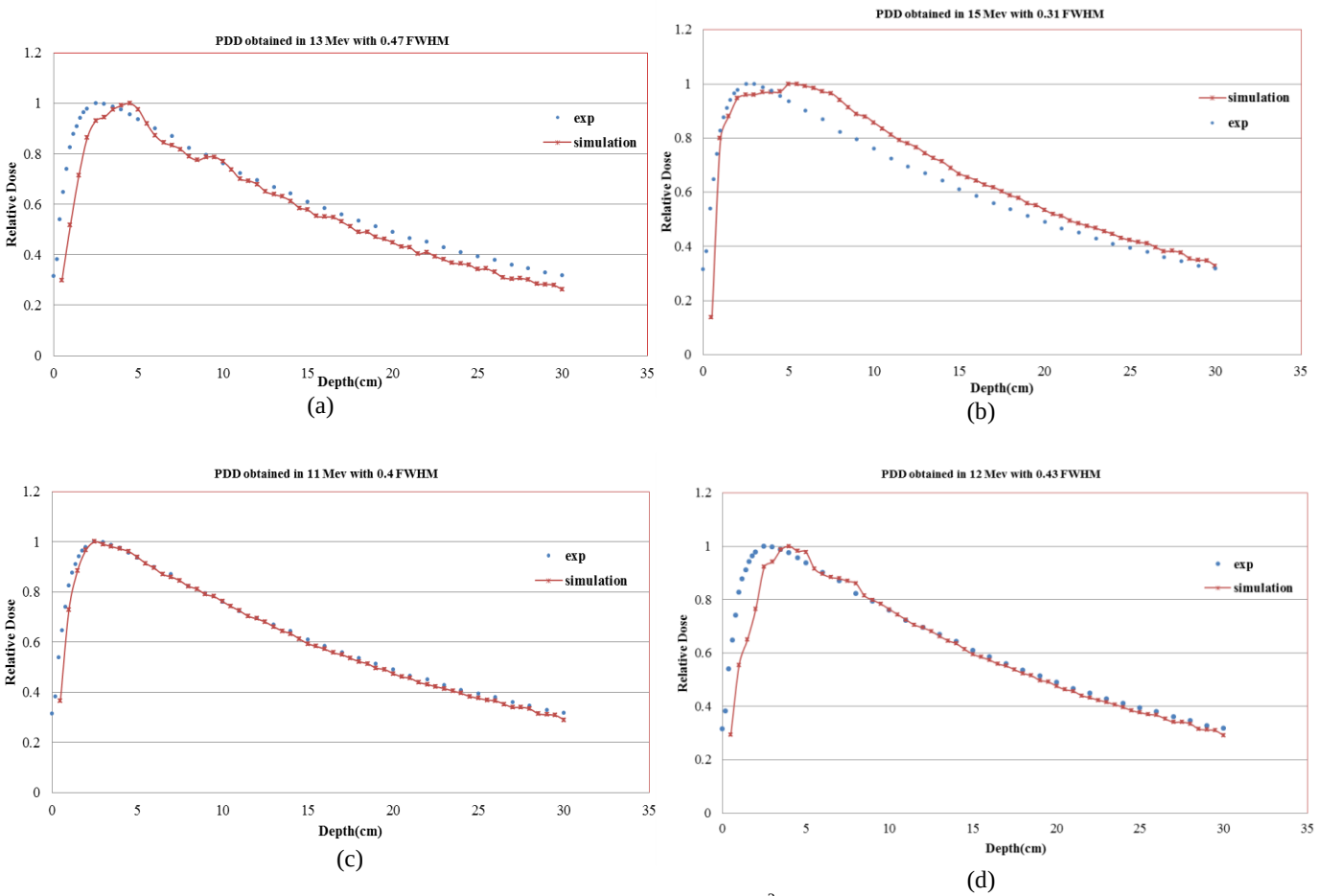

Figure 2. Percentage depth dose at 15 MV beam with a field size of 10×10cm^2; (a) 13 MeV (b) 15 MeV (c) 11 MeV (d) 12 MeV

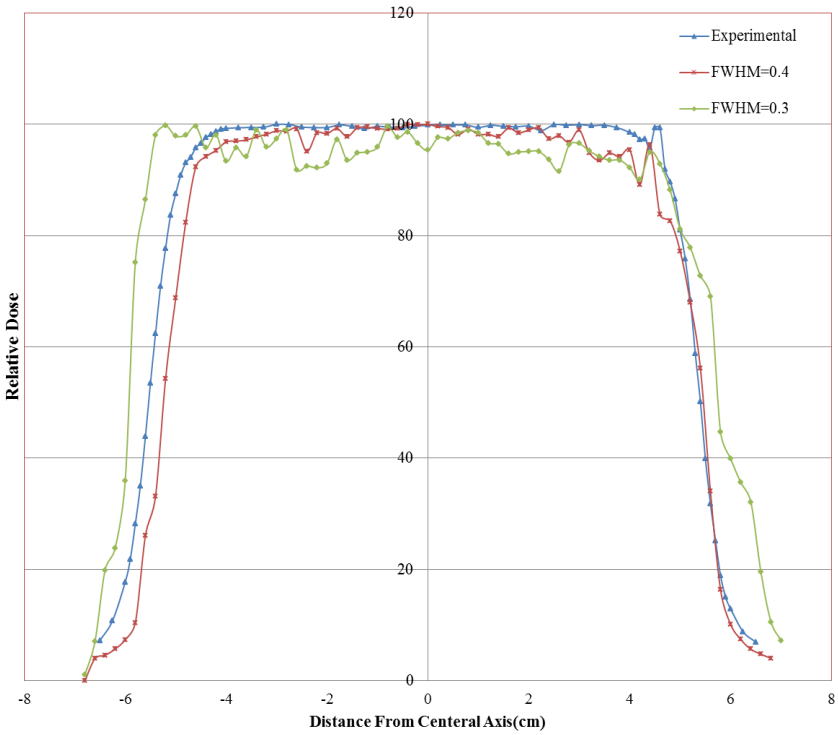

Figure 3. Calculated beam profile at 15 MV. (green) 11 MeV and FWHM of 0.3, (blue) 11MeV and FWHM of 0.4 and (red) the experimental data

As anticipated, with an electron beam with primary energy of 11 MeV and FWHM of 0.4, there exists a good agreement between 15 MV dose profile simulated with Monte Carlo modeling and those measured with ionization chamber (Figure 3).

DISCUSSION

Determination of electron beam parameters is an essential part of simulating radiation transport using Monte Carlo methods. This helps one to find out some real parameters of a beam with nominal energy including real energy and FWHM of the exit beam. Javier Pena *et al*. [6] presented a method for commissioning photon beams that employs depth doses and lateral profiles. By simultaneous comparison of measurements and simulations for several mean energy/radial FWHM combinations, one is able to determine the values that yield best matching. In this study, PDDs were obtained from simulation for the field size of 10×10 cm^2 in 15 MV beam with an electron energy of 11, 12, 13 and 15 MeV with FWHM of 0.3 and 0.4 for a Siemens primus linac. The difference between the calculated and measured doses for both energies were about 1.2%, well below 2% which was chosen as a standard to set the useful results for modeling linac [8]. At 15 MV beam, a good agreement was obtained in 11 MeV primary electron energy with 0.4 FWHM of the intensity distribution.

In this study, the significant components of primary electron beam in final results were obtained and it was shown that a small change in electron beam properties has strong effects on deposited dose in the water phantom. A Monte Carlo simulation of a Siemens primus linac was performed the results of which will be used for future studies. The results of phase space can be used for MLC leakage and calculation of scattering due to them. Jabbari *et al*. [8] found out a good agreement for 6 MV beam in 6.5 MeV primary electron energy with 0.31 FWHM of the intensity distribution and at 18 MV in 15 MeV primary electron energy with 0.29 FWHM of the intensity distribution.

CONCLUSION

The percentage depth dose (PDD) and beam profile were calculated using Monte Carlo simulation and compared to the measurement performed by a farmer chamber in water phantom. Respectable agreement between the calculated PDD and beam profile using MC simulation with that calculated using chamber was detected. The results showed that 11 MeV primary electron energy with FWHM of 0.4 has very good agreement in calculating dose distribution for 15 MV photon beam. A Monte Carlo model of primus linear accelerator built in this study can be used to calculate dose distribution in physical phantoms.

ACKNOWLEDGMENTS

This work was a part of Mr. Seifi thesis for the degree of M.Sc. in Medical Physics supported by deputy of research and technology of Semnan University of Medical Sciences.

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