Australian Journal of Basic and Applied Sciences, 7(10): 340-346, 2013
ISSN 1991-8178

Monte Carlo Modeling of a Siemens Primus 6 MV Photon Beam Linear Accelerator

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Abstract: Monte Carlo calculation method is considered to be the most accurate method for dose calculation in radiotherapy. The purpose of this study is to examine the accuracy of the radiotherapy dose calculations calculated by treatment planning computer system in water by comparison with Monte Carlo model. Monte Carlo model for the photon-beam output from the Primus linear accelerator was validated by plotting the energy spectrum of photon beam and calculating the percentage depth dose (PDD) and beam profiles for the 5 x 5 cm^2 and 10 x 10 cm^2 field sizes. BEAMnrc and the DOSXYZnrc codes were used to perform all dose calculation in this project. The simulated PDD and beam profile obtained were compared with that calculated using treatment planning system (TPS). Good agreement was found between calculated PDD and beam profile using Monte Carlo simulation and TPS calculation with maximum dose difference of 2% for PDD and 6 % for beam profiles. The results showed that the different components of the simulated primus linear accelerator were accurately modeled using Mote Carlo simulation. In conclusion, the BEAMnrc and DOSXYZnrc codes package have very good accuracy in calculating dose distribution for 6 MV photon beam and it can be considered as a promising method for patient dose calculations.

Key words: Monte Carlo simulation, BEAMnrc, DOSXYZnrc, Radiotherapy, 6 MV Photon beam.

INTRODUCTION

The main purpose of radiotherapy is to deliver the highest dose to the tumor and the minimum dose to the surrounding health tissues. To achieve this purpose, the dose distribution in the treatment area must be calculated and verified by an accurate method.

The Monte Carlo method is widely accepted as the most accurate method for modeling radiotherapy treatments (Kawrakow, 2000; Rogers, 2006; Rogers *et al*., 2009) and has started to become more accessible since technological advances in computer systems fields. The Monte Carlo method is designed to solve problems consisting of many independent smaller ones using a random number generator. Various publications have shown that the Monte Carlo simulation has many applications in medical radiation field including radiation therapy (Lin *et al*., 2001; Yamamoto *et al*., 2002). Monte Carlo techniques are used in radiation therapy applications due to the ability of these techniques to simulate precisely the transport of electrons and photons in matter. It has scattering models for different interaction processes and for a large range of energies. The calculated cross sectional data and the numerical tabulated values are combined in these models (Kawrakow *et al*., 2009).

The aim of this work is to calculate absorbed dose of 6 MV photon beam linac (Siemens primus, USA) using Monte Carlo method. The BEAMnrc and DOSXYZnrc codes were used in the current work to model 6 MV Primus linac head and to measure the PDD and beam profile in the modeled water phantom. The data were compared with that calculated using treatment planning system computer (Oncentra, Nucletron B.V, Netherlands) in water.

MATERIALS AND METHODS

Monte Carlo simulation was carried out using BEAMnrc and DOSXYZnrc codes to perform all dose calculation in this project. Both programs are based on an electron gamma shower user code (EGSnrc) that come as a package under license to the National Research Council of Canada (nrc) (Kawrakow *et al*., 2009). The Monte Carlo simulations in this project were run using a computer with Intel (R) Xenon processor of 2.2 GHz speed. Primus Linear accelerator head geometry was modeled using BEAMnrc code to carry out Monte Carlo simulation. All the materials and the dimensions for the Linear accelerator head were built based on manufacturer's specification spreadsheet provided from Siemens Healthcare Company (USA). The individual component modules (CMs) of the accelerator geometry that is perpendicular to the beam axis were built using BEAMnrc program as shown in figure 1. PEGS4 (EGS preprocessor) cross-section data for the specific materials in the accelerator were from 700icru.PEGS4data file. This data file contains cross-section data for particles with kinetic energy as low as 0.01 MV and physical density such as mass density, atomic number and, electron density for all the different materials used in the accelerator. A total of 2 x 10^6 histories were run in the

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accelerator head calculations. The electron cut-off energy (ECUT) was set to 0.7 MeV while the photon cut-off energy (PCUT) was set to 0.01 MeV (Ceberg *et al*., 2010). The Directional bremsstrahlung splitting (DBS) option to split electrons at flattening filter is used in all simulations. The DBS splitting number was set to 1000. The primary output of the BEAMnrc simulation for the head of linear accelerator is a file called phase space file which has information about all the particles leaving the accelerator. This phase space was scored in a plane perpendicular to the beam axis at 100 cm distance from the target. The BEAMDP program (BEAM utility program) was used to read and process the data in the phase space files to plot energy spectrum of photon beam. To validate the Monte Carlo model for the photon-beam output from the Primus linear accelerator, two phase space files were created with 5 x 5 cm^2 and, 10 x 10 cm^2 field sizes. These files can be used as input file to DOSXYZnrc simulation to determine the dose distribution in water phantom created by DOSXYZnrc program. The water phantom was created using DOSXYZnrc code. The voxel size used was 0.5 x 0.5 x 0.2 cm. The water phantom was located at source to surface distance (SSD) of 100 cm. The electron cut-off energy (ECUT) was set to 0.7 MeV, the photon cut-off energy (PCUT) was set to 0.01 MeV. A total of 1 x 10^9 histories were run in the phantom simulation, the statistical uncertainty of the simulation was kept less than 1%. The output file from DOSXYZnrc program was analysed by code called STATDOSE code. The STATDOSE code was used to analyse the dose distribution in the water phantom to visualize it as percentage depth dose (PDD), and beam profiles.

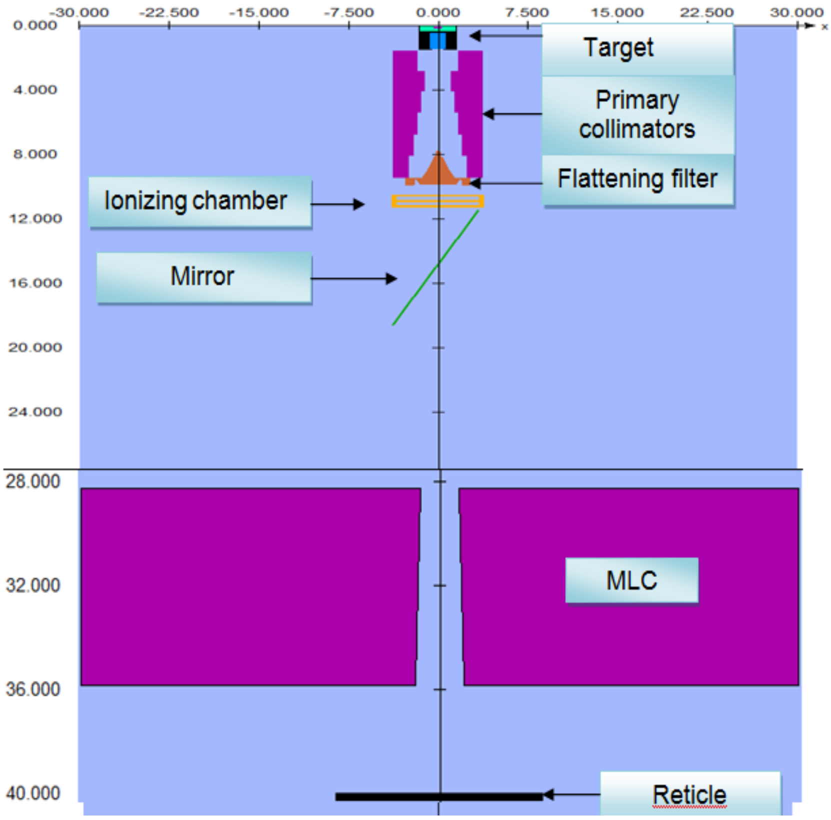

Fig. 1: Simulated linear accelerator head (xy view).

The percentage depth dose (PDD) and beam profile were normalized to the maximum dose ad plotted for 5 x 5 cm^2 and 10 x 10 cm^2 file size, at depth = 1.5 cm, 5 cm and 10 cm. The simulated PDD and beam profile were compared with that calculated using treatment planning computer system (TPS) in water.

RESULTS AND DISCUSSIONS

To validate the photon production of the modelled primus linear accelerator, the photon spectrum and dose distribution were calculated using Monte Carlo simulation. The photon energy spectrum as a function of photon energy is shown in figure 2. The spectrum was plotted at the phantom surface (SSD = 100 cm) for the 10 × 10 cm^2 field size. It was found that the average photon energy of 6 MeV photon beam is about one-third of the maximum nominal energy. The energy spectra of incident photons peak was found at 0.5 MeV, which is similar to previous observations by Mohan *et al.* and Ding *et al.* (Ding, 2002; Mohan *et al*., 1985).

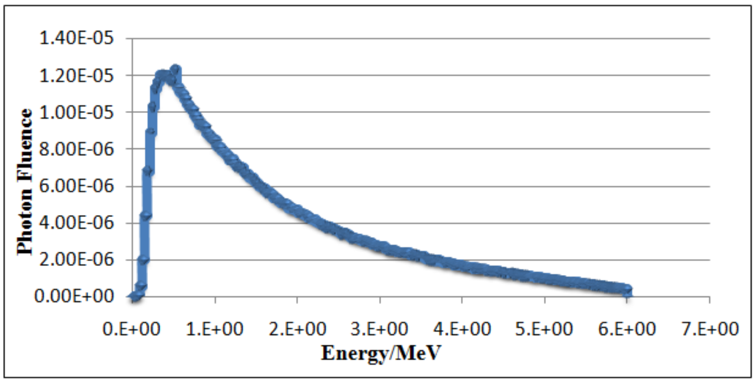

Fig. 2: The energy spectrum of photons for a 6 MV beam.

The simulated PDD for the 5 x 5 cm^2 and 10 x 10 cm^2 field sizes were compared with that calculated using treatment planning computer system (TPS) in water as shown in Figure 3 and Figure 4, respectively. Comparison showed a very good agreement between simulated and calculated data at build up region with a similarity in the shape of the curves. However, there was an obvious difference at the surface region of both curves. This difference may be ascribed to electron contamination in the photon beam that interacts at the surface region of the simulated water phantom. This leads to difficulty to predict the actual value of deposited dose at the surface region (Becker *et al*., 2007; Sheikh-Bagheri and Rogers, 2002). The simulated and calculated data for the depths beyond dmax agreed well, within 2% difference.

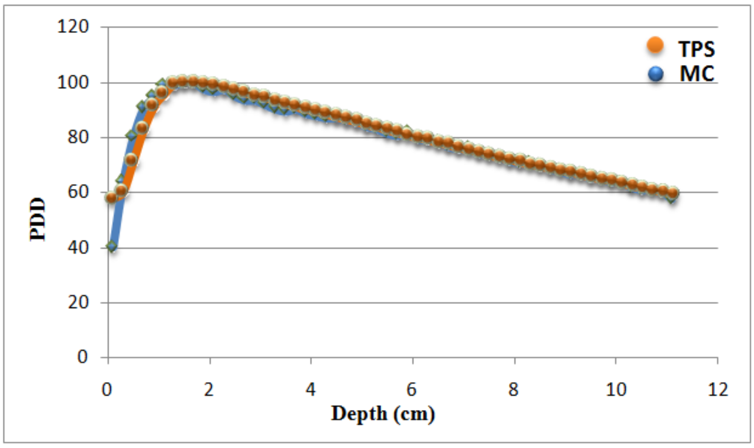

Fig. 3: Depth-dose comparison of calculated and Monte Carlo (MC) results for a 5 x 5 cm^2 field size.

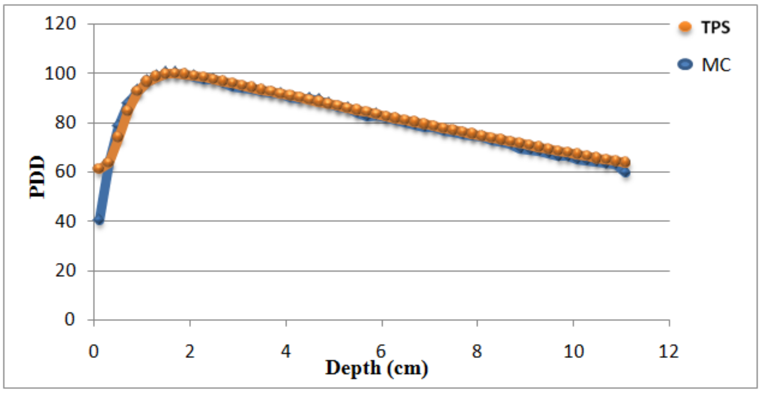

Fig. 4: Depth-dose comparison of calculated and Monte Carlo (MC) results for a 10 x 10 cm^2 field size.

The beam profile is very important in validation of Monte Carlo simulation because it gives information about accuracy of building of each component in the linear accelerator head. The main components that have a major effect on the beam profile are the flattening filter and the secondary collimators. Any change on size or position of one of these components will affect directly on the shape of the beam profile. Therefore, the beam profiles for both field sizes were plotted at deferent depths.

At 1.5 cm depth, the beam profiles determined by MC simulation and TPS calculation for the 5 x 5 cm^2 field size are shown in Figures 5. It was obvious that the shape of the simulated beam profile matched very well with that calculated at the central region. As mentioned above, the beam profile is affected by design of the flattening filter. The flattening filter is thicker at the centre of the radiation beam than at the edges to attenuate the lower energy X-ray at the center of the beam. This design produces uniform fluence across the radiation beam. An increase or decrease in thickness of the modeled flattening filter at the center region will impact on the output and the quality of beam profile. This confirms that the flattening filter at the center region was accurately modeled using Monte Carlo method. The simulated penumbra was also in good agreement with that calculated using TPS, within 0.3 mm difference. The correct position of the secondary collimators can be verified by measuring beam edge, where the dose in the profile drops to 50% relative to the central axis. The simulated beam edges show that the distance across the 50% level was in good agreement with the actual field size. This confirms that the jaws of the secondary collimator position were also accurately modeled. It was also found that there was no difference at 80% intensity (symmetry) of simulated beam profile. The difference at 80% intensity of calculated beam profile was found to be 1 mm (4.5%). The maximum disagreement of the dose value between the simulated and calculated beam profiles was found to be ±3%.

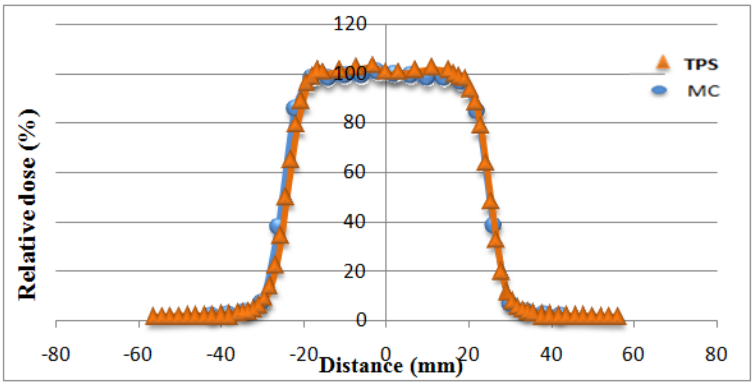

Fig. 5: Beam profile comparison of calculated and Monte Carlo results at dmax (5 x 5 cm^2 field size).

The beam profiles at 5 cm and 10 cm depths determined by MC simulation and TPS calculation for the 5 x 5 cm^2 field size are shown in Figures 6 and Figure 7, respectively. The beam profiles showed very good matching with that calculated using TPS for both depths. At the center of the beam, the curves matched very well with a small difference due to the random error that resulted during the simulation. However, they were well within the tolerance. The simulated and calculated penumbrae were in very good agreement for both depths. The values of simulated beam edges were also matched very well with that calculated using TPS. There was no difference at 80% intensity for the simulated beam profiles for both depths. At 5 cm and 10 cm depths, the maximum disagreement of the dose value between the simulated and calculated beam profiles was found to be ±3% and ±4%, respectively.

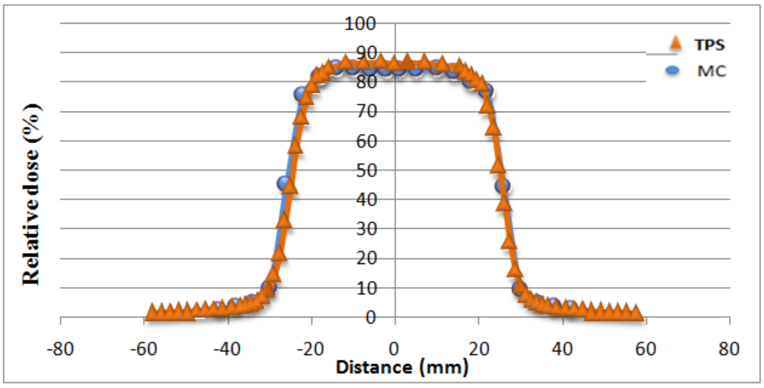

Fig. 6: Beam profile comparison of calculated and MC results at 5 cm depth (5 x 5 cm^2 field size).

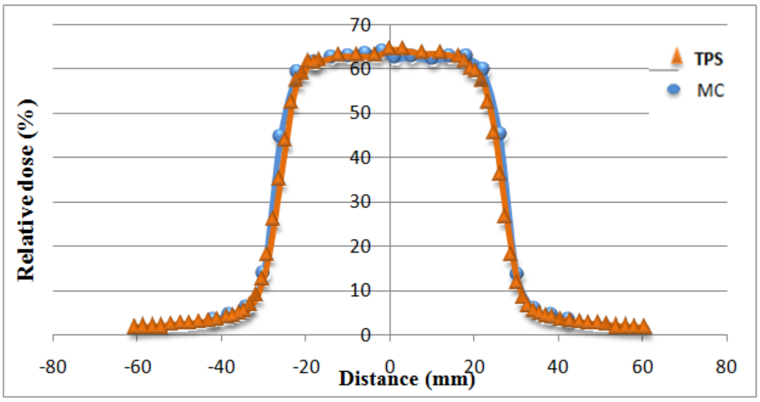

Fig. 7: Beam profile comparison of calculated and MC results at 10 cm depth (5 x 5 cm^2 field size).

At 1.5 cm depth, the beam profiles determined by MC simulation and TPS calculation for the 10 x 10 cm^2 field size are shown in figure 8. It was obvious here that the shape of the simulated beam profile matched very well with that calculated using TPS. Also, very good matching is obtained in the central axis of beam profile. This provides further confirmation that the flattening filter was accurately modeled for 6 MV photon beam. The simulated and calculated penumbrae agreed very well. The simulated beam edge was found to be 50 mm on the left of the central axis of the beam and 51 mm on the right side. The collimator position was also correct based on beam edge values. The symmetry of simulated beam profile was in good agreement with that calculated, within 0.5 mm (1%) difference. The maximum disagreement of the dose value between the simulated and calculated beam profiles was found to be ± 6%. This disagreement between simulated and calculated beam profile could be related to the resolution of the calculated data. The calculated data was finer than that obtained from MC simulation due to voxel size. The voxel size used in simulation process had a dimension of 0.5 cm, which corresponded to number of points (26 points), required to determine the dose profile using Monte Carlo simulation. The number of points used in TPS calculation was 79 points. This difference in the number of points reduces the accuracy of the beam profiles. A study by Pena *et al.* reported a difference between the simulated and calculated beam profiles for a wide range of field sizes. They conclude that this difference could be due to a non monoenergetic energy spectrum or to geometrical modelation details that may differ between the simulation and the actual accelerator (Pena *et al*., 2007).

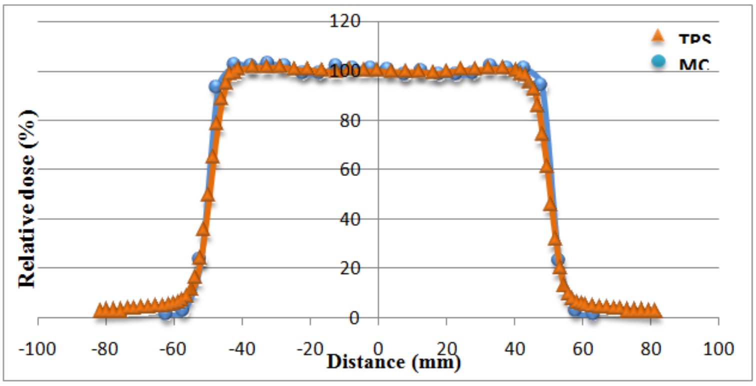

Fig. 8: Beam profile comparison of calculated and MC results at dmax (10 x 10 cm^2 field size).

The beam profiles at 5 cm and 10 cm depths determined by MC simulation and TPS calculation for the 10 x 10 cm^2 field size are shown in Figure 9 and Figure 10, respectively. It was obvious that the beam profiles were in good agreement with that calculated using TPS. At the center region, the data match very well with small differences due to simulation random error. The simulated and calculated penumbrae were also in good agreement for both depths. The values of simulated beam edges were very close to calculated beam edge values for both depths. At 5 cm and 10 cm depths, the differences at 80% intensity of the simulated beam profile were found to be 0.5 mm (1%) and 1 mm (1.87%), respectively. At 5 cm and 10 cm depths, the maximum disagreement of the dose value between the simulated and calculated beam profiles was found to be ±5% and ±6%, respectively.

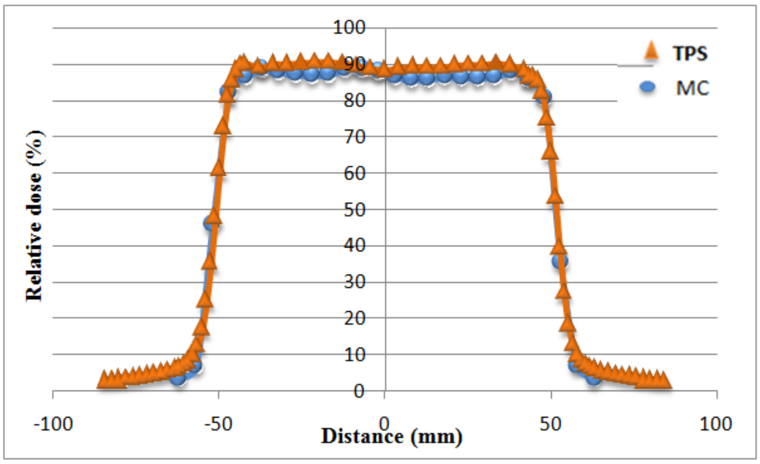

Fig. 9: Beam profile comparison of calculated and MC results at 5 cm depth (10 x 10 cm^2 field size).

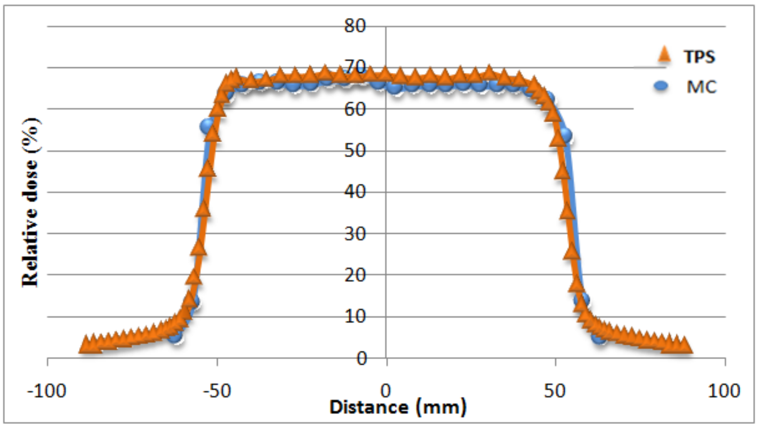

Fig. 10: Beam profile comparison of calculated and MC results at 10 cm depth (10 x 10 cm^2 field size)

Conclusion:

The percentage depth dose (PDD) and beam profile were calculated using Monte Carlo simulation and compared with that calculated using TPS in water for 5 x 5 cm^2, 10 x 10 cm^2 field sizes. Good agreement between the calculated PDD and beam profile using MC simulation with that calculated using TPS was observed. The results showed that the BEAMnrc and DOSXYZnrc codes have an excellent performance in calculating the depth dose and beam profile measurements for 6 MV photon beam. The Monte Carlo model of primus linear accelerator built in this study can be used as promising method to calculate the dose distribution for cancer patients.

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