The Feasibility Study on the Monte Carlo Based RTP Commissioning

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The commissioning of a treatment planning system of model-based dose calculation algorithm requires a lot of parameters to be selected to fit measured data, in which process physical insights for the parameters are often forgotten. We present the photon beam commissioning of Pinnacle^3 with the help of Monte Carlo (MC) simulation and evaluate the parameters Pinnacle^3 demands. Even though the MC calculation produces reasonable values for the commissioning, the thorough physical basis of the Pinnacle^3's commissioning process is needed to use the MC derived parameters directly.

Key Words: RTP commissioning, Monte Carlo, convolution/superposition algorithm

INTRODUCTION

Photon dose calculation methods of recent 3D radiation treatment planning systems are based on the convolusion/superposition algorithm, where the energy deposition kernels obtained from the Monte Carlo (MC) calculation are convolved with the total energy released per unit mass (TERMA) [1, 2]. For the commissioning of these model-based RTPs, many physical parameters such as the energy spectrum of primary photons, head scatter components, and electron contaminations shall be derived from comparisons of the calculated and measured dose curves. Although those parameters have clear physical meanings, it is uncertain for users whether the derived parameters are reasonable or not since those parameters can not be measured directly and affect the depth dose and/or off-axis profiles at the same time in a complicated manner.

The purpose of this work is to investigate the physical model of Pinnacle^3 (Philips Radiation Oncology Systems, Madison, WI) and compare their parameters derived by RTP and Monte Calro simulation in order to evaluate the feasibility of RTP commissioning with the help of parameters from Monte Calro calculation.

MATERIALS AND METHODS

A Siemens Primus linear accelerator (Concord, CA) with nominal energies of 6 and 10 MV for open beams were commissioned using a Pinnacle^3 treatment planning system. PDDs and cross beam profiles were measured in a water phantom (PTW, Germany) using a PTW 0.125 cc ion chamber. The depth doses in the build-up region were replaced with measurements using an Attix plane parallel chamber (RMI model 449, Middleton, WI). The BEAM/DOSXYZ [3] system was used for the modeling of a linac head and depth dose calculations.

RESULTS

Energy spectrum:

The spectra used in Pinnacle^3 are based on a discrete set of kernels, which are not equally spaced in energy. From a private communication [Dr. Todd R. McNutt, Philips Radiation Oncology Systems, Madison, WI], if the energies are E_1, E_2, ..., E_{n-1}, E_n, E_{n+1}, ..., E_{max-1}, E_{max} in the energy spectrum, the bin sizes are (E_2-E_1), $(E_3-E_1)/2$, ..., $(E_{n+1}-E_{n-1})/2$, ..., $(E_{max}-E_{max-1})$ for each energy and the relative number of primary photons per unit energy should be used. Pinnacle^3 considers the unequal energy bin sizes in the calculation of e.g. mean energy as $\bar{E} = \Sigma \Phi_i E_i \Delta E_i$ where $_i$ is the number of primary photons per unit energy and ΔE_i is the bin size for energy. Figure 1 represents the MC simulated spectral distributions with the spectra from the Pinnacle^3 which are the results from the auto modeling based on the measured depth doses. The apparent difference of the spectra between those of the Pinnacle^3 and the MC results can be attributed to the deficient of kernel hardening of the Pinnacle^3 along the depth [4].

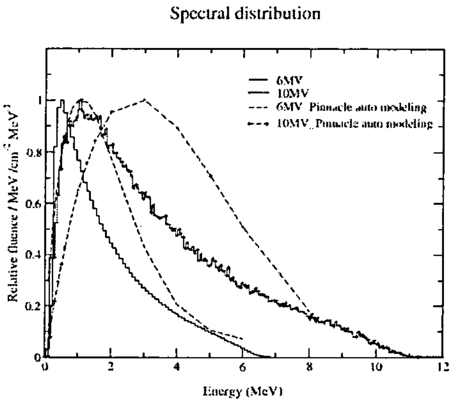

Figure 1: Primary energy spectra from the linac head derived from the MC simulation and auto modeling of Pinnacle^3 for 6 and 10 MV.

Electron contamination parameters:

The Pinnacle^3 uses the parameters of the electron contamination as the quantities that compensate for the difference of the build-up dose between the measured and calculated PDDs [5]. The MC simulated electron contamination was less than 3% of the maximum dose from primary photons below the field size of a 5x5 cm^2, and increased up to 30% at field size of a 40x40 cm^2 for 6 MV. For the case of 10 MV, the contamination of a 5x5 cm^2 was 3%, and amounted to 34% for a 40x40 cm^2. Both cases of energy showed the linear relationship between the field sizes and the contaminated electrons (correlation coefficients of larger than 0.999). The depth dose calculations using the MC derived parameters agreed with the measured data within 2%.

Off-Axis softening parameter:

The off-axis softening refers to the increase of the lower energy photons relative to those of higher energy due to the different beam attenuation through the flattening filter, making the mean energy decrease with the off-axis distance. For the beam softening effects, Pinnacle^3 uses the following equation

$$W_i' = W_i \times \left(1 + \left(\frac{E_i}{E_{\max}}\right)\right)^{-S\theta} \tag{1}$$

where

W_i = the original, central axis spectral weight for bin 'i' which has an effective energy E_i

S = off-axis softening parameter to be determined

θ = the off-axis angle between a ray line and the central axis

To determine the S parameter from MC derived spectra, we obtained the spectral distributions at off-axis distances of 3 cm (near-central axis: from 2.5 cm to 3.5 cm) and 14 cm (near-edge: from 13.5 cm to 14.5 cm) at the phantom surface. Figure

2 shows the case of 10 MV for a 30x30 cm^2 field size. For the Pinnacle^3's description from Eq. (1), we calculated the spectral distributions at the off-axis distances of 3 and 14 cm using the MC derived spectrum on central axis. The results are shown in Fig. 2 in normalized form with S = 25 which is the maximum value in Pinnacle^3. The MC derived spectrum and that from Eq. (1) show similar behavior at the off-axis of 3 cm due to the small softening. However, in the case of 14 cm, Pinnacle^3 overestimates the particle weights for 1 ~ 3 MV and underestimates for less than ~0.5 MV, thus the softening of low and mid energies are not adequately described with the Eq. (1).

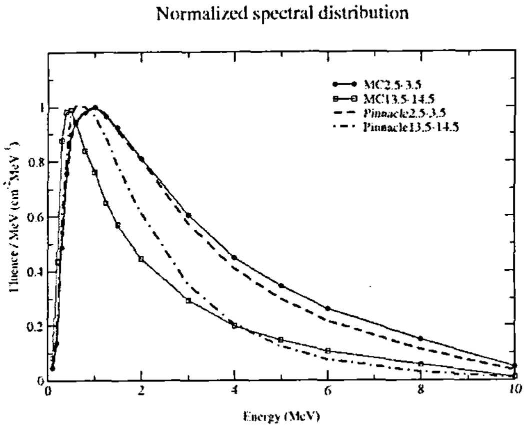

Figure 2 : Normalized spectral distributions for 10 MV from the MC simulation and from Eq. (3) for two off-axis distances of 3.0 cm and 14.0 cm from the central axis with 1.0 cm width. The S parameter in Eq. (1) is set to 25 to magnify the softening effect.

The incomplete description of softening in Pinnacle^3 can be also seen in the variation of the mean energy along the off-axis. From the MC simulation, we can identify the nearly linear decrease of mean energy along the off-axis. Pinnacle^3 also presents decrease of mean energy with the off-axis distance, however, the graph of mean energy contains downward convex tendency along off-axis. Since the mean energy at one position is the product of the energy and its particle weight at that position, this difference reflects the wrong behavior of the spectral weights with the off-axis distances.

The cone radius and fluence increase/cm parameters:

The cone radius parameter limits the off-axis distance within which fluence variation occurs and after this limits, the fluence is held constant, modeling the initial incident fluence shape across the diameter of the beam. Fig. 3 shows the particle fluence for 10 MV with field size of a 30x30 cm^2 and the energy fluence is also represented for comparison. However, when the parameter extracted from the particle fluence in MC was applied to Pinnacle^3, the off-axis profile increased very steeply outward from the central axis, far from describing the beam profile. The same behavior was reported previously [5].

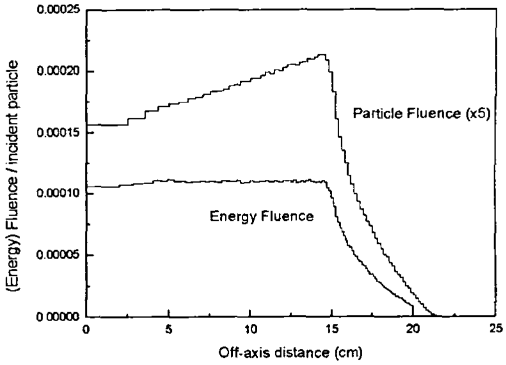

Figure 3 : Energy and particle fluences obtained from the MC for 10 MV with field size of 30x30 cm^2. The particle fluence (x5) shows steep increase while the energy fluence remains almost constant along the off-axis distance.

One of the probable causes for this unexpected behavior is the improper estimation of the off-axis-softening for the low and mid energy photons in Pinnacle^3 mentioned before. The insufficient predictions for the low energy photons or the overestimation for the mid energy photons need the less particle fluence for the same mean energy along the off-axis. Also, the fact that the kernel softening is not incorporated in the Pinnacle^3 can be another source for the fluence behavior. Lastly, the parameter of fluence increase in Pinnacle^3 might account for other effects beside true fluence increase. Further investigations for the fluence behavior are needed.

CONCLUSION

Through the MC simulation, we can obtain valuable informations such as the energy spectrum and the portion of the electron contaminated dose, which can be a guide to users for the determination of the parameters in the commissioning process. However, the off-axis softening parameter and the fluence increase from the MC calculation were not adequate for the Pinnacle^3, which might be caused from the fact that the kernel hardening is not adopted and the off-axis softening is not described well in Pinnacle^3.

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