

Monte Carlo Simulation of 6 MV Flattening Filter Free Photon Beam of TrueBeam STx LINAC at Songklanagarind Hospital

(Simulasi Monte Carlo 6 MV Perataan Tanpa Penurunan Alur Foton *TrueBeam*
STx LINAC di Hospital Songklanagarind)

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ABSTRACT

In this study, 6 MV photon beam of TrueBeam STx Varian LINAC with Flattening Filter Free (FFF) was simulated using PRIMO code. The depth dose profiles for various jaws open fields and cross beam profiles for various depths inside water phantom were determined using Monte Carlo (MC) simulation technique and validated with experimental result. The experiments were performed using the Source to Surface Distance (SSD) technique with a 100 cm distance from target to the surface of water. Simulation used 10^9 histories with the same configurations with experiments. The depth dose profiles and cross beam profiles of 6 MV FFF photon beam was determined using MC simulations and compared with experimental results. The results showed that depth dose profiles and cross beam profiles by MC simulation accurately matched with experimental results. The best result of depth dose profile was obtained at 10×10 cm² jaws open field with 98.53% passing criterion whereas cross beam profile was obtained at 10 cm depth inside water phantom with 88.96% passing criterion. The discrepancies were caused by scatter of particle and incompatibility of primary beam in PRIMO with experiment.

Keywords: Flattening Filter Free (FFF); Linear Accelerator (LINAC); Monte Carlo simulation; PRIMO Code

ABSTRAK

Dalam kajian ini, 6 MV alur foton daripada TrueBeam STx Varian LINAC dengan perataan tanpa penurasan (FFF) disimulasikan menggunakan kod PRIMO. Profil kedalaman dos untuk pelbagai ukuran rahang dan profil melintang alur untuk pelbagai kedalaman dalam fantom air telah ditentukan dengan menggunakan teknik simulasi Monte Carlo (MC) dan disahkan secara eksperimen. Uji kaji telah dijalankan dengan menggunakan teknik jarak sumber kepada permukaan (SSD) dengan jarak 100 cm dari sasaran ke permukaan air. Simulasi menggunakan 10^9 peristiwa, konfigurasi yang sama dengan uji kaji. Profil kedalaman dos dan profil melintang alur daripada 6 MV FFF alur foton ditentukan dengan menggunakan simulasi MC dan dibandingkan dengan keputusan uji kaji. Hasil kajian menunjukkan bahawa hasil simulasi MC daripada profil kedalaman dos dan profil melintang alur adalah sepadan tepat dengan keputusan uji kaji. Keputusan terbaik profil kedalaman dos adalah pada 10×10 cm² dengan kriteria lulus 98.53%. Keputusan terbaik profil melintang alur adalah pada kedalaman 10 cm dalam fantom air dengan kriteria lulus 88.96%. Percanggahan adalah disebabkan oleh serakan zarah dan ketidaksesuaian alur utama dalam PRIMO berbanding dengan uji kaji.

Kata kunci: Kod PRIMO; pemecut linear (LINAC); perataan tanpa penurasan (FFF); simulasi Monte Carlo

INTRODUCTION

Cancer is a genetic disease caused by mutation of cell (American Cancer Society 2015). One of basic methods to treat cancer is radiotherapy (Sardari et al. 2010; Tartar 2014). Linear Accelerator (LINAC) has been widely used in radiotherapy, almost available in many hospitals and cancer centers (Konefał et al. 2015). LINAC main components in photon mode from top to bottom are target, primary collimator, flattening filter, ion chamber and secondary collimator usually called jaws. Flattening filter in a medical LINAC is used to homogenize beam profiles from the photon beam at a patient or water phantom (Mayles et al. 2007). However, in modern radiotherapy techniques such as Intensity Modulated Radiation Therapy (IMRT) and Volumetric Modulated Arc Radiotherapy (VMAT), the flattening filter was removed in order to increase dose rate

and reduce the treatment time (Huang et al. 2012; Xiao et al. 2015).

Medical physicists need to deliver an absorbed dose in radiotherapy treatment with an error of less than 5%. This condition can be reached only if the error of dose calculation in treatment planning system is less than 2% (Abdul Haneefa et al. 2014). Monte Carlo (MC) simulation technique has become the most powerful tool in dosimetric calculation, quality control tests and modeling of LINAC (Abdul Haneefa et al. 2014; Reis Junior et al. 2014; Tartar 2014). In the future, the speed-up of computer power every year would make the MC simulation is more capable of using for the treatment planning system in radiotherapy.

Knowledge of dose distributions in medical LINAC is required for radiation quality and treatment planning system. Two basic dose distributions in radiotherapy are

depth dose profiles and cross beam profiles (Abdul Haneefa et al. 2014; Konefał et al. 2015). The method to determine dose distribution in medical LINAC are by experiment and MC simulation (Konefał et al. 2015). Experiments use a cube filled with water usually called water phantom. Inside the water phantom there is an ionization chamber use to scan the depth dose profiles in vertical direction and cross beam profiles in both horizontal directions. For MC simulation, head of LINAC geometry and water phantom will be modeled using a distance from target to the water surface of 100 cm.

General code of MC simulation needed the detail of geometry and long period of simulation process. The specific code of MC simulation, PRIMO, has been introduced to simulate several types of Varian and Elekta LINACs (Rodriguez et al. 2013). Truebeam STx Varian LINAC was also provided in PRIMO code and some works on it have been published (Belosi et al. 2014; Rodriguez et al. 2015).

Truebeam STx Varian LINAC is the latest model from Varian. Several features are different with the previous Varian model such as availability of Flattening Filter Free (FFF) for photon beam (Beyer 2013). The Truebeam STx Varian LINAC is capable of delivering radiation at a faster dose rate than the previous Varian model by FFF function. This advance features make treatment time half shorter than the previous Varian model. Truebeam STx Varian LINAC is very suitable for IMRT and VMAT techniques.

In this work, we simulated 6 MV FFF Truebeam STx Varian LINAC with FakeBeam geometry model in PRIMO. Depth dose profiles for several jaws open field and cross beam profiles for various depths inside water phantom were simulated. Simulation results were compared with experimental data which were taken from Truebeam STx Varian LINAC machine in Songklanagarind Hospital.

MATERIALS AND METHODS

SIMULATION

The PRIMO code (Rodriguez et al. 2013) was used to simulate the photon beam of TrueBeam STx Varian Linear Accelerator (LINAC). Simulations were performed using 6 MV Flattening Filter Free (FFF) of photon beam with 10^9 histories. The 6 MV photon beam was chosen because it is the most frequent energy used to treat patient in Songklanagarind Hospital, Songkhla, Thailand. Initial electron beam for 6 MeV possesses Gaussian distribution characteristic with mean energy 5.8 MeV, 0.058 FWHM (1%) and 0.15 cm focal spot FWHM (Rodriguez et al. 2015). Geometry of head of TrueBeam STx Varian LINAC was provided in PRIMO code. Water phantom was modeled as place to distribute the photon beam's dose. Set up of configuration used the Source to Surface Distance (SSD) technique with a 100 cm distance from target to the surface of water phantom. Based on report of The American Association of Physicist in Medicine (AAPM) task group no. 105, MC simulations should make the same

configuration with the experimental set up (Chetty et al. 2007). Simulation set up and detail of material used in the LINAC head was shown in Figure 1. Jaws were set for 4×4 , 10×10 and 40×40 cm² open fields for measuring depth dose profiles. For the cross beam profiles jaws were set constantly at 10×10 cm² open field. The cross beam profiles were simulated on the X axes and calculate the relative dose inside water phantom at depth 1.5, 5 and 10 cm.

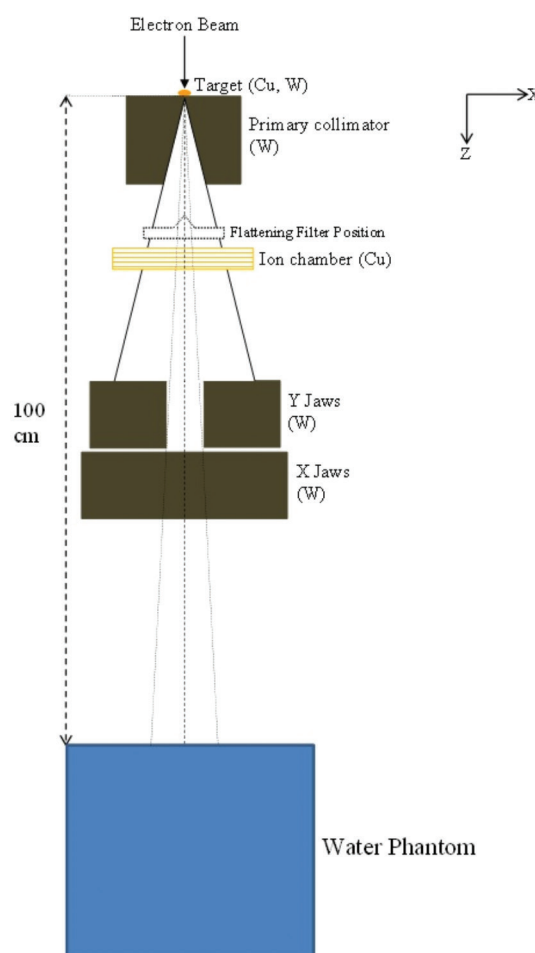


FIGURE 1. Simple drawing of the LINAC head geometry and water phantom

EXPERIMENTAL DETAILS

Experiments were performed using water phantom and Source to Surface Distance (SSD) technique with a 100 cm distance from target to the surface of water. In this work, we used a commercial water phantom from IBA Dosimetry GmbH, Schwarzenbruck, Germany, named blue phantom². Dose distributions of 6 MV FFF photon beam of TrueBeam STx Varian LINAC were characterized using blue phantom². IBA cc13 ionization chamber was used inside blue phantom² to scan the depth dose profiles and the cross beam profiles in vertical and horizontal directions (Atarod et al. 2013; Konefał et al. 2015).

COMPARISON

Experimental results were imported to PRIMO code for comparison of measured and calculated doses using gamma analysis proposed by Low et al. (1998). Experimental results were used as reference data and simulation results as evaluation data. Gamma index (Γ) for experimental point p and the dose at that point $d_e(p)$ is calculated based on (1).

$$\Gamma = \min \left\{ \sqrt{\left(\frac{\Delta d_i}{\Delta D} \right)^2 + \left(\frac{\Delta s_i}{\Delta S} \right)^2} \right\} \quad (1)$$

where ΔD is acceptance criterion for the dose difference; ΔS is acceptance criterion for the distance to agreement; Δd_i is the difference between $d_e(p)$ and the simulated dose at a certain point p_i ; and Δs_i is the distance between p and p_i .

In this work, the lowest acceptance criteria in PRIMO used 1% for the dose difference (ΔD) and 1 mm for the distance to agreement (ΔS).

RESULTS AND DISCUSSION

The depth dose profiles and cross beam profiles are two important dosimetric parameters on the commissioning of medical Linear Accelerator (LINAC). The depth dose profiles are used for beam quality parameter while cross beam profiles are for radiation dose reliability parameter. The differences between simulation and experimental results may be caused by incompatibility of initial electron beam parameters.

DEPTH DOSE PROFILES COMPARISON

The depth dose profiles are normalized to the central axis of the beam. Measurements are taken at 4×4, 10×10 and 40×40 cm² jaws open field with SSD 100 cm technique. Open field 4×4 and 40×40 cm² are the smallest and the biggest sizes of jaws that can be reached by LINAC whereas open field 10×10 cm² is the standard operation size of jaws open field in LINAC (Abdul Haneefa et al. 2014). Measurements are taken up to depth 30 cm along central axis inside water phantom. Figure 2 shows the comparison for simulation results and experimental results of depth dose profiles for each jaws open field. The depth dose profiles are presented with relative dose in percent. Every dose at certain point is normalized to the maximum value as shown in (2).

$$\text{Relative dose (\%)} = \frac{D_p}{D_{\max}} \times 100\%, \quad (2)$$

where D_p is the dose at any position; and D_{\max} is the dose maximum.

The depth dose profiles curves are separated into two regions. The first region is from surface of water to a depth at maximum dose called build-up region and the second is the depth after dose maximum called equilibrium region. The detail of gamma analysis for each jaws open field is shown in Table 1. It can be seen that the difference

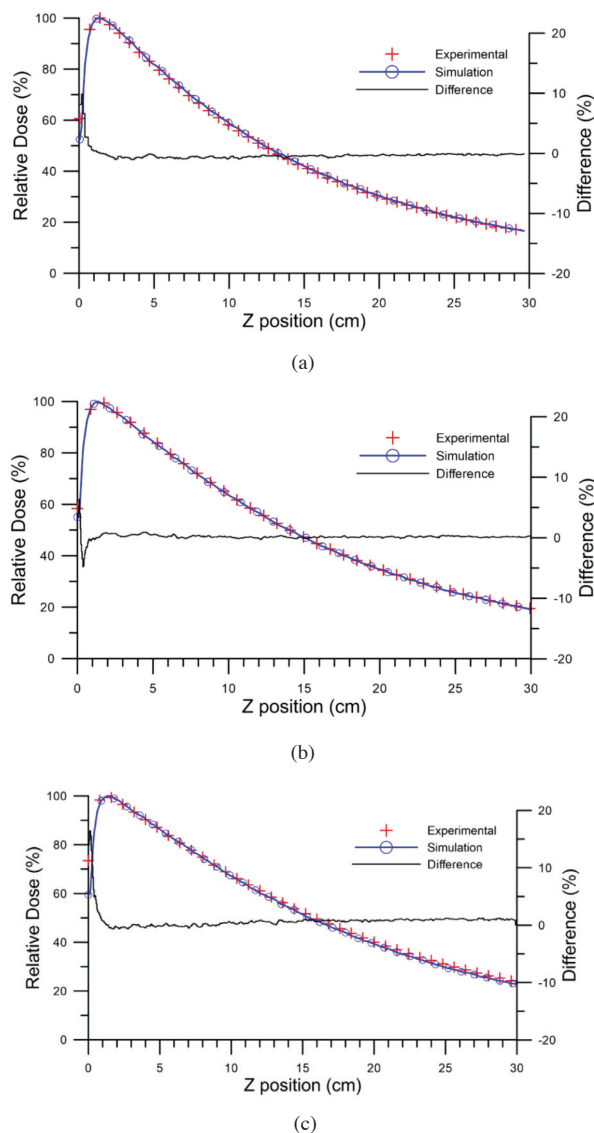


FIGURE 2. Depth dose profiles comparison for (a) 4×4 cm², (b) 10×10 cm² and (c) 40×40 cm² jaws open field

is quite small with high percentage passing criterion of 98.40% and 98.53% at 4×4 and 10×10 cm² jaws open field, respectively, as shown in Figure 2(b). When jaws open field becomes bigger at 40×40 cm², the percentage passing criterion is lower. This is probably due to the less number of particles in the outer area are simulated and big error will be obtained.

From Table 1, the average gamma index is bigger in the build-up region than in the equilibrium region. It is because in the build-up region there are several free electrons originated and caused interactions as well, such as Compton scattering, photoelectric effect, and pair production. High energy electrons will be ejected when high energy photon (in this case 6 MV) interacts with water phantom. These electrons will deposit their energy to the water. The production of electrons will decrease with depth inside water phantom since photon energy fluence continuously decreased. Because of electrons fluence, the

TABLE 1. Gamma analysis of depth dose profiles curve

No	Jaws open field (cm ²)	Average gamma index		Percentage passing criteria (%)
		Build-up region	Equilibrium region	
1	4×4	1.01	0.12	98.40
2	10×10	0.78	0.20	98.53
3	40×40	1.20	0.64	80.97

absorbed dose will increase with depth until reach the maximum.

CROSS BEAM PROFILES COMPARISON

Cross beam profiles are simulated and measured at 10×10 cm² jaws open field, at 1.5, 5 and 10 cm depths inside water phantom. Figure 3 shows the comparison of simulation and experimental results of cross beam profiles for each depth inside water phantom.

The comparison is normalized to the maximum value. Cross beam profiles curves can be divided into three regions. The first is inside field where the area is covered by jaws open field, the second is penumbra where the dose fall down rapidly at the beam edge and the third is outside field where the area is not covered by the jaws open field.

Gamma analyses for each depth inside water phantom as shown in Table 2, indicate that gamma indices in outside field and penumbra region are bigger than those in the inside field. This differences probably represent the number of simulated particles in which less number of simulated particles will be found in penumbra and outside field regions and result in a big statistical fluctuations in MC simulation and big gamma index (Graves et al. 2013; Saidi et al. 2013).

CONCLUSION

Monte Carlo simulation results of 6 MV Flattening Filter Free (FFF) of photon beam of TrueBeam STx Varian Linear Accelerator (LINAC) using PRIMO code show a good agreement with experimental results. The depth dose profiles give a good agreement with more than 80% passing criteria. The average gamma index in cross beam profiles are less than 0.6 in inside field region, less than 2.5 in penumbra region, and less than 0.6 in outside field region. All of gamma index use the lowest dose difference acceptance criteria of 1% and distance to agreement criteria of 1 mm. The difference is probably caused by

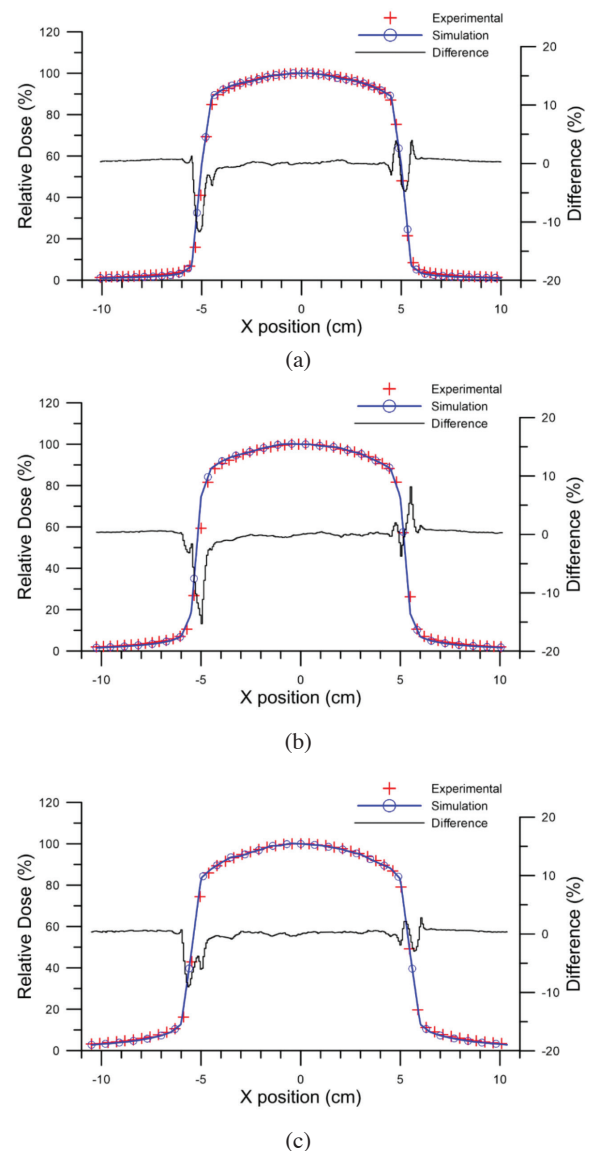


FIGURE 3. Cross beam profiles comparison for 10×10 cm² jaws open field inside water phantom at depth, (a) 1.5 cm, (b) 5 cm and (c) 10 cm

TABLE 2. Gamma analysis for cross beam profiles

No	Depth inside water phantom (cm)	Average gamma index			Percentage passing criteria (%)
		Inside field	Penumbra region	Outside field	
1	1.5	0.46	2.42	0.58	87.87
2	5	0.52	2.09	0.52	84.93
3	10	0.49	1.50	0.53	88.96

incompatibility of initial electron beam parameters between simulation and experiment. This discrepancy can be overcome by tuning of initial electron beam parameters in simulation. In conclusion, PRIMO code can be successfully used as an alternative for dosimetric calculation instead of traditional analytical treatment planning.

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