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Dosimetric Characteristic of Enhanced Dynamic Wedges used in Radiation Therapy

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Abstract: ***Modern linear accelerators are equipped with a dynamic wedge option. It is a form of dose distribution which makes use of dynamic movement pairs of collimator jaws to improve the dose uniformity from the target. The aim of this study is to compare the calculated and measured dosimetric properties of enhanced dynamic wedges used in radiation therapy. The effect of enhanced dynamic wedge on the photon beam produced by Varian 2100C accelerator was studied with the EGSnrc Monte Carlo code. Depth doses and beam profiles for wedged photon beams were obtained for 6 and 15 MV. Four standard wedge angles of 15^o, 30^o, 45^o and 60^o were modelled in this study. Various field sizes were defined at 100 SSD in water phantom. Data calculated with our simulation model and measurements agreed well within 2% for all wedges. The calculated wedge dose profiles matched very well with the measurement, except at the toe area of 60^o wedge angle for 20×20 cm^2. The observed wedged PDD increased with increasing wedge angle, field size and decreasing the beam energy. The results evidently showed that the Monte Carlo simulation is a useful method for evaluating the dosimetric properties of enhanced dynamic wedge.***

Keywords: Monte Carlo Method, photon beam, enhanced dynamic wedge, simulation

1. Introduction

Radiotherapy is one of the methods used for treatment of cancer. It uses external radiation beams which are directed and intersect at the target volume. The purpose of modern radiotherapy is to receive a maximum dose distribution in the target volume while sparing surrounding healthy tissue [1]. In radiotherapy wedge filters are commonly used to modify the dose distribution of photon beams and to achieve a uniform dose distribution within the target volume. When the wedge filters are placed in the path of a photon beams, the beam quality is altered and the beam intensity is decreased [1-6]. Varian has upgraded its dynamic wedge to enhanced dynamic wedge (EDW), where some improvements have been introduced [7]. The EDW employs the movement of collimators with the help of computer to generate wedged dose profiles [8]. Radiation therapy relies on the knowledge of the penetration of the beam into the patient. The presence of enhanced dynamic wedges as a beam modifier changes the beam quality and the depth dose distribution [9-12]. The number of parameters has been used for specifying the beam quality such as percentage depth dose at the depth of 20 cm relative to the depth at 10 cm, the beam profiles and the beam output [13, 14].

Monte Carlo simulation is one of the most accurate methods use in simulating radiation transport and predicting dose [13, 14, 22, 25]. In this study enhanced dynamic wedge have been studied using the EGSnrc Monte Carlo code. The purpose is to compare the calculated percentage depth dose (PDD), beam profiles, wedge factors and output factors in water phantom with the measured data.

2. Methodology

2.1 Monte Carlo Simulation

The study was based on a model of the Varian 2100C linear accelerator (Linac) head operated at nominal photon energies of 6 and 15 MV. Adjusting both the mean energy and radial intensity distribution of the electron beam were performed until the agreement between the calculated PDD and beam profile curves and measured data were within the pre-defined acceptance criteria. The measured and calculated depth dose curves yielded the following values for the primary electron energy 5.82 and 15.21 MeV for 6 and 15 MV beams respectively. These energies were used for the dosimetric verification of our model. The Monte Carlo simulations for open and wedged beams were performed using the EGSnrc code system [15, 16]. The code breaks the simulation of the beam into two. Firstly the accelerator head components were simulated by using BEAMnrc user-code [17-19]. Secondly, the dose in the water phantom was calculated using DOSXYZnrc user-code [20]. The BEAMDP (Beam Data Processor) code [21] was used for phase space data processing. In all calculations the transport parameters were set as, AE = 0.7 MeV, AP = 0.01 MeV, ECUT = 0.7 MeV, PCUT = 0.01 MeV. The Directional Bremsstrahlung Splitting was used as a variance reduction method. The statistical uncertainties obtained were better than 1%. This verification was accomplished by comparisons between measured and calculated depth dose curves and dose profiles in a 50 × 50 × 50 cm^3 water phantom with source-surface-distance (SSD) defined at 100 cm.

2.2 Linear Accelerator Head Model

The geometrical input data for the 6 and 15 MV photon beams were based on specifications provided by the manufacturer [7, 22]. The geometry and the material used in the simulation reflected a realistic construction of the linear accelerator. The BEAMnrc code uses a series of component modules (CMs) to model each component of a linac head. The target, primary collimator, flattening filter, monitor chamber, mirror and secondary collimator were constructed using the following component modules SLAB, CONS3R, FLATFILT, CHAMBER, MIRROR AND DYNJAWS respectively. DYNJAWS has been incorporated in the

BEAMnrc code for modelling the enhanced dynamic wedge [19]. The code is capable of simulating an enhanced dynamic wedge using the step and shoot as well as the dynamic delivery techniques. The phase space file obtained as BEAMnrc output, was used as the input data for the calculations in water phantom [23].

2.3 Experimental Measurements

In order to validate the Monte Carlo simulations in this study, a water phantom with 0.125 cm^3 PTW ionization chamber (PTW-31010) was used to measure depth doses and beam profiles for wedge angles of 15^o, 30^o, 45^o and 60^o. The Wellhofer linear detector array having 99 high resolution semiconductor detectors was used for measuring the wedge beam profiles. The linear array was chosen because it can be used to obtain integrated dose profiles reproducibly and quickly [24]. The linear chamber array was mounted on the scanning drive of a water phantom. The dosemeter was used to connect the chamber array to a computer. Beam profiles were acquired in a water phantom at depths of maximum dose (d_{max}), 5 and 10 cm for both 6 and 15 MV photon beams. For all measurements, 200 monitor units (MU) were delivered at 600 MU/min with the Y1-IN wedge orientation and 0^o gantry angle for 100 cm SSD. The collimator was rotated to provide jaw motion parallel and perpendicular to the platform motion.

3. Results and Discussion

The following sections summarize the results of the 6 and 15 MV Varian Clinac 2100C linear accelerator model. All simulations were run on a 3 GHz Intel CPU. A total of 5.0×10^7 and 3.0×10^7 electrons were sampled for 6 and 15 MV photon beams for all field sizes, respectively. For the 15 MV simulations, 7.0×10^6 electrons were sampled for the 20 × 20 cm^2 field size. The field required less electrons since more collisions occurred in the phantom due to larger field sizes [25].

3.1 Validation of the simulated radiation beam

Table 1 shows comparison between the measured and calculated PDD for the 6 and 15 MV photon beam. Data were collected at 10 and 20 cm depths in a water phantom for 5 × 5, 10 × 10, 15 × 15 and 20 × 20 cm^2 field sizes. Data for each field was normalized with 100% at d_{max}. For the 6 MV photon beam, good agreement between the calculated and measured photon dose values can be seen. The calculated d_{max} for the 10 × 10 cm^2 field size was 1.4 cm compared to a measured value of 1.5 cm. The percentage difference between measured and calculated PDD values at 10 cm depth are 1.2%, 1.6%, 0.9% and 0.6% for 5 × 5, 10 × 10, 15 × 15 and 20 × 20 cm^2 field sizes, respectively. At 20 cm depth, the percentage difference between the measured and calculated PDD values are 1.9%, 0.9%, 1.5% and 0.2% for 5 × 5, 10 × 10, 15 × 15 and 20 × 20 cm^2 field sizes, respectively.

The 6 MV dose profiles measured and calculated at the depth of d_{max} were also compared. For all field sizes, the percentage difference between the calculated and measured dose on the plateau was within the acceptance criteria of 2%, while dose in the penumbra region was also within acceptance criteria of 2 mm.

Table 1: Percentage depth dose measured and calculated at 10 and 20 cm depths for 6 and 15 MV photon beams for varies field sizes.

Energy	*Field size*	*10 cm depth*		*20 cm depth*	
		Meas	*Calc*	*Meas*	*Calc*
6 MV	5×5	67.1	66.3	42.4	41.6
	10×10	68.9	67.8	44.6	45.0
	15×15	69.8	69.2	46.5	47.2
	20×20	71.2	70.8	48.1	48.0
15 MV	5×5	75.2	75.4	47.1	47.4
	10×10	75.7	75.9	49.9	49.7
	15×15	76.4	76.7	50.8	50.9
	20×20	76.6	76.9	52.4	52.6

For the 15 MV photon beam, the calculated d_{max} for the 10 × 10 cm^2 field size was 2.4 cm compared to a measured value of 2.5 cm. The percentage difference between measured and calculated PDD values at 10 cm depth are 0.3%, 0.3%, 0.4% and 0.4% for 5 × 5, 10 × 10, 15 × 15 and 20 × 20 cm^2 field sizes, respectively. At 20 cm depth, the percentage difference between the measured and calculated PDD values are 0.6%, 0.4%, 0.2% and 0.4% for 5 × 5, 10 × 10, 15 × 15 and 20 × 20 cm^2 field sizes, respectively. The best agreement between the calculated and measured was achieved for all field sizes.

The maximum values of gamma index (γ) for 10 × 10 cm^2 field size at d_{max} were 0.78 and 0.63 for 6 and 15 MV photon beams, respectively. The values of γ index at other specific points were less than 1.0, which indicates that the calculated data has passed the acceptance test [26]. The statistical uncertainties in the Monte Carlo calculations were less than 1.0%.

3.2 Percentage depth Dose

Figures 1 and 2 show the PDD curves for the 6 and 15 MV photon beams, respectively. Measured and calculated PDD curves for 60^o wedge angle for 20 × 20 cm^2 field sizes are compared. Curves were normalized at d_{max}. For 6 MV photon beam, the calculated d_{max} for 60^o wedge angle for 20 × 20 cm^2 field sizes was equal to the measured value at 1.4 cm. For all doses below the d_{max}, the percentage difference between the measured and calculated PDD curves was 1.6%. The largest percentage difference of 2% was obtained at the depth of 35 cm. Good agreement between the measured and calculated curves can be seen. The measured and calculated ratios of EDW and open field depth doses for the 6 MV photon beams differed by less than 0.5%.

Excellent agreement was also achieved for the 15 MV photon beam, where the calculated d_{max} was 2.4 cm, which compares well with the measured d_{max} of 2.5 cm. The largest difference of 2.3% was obtained for the 15 MV photon beam, at the depth of 40 cm. The measured and calculated ratios of EDW and open field depth doses for the 15 MV photon beams differed by less than 0.7%.

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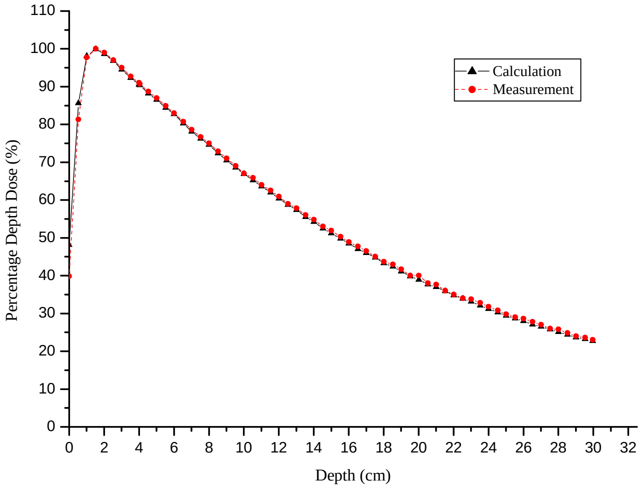

Figure 1: Comparison of the measured and calculated PDD curves from the 6 MV photon beam with 60^o EDW for 20 ×20 cm^2 field size defined at 100 cm SSD.

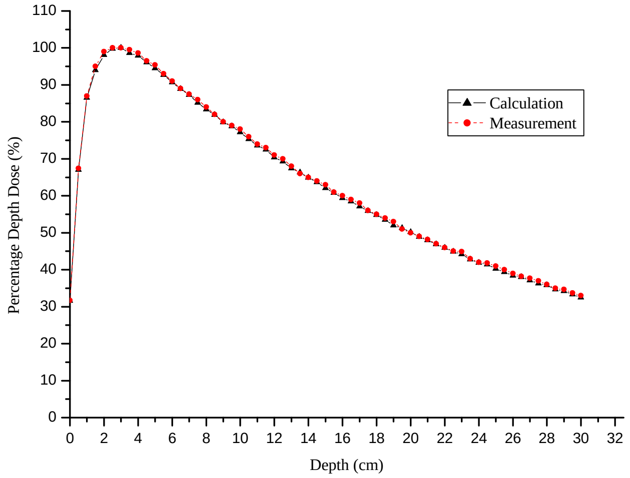

Figure 2: Comparison of the measured and calculated PDD curves from 15 MV photon beam with 60^o EDW for 20 ×20 cm^2 field size defined at 100 cm SSD.

3.3 Dose profiles

Figures 3 and 4 show the measured and calculated dose profiles for 6 and 15 MV photon beams, respectively. The wedged profiles were measured and calculated for 10 × 10 cm^2 field size defined at the depth of d_{max} in water phantom. Same conditions applied under measurements were also applied for Monte Carlo calculations. Relative dose profiles for wedge angles 15^o, 30^o, 45^o and 60^o were compared. The shape of the beam profiles was found to vary with beam energy more than the shape of the depth dose curves. Similar results were obtained in literature [27]. The largest deviation between the calculated and measured dose profiles for the 6 and 15 MV photon beams were found to be approximately 4% and 3% at the depth of d_{max} in the toe of 10 × 10 cm^2 field size for 60^o wedge angle respectively. For 6 MV photon beam, the deviations between the measured and calculated peripheral doses were typical less than 3%, while inside the geometrical field edges were less than 2%.

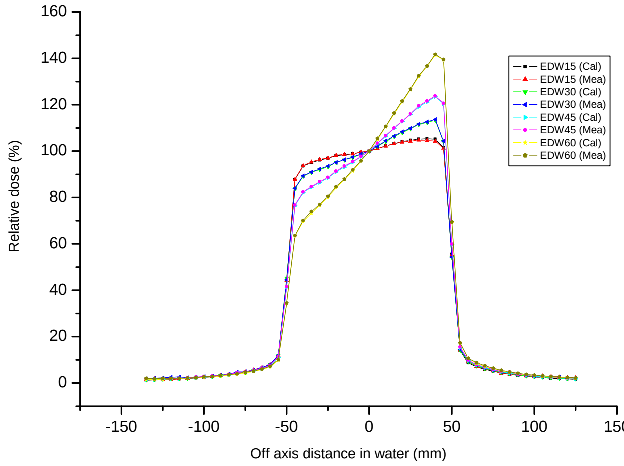

Figure 3: Comparison of the measured and calculated beam profile curves from 6 MV photon beam with 15^o, 30^o, 45^o and 60^o EDWs for 10 × 10 cm^2 field size defined at depth of d_{max}.

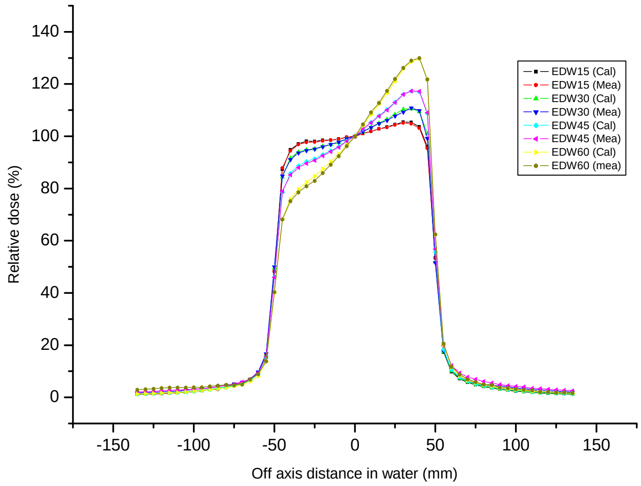

Figure 4: Comparison of the measured and calculated beam profile curves from 15 MV photon beam with 15^o, 30^o, 45^o and 60^o EDWs for 10 × 10 cm^2 field size defined at depth of d_{max}

For the 15 MV photon beam, the deviations between calculated and measured peripheral doses were less than 2%. Inside the geometrical field edges the deviation were also less than 2%. In general, the calculated and measured dose profiles for all field sizes are in good agreement.

3.4 Wedge factors

Table 2 shows the wedge factors measured and calculated for 15^o, 30^o, 45^o and 60^o wedge angles of the 10 × 10 cm^2 field size defined at the depth of 10 cm in water phantom. The wedge factors were observed to decrease with increasing wedge angles and decreasing the photon beam energies. For the 6 MV photon beam, the percentage difference between measured and calculated wedge factors at 10 cm depth are 1.1%, 0.2%, 0.3% and 0.3% for 15^o, 30^o, 45^o and 60^o wedge angles, respectively. For all wedge angles, the differences are within 0.3% with the largest difference of 0.3% obtained with 60^o and 45^o wedge angles.

Table 2: Comparison of the measured and calculated wedge factors at the 10 cm depth for 10 × 10 cm^2 field size for 6 and 15 MV photon beams.

Wedge angle	*6 MV*		*15 MV*	
	Meas	*Calc*	*Meas*	*Calc*
15^o	0.925	0.924	0949	0.948
30^o	0.891	0.889	0.894	0.892
45^o	0.770	0.768	0.829	0.828
60^o	0.663	0.661	0.737	0.735

For the 15 MV photon beam, the percentage difference between measured and calculated wedge factors at 10 cm depth are 1.1%, 0.2%, 0.1% and 0.3% for 15^o, 30^o, 45^o and 60^o wedge angles, respectively. For all wedge angles, the differences are within 0.3% with the largest difference of 0.3% obtained with 60^o wedge angle.

3.5 Output factors

Output factor is defined as the ratio of doses at a reference depth with and without wedge filter for identical field size under similar conditions [28]. Wedge factor along the central axis of the beam was calculated by using equation (1).

$$WF(fs,d) = \frac{D_w(fs,d)}{D_o(fs,d)} \qquad (1)$$

Where d is the depth in water, fs is the field size along the central axis, $D_w(fs,d)$ is the dose at specific point along the central axis for a specific field size with the wedge in place and $D_o(fs,d)$ is the dose at the same point in an open field of equal dimensions. Figure 5 shows the measured and calculated output factors for 45^o wedge angle as a function of field sizes at the depth of 10 cm for the 6 and 15 MV photon beams.

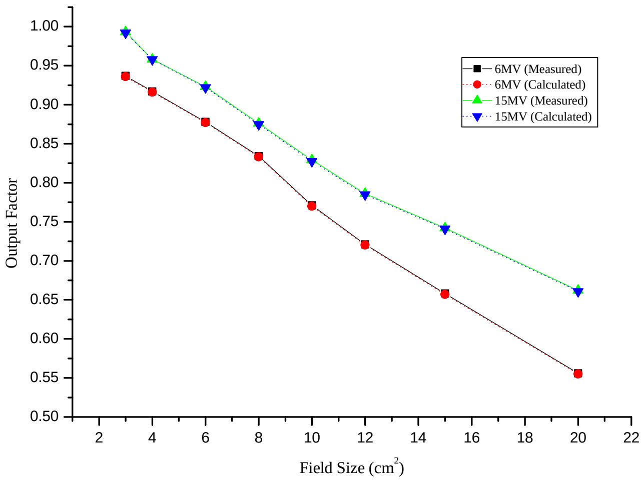

Figure 5: Comparison of the measured and calculated output factors at the depth of 10 cm for 45^o wedge angle for 6 and 15 MV photon beams.

The largest difference of 1.8%, observed at a field size of 20 × 20 cm^2. The calculate and measured curves agree well within 2%, with the largest different observed with 20 × 20 cm^2 and 10 × 10 cm^2 filed sizes for 6 and 15 MV photon beams respectively. The wedge factors were observed to increase with photon beam energy. There is a negative linear dependence of output factor with field size for both energies. There is a 40.66% and 40.71% decrease in wedge factors between 3 × 3 cm^2 to 20 × 20 cm^2 field sizes for measured and calculated 6 MV photon beam, respectively. For 15 MV, the decrease is 33.33% and 33.37% for measured and calculated data, respectively. Our data compared very well with published data. Comparing our results, we found an excellent agreement for 6 MV photon beam [29-32] and for 15 MV photon beam [31, 33].

4. Conclusion

This paper described the comparison of measured and calculated dosimetric characteristic of enhanced dynamic wedges of the Varian 2100C accelerator operating at 6 and 15 MV beam energies. Measurements and calculations were conducted and successfully generated dose distributions for various standard wedge angles and field sizes. The Monte Carlo calculations showed a good agreement with measured data. The results showed that Monte Carlo simulation is a useful method for investigating and understanding the dosimetric characteristics of enhanced dynamic wedge. The finding of this study is that, the choice of the type of wedge filter required for a specific radiation treatment plan should be based on the wedges angles and field sizes as well as photon beam energy.

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