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A Monte Carlo simulation and dosimetric verification of physical wedges used in radiation therapy

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Background: The presence of a wedge filter in the beam trajectory can modify the beam quality and cause some changes in the dosimetry parameters which are usually difficult to be measured directly and accurately. *Material and Methods:* In this study the MCNP-4C Monte Carlo code was used to simulate the 9 MV photon beam generated by a linear accelerator. Upon getting a good agreement between the Monte Carlo simulated and measured dose distribution in open fields, the model was used to simulate the physical wedges. The steel wedges with angles from 15º-60º were modeled and the primary and the secondary photon beams were calculated. The beam profiles and wedges factors were calculated for each wedge. The output factors were determined for 45 ˚ wedge. The calculated data were compared with the measured values of the same parameters. *Results:* The results showed that the use of wedges reduced the fluencies of the primary and scattered photons and also increased the average energy of the primary and the scattered photons. The agreement between the calculated and the measured data was better than 2% for all wedges. The results also showed that as the wedge angle increased, the electron contamination of photon beam decreased. *Conclusion:* The presence of a wedge in a 9 MV photon beam alters the primary and the scattered components generated by a linear accelerator. The simulated linac machine and its associated data can be used to predict the dose distribution in other complex fields. **Iran. J. Radiat. Res., 2010; 7 (4): 223-227**

Keywords: *Monte Carlo, photon spectra, physical wedge, MCNP4c code, simulation.*

INTRODUCTION

The most commonly used beam modifiers in radiotherapy are the wedge filters. These filters usually are made of dense materials and inserted in the beam at the specific distance from the patient to optimize the dose uniformity in the target volume. The presence of wedge filter in the beam trajectory can modify the beam characteristics such as intensity and quality which are usually difficult to be measured directly and accurately (1). In addition, the scatter photons and electron beam contamination produced by any beam modifiers should be carefully taken into account when calculating patient dose. Therefore photon beam perturbations generated by physical wedges need to be investigated in more detail.

Currently, Monte Carlo simulation is one of the most accurate methods of simulating radiation transport and predicting doses in radiotherapy (2-5). Dose calculations in the unusual and complex situations such as presence of beam modifiers in the treatment fields are possible using these methods (6-8). In this study physical wedges have been studied in detail using the MCNP-4c Monte Carlo code to determine their effects on some properties of X-ray beam, such as the photon fluency, mean energy, beam profiles, wedge factors, output factors and electron contamination of photon beam. This code is a general purpose MC code

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which can be used for neutron, photon, electron, or coupled neutron/photon/electron transport [9].

MATERIALS AND METHODS

The MCNP-4C Monte Carlo code was used to simulate the 9 MV photon beam generated by a Neptun 10PC linear accelerator. The accelerator was modeled as a combination of its components consisting of a target, exit window, initial collimator, primary collimator, flattening filter, monitor chamber and secondary collimator. The geometrical details and composition of each component were either obtained from the manufacturer [10] or calculated directly from our own measurement. The simulation of source was performed in two steps, at first we defined electron source and then used bremsstrahlung energy spectra and fluence distribution at the scoring planes for definition of photon source [3, 11-13]. The electron beam energy and its intensity in the simulation were taken as a Gaussian distribution. In order to define photon source, the emerging X-ray energy spectrum and angular distribution scored in planes perpendicular to the central axis were placed 1mm below each component and extending beyond the outer edge of the component [11]. The X-ray spectrum and angular distribution obtained at the scoring plane below flattening filter were redefined as a generalized point source. To compute photon beam data a 50 × 50 × 40 cm^3 water phantom located at SSD = 100 cm was simulated. Depth dose and dose profile curves were calculated for four usual open field sizes (5×5 cm^2, 10×10 cm^2, 20×20 cm^2 and 30×30 cm^2) and compared with measured values of the same parameters. The details of simulation and results are demonstrated elsewhere [14]. When excellent agreement was obtained between the Monte Carlo simulated and measured dose distributions in water phantom, the model was used to simulate the wedge fields. The wedges were made of steel and assembled below secondary collimator at 40 cm from phantom surface [10]. The Monte Carlo simulation geometry is shown in figure 1.

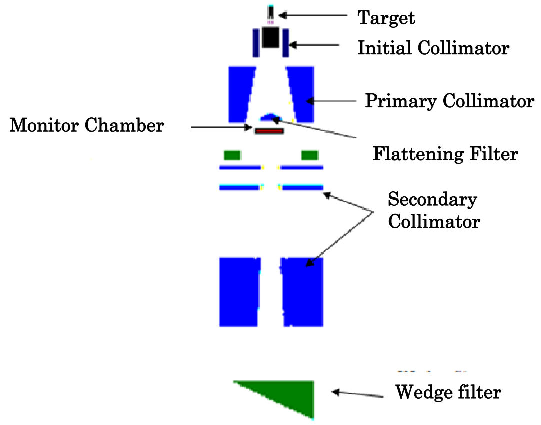

Figure 1. Monte Carlo model of linear accelerator showing the major components and wedge filter.

In this study the steel wedges with angles of 15°, 30°, 45° and 60° were modeled and the primary and the secondary photon beam spectra at the surface of water phantom (SSD=100 cm) were calculated. The flounce of contaminant electron and electron/photon ratio has also been calculated for better understanding of the photon beam perturbation generated by physical wedges. The beam profiles and wedges factors were calculated for each wedge with respect to a field size of 10×10 cm^2. The output factors were determined for 45° wedge in field sizes of 5×5cm^2 to 15×15cm^2. The low-energy cut-off for photon and electron was 10 and 500 keV, respectively. The measurements were carried out by a Scanditronix dose scanning system and 0.12 cm^3 RK ionization chambers and diode dosimeters. The calculated data were then compared with the measured values of the same parameters.

RESULTS

Effect on beam quality: Figures 2 and 3 show the primary and secondary photon energy spectra at the surface of water phantom. The results show that the use of wedges with 15°, 30°, 45° and 60° angles reduces the fluency of the primary photons by about 16, 24, 26 and 37% and for the scattered photons by about 19, 28, 31 and 42%, respectively.

The physical wedges with angles from 15°, 30°, 45° and 60° increased the average energy of the primary and the scattered photon by about 2 - 6% and 3 - 9% respectively.

Electron contamination

Electron contamination in photon beam has been calculated at the surface of phantom (SSD=100 cm) in open and wedge fields. The results show that the use of wedges with 15°, 30°, 45° and 60° angles changed the flounce of the electrons by about 1.15, 0.99, 0.87 and 0.79 respectively compared to the open field. The ratio of electron/photon fluence for the open and wedge fields (15°-60°) were calculated as 0.0029, 0.004, 0.0038, 0.0037 and 0.0036 respectively.

Dose distribution in the water phantom

Figures 4 and 5 show the dose profiles at the depths of 2 and 10 cm along the wedge gradient direction, respectively. The results show good agreement between the calculated and the measured data, with the difference in the percent dose less than 2.5% for all the wedges.

Table 1 shows the wedge factors measured and calculated for various wedges at the depth of 10 cm of the 10×10 cm^2 field. Figure 6 shows the output factors as a function of field size for 45° wedge at the depth of 10 cm.

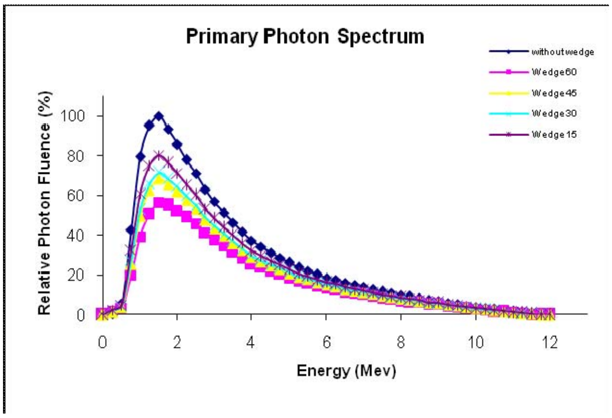

Figure 2. Primary photon spectral distribution at the surface of water phantom in open and wedge fields.

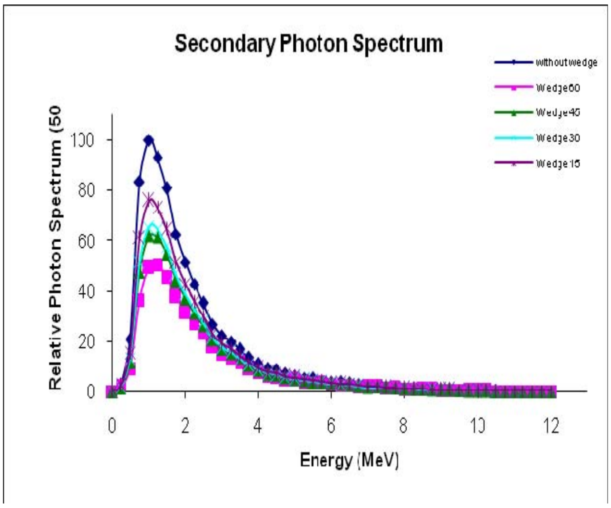

Figure 3. Secondary photon spectral distribution at the surface of water phantom in open and wedge fields.

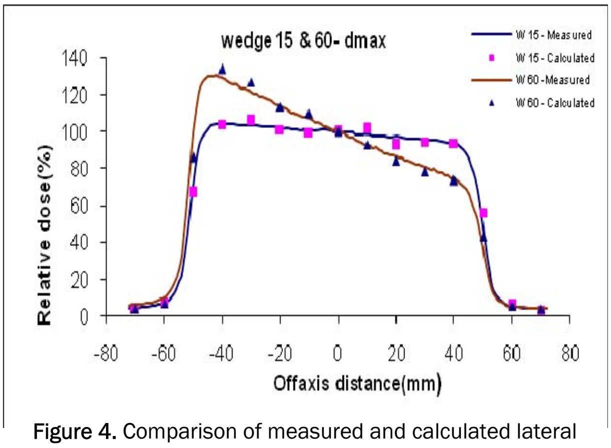

Figure 4. Comparison of measured and calculated lateral dose profiles in water phantom for 15º and 60º wedges at 2cm depth for 10×10 cm^2 field.

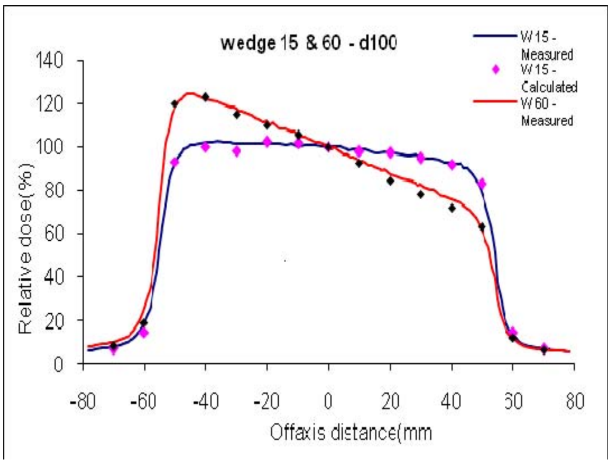

Figure 5. Comparison of measured and calculated lateral dose profiles in water phantom for 15° and 60° wedges at 10cm depth for 10×10 cm^2 field.

Table 1. Comparison of Monte Carlo wedge factors against experiments for various wedges at the depth of 10 cm of the 10×10 cm² field.

Wedge angle	Wedge factors	
	Measured	Calculated
15°	0.837	0.835
30°	0.772	0.762
45°	0.753	0.742
60°	0.659	0.637

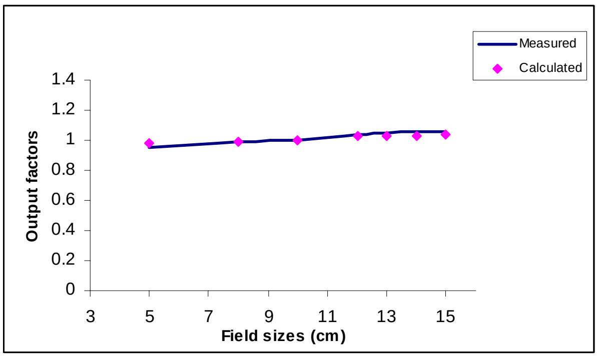

Figure 6. The output factors as a function of field size for 45º wedge at the depth of 10 cm.

DISCUSSION

Figure 7 shows the total photon spectra calculated at the surface of water phantom in the 10 × 10 cm² field size. According to our results the use of wedges with 15°, 30°, 45° and 60° angles in 9 MV photon beam, decreases the photon fluence by about 16%, 24%, 27% and 37% respectively compared to open field. Figures 2, 3 and 7 showed that the effect of wedges on the low energy photons are greater than high energy photons which caused increase of mean energy of the photon beams [1, 15, 16]. Our results showed that the use of wedges with 15 45˚ ,30˚ ,and 60 ˚angles in 9 MV photon beam, increases the average energy of the photon beam about 2.2%, 3.6%, 4.4% and 6.4% respectively compared to open field [15].

The results also show that as the wedge angle increased, the electron contamination of photon beam decreased [17, 18]. This decrease indicates that the number of electrons produced in the wedge is less than the number of electrons eliminated by the wedges. The increase of electron/photon ratio with increase of wedge angle indicates that the photon fluencies decrease more with wedges compared to electron fluencies.

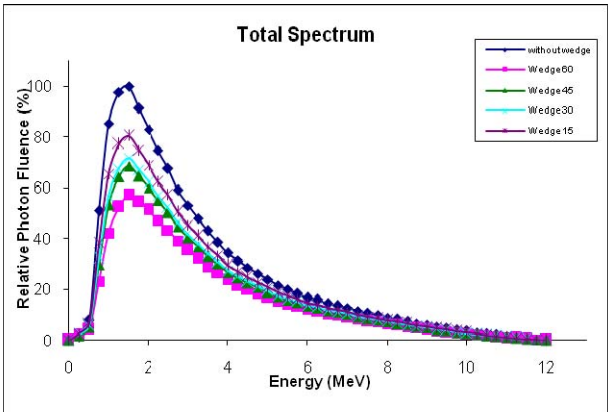

Figure 7. The total photon spectra calculated at the surface of water phantom in the 10 × 10 cm² field size.

The comparison of the measured profiles with those calculated by the MCNP-4C code shows slight differences in the 10 × 10 cm² treatment field. As the wedge angle increased, the difference increased as well [16]. A maximum discrepancy about 2.5% was found for 60 ˚wedge which may be related to little uncertainties in the real steel composition to which it was Sadeghi activity in the nodules.modeled [1].

Table 1 shows that the Monte Carlo calculation of wedge factors agrees with the measured data within 2% accuracy. The calculated wedge factors at the depth of 10 cm are less than the measured data, which could be caused by small amount of discrepancy in modeling the wedge filters composition. Figure 6 shows the relative output factors as a function of field size of 45 ˚wedge in 9 MV photon beam. The output factors are correlated to the value at the depth of 10 cm of the 10 × 10 cm² field. The data show good agreement (better than 2%) between the calculated and the measured output factors.

In conclusion the results showed that the presence of a wedge alters the primary and scattered components generated by a linear accelerator and causes beam hardening in 9 MV. The beam hardening increased as the wedge angle increased.

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