

Original Article:**Dosimetric verification of the Elekta motorized wedge****Mahdie Behjati¹, Mostafa Sohrabpour¹, Seyed Pezhman Shirmardi^{2,*}, Fathollah Bouzarjomehri³, Mohammad Amin Mosleh Shirazi⁴**¹Nuclear Engineering Unit, Department of Energy Engineering, Sharif University of Technology, Tehran, Iran²Nuclear Science and Technology Research Institute (NSTRI), Tehran, Iran³Medical Physics Unit, Department of Medical Physics and Environment Health, Shahid Sadoghi University of Medical Sciences, Yazd, Iran⁴Physics Unit, Department of Radiotherapy and Oncology, Ionizing and Non-ionizing Radiation Protection Research Center, Shiraz University of Medical Sciences, Shiraz, Iran*Corresponding Author: email address: p_shirmardi@aut.ac.ir (P. Shirmardi)**ABSTRACT**

Elekta linear accelerator is equipped with a motorized wedge which produces the wedge angles of less than 60° continuously by the combination of a wedged field and an open field with appropriate proportions. The effective wedge angles for various field sizes and depths were calculated using an analytical formula and a 2-D array detector data. The validity of the effective wedge angles has been done by determining wedge angles in accordance with ICRU-24. The effect of the field size on the wedge angle and wedge factor was investigated for motorized wedge. The maximum difference between planned and measured angles was found to be about 10°. The planned dose for different wedge angles and field sizes compared with measured doses and their differences were found to be less than 3%. The calculating wedge factor throughout linear interpolation method for all field sizes from a few selected measurements had been proved for physical wedge beforehand. This method was applied to obtain the wedge factors with field size and compared with measured data for motorized wedge. The errors were in agreement with ICRU proposed error and less than treatment planning system error. The linear relation between wedge angle and output factor and depth were investigated and the linear interpolation method was proved to calculate wedge angle for any output factor and depth.

Keywords: Motorized Wedge; Wedge Angle; Wedge factor; Treatment planning**INTRODUCTION**

Wedge filters are used in radiotherapy to modify photon beam characteristics and improve dose uniformity in the target volume. Multiple choices are available for creating wedged isodose distribution. Elekta compact linear accelerators generate a wedge isodose distribution using a single fixed motorized wedge (MW) that is mounted inside the head and its position is controlled remotely [1]. In this kind of wedge, the wedge angles less than 60° can be generated by combining open and wedge field irradiation with

appropriate proportions. The wedge angle and wedge factor are two important characters of wedge filters. The wedge angle is defined as the angle between a given isodose line and the central axis of the beam in a central plane parallel to the wedge gradient [2]. The specification of depth is important for determination of nominal wedge angle. The ICRU has recommended the wedge of reference depth of 10 cm [3]. The verification of wedge filters characteristics was reported through the previous articles [4-9]. There are several papers that studied the motorized wedges and

obtained the effective wedge angles for various field sizes based on Tatcher equation [10-13]. The relation between wedge angle and field size and depth was not discussed in these papers. The wedge filters are used for various field sizes and depths. The dependence of wedge factor on field sizes and depth has been investigated by these researches [14-23]. The linear relation between wedge factor and field size was observed in these studies.

Since few measurements were performed on commissioning of accelerator, a method is required for calculating wedge angle and wedge factor for treatment field size and depth based on few measurements. Popple et al. demonstrated a simple method for obtaining a wedge factor for any field size from a few selected measurements based on interpolation [24].

The present study verified the dosimetric characteristics of a wedge factor and wedge angle of a motorized wedge filter for 6 MV Elekta linear and the interpolation method was applied for wedge angle and wedge factor against the field size and depth to improve the accuracy of the treatment planning system (TPS).

MATERIAL AND METHODS

Verification of wedge angles

The profiles for the nominal MW angle and the appropriate open and wedged beam weights were measured for the square field sizes of 5×5 , 10×10 , 15×15 , 20×20 cm² at a fixed depth of 10 cm, using a 2-D array detector. The wedge angles were calculated using an analytical formula and profile data.

The analytical formula has been shown in equation (1): [25]

$$\theta_E = \arctan \frac{\ln \frac{D_1}{D_2}}{0.5 \times F_s \times \mu} \quad (1), \text{ where } F_s \text{ is a length}$$

of the field size in cm, D_1 and D_2 are dose values at positions $+0.25 \times F_s$ and $-0.25 \times F_s$ which are measured by two separate detectors at 10 cm depth using a 2-D array detector. To measure D_1 and D_2 , solid water slabs of 10cm thickness were placed on the surface of 2-D array detector. μ is linear attenuation coefficient which is calculated according to the following equation:

$$\mu = \frac{\ln \frac{d_5}{d_{10}}}{h_5 - h_{10}} \quad (2), \text{ where } d_5 \text{ and } d_{10} \text{ are open field dose values at depths of } h_5 \text{ and } h_{10} \text{ respectively. The } d_5 \text{ and } d_{10} \text{ were measured using FC65-G ionization chamber in a water phantom of } 30 \times 30 \times 30 \text{ cm}^3 \text{ dimensions. The effective wedge angles were calculated from the equation (1) for the field sizes of } 5 \times 5, 10 \times 10, 15 \times 15, 20 \times 20 \text{ cm}^2 \text{ and various planned wedge angles. The effective wedge angle } 60^\circ \text{ was validated with the wedge angles that were determined from isodose curves according to ICRU24. The isodose curves were measured in the large water phantom using Diode and Omni-pro software.}$$

Omni-pro software has produced isodose curves for 60° wedge angle at different field sizes from 3×3 to 20×20 cm².

Measurements of wedge factors

Wedge factor is defined as the ratio of dose in water at a point on the central axis with and without the wedge for same number of monitor units [12].

$$WF(\theta, d, s, E) = \frac{D(\theta, d, f, E)}{D(d, f, E)} \quad (3), \text{ where } \theta \text{ is the wedge angle, } d \text{ is the depth, } f \text{ is the field size, and } E \text{ is the nominal beam energy.}$$

The wedge factors were measured with FC65-G ionization chamber in a water phantom of $30 \times 30 \times 30$ cm³ at a depth of 5 cm under SSD setup according to IAEA TRS-398 protocol [26].

Wedge factors were measured for 5×5 , 10×10 , 15×15 , 20×20 cm² field sizes, at 15° , 30° , 45° , 60° angles.

Verification of planned dose with motorized wedge

The monitor unit (MU) of wedged and open fields were calculated to deliver 100 cGy dose at 5cm depth for 15° , 30° , 45° angles and 5×5 , 10×10 , 15×15 , 20×20 cm² field sizes. The water phantom $30 \times 30 \times 30$ cm³ was irradiated and dose calculated using an FC65-G ionization chamber and was compared with a planned dose 100 cGy.

The algorithm based on linear interpolation

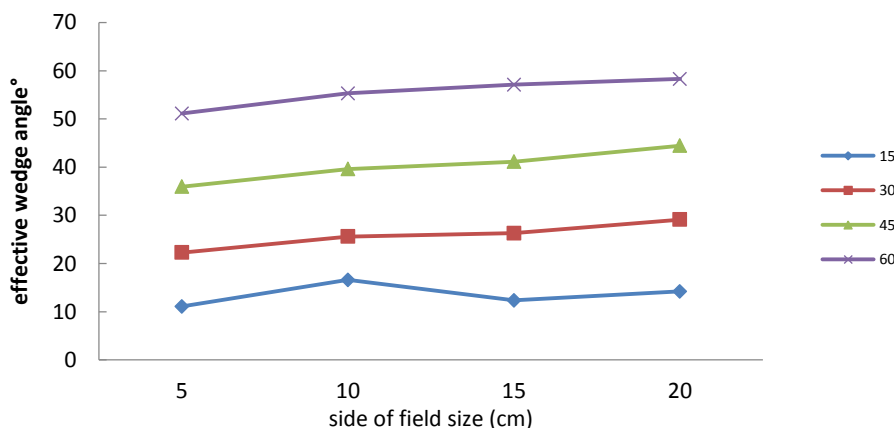
Popple's established wedge factors is proportional to field area or equivalent square field for physical wedge of Varian linac [24]. Based on this research, the present study investigated the relationship between wedge factor and equivalent square field for Elekta

motorized wedge. The wedge factors were determined for all field sizes by linear interpolation based on field area in the range of the indicated field sizes. Measurements were taken for the 3× 4.5, 7× 7, 12×12, 16× 18.5 cm² field sizes for 15°, 30°, 45° and 60° to validate interpolated wedge factors with the field area. This study investigated the relationship between wedge angle and field sizes for 15°, 30°, 45° and 60° motorized wedge. The variation of the wedge angles with field size was probably due to increase photon scatter from the wedge. The scattering from the thick side of the wedge is more than the scatter from its thin side. The output factor determines the increased scatter as the field size increases. Thus, the relationship between wedge angle and output factor for 60° motorized wedge was investigated. The wedge angles at other field sizes were determined by linear interpolation. The interpolate wedge angles were validated by measurement isodose curves and determined wedge angle according to ICRU-24. The dependence between the wedge angle and

the depth was also investigated for 30° motorized wedge and 15× 15 cm field size. The wedge angles were determined at different depths by the linear interpolation between the tangent wedge angle and depth. The interpolated wedge angles were compared with the experimental data, which was determined using equation (1) and 2-D array detector.

RESULTS

The effective wedge angle Θ_E was determined for various field sizes as per equation (1) for planned wedge angles 15°, 30°, 45°, 60° and as shown in figure-1. The effective wedge angles are nearly linear function of field size and increase with the field size for 30°, 45° and 60°. It is observed that the wedge angles for 60° planned angle increases from 51° to 58° for 5cm× 5cm to 20 cm× 20cm field size. This increase is less for smaller planned wedge angles. The increase wedge angle with field size isn't specific for 15° planned wedge angle.



Figur1. Effective wedge angle Θ_E against the field size.

Table1. comparison effective wedge angle Θ_E and wedge angle determined the isodose curve as per ICRU24 definition

Field size (cm ²)	effective wedge angle Θ_E	The experimental isodose curve wedge angle	Deviation in degree between effective and experimental isodose wedge angle
5×5	51.1	51	0.1
10×10	55.3	54.2	-1.1
15×15	57.1	58	0.9

Table 1 shows the wedge angles that were determined from experimentally isodose curves as per ICRU24 definition and wedge angles Θ_E were calculated using equation (1) from $5 \times 5 \text{ cm}^2$

to $15 \times 15 \text{ cm}^2$ field size. The deviation between effective and experimental isodose wedge angle in degree is less than 1.1° .

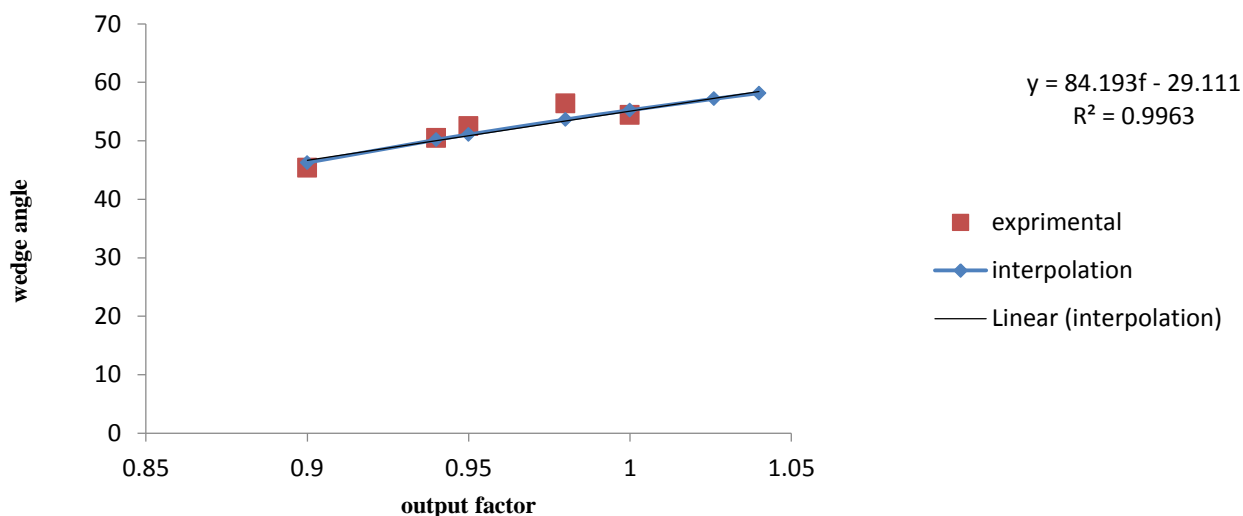
Table2. Planned and effective wedge angle Θ for $15\text{cm} \times 15\text{cm}$ field size.

Planned wedge angle	Effective wedge angle(Θ_E) $\Delta=\pm 0.2^\circ$	Deviation in degree
5	3.25	1.75
15	12.35	2.65
30	26.29	3.71
45	41.12	3.88
50	46.44	3.56
60	57.10	2.9

Table2 shows the planned wedge angle and effective wedge angle Θ_E that were calculated using equation (1) and their deviations for $15\text{cm} \times 15\text{cm}$ field size. It is observed that the

deviation between effective and planned wedge angles were less than 4° .

Figure2 shows the wedge angle Θ as a function of output factor for 60° wedge angle.



Figur2. Comparison wedge angles that were determined in two methods of linear interpolation and the experimentally wedged angle according to icru-24.

Solid line indicates the interpolated values from few selected measurement and were compared with the wedge angles that determined according

to ICRU-24. The maximum difference between the linear interpolation and experimentally wedged angles was 2.7° .

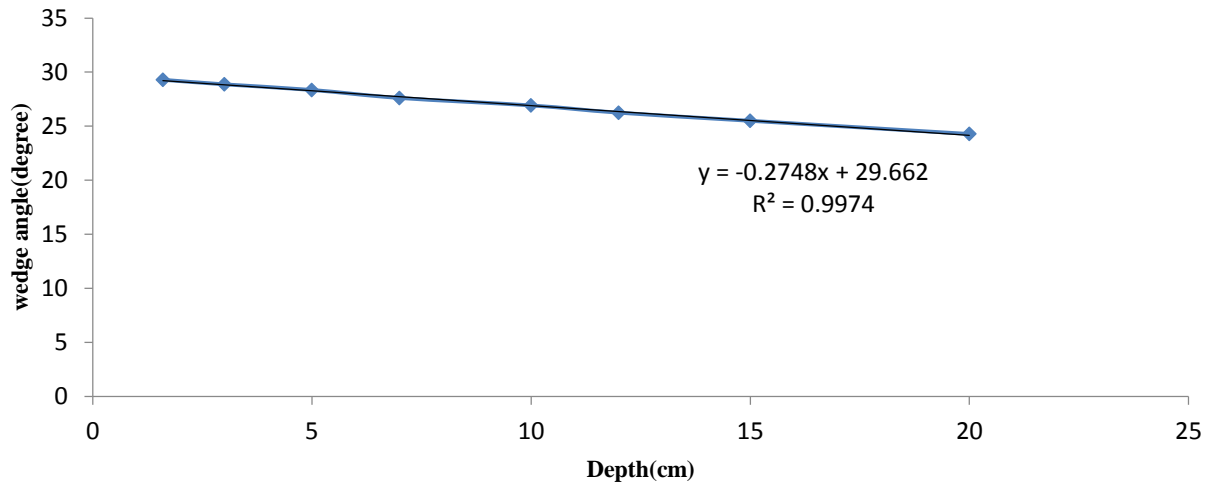


Figure3.The variations of wedge angles against to the depths for the 30° wedge angles and 15×15cm² field size.

Figure3 shows the variation of calculated wedge angle for 30° wedge angle and 15 ×15 cm² field size against to the depths. It is observed that the

wedge angle decreases with increasing depth in the phantom due to the presence of scatter radiation.

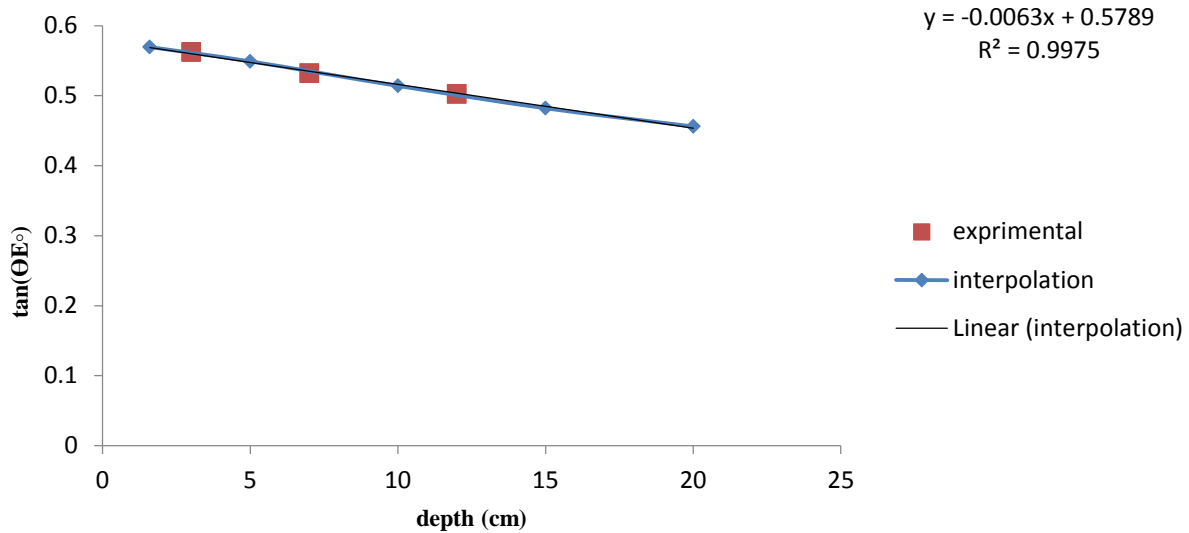


Figure4. Comparison the wedge angles that determined in difference depth in two methods linear interpolation and experimentally according to ICRU-24.

Figure 4 shows the linear interpolation wedge angles based on depth (solid line) and the calculation wedge angles using equation (1). The

mean difference between the linear interpolation wedge angles and experimentally wedged angles were found to be 0.48%.

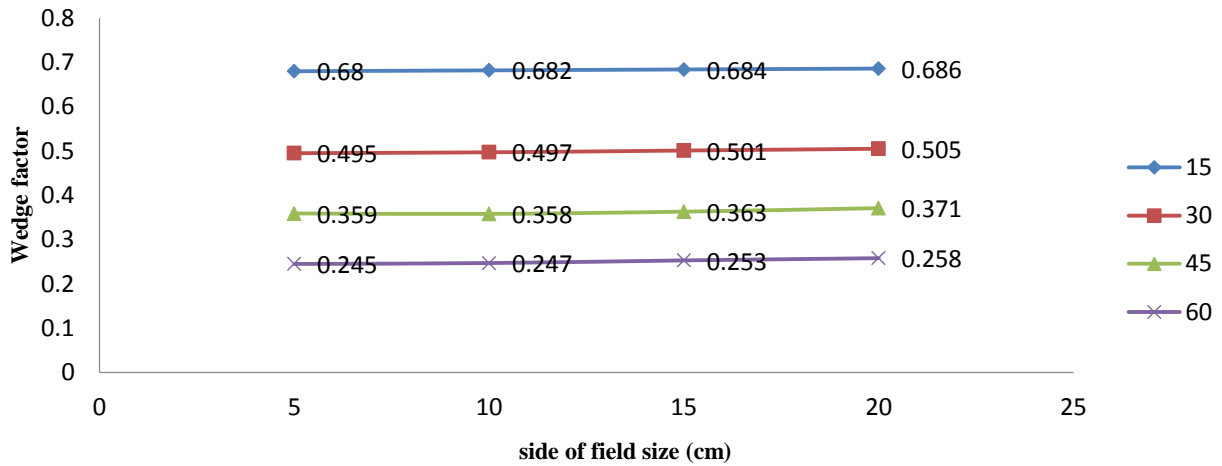


Figure5. Wedge factors against the field size

Figure5 shows the wedge factors (WF) increase with the field size due to increased scatter radiation for larger field size. More increase in the wedge factor with field size is also observed

for larger wedge angle due to greater wedge MU. For more precision, the dependence of the WF on the field size was investigated, shown in figure 6 and 7.

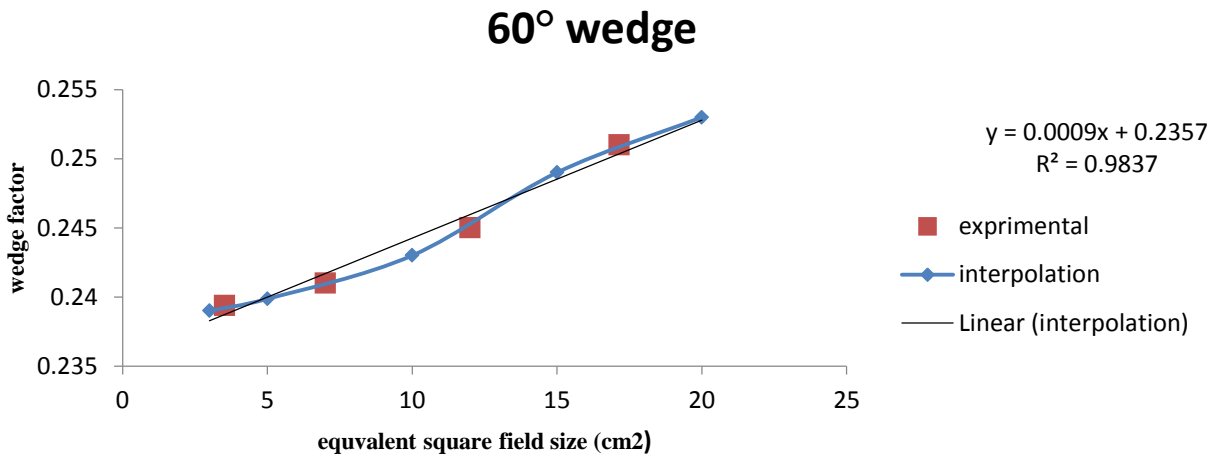


Figure6. Wedge factor versus field size for 60° wedge angle in two methods linear interpolation and measurement.

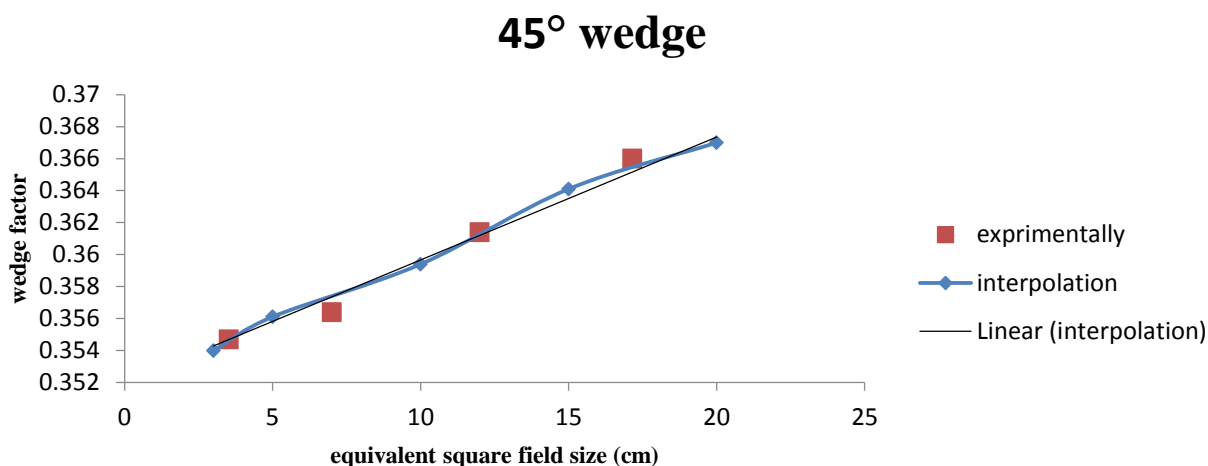


Figure7. Wedge factor versus field size for 45° wedge angle in two methods linear interpolation and measurement.

Figure 6 and 7 show the wedge factors versus the equivalent field size for 60° and 45°. The interpolation values from 5×5, 10×10, 15×15, 20×20 cm² field sizes were in good agreement with measured values and the relative errors for

60° and 45° wedge angles were found to be respectively 0.48% and 0.38%.

The relative error interpolation wedge factors with the relative error reference wedge factor method were compared table 3.

Table3. Comparison the error of interpolation method and TPS method.

Wedge angle	Interpolation method		Reference wedge factor	
	Mean relative error	Range	Mean relative error	Range
60	0.48%	0.0033%-1.12%	1.96%	0.81%-3.9%
45	0.38%	0.028%-0.47%	1.23%	0.57%-1.9%
30	0.18%	0.033%-0.36%	0.7%	0%-1.6%
15	0.25%	0.1%-0.33%	0.27%	0.1%-0.53%

The maximum relative error of interpolation method is the quarter of the TPS relative error. The maximum error of interpolation method is 1.12% that is a small error in radiotherapy. Table

4 shows the difference between measured and planned dose value using Elekta motorized wedge.

Table4. Comparison of planned and measured dose for various field sizes and wedge angles

Field size(cm ²)	wedge angle(degree)	Measured dose(cGY)	Planned dose(cGY)	Variation %
5cm×5cm	15	100.04	100	0.04
	30	98.24	100	1.78
	45	99.11	100	0.89
10cm×10cm	15	100.23	100	0.23
	30	99.46	100	0.54
	45	99.18	100	0.82
15cm×15cm	15	99.89	100	0.11
	30	99.06	100	0.94
	45	99.27	100	0.73
20cm×20cm	15	97.14	100	2.86
	30	97.42	100	2.58
	45	99.34	100	0.66

It is observed that the deviations between planned and measured doses from $5\text{cm} \times 5\text{cm}$ to $15\text{cm} \times 15\text{cm}$ field size are less than 1% and for $20\text{cm} \times 20\text{cm}$ field size are less than 3%. High error for $20\text{cm} \times 20\text{cm}$ field size implies that the Elekta motorized wedge is used for field sizes smaller than $20\text{cm} \times 20\text{cm}$.

DISCUSSION

The dosimetric characteristic of Elekta motorized wedge was studied in this paper. The effective wedge angle was measured for various field size and indicated the linear increase with field size. The effective wedge angles are linear function of field size except wedge angle 15° as shown in Petti et al. and Wu et al. researches [10,27]. But Kumar et al indicated a small variation wedge angle with field size [12]. The behavior of wedge angle 15° with field size may be related to the decreased present wedge filter time in treatment with decrease the wedge angle. The maximum influence of field size on wedge angle has occurred for 60° wedge angle because of the great time of present wedge filter in treatment as a result of increasing scatter radiation. The maximum difference between planned and measured wedge angle for various field size was found to be about 9° . This difference is higher than the published data [10, 12].

The effective wedge angles differ with isodose wedge angle and these differences were less than 1.1° and were lower than Kumar data [12]. But the differences between planned wedge angle and effective wedge angle is found to be less than 4° that are higher than ICRU proposed uncertainty $\pm 2^\circ$ and Kumar research for cobalt unit [3,12]. Every effective wedge angle was less than planned wedge angle because of neglect of beam hardening in Tatcher equation [13]. The beam hardening effect was more significant for 6MV linac relative to the cobalt unit due to its energy [2]. The effect of output factor and depth on wedge angle was investigated and the linear functions between them were obtained. The linear correlation coefficients were greater than 0.99 for both of them. Thus, the linear interpolation was used to calculate unmeasured angles against depth and output factor and was compared with measured data. There was a good agreement

between interpolated and measured wedge angle as shown in figure 2 and 4. The ascertainment effect of output factor on wedge angle indicated the influence of field size on wedge angle; accordingly, it is possible to obtain wedge angle against field size. The variations of the other characteristic of wedge filter, the wedge factor, with field size were studied in figure 5,6 and 7. The linear relation between wedge factor and field size was observed, and proved to be in agreement with the other publications [17,19,24]. The wedge factors were computed according to Popple et al. interpolation method for field sizes that were not measured [24]. The linear interpolation method can reduce the required measurements to complete the table of wedge factor and improve the accuracy of TPS. TPS used a method to measure wedge factor at reference field size and generalize it for all field sizes. The errors of interpolation and TPS methods were compared in table 4 and the interpolation method errors were recorded as less than 1.12% while the TPS errors were up to 4%. The interpolation method for motorized wedge factor was more accurate than Popple results [24].

CONCLUSION

This study verified the accuracy of treatment using Elekta motorized wedge. The effective wedge angles were obtained for various field size and depth that were required for TPS. The beam hardening and scatter of the wedge effect caused the difference between effective wedge angle and planned wedge angle. Scattering of the wedge increased with field size and could be reduced by modification of the wedge shape and material. The influence field size on effective wedge angle was higher than proposed uncertainty $\pm 2^\circ$ [3]. So this effect in treatment planning system should categorically be considered. The required dosimetric characteristic of TPS for all field sizes could not be measured in the present study. This paper applied the algorithm based on linear interpolation with the field size to determine the wedge factor. This algorithm was validated with measuring data successfully. The efficiency of the linear interpolation method was proved to calculate wedge angle based on factors of field size and depth. Therefore, the interpolation

method can be used as an alternative method for TPS by minimum required measurement.

“The authors declare no conflict of interest”

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