THE FIELD SIZE AND DEPTH DEPENDENCE OF WEDGE TRANSMISSION FACTOR FOR HIGH ENERGY PHOTON BEAMS

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The wedge transmission factors (WTF) usually were assumed to be used for clinical treatment planning system by independence on field size and depth of measurement. For this study, the field size and depth dependence of the in phantom WTF has been determined for Co-60 teletherapy unit and three Linear Accelerator energies of 6, 10 and 15 MV X-ray beam, containing 15°-60° lead, brass and alloy wedge filters. All measurements were made with a cylindrical ionization chamber in water or solid water phantom with a source-skin distance of 80 cm or 100 cm. Field sizes varied from 4x4 cm^2 up to a maximum allowable size for each wedge filter. Several depths of measurement were selected: d_{max}, 5 cm (AAPM TG-21 calibration depth), 10 cm and 15 cm.The results show that use of single wedge WTF measured for 10x10 cm^2 field introduces error less than 3% for field size not exceeding than 15x15 cm^2 for all energies, but for a 22x22 cm^2 field size, the error is up to 5%, 5.5%, 6% and 4.5% for Co-60, 6, 10 and 15 MV respectively. Moreover, for a 25x25 cm^2 field size the error is up to 7.6% and 5.7% for 6 and 15 MV respectively . For the depth dependence study, we conclude that the WTF at depth for Co-60 differ not exceeding 3.5% from the determined values at TG-21 calibration depth and for 6, 10 and 15 MV X-ray there are about 4.4%, 2% and 2.8% difference respectively. In this paper we have attempted to show that there is a definite dependence of WTF on field size and depth. Therefore a WTF measurement for a reference field size and depth may not be valid for all field sizes and depths.

INTRODUCTION

The use of wedge filters to obtain desirable dose distributions in external beam treatment planning is well established technique in radiation therapy. This is used to optimize dose distributions with high energy photon beams. The wedge transmission factor (WTF) in dosimetry calculation are very common, but various methods have been used in measuring this factor. Conventionally, it is recommended that the reference field size and the reference depth be used instead of the dose maximum for these kinds of measurements to avoid the influence of contaminating electron in the beam.[1] The WTF used for clinical treatment planning system is generally assumed to be independent on field size and depth of measurement. We intended to investigate the field size and depth dependence of WTF for various beam energies. This paper reveals our findings which effects the accuracy of dose calculations for patients treatments .

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MATERIALS AND METHODS

The WTFs were determined in water phantom or solid water phantom, using a Farmer type 0.6 cm^3 ion chamber with a Farmer type 2570/1 electrometer for cobalt -60 gamma rays from a Theratron 780C (manufactured by Theratronix International Limited), 10 MV X-rays from a ML-15M linear accelerator (manufactured by Misubishi), 6 MV and 15 MV X-rays from MD and KD Mevatron linear accelerators (manufactured by Siemens Medical System). Measurements were taken by varying field sizes from 4x4 cm^2 up to a maximum allowable sizes for each wedge filter containing 15° - 60° lead, brass and alloy wedges. Measurement were also taken at the beam center of each machine (80 cm or 100 cm SSD): for the depth of d_{max}, the calibration depths recommended by the AAPM protocol TG 21 (5 cm: Cobalt-60, 6, 10 and 15 MV);[2] the recommended depth of 10 cm for wedge angle specification (ICRU);[3] and another depth, of 15 cm, relevant of treatment planning considerations of deep tumors. To confirm that the wedge was centered, measurements were performed with the two possible wedge positions and various collimator orientations. The WTFs were then calculated by taking the ratio of the central axis ionization reading with wedge filter in place to the open field reading for the same field size and depth of measurement. Results were further shown with WTF normalized to 10x10 cm^2 field for the field size dependence study in table I-IV in the term of relative wedge factor (RWFa).

RWFa = WTF (d, a) / WTF (d, 10x10)

Furthermore, the results for the depth dependence study were shown with WTF for 10x10 cm^2 field normalized to the TG-21 calibration depth in table V-VIII in the term of relative wedge factor (RWFd).

RWFd = WTF (d) / WTF (d 5 cm)

RESULTS

The WTFs were found to be similar for each energy: for the field size dependence, the WTF increased with increasing field sizes and for the depth dependence, the WTF increased with increasing depths. Table I-IV showed the relative wedge factors as a function of field size normalized to the field size 10x10 cm^2 for each energy. For cobalt-60 (Table I) there was a small percentage difference for the field size not more than 15x15 cm^2, the maximum values were 1.3%, 1.7%, 2.3% and 3% at the depth of d_{max} , 5 cm , 10 cm and 15 cm respectively. But for the field size greater than 15x15 up to 22x22 cm^2, the maximum percentage difference were 5.0%, 4.6%, 4% and 3.7% at the depth of d_{max}, 5 cm, 10 cm and 15 cm respectively.

TABLE I. Relative Wedge factors for cobalt-60 teletherapy unit. Factors normalized to the field size 10x10 cm^2

Wedge angle	Measurement position (depth)	Side of equivalent square field (cm) 5	6	8	9	10	12	15	18	20	22
	d_{max}	0.992	0.994	0.9970	0.999	1.000	1.006	1.012			
15°	5.0 cm	0.992	0.993	0.997	0.997	1.000	1.006	1.006			
	10.0 cm	0.991	0.991	0.997	0.998	1.000	1.006	1.014			
	15.0 cm	0.985	0.985	0.996	0.999	1.000	0.998	0.998			
	d_{max}	0.999	0.998	0.999	0.999	1.000	1.003	1.008			
30°	5.0 cm	1.001	1.001	1.003	1.002	1.000	1.005	1.006			
	10.0 cm	0.995	0.994	0.997	0.997	1.000	1.001	1.005			
	15.0 cm	0.993	0.984	0.994	0.999	1.000	0.988	0.991			
	d_{max}	0.991	0.992	0.995	0.997	1.000	1.004	1.012			
45°	5.0 cm	1.000	1.009	1.007	0.998	1.000	**1.017**	1.006			
	10.0 cm	0.995	0.992	0.997	0.999	1.000	1.008	1.016			
	15.0 cm	0.991	0.990	1.005	1.008	1.000	1.010	1.008			
	d_{max}	**0.987**	0.989	0.994	0.997	1.000					
60°	5.0 cm	0.983	0.986	1.006	0.991	1.000					
	10.0 cm	**0.977**	0.981	0.988	0.995	1.000					
	15.0 cm	**0.970**	0.970	0.985	0.986	1.000					
	d_{max}	0.994	0.995	0.997	0.998	1.000	1.004	1.011	1.019	1.026	1.031
30°	5.0 cm	0.997	0.998	0.997	0.997	1.000	1.004	1.007	1.020	1.023	1.028
	10.0 cm	0.993	0.990	0.997	0.997	1.000	1.002	1.007	1.014	1.016	1.020
	15.0 cm	1.000	0.992	0.995	0.997	1.000	0.992	0.996	1.001	1.016	1.020
	d_{max}	0.991	0.990	0.997	0.996	1.000	1.020	1.019	1.033	1.041	**1.050**
25°	5.0 cm	0.992	0.990	0.996	0.997	1.000	1.008	1.013	1.033	1.038	**1.046**
	10.0 cm	0.986	0.988	0.996	0.997	1.000	1.004	1.015	1.026	1.032	**1.040**
	15.0 cm	0.992	0.985	1.004	0.997	1.000	1.004	1.005	1.019	1.009	**1.037**

TABLE II. Relative Wedge Factors for 6 MV photon beam. Factors normalized to the field size 10x10 cm^2.

Wedge angle	Measurement position (depth)	Side of equivalent square field (cm) 4	5	6	8	10	12	15	17	20	22	25
	d_{max}	1.002	1.005	1.000	1.002	1.000	1.000	1.004	1.008	1.013	1.015	1.025
15°	5.0cm	1.002	1.000	1.001	0.998	1.000	1.001	0.999	1.003	1.006	1.012	1.016
	10.0cm	1.024	1.023	1.024	1.023	1.000	1.019	1.017	1.017	1.018	1.027	1.032
	15.0cm	1.002	0.999	0.998	1.002	1.000	0.994	0.998	0.995	0.998	1.005	1.008
	d_{max}	1.000	1.006	1.006	1.006	1.000	1.005	1.010	1.018	1.028	1.032	1.042
30°	5.0cm	1.000	0.996	0.999	0.995	1.000	1.002	1.002	1.009	1.017	1.022	1.034
	10.0cm	1.022	1.025	1.019	1.018	1.000	1.019	1.018	1.023	1.031	1.038	1.040
	15.0cm	1.009	1.008	1.006	1.008	1.000	1.003	1.001	1.004	1.007	1.011	1.020
	d_{max}	0.987	0.993	0.995	0.995	1.000	1.002	1.012	1.021	1.036	**1.048**	**1.076**
45°	5.0cm	1.010	1.006	1.005	0.995	1.000	1.008	1.012	1.031	1.043	**1.055**	**1.073**
	10.0cm	1.016	1.018	1.015	1.018	1.000	1.014	1.019	1.027	1.041	**1.055**	**1.068**
	15.0cm	1.016	0.987	1.008	0.998	1.000	1.012	**1.018**	1.008	1.028	1.029	**1.049**
	d_{max}	0.992	0.999	0.999	0.997	1.000	1.000	**1.017**	1.025	1.037		
60°	5.0cm	1.000	1.003	1.000	0.997	1.000	1.006	**0.987**	1.025	1.035		
	10.0cm	1.028	1.027	1.022	1.021	1.000	1.023	**1.026**	1.032	1.020		
	15.0cm	1.013	1.001	1.010	1.002	1.000	1.008	1.011	1.014	**1.031**		

TABLE III. Relative Wedge factors for 10 MV photon beam. Factors normalized to the field size 10x10 cm^2.

Wedge angle	Measurement position (depth)	Side of equivalent square field 5	6	8	10	12	15	17	20	22
15°	d^{max}	0.988	0.986	0.993	1.000	1.006	**1.023**	1.029	1.051	**1.060**
	5.0 cm	0.989	0.994	0.995	1.000	1.006	**1.021**	1.031	1.041	**1.045**
	10.0 cm	0.991	0.992	0.995	1.000	1.006	**1.018**	1.025	1.033	**1.039**
	15.0 cm	0.997	0.997	0.998	1.000	1.007	**1.017**	1.023	1.030	**1.039**
30 °	d_{max}	0.994	0.997	0.999	1.000	1.007	1.017	1.021	1.038	1.045
	5.0 cm	0.989	0.991	0.995	1.000	1.002	1.013	1.020	1.030	1.034
	10.0 cm	0.992	0.993	0.995	1.000	1.006	1.013	1.018	1.027	1.033
	15.0 cm	0.988	0.989	0.993	1.000	1.003	1.012	1.014	1.022	1.028
45°	d_{max}	0.996	0.994	0.995	1.000	1.004	1.011	1.016	1.034	1.041
	5.0 cm	0.989	0.993	0.996	1.000	1.003	1.013	1.020	1.031	1.032
	10.0 cm	0.992	0.992	0.994	1.000	1.005	1.012	1.017	1.025	1.031
	15.0 cm	0.990	0.991	0.992	1.000	1.000	1.008	1.010	1.018	1.024
60 °	d_{max}	0.996	0.990	0.994	1.000	1.004	1.012	1.016		
	5.0 cm	0.991	0.993	0.995	1.000	1.003	1.013	1.018		
	10.0 cm	0.992	0.993	0.996	1.000	1.005	1.014	1.023		
	15.0 cm	0.989	0.989	0.994	1.000	1.007	1.016	1.024		

TABLE IV. Relative wedge factors for 15 MV photon beams. Factors normalized to the field size 10x10 cm^2.

Wedge angle	Measurement position (depth)	Side of equivalent square (cm) 4	5	6	8	10	12	15	17	20	22	25
15 °	d_{max}	1.004	1.006	0.999	0.998	1.000	1.002	1.004	1.003	1.004	1.010	1.011
	5.0 cm	0.997	1.000	1.003	1.005	1.000	1.009	1.012	1.011	1.013	1.012	1.017
	10.0 cm	1.006	1.007	1.010	1.001	1.000	0.991	1.000	0.995	1.005	1.000	1.017
	15.0 cm	0.995	0.994	0.989	1.002	1.000	1.002	0.999	0.999	1.002	1.005	1.010
30 °	d_{max}	0.992	0.991	1.003	0.999	1.000	1.000	1.005	0.997	1.005	1.012	1.021
	5.0 cm	0.995	0.993	0.997	0.992	1.000	1.003	1.009	1.013	1.007	1.004	1.011
	10.0 cm	0.994	0.989	0.999	0.983	1.000	0.996	1.003	1.004	1.000	1.017	1.022
	15.0 cm	0.994	0.993	0.994	1.001	1.000	1.017	1.012	1.014	1.023	1.014	1.026
45°	d_{max}	0.980	**0.976**	0.992	0.993	1.000	0.993	1.003	1.008	1.004	1.023	**1.039**
	5.0 cm	0.993	0.988	1.001	0.995	1.000	**1.014**	1.021	1.025	**1.034**	1.026	**1.042**
	10.0 cm	1.002	1.001	1.009	0.993	1.000	1.007	**1.017**	1.025	1.043	**1.045**	**1.056**
	15.0 cm	0.989	**0.979**	0.980	0.984	1.000	1.001	1.008	1.018	1.027	**1.041**	**1.057**
60°	d_{max}	0.993	0.996	1.002	1.002	1.000	1.004	1.001	1.005	1.015	**1.027**	1.035
	5.0 cm	0.992	0.986	0.996	0.989	1.000	1.004	1.010	1.018	1.026	1.020	1.032
	10.0 cm	1.000	0.997	1.002	0.995	1.000	1.005	1.013	1.020	1.027	1.037	1.047
	15.0 cm	0.984	0.986	0.998	0.999	1.000	0.999	1.005	1.013	1.021	1.034	1.048

TABLE V. Relative Wedge factors for 10x10 cm^2, a cobalt-60 teletherapy unit. Factor normalized to 5 cm depth.

Depth (cm)	Wedge angle					
	15°	30°	45°	60°	30°	25°
d_{max}	0.993	0.994	1.000	**0.972**	1.000	0.997
5	1.000	1.000	1.000	1.000	1.000	1.000
10	1.000	1.013	1.001	**1.032**	1.007	1.008
15	1.013	1.024	1.013	**1.035**	1.015	1.008

TABLE VI. Relative wedge factors for 10x10 cm^2, 6 MV photon beam, Factor normalized to the 5 cm depth.

Depth (cm)	Wedge angle			
	15°	30°	45°	60°
d_{max}	0.986	**0.977**	0.982	0.979
5	1.000	1.000	1.000	1.000
10	0.987	1.010	1.021	**1.023**
15	1.017	1.023	**1.044**	1.042

TABLE VII. Relative wedge factors for 10x10 cm^2 , 10 MV photon beam. Factor normalized to the 5 cm depth.

Depth (cm)	Wedge angle			
	15°	30°	45°	60°
d_{max}	0.990	**0.988**	0.997	0.996
5	1.000	1.000	1.000	1.000
10	0.997	0.990	0.998	**0.980**
15	1.006	1.006	**1.015**	1.000

TABLE VIII. Relative wedge factors for 10x10 cm^2, 15 MV photon beam. Factor normalized to the 5 cm depth.

Depth (cm)	Wedge angle			
	15°	30°	45°	60°
d_{max}	0.993	0.992	1.007	**0.972**
5	1.000	1.000	1.000	1.000
10	0.999	0.999	1.001	**0.996**
15	1.017	0.997	**1.018**	1.005

For the 6 MV X-rays (Table II) there were a small percentage difference for the field not exceeding 15x15 cm^2, the maximum values were 1.7%, 1.3%, 2.6% and 1.8% at the depth of d_{max}, 5 cm, 10 cm and 15 cm respectively. But for the field sizes greater than 15x15 up to 22x22 cm^2, the maximum percentage differences were 4.8%, 5.5%, 5.5% and 3.1% at the depth of d_{max}, 5 cm, 10 cm and 15 cm respectively.

For the field size 25x25 cm^2 the maximum percentage differences were 7.6%, 7.3%, 6.8% and 4.9% at the depth of d_{max}, 5 cm, 10 cm and 15 cm respectively. For the 10 MV X-rays (Table III) there were a small percentage differences for the field size not exceeding 15x15 cm^2, the maximum values were 2.3%, 2.1%, 1.8% and 1.7% at the depth of d_{max}, 5 cm, 10 cm and 15 cm respectively. But for the field sizes greater than 15x15 up to 22x22 cm, the maximum percentage differences were 6.0%, 4.5%, 3.9% and 3.9% at the depth of d_{max} 5 cm, 10 cm and 15 cm respectively.

For the 15 MV X-rays (Table IV) there were a small percentage differences for the field size not exceeding 15x15 cm^2, the maximum values were 2.4%, 1.4%, 1.7% and 2.1% at the depth of d_{max}, 5 cm, 10 cm and 15 cm respectively. But for the field size greater than 15x15 up to 22x22 cm^2, the maximum percentage differences were 2.7%, 3.4%, 4.5% and 4.1% at the depth of d_{max}, 5 cm, 10 cm and 15 cm respectively. But for the field size of 25x25 cm^2, the maximum percentage differences were 3.9%, 4.2%. 5.6% and 5.7% at the depth of d_{max}, 5 cm, 10 cm and 15 cm respectively.

For the depth dependence study, the variation of relative wedge factors were shown in table V-VIII. Table V- VIII present the relative wedge factor as a function of depth normalized to TG-21 recommendation depth (5 cm) for the field size of 10x10 cm^2 for each energy.

For cobalt-60 (Table V), the maximum percentage differences were 2.8%, 3.2% and 3.5% at the depth of d_{max}, 10 cm and 15 cm respectively.

For 6 MV X-rays (Table VI), the maximum percentage differences were 2.3%, 2.3% and 4.4% at the depth of d_{max}, 10 cm and 15 cm respectively.

For 10 MV X-rays (Table VII), the maximum percentage differences were 1.2%, 2.0% and 1.5% at the depth of d_{max}, 10 cm and 15 cm respectively.

For 15 MV X-rays (Table VIII), the maximum percentage differences were 2.8%, 0.4% and 1.8% at the depth of d_{max}, 10 cm and 15 cm respectively.

DISCUSSION

This study supports previous report by the others. Jatnitor R et al[4] had studied with 4 and 6 MV X-rays measuring the variation of wedge factor for various field sizes. In their experiments, the variation of wedge factors with a 60° wedge, the use of single wedge factor measure for 10x10 cm^2 field introduced errors of up to 3.5% and 7% for a 16 cm and 20 cm wide field respectively. McCullough et al[5] showed a change in wedge factors of less than 2% for a 30° wedge filter at depth down to 10 cm. For deeper depths and larger wedge angles, greater changes were found up to 5%. Since there was no data for supporting the cobalt-60 machine and 15 MV high energy photon beams that we have used in Thailand. Therefore, it is encouraging to perform this study.

The results of this study revealed a small field size dependence for the field size less than 15x15 cm^2 for all energies, but for the field size larger than 15x15 cm^2, the difference in WTF was significant. The variation of WTF for the field size dependence may be attributable to change in (i) the scatter radiation in the water phantom due to the nonuniform primary photon fluence, (ii) the amount of backscatter radiation from the wedge filter into monitor chamber, and (iii) head scatter radiation. This is the amount of scatter photons that reach the point of measurement after undergoing interactions in the flattening filter, the primary collimator, and the secondary field defining collimator.[6]

The variation of WTF with depth is probably due to beam hardening effects where the low energy photons are attenuated much more than the high energy ones.[7] This can explain the greater change in cobalt-60 (3.5%) and 6 MV (4.4%) compared to the 10 MV (2.0%) and 15 MV (2.8%).

CONCLUSIONS

In this paper we have attempted to show that there is a definite dependence of wedge transmission factors on field size and depth. Therefore, a wedge factor measured for a reference field size and depth may not be valid for all field sizes and depths. The magnitude of error in assuming one wedge factor is less than 3% for the field sizes less than 15x 15 cm^2 and the depth is less than 10 cm. But for the field size greater than 15x15 cm^2 up to 25x25 cm^2 and the depth deeper than 10 cm, the error is seem to be significant.

It is suggested that, before a new cobalt-60 unit and linear accelerators are accepted for treatment it is very important to perform thorough studies of all mentioned parameters when using wedge filters.

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