Romanian Reports in Physics, Vol. 65, No. 2, P. 456–467, 2013

ISSUES IN RADIOTHERAPY PRACTICE DUE THE PRESENCE OF WEDGE FILTERS

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Received June 20, 2012

Abstract. The theoretical determination of wedge factor and the spinning angle of isodose plane given by the introducing of the wedge in the beam and the practical verification through measurements performing at the Co-60 radiotherapy unit from Radiotherapy Department from the "Sf. Ap. Andrei", Emergency Clinical Hospital Galati. The wedge filters raise two problems in the radiotherapy practice: progressive attenuation of beam across the field (the thinner side of the wedge attenuates the beam less than the thicker side) and spinning of isodoses curves plate.
In our study we tried to find the concordance between the different values of wedge factor (W_f) calculated after measurements at the radiotherapy Co-60 unit, with theoretical values of W_f calculated from formulas and given in Theraplan Planning System Charts. Our results are encouraging because we observed that the values are in very good concordance with not statistically significant differences between the two data sets. Also we calculated he spinning angle of isodose plate conform a theoretical relation and compared with the data from Theraplan Planning System Charts. The concordance between the theoretical and the experimental values was very good.

Key words: wedge filter, angle, isodose curves, and radiotherapy.

1. INTRODUCTION

The theoretical determination of wedge factor and the spinning angle of isodose plane given by the introducing of the wedge in the beam and the practical verification through measurements performing at the radiotherapy machine from Radiotherapy Department from the Emergency Clinical Hospital "Sf.Ap. Andrei", Galati.

In radiotherapy practice, the central axis depth dose distribution is not sufficient to characterize a radiation beam. In practice, special filters are place in the path of the beam in order to modify the isodose distribution. The most frequently used are the wedge filters, which raise two problems in the radiotherapy practice: progressive attenuation of beam across the field (the thinner side of the wedge attenuates the beam less than the thicker side) and spinning of isodoses curves plate [1].

The volumetric or planar variations of absorbed dose are given by isodose curves. An isodose curve is the line passing through points of equal dose. In other words, the isodose curve represents the level of absorbed dose and, also is the expression of percentage of the dose at a reference point.

The isodose charts show important information about gamma – ray dose distribution. For ^{60}Co γ ray these might be: on the central axis of the beam, the beam is greatest for any depth, the dose rate decreases rapidly in the penumbra region (near the beam's edges) [2, 3].

These cause a progressive decrease of the beam intensity and the result is the tilt of isodose curve [1]. The wedge filter is made by material with high density (*e.g.* steel or lead), is mounted on a special tray and can be placed at a certain distance from de source in the beam. The wedge filter is characterized by the wedge angle and by the transmission factor [4].

There are more definitions of the wedge angle. One of them indicates that the angle through which an isodose curve is tilted at the central ray of a beam at a specified depth [4] or the wedge angle is defined as the angle between the wedge isodose lines and a line perpendicular to the central axis of the beam at a specific depth and for a specified filed size [5]. Other definition is: the wedge angle is the angle between the 50% isodose curve and the normal to the central axis. The depth specification is important because the degree of tilt changes with depth [6].

We made measurements for a radiotherapy ^{60}Co unit, Theratron Elite 100 (Radiotherapy Department, Emergency Clinical Hospital, Galati). Depending of nature of target volume and irradiation geometry the spinning angle of isodose plate and the absorption factor of wedge filter have been calculated. It was used different wedges with the same angle (45°) but with different filter side for different irradiation field side and the experimental values have been compared with the calculated values.

2. MATERIALS AND METHODS

2.1. THEORETICAL PRINCIPLE OF THE SPINNING ANGLE OF ISODOSE PLATE

The percent depth dose in M' point at the edge of the field so is not affected by wedge presence [7] in the beam is:

$$P_{M'} = \frac{T(S,h)}{T(S_0,h_0)}\left(\frac{D_C - h + h_0}{D_C}\right)^2 . \qquad (1)$$

The percent depth dose in A' point situated on the central axis, in the middle of field is:

$$P_{A'} = \frac{T(S',h')}{T(S_0,h_0)}\left(\frac{D_C - h + h_0}{D_C - \Delta h}\right)^2 \varepsilon \cdot \mathrm{e}^{-\mu x}, \qquad (2)$$

where ε is the supplementary attenuation induce by the wedge support; P_M' – percent depth dose in the point M'; P_A' – percent depth dose in the point A'; $T(S, h)$ – the tissue-air ratio at depth h for a square field on dimensions ($S \times S$) at depth h; $T(S_0, h_0)$ – the tissue-air ratio at depth h_0 for a square field on dimensions ($S_0 \times S_0$) at depth h_0; D_C – evaluation point-source distance; Δh – depth h – source distance.

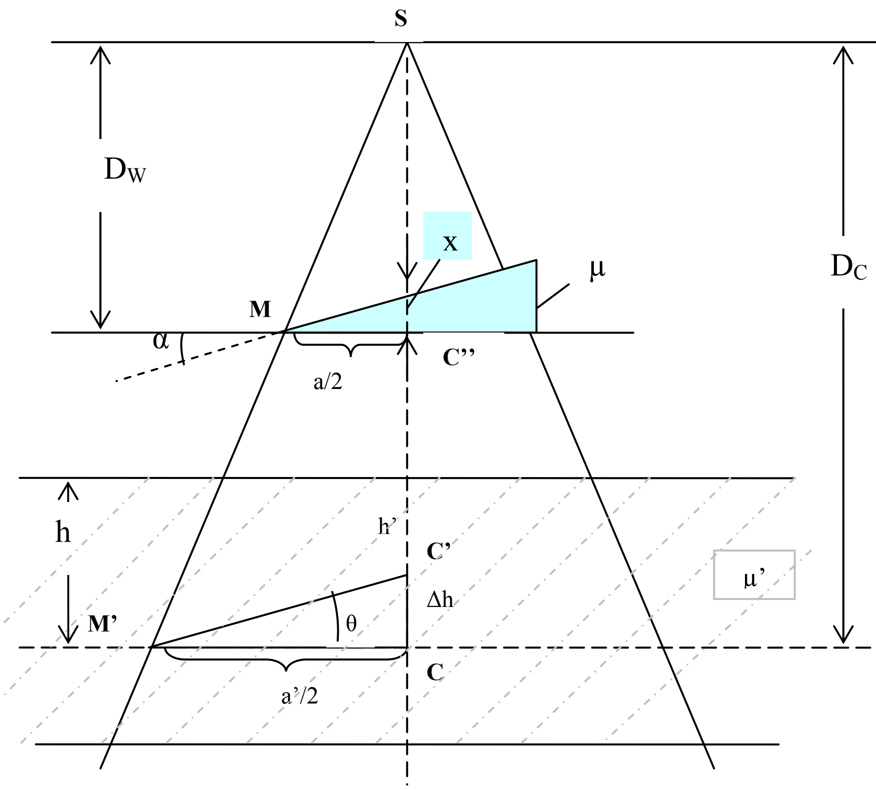

Fig. 1 – Irradiation's geometry; S – radioactive source position; α – wedge angle; μ – absorption coefficient of wedge material, μ = 0.640 cm^{-1}; μ'– attenuation coefficient of irradiated medium – water equivalent soft tissue, μ' = 0.063 cm^{-1}; a' – irradiation field size; a – wedge length placed in beam; θ – rotation angle of isodose plateau; D_w – wedge source distance; D_C – evaluation point-source distance.

Given the material that is made of, the wedge support induces a supplementary attenuation by so the $\varepsilon \approx 1$.

In the condition of the two points being on the same isodose, we are obtaining:

$$P_{M'} = P_{A'}, \tag{3}$$

$$T(S,h) = \left(\frac{D_C}{D_C - \Delta h}\right)^2 \cdot T(S',h') \cdot \varepsilon \cdot \mathrm{e}^{-\mu \cdot x}. \tag{4}$$

We also, consider the limit of small fields:

$$T(S,h) = \mathrm{e}^{-\mu'(h-h_0)}, \tag{5}$$

$$T(S',h') = \mathrm{e}^{-\mu'(h'-h_0)}. \tag{6}$$

Replacing the relation (5) into relation (4), we are obtaining:

$$\mathrm{e}^{-\mu'\Delta h} = \left(\frac{D_C}{D_C - \Delta h}\right)^2 \cdot \varepsilon \cdot \mathrm{e}^{-\mu \cdot x}. \tag{7}$$

We logarithm and develop in Mac Laurian serial, stopping at the first order terms, and with condition: $\Delta h \ll D_C$. Thus, we are obtaining:

$$\ln\left(\frac{D_C}{D_C - \Delta h}\right)^2 = 2\ln\left(\frac{D_C}{D_C - \Delta h}\right) = 2\frac{\Delta h}{D_C}, \tag{8}$$

$$\begin{aligned} &-\mu'\Delta h = 2\frac{\Delta h}{D_C} - \mu \cdot x + \ln \varepsilon, \\ &\varepsilon \approx 1, \ \ln \varepsilon \approx 0, \end{aligned} \tag{9}$$

$$\Delta h\left(\mu' + \frac{2}{D_C}\right) = \mu \cdot x. \tag{10}$$

From triangle similitude, Δ SMC'' and Δ SM'C, we can write:

$$\frac{a}{2D_W} = \frac{a'}{2D_C} \Rightarrow \frac{a}{2} = \frac{a'}{2} \cdot \frac{D_W}{D_C}. \tag{11}$$

We put the conditions:

$$\begin{aligned} \mathrm{tg}\theta &= \frac{2\Delta h}{a'}, \\ \mathrm{tg}\alpha &= \frac{2x}{a}, \end{aligned} \tag{12}$$

$$\Delta h\left(\mu' + \frac{2}{D_C}\right) = \frac{D_W}{D_C}\mu \cdot \mathrm{tg}\alpha, \tag{13}$$

we are obtaining:

$$\mathrm{tg}\theta = \frac{D_W}{D_C} \cdot \frac{\mu}{\mu' + \dfrac{2}{D_C}} \times \mathrm{tg}\alpha \Rightarrow \mathrm{tg}\theta = \frac{\mu D_W}{\mu' D_C + 2} \cdot \mathrm{tg}\alpha. \tag{14}$$

In above relations for $\mu = 0$ (without wedge), $\theta = 0$ and for $\alpha = 0$ (also without wedge), $\theta = 0$

$$\theta > \alpha, \text{ because } \frac{\mu D_W}{2 + \mu' D_C}.>1 \tag{15}$$

For small values of α angle, the differences are coming from the corrections of ln ε term, which become important for small values. Increasing D_C, the angle θ decreases. For $D_C \to \infty, \theta \to 0$.

For air (μ'=0), the relation (14), becomes:

$$\mathrm{tg}\theta = \frac{\mu D_W}{2}\mathrm{tg}\alpha. \tag{16}$$

From relation (14) it can be elaborate the premises that can allowed the simulation of an angled surface in the irradiation conditions (the angle is noted α'); this angled surface can be assimilated with a wedge tissue at the distance SSD (skin-source distance) = $D_C - h$, which will produce a spinning conforming to the relation below:

$$\mathrm{tg}\theta' = \frac{\mu'(D_C - h)}{\mu' D + 2} \cdot \mathrm{tg}\alpha'. \tag{17}$$

We put the condition: $\theta = \theta'$, we are making equal between the relations (14) and (17), we are obtaining:

$$\text{tg}\alpha = \frac{(D_C - h)\mu'}{D_W \mu}\text{tg}\,\alpha'. \tag{18}$$

This equation shows that the wedge angle influences the wedge tissue angled with an angle α' and we must take into account this angled surface of the patient during the planning treatment performing. If we are using a single type of wedge, the absorption coefficient of wedge material and the wedge angle remain unchanged but if we have to use, in the planning treatment performing, more than one type of wedge filter, we must to take in to account these parameters because they are modifying the spinning angle of isodose plate and consequently the dose distribution into the target volume and, also into the normal surrounding tissues.

2. THE WEDGE TRANSMISSION FACTOR

It is defined as the ratio of dose at a specified depth (usually $z_{\max}$) on the central axis with the wedge in place (D_W) to the dose under the same conditions without the wedge (D_0) [8, 9]. This factor is used in MU calculations to compensate for the reduction in beam transmission produced by the wedge. The transmission factor depends on the depth and side of the square field.

In practice there are two types of wedge filters, individualized wedge system and universal wedge. For cobalt teletherapy are preferred the individualized wedge filters [5]. It is well known that the presence of wedge filters modifies the beam quality, by hardening and by softening beam. For the ^{60}Co beam the presence of the wedge filter does not significantly change the central axis percent depth dose distribution, because the primary beam is mainly monoenergetic.

Theoretical principle of the absorbtion factor of wedge filters:

$$W_F = \frac{\Delta_W}{\Delta_0}, \tag{19}$$

$$W_F = \frac{I_0 \cdot \text{e}^{-\mu x}}{I_0} = \text{e}^{-\mu x}, \tag{20}$$

$$x = \frac{\Delta_W}{\Delta_C} \cdot \frac{l_W}{2}\,\text{tg}\alpha,$$

$$W_F = \mathrm{e}^{-\mu \frac{\Delta_W}{\Delta_C} \cdot \frac{l_W}{2} \cdot \mathrm{tg}\alpha}, \tag{21}$$

where: l_W is the filter side, $l_W = a/2$ (Fig. 1): Δ_W, Δ_0 are the dose rate with and respective, without wedge filter.

The equation (21) is important given the wedge filter dependence of the wedge angle and the filter side. A specified filer side is used for a specified treatment field side, in the planning treatment performing.

3. RESULTS AND EXPERIMENTAL DATA

A physical wedge is an angled piece of lead or steel that is placed in the beam to produce a gradient in radiation intensity. Manual intervention is required to place physical wedges on the treatment unit's collimator assembly.

The measurements have been performed at the radiotherapy unit Theratron Elite 100 (Radiotherapy Department, Emergency Clinical Hospital, Galati). The irradiation geometry is similar with those from Fig. 1. It was used different wedges with the same angle (45^o) but with different wedge side, for different field sizes at different depths.

All measurements were carried out with 100 cm SAD. Data were collected using a PTW 0.6 cm^3 cylindric ionisation chamber inserted in a PTW water phantom ($30\times30\times30$ cm^3).

3.1. THE SPINNING ANGLE OF ISODOSE PLATE

With relation (14), knowing D_W for each type of wedge, D_C = 100 cm, the values of wedge angle, the value of absorption coefficient of wedge material, μ = 0.640 cm^{-1} and the value of attenuation coefficient of irradiated medium – water equivalent soft tissue, μ' = 0.063 cm^{-1}, we can determine the spinning angle of isodose plate. The experimental data are comparing with data from Theraplan Planning System Charts (TPS Charts).

Table 1

The spinning angle of isodose plate conform relation (14)

Wedge type Wedge angle = 45^0	D_W (cm)	D_C (cm)	θ (relation 14)	θ (TPS Charts)
7.5W ×18.5	46.8	100	73.92	75
10W × 18.5	46.8	100	73.92	75
12.5W × 18.5	47.0	100	73.98	75

Variation of the spinning angle of isodose plate with the depth in case of angled surface's irradiation. Relation 17 allows finding the spinning angle of isodose plate function of depth in case of angled surface's irradiation. With increasing of depth, the spinning angle decreases (Table 2, Fig. 2).

Table 2

The spinning angle of isodose plate conform relation (17)

Wedge type Wedge angle = 45^0	D_W (cm)	D_C (cm)	h (cm)	α
7.5W × 18.5	46.8	100	0.5 5 10	12.29 11.75 11.14
10W ×18.5	46.8	100	0.5 5 10	12.29 11.75 11.14
12.5W × 18.5	47.0	100	0.5 5 10	12.23 11.69 11.09

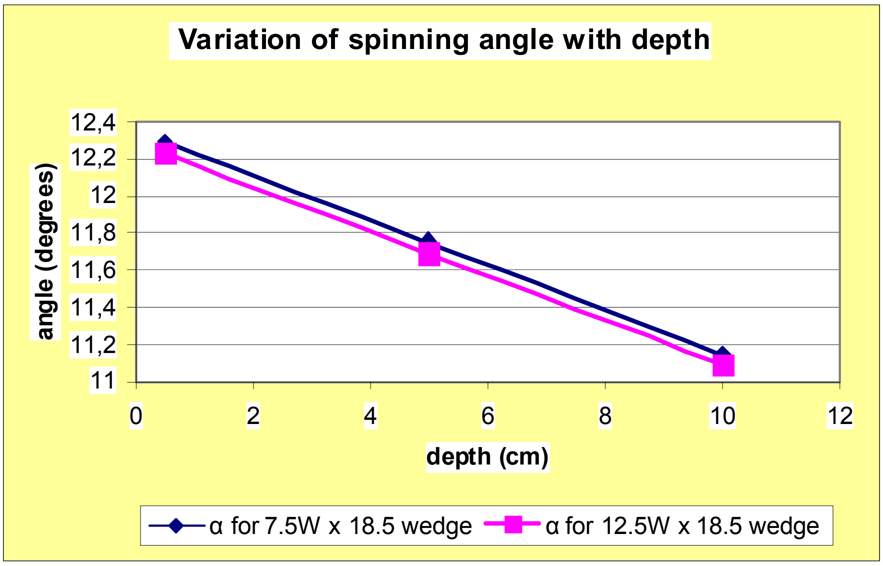

Fig. 2 – Variation of spinning angle with depth.

3.2. THE ABSORBTION FACTOR OF WEDGE FILTERS

The theoretical calculated wedge factor values are conforming to relation (21), and shown in Table 3.

Table 3

The calculated wedge factor conform relation (21)

Wedge type Wedge angle = 45^0	l_w (cm)	D_W (cm)	D_C (cm)	**W_f calculated (relation 21)**	**W_f TPS Charts**
7.5W x 18.5	7.5	46.8	100	**0.71**	**0.683**
10W x 18.5	10	46.8	100	**0.64**	**0.631**
12.5W x 18.5	12.5	47.0	100	**0.60**	**0.581**

In order to confirm the theoretical results and to establish the concordance between theory and daily practice, we have performed measurements at the unit radiotherapy treatment, Theratron Elite 100. The results of measurements are summarized in Table 4. All measurements were carried out at the different moments of time (July, October and, respective, December 2011), with 100 cm SAD. Data were collected using a PTW 0.6 cm^3 cylindric ionisation chamber inserted in a PTW water phantom ($30\times30\times30cm^3$). The radiation field size was taken at the open $10\times10cm^2$.

Table 4

The calculated wedge factor conform relation (19) after measurements at the radiotherapy treatment unit, Theratron Elite 100

	Wedge type wedge angle = 45^0	7.5W × 18.5	10W × 18.5	12.5W × 18.5
July 2011 ε=2.0%	$\check{D}_W$ (cGy/min) $\check{D}_0$ (cGy/min) **W_f**	45.5 65 **0.7**	42.25 65 **0.65**	37.07 65 **0.57**
October 2011 ε =1.6%	$\check{D}_W$ (cGy/min) $\check{D}_0$ (cGy/min) **W_f**	44 64 **0.69**	40 64 **0.63**	36 64 **0.56**
December 2011 ε =1.6%	$\check{D}_W$ (cGy/min) $\check{D}_0$ (cGy/min) **W_f**	43.20 62.72 **0.69**	39.48 62.72 **0.63**	36.2 62.72 **0.58**

The statistical analysis was performed using the XLSTAT program. Differences between the data sets were evaluated by using the Student t test. 1-Way Anova Test and the Pearson correlation coefficient were performed in order to find the concordance between theoretical and experimental values.

Comparing the different values of W_f calculated after measurements with theoretical value of W_f we observed that the values of Pearson coefficient indicates a very good concordance (r = 0.85, 0.66, and respective 0.73) with not statistically significant differences between the data sets, p = 0.85, 0.66 and respective 0.73 (Table 5).

Table 5

The comparison of the reference values of W_f with the experimental values

Wedge type Wedge angle = 45^0	W_f **reference**	W_f **07. 2011**	W_f **10. 2011**	W_f **12.2011**
7.5W × 18.5	0.71	0.7	0.69	0.69
10W × 18.5	0.64	0.65	0.63	0.63
12.5W × 18.5	0.6	0.57	0.56	0.58
		$r = 0.96$ $p = 0.85$	$r = 0.92$ $p = 0.66$	$r = 0.97$ $p = 0.73$

Comparing the different values of W_f calculated after measurements with value of W_f from Theraplan Planning System Charts, we observed that the Pearson coefficient values ($r = 0.87$, 0.92, and respective 0.97) indicates, also, a very good concordance, with not statistically significant differences between the two data sets, $p = 0.87$, 0.92 and respective 0.97 (Table 6).

Table 6

The comparison of W_f values from TPS Charts with the experimental values

Wedge type Wedge angle = 45^0	W_f **TPS Charts**	W_f **07. 2011**	W_f **10. 2011**	W_f **12.2011**
7.5W × 18.5	0.683	0.7	0.69	0.69
10W × 18.5	0.631	0.65	0.63	0.63
12.5W × 18.5	0.581	0.57	0.56	0.58
		$r = 0.98$ $p = 0.87$	$r = 0.99$ $p = 0.92$	$r = 0.99$ $p = 0.97$

Parametrical concordance tests showed a very good concordance between theoretical values (Tables 5, 6) and respective TPS Charts values of W_f (Table 4) and the experimental values.

4. DISCUSSIONS AND CONCLUSIONS

In radiotherapy practice, the central axis depth dose distribution is not sufficient to characterize a radiation beam and frequently wedge filters are used. These raise two problems in the radiotherapy practice: progressive attenuation of beam across the field and spinning of isodoses curves plate.

To calculate the absorbed dose along the central axis of a wedged beam, many treatment-planning systems use a single or multiple wedge factor to correct for the corresponding attenuation [10]. Usually this factor is measured, for each wedge, on the central axis at fixed reference conditions of field size, depth and source to surface distance (SSD).

In our study we tried to find the concordance between the different values of W_f calculated after measurements at the radiotherapy Co-60 unit, with theoretical values of W_f calculated from formulas and given in Theraplan Planning System Charts. Our results are encouraging because we observed that the values are in very good concordance with not statistically significant differences between the two data sets. Also we calculated he spinning angle of isodose plate conform a theoretical relation and compared with the data from Theraplan Planning System Charts. The concordance between the theoretical and the experimental values was very good, that means we can use our experimental results for determination of treatment time for our patients.

Also, our study has a limit because we did not make the measurements in order to identify the wedge factor variation with field size and depth and the effect of wedge orientation (IN, OUT, LEFT, RIGHT) on wedge factor.

Richard A. Popple *et al.* [9] have demonstrated that wedge factors for externally mounted wedges are not dependent on orientation and can be determined using a small set of measurements spanning the range of minimum and maximum available field sizes.

Heukelom *et al.* [10] have observed that the magnitude of the wedge-induced change of the head scatter dose component is almost completely determined by the amount of irradiated wedge volume and, furthermore, that the W_f is proportional to the irradiated wedge volume [12].

Future studies will bring out more information about the effect of wedge orientation on wedge factor.

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