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Generation of predetermined isodose inclination with the use of a motor driven wedge filter

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Summary

Aim The aim of this work was to determine an algorithm to obtain a predetermined inclination angle of isodoses for the Saturn 43F linear accelerator with the use of a motor driven wedge filter.

Materials/Methods It was assumed that a predetermined inclination angle of a reference isodose could be obtained after combining absorbed doses during irradiation with an open field and with a field with a constant 60° wedge. In order to find relations between isodose angles and the irradiation time doses were measured first in a plexiglas phantom and then in a water phantom at the reference depth for the combination of an open field and a field with a 60° wedge. The doses measured under the wedge were normalized with use of the 60° wedge coefficients and converted using tabulated values of the percent depth doses into depth values. Then the angles of isodose slope were calculated.

Results The results are presented in tables and in figures. The polynomials used to calculate times t_0 and t_{60} for predetermined isodose angles were obtained.

Conclusions The polynomials obtained differ from energy to energy. The differences in isodose inclination angles increase with irradiation time using a 60° wedge. The higher is the energy of the beam, the greater is the inclination of the isodoses using the same physical wedge. The differences between the results of measurements in a solid phantom and in a water phantom are due to the differences in depth dose distributions between both materials.

Key words dose measurements • time calculations • motor driven wedge filter • Saturn

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Background

The use of wedge filters in radiotherapy has two aims: first to obtain reduction in the doses in places where their accumulation is not recommended, and the other to make it possible to obtain a predetermined shape of the isodoses in the tumour volume [1,2]. Therapeutic machines used to be equipped with a set of variable solid wedge filters. Their day-to-day use had several disadvantages such as a limited number of filters available, their size and weight which made routine application difficult for the staff.

One way to avoid this inconvenience was the implementation of motor driven wedge filters. In the Saturn 43F accelerator a solid 60° wedge filter was installed inside the collimator. The predetermined inclination of isodoses inside the irradiated object was obtained by appropriate splitting the irradiation with the wedge and then without the wedge (open field) [3].

Aim

The aim of this work was to determine the algorithm of calculating the proportions of the irradiation time with the open field (t_0) and with a 60° wedge filter (t_{60}) to obtain the predetermined inclination angle of the isodose.

Materials and Methods

First we measured coefficients of a 60° wedge on the central axis for energies of 6, 15 and 25 MV: the dose rate in the open field was divided by the dose rate under the wedge [4].

By definition a wedge filter angle [3] is equal to an angle of the isodose slope at a reference depth (Figure 1). An isodose must be drawn crossing the perpendicular to the beam axis at the reference depth. The line between two points from this isodose (in ¼ and ¾ of the field width) and the perpendicular to the beam axis form a wedge angle.

Measurements were carried out in two stages. In the beginning stage the measurements of the doses were made with the use of an IONEX 2500/3A dosimeter with a graphite ionization chamber 2571 in a solid plexiglas phantom at the depth of 10 cm for 15 MV and 25 MV photons and at the 5 cm for 6 MV photons. The measurements were carried out for the field size of 10 cm × 10 cm at the distance from the source to the phantom surface (SSD) of 100 cm alternatively for the open field and then for the 60° wedged field.

The doses were measured on a central axis (CAX) and at the off-axis points at the distance of 2.5 cm from CAX in both directions (along the wedge). The doses measured under the wedge were normalized to those measured in the open field at CAX. Finally, for any photon energy a set of three normalized doses was obtained. Each dose corresponds to a position in CAX or in ±2.5 cm off CAX at the same depth in a phantom, under the wedge. In radiotherapy the curve derived from these points is called a dose profile. The profile inclination corresponds to the wedge angle but obviously is not equal to the inclination of the isodose at the reference depth. Therefore, a recalculation was made using tabularized values of percent depth doses (PDD). For each of the three points, the measured and normalized dose was fit to the percent depth dose (PDD) and the appropriate depth was read off. Finally, an isodose could be drawn for the three points above. Its inclination to the open field isodose was adopted as the predetermined wedge angle. The tangent of the wedge angle could be obtained by dividing the difference between depths for off-axis points by the distance between these points.

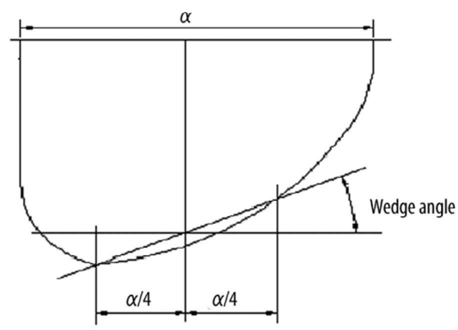

Figure 1. Definition of a wedge filter angle (α is a field width).

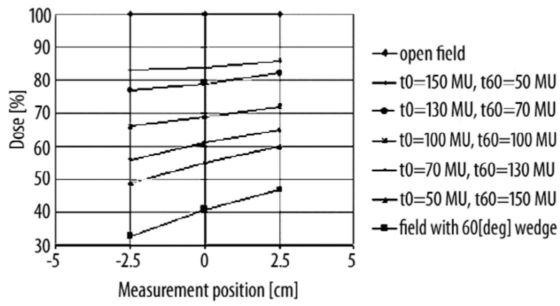

Figure 2. Doses for 6 MV photons at the depth of 5 cm at the points along the wedge: in CAX (0) and at the distance of ±2.5 cm off the CAX for some selected combinations of irradiation time with (t_{60}) and without the wedge (t_0).

During the measurements the irradiation time was set to 200 monitor units [MU]. Doses were measured for various portions of the irradiation time with (t_{60}) and without wedge (t_0). The combinations of t_0/t_{60} were: 200/0; 150/50, 130/70, 100/100, 70/130, 50/150, 0/200. The least squares method was used to match the obtained angles to polynomials, thus making it possible to calculate times t_0 and t_{60} for the predetermined isodose angle.

In the stage of our experiment the measurements were made in a water phantom, with the use of an Ion Chamber Array LA-48 PTW and a Multidos dosimeter. The Array LA-48 allows obtaining a complete profile of the beam with 47 small ion chambers. Its measuring length is 37 cm, and the spatial resolution is 8 mm. The profile was measured along the wedge, and it passed through CAX. The irradiated field size was 20×20 cm (the maximum field with wedge filters). The measurements were carried out at the

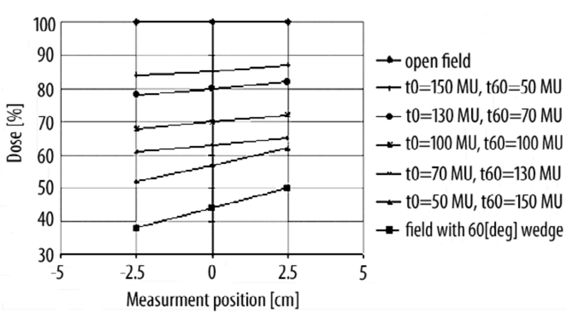

Figure 3. Doses for 15 MV photons at the depth of 10 cm at the points along the wedge: in CAX (0) and at the distance of ±2.5 cm off the CAX for some selected combinations of irradiation time with (t_{60}) and without the wedge (t_0).

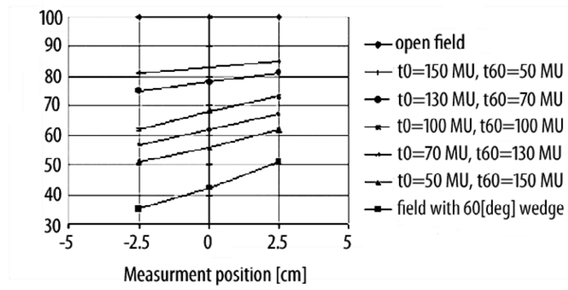

Figure 4. Doses for 25 MV photons at the depth of 10 cm at the points along the wedge: in CAX (0) and at the distance of ±2.5 cm off the CAX.

Table 1. The coefficients of a 60° wedge measured on the central axis at the reference depth.

Energy	6 MV	15 MV	25 MV
60º	0.416	0.434	0.422

reference depth. The data from all 47 chambers were collected simultaneously with the Mephysto program, which shows the data from each chamber as a point in the graph (dose as a function of distance from CAX). Times t_0 and $t_{60,}$ for which the expected wedge angles were 5°, 10°, 15°, 20°, 30°, 45°, were calculated on the basis of polynomials obtained at the initial stage. Series of measurements were made for the irradiation time of 200 MU and for all the calculated proportions of t_0 and t_{60} (every ratio of the range {calculated t_{60} –3 MU; calculated t_{60} +3 MU} was tested). The doses in CAX and in ¼ and ¾ field widths were determined on the basis of the profiles collected. The doses measured under the wedge were normalized, i.e. the dose at the reference depth in PDD multiplied by the coefficient of the wedge was divided by the dose under the wedge in CAX. Then the result was multiplied by the doses in ¼ and ¾ of field widths. Normalized doses were converted by tabularized values of PDD into depths. Then the difference between depths (determined for doses in ¼ and ¾ field widths) was divided by 50% of the field width and the tangent of the wedge angle was obtained. As before, the least squares method was used to match the obtained angles to polynomials describing the dependence between the proportion of the irradiation time and the isodose inclination angle.

RESULTS

The coefficients of a 60° wedge measured on the central axis for 6 MV, 15 MV and 25 MV at the reference depth are presented in Table 1.

The dose dependence for selected combinations of an open field and a 60° wedge field, determined in a solid phantom, are presented in Figures: 2 – for 6 MV photons at 5 cm depth, 3 – at 10 cm depth for 15 MV photons, and 4 – at 10 cm depth for 25 MV photons.

Equations (1–3) represent polynomial algorithms used to calculate times t_{60} for predetermined isodose inclination angle:

$$t_{60,6} = 0{,}00008\,\alpha^3 - 0{,}0172\,\alpha^2 + 2{,}6233\,\alpha \text{ for 6 MV} \quad (1)$$
$$t_{60,15} = 0{,}0003\,\alpha^3 - 0{,}0360\,\alpha^2 + 2{,}7765\,\alpha \text{ for 15 MV} \quad (2)$$
$$t_{60,25} = 0{,}0003\,\alpha^3 - 0{,}0307\,\alpha^2 + 2{,}5056\,\alpha \text{ for 25 MV} \quad (3)$$

where α is the predetermined reference isodose inclination angle, and t_{60} represents time in percentages of the total irradiation time.

The relation between t_0 and t_{60} is represented by

$$t_0 = 100\% - t_{60}\ [\%] \quad (4)$$

Table 2 is a list of wedge angles obtained for some chosen durations of irradiation, calculated on the basis of the measurements in a solid phantom. Table 3 shows irradiation times in MU for the open field (t_0) and for the 60° wedge field (t_{60}), calculated with the use of equations (1–3) for routine clinical situations. The simulated values of α were: 5°, 10°, 15°, 20°, 30°, 40°, 45°.

Diagram in Figure 5 shows the dependence between the effective isodose angle and the portion of the irradiation time with a wedge (total time of irradiation is constant and equal to 200 MU) obtained from the measurements in a solid phantom.

Table 4 is a comparison between wedge angles, calculated from a treatment planning system (on the basis of two profiles of isodoses: that measured with an open field and that with a 60° wedge using a field analyzer) and the effective wedge angles obtained using the algorithms described above. Row 1 lists effective isodose angles used in the calculations of t_0 and t_{60}, whereas the next rows represent isodose angles, calculated from TPS, which result from using of the calculated times in the system.

Figure 6 shows wedge angles calculated on the basis of the measurements, carried out in a water phantom for 6 MV, 15 MV and 25 MV photons at reference depths.

Table 2. Wedge angles for some selected combinations of irradiation time in a solid phantom.

		Open field	wedge 1	wedge 2	wedge 3	wedge 4	wedge 5	60^0 wedge
	t_0 (MU)	200	150	130	100	70	50	0
	t_{60} (MU)	0	50	70	100	130	150	200
E 6 MV	Wedge angle	0	10	15	22	29	36	51
E 15 MV	Wedge angle	0	11	14	24	35	39	56
E 25 MV	Wedge angle	0	11	17	27	38	44	61

Table 3. Data for frequently used wedged beams obtained on the basis algorithms 1–3 (for solid phantom).Portions (in percentages) of the irradiation time with an open (t_0) and wedged (t_{60}) beam make it possible to obtain a predetermined wedge angle.

Photons' Energy [MV]	6		15		25	
Wedge [^{0}]	t_{60}[%]	t_0[%]	t_{60}[%]	t_0[%]	t_{60}[%]	t_0[%]
5	13	87	13	87	12	88
10	25	75	24	76	22	78
15	36	64	35	65	32	68
20	46	54	44	56	40	60
30	65	35	59	41	56	44
40	83	17	73	27	70	30
45	91	9	79	21	78	22

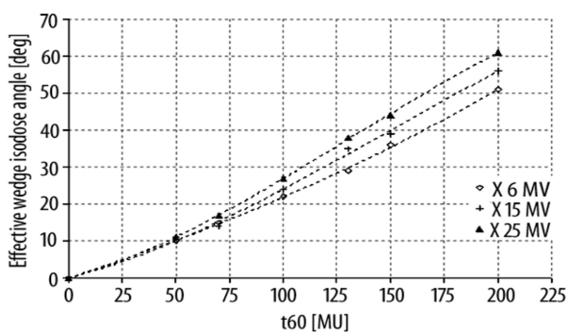

Figure 5. Dependence between the effective isodose angle and the time of irradiation with a 60° wedge on the assumption that the total irradiation time is constant: $t_{60}+t_0 = 200$ MU (measurements in a solid phantom).

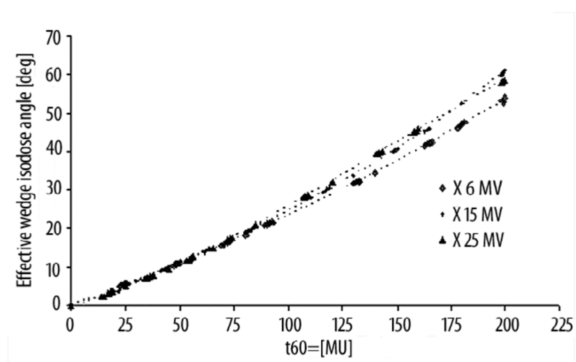

Figure 6. Dependence between the effective isodose angle and the time of irradiation with a 60° wedge on the assumption that the total irradiation time is constant: $t_{60}+t_0 = 200$ MU (measurements in a water phantom).

Formulas (5–7) represent, in the form of polynomial algorithms, the dependence between the duration of the irradiation with a 60° wedge (in percentages of the total irradiation time) and the isodose inclination angle:

$$t_{60,6} = 0{,}00002\ \alpha^3 - 0{,}0104\ \alpha^2 + 2{,}3708\ \alpha \text{ for 6 MV} \quad (5)$$

$$t_{60,15} = 0{,}00007\ \alpha^3 - 0{,}0167\ \alpha^2 + 2{,}4144\ \alpha \text{ for 15 MV} \quad (6)$$

$$t_{60,25} = 0{,}0003\ \alpha^3 - 0{,}03150\ \alpha^2 + 2{,}5933\ \alpha \text{ for 25 MV} \quad (7)$$

where α is the predetermined wedge angle.

Table 6 represents times of irradiation with a 60° wedge (in percentages of the total irradiation time) for measurements in a water phantom in comparison with those calculated from the measurements in a solid phantom.

Discussion

Since there is no significant relation between the size of fields and isodose inclination angles [5–7], the measurements in a water phantom with a 20×20 cm field should be made in agreement with those in a solid phantom carried

Table 4. A comparison between the wedge angle generated by a treatment planning system and the effective isodose angle calculated according to the algorithms obtained from measurements in a solid phantom.

Effective wedge isodose angle [deg]	15	30	45
TPS isodose angle[deg] (X6MV)	15	31	43
TPS isodose angle [deg] (X15MV)	14	33	45
TPS isodose angle [deg] (X25MV)	17	27	42

Table 5. Data for frequently used wedged beams obtained on the basis of algorithms 5 -7 (for water phantom). Portions (in percentages) of the irradiation time with an open (t_0) and wedged (t_{60}) beam make it possible to obtain predetermined wedge angles.

Photons' Energy [MV]	6		15		25	
Wedge [^{0}]	t_{60}[%]	t_0[%]	t_{60}[%]	t_0[%]	t_{60}[%]	t_0[%]
5	12	88	12	88	12	88
10	23	77	23	77	23	77
15	33	67	33	67	33	67
20	43	57	42	58	42	58
30	62	38	59	41	58	42
40	79	21	74	26	73	27
45	87	13	81	19	80	20

Table 6. A comparison between t_{60} obtained from measurements in a solid phantom and t_{60} obtained in a water phantom for some selected wedge angles.

Energy	6 MV		15 MV		25 MV	
Wedge angle	Solid phantom	Water phantom	Solid phantom	Water phantom	Solid phantom	Water phantom
5	13	12	13	12	12	12
10	25	23	24	23	22	23
15	36	33	35	33	32	33
20	46	43	44	42	40	42
30	65	62	59	59	56	58
40	83	79	73	74	70	73
45	91	87	79	81	78	80

out for a 10×10 cm field. The depths of 5 cm for 6 MV photons and 10 cm for 15 MV and 25 MV photons are taken as reference depths, where the absorbed radiatiation is in the state of electron equilibrium [8]. Moreover, the measurements were carried out with the use of a source to phantom surface distance (SSD) of 100 cm, which is the distance most often used in routine radiotherapeutic techniques. The selection of measurement points was determined by the field size – by the definition of a wedge filter these points should be in ¼ and ¾ of field widths [4,9]. As a result of standardized doses for the wedge field according to open field doses, it was possible to change the dose differences at points under different wedge thicknesses into suitable depth differences using percentage tables for depth doses.

The measurements of PDD under the wedge filter and in an open field were carried out for all three energies and fields of 10×10 cm and 20×20 cm. Thus it was found that there were no significant difference in depth dose distributions between the wedge field and the open field. Therefore tables of PDDs for an open field could be used for a field with a wedge.

The polynomials obtained varied from energy to energy. The differences in the inclination angles of the isodoses increased with portion of irradiation time with a 60° wedge. These differences can be explained by the formation of secondary particles by wedge filters; the magnitude of this effect is dependent on the beam energy [7]. From Figure 5 it can be concluded that the higher is the energy of the beam the greater inclination of the isodoses could be obtained with the same physical wedge. The use of the nominal 60° wedge in the Saturn leads in fact to slightly different inclinations of the isodoses for different energies.

The differences between the results of the measurements in a solid phantom and in a water phantom are due to the differences in the results of dose measurements between both materials (in plexiglas a cumulated charge can change results even by 10% [3]).

On the basis of measurements, the proportion of the irradiation time with a wedge and with an open field could be determined, which make it possible to obtain a predetermined wedge angle (Table 5). In order to calculate the total irradiation time, which is necessary to obtain the dose required, we must use the following equation

$$T_{kl} = T_0 \,/\, (a*1+b*W) \qquad (8)$$

where T_{kl} is the total irradiation time (with and without a wedge), T_0 is the time which is necessary to use the predetermined dose in open field (it is dependent on the dose rate in the accelerator), *a* and *b* are times calculated for the predetermined wedge angle, in percents (*a* is time with an open field and *b* is time with a wedge field), W is the coefficient of reduction of a dose measured under the wedge (Table 1).

The above formula is a result of a simple dependence

$$D_0*T_0 = a* D_0*T_0 + b*D_{kl60}*T_{kl60} \qquad (9)$$

where D_0 is the dose rate for an open field, D_{kl60} is the dose rate under the wedge.

Conclusions

Modern treatment planning systems allow calculating the proportion of the irradiation time with an open field and with a wedge for a predetermined isodose inclination angle only on the basis measurements made with a field analyzer. The simple algorithms obtained in this work help to verify treatment plans by hand, i.e. with PDD tables and a calculator. Using these algorithms it is possible to plan treatment with any wedge angle (<60°), which is useful clinically (treatment planning systems often limit the number of used wedge filters to a basic few).

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