Variation in Depth Dose Data between Open and Wedge Fields for 6 MV X-Rays

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Central axis depth dose data for 6 MV X-rays, including tissue maximum ratios, were measured for wedge fields according to Tatcher's equation. In wedge fields, the differences in magnitude which increased with depth, field size, and wedge thickness increased when compared with the corresponding open field data. However, phantom scatter correction factors for wedge fields differed less than 1% from the corresponding open field factors. The differences in central axis percent depth dose between two types of fields indicated beam hardening by the wedge filter. The deviation of percent depth doses and scatter correction factors between the effective wedge field and the nominal wedge field at same angle was negligible. The differences were less than 3.26% between the nominal or effective wedge fields and the open fields for percent depth doses to the depth 7 cm in 6 cm×6 cm field. For larger (10 cm×10 cm) field size, however, the deviation of percnet depth doses between the nominal or effective wedge fields and the open fields were greater-dosimetric errors were 3.56% at depth 7 cm and nearly 5.30 % at 12 cm. We suggest that the percent depth doses of individual wedge and wedge transmission factors should be considered for the dose calculation or monitor setting in the treatment of deep seated tumor.

Key Words: Dosimetry, Wedge, Tatcher's Equation

INTRODUCTION

The radiotherapist has used the effective wedge angles by a combination of open field and wedge field in certain clinical situations, especially in head and neck cancer treatment. However, it is widely assumed that the central axis percent depth doses for the wedge fields and for the corresponding nonwedged or open fields are same[1~3] and only the asymmetric shaping of the transverse dose distribution by the wedge filter seems to be taken into account. Thus, for a given wedge field, the transmission factor combined a single wedge with open field is generally used with the corresponding open field depth dose data to compute depth doses and treatment time.

Using the modified wedge filter in clinical situations, the output variation occurs. Thus, it is necessary to verify the predicted dose distributions, the effect of the wedge filters of open field collimator and phantom scatter correction factors.

In this work, we report experimental verificaton of wedge filter, a collimator and phantom scatter correction factors for 6 MV X-ray beam.

MATERIALS AND METHODS

The wedge angle can be modified by some combination of open field and wedge field. The sum of the two dose distributions results in an effective wedge angle.

Tatcher[4] reported that the correct ratio of open to nominal wedge field can be calculated from a single equation to yield any desired effective wedge angle smaller than the nomial wedge angle. Tatcher's equation is as follows

$$\theta_{eff}=(1-F)\times\theta_n$$

where θ_{eff} is the resultant or the effective wedge angle, θ_n is the original or the nominal wedge angle.

If the desired effective wedge angle is known, then F can be calculated from following equation

$$F=D_{open}/(D_{open}+D_{wedge})$$

where F is the ratio of the given dose without wedge to the total given dose with and without nominal wedge and D_{open} is the given dose in an open field, and D_{wedge} is the given dose in a nominal wedge field.

The phantom scatter correction factor S_p (W) was determined indirectly for both open and nominal wedge fields from the equation[5]

$$S_p(W)=S_{c,p}(W)/S_c(W)$$

where W is the field size at surface, $S_{c,p}$ (W) is the total scatter correction factor which includes the scatter contribution to the dose at depth from both the collimator and the phantom, and $S_c(W)$ is the collimator scatter correction factor.

Total scatter correction factors $S_{c,p}(W)$ for the various field sizes and nominal wedge fields were obtained by direct measurements of doses at the depth of maximum ionization (1.5 g/cm^2) and at the constant source-to-surface distance of 100 cm for both open and nominal wedge fields. Collimator scatter correction factors $S_c(W)$ for the various field sizes and nominal wedge fields were determined from direct measurements in air[5] with a 6 MV build up cap made of polystyrene and placed over the Farmer chamber at 100 cm source-to-chamber distance.

Central axis percent depth dose (*PDD*) data in this study were obtained by direct measurements using water phantom. However, Tissue Maximum Ratio's (TMR's) could be calculated from PDD data using the equation

$$TMR(d,\ W_d) = \frac{PDD(d, W, SSD)}{100} \times \frac{(SSD+d)^2}{(SSD+t)^2} \times \frac{Sp(W_t)}{Sp(W_d)}$$

where W_t and W_d are the field sizes at depth t and d, respectively, SSD is the source-to-surface distance (100 cm in our experiment), and t is the depth of maximum electronic buildup. The value of the measurements was normalized to 1.0 for the reference field size of 10 cm×10 cm in both $S_{c,p}(W)$ and $S_c(W)$.

In effective wedge fields, however, *PDD's* were direct measurements using the combination of open and nominal wedge beam, appropriately weighted to each nominal wedge. Scatter correction factors and *TMR* data are calculated by the following equations

$$S_{e,c}(W) = (1-F) \times S_{e,c}(W) + F \times S_{o,c}(W)$$

$$S_{e,c,p}(W) = (1-F) \times S_{n,c,p}(W) + F \times S_{o,c,p}(W)$$

$$TMR_e(d,W) = (1-F) \times TMR_n(d,W) + F \times TMR_o(d,W)$$

where o,e and n represent open field, effective wedge field and nominal wedge field, respectively.

All data in this paper were measured for 6 MV X-rays from the Siemens M-class 6067 Mevatron. Doses were meausred in both the waterphantom and the polystyrene phantom (density=1.105 g/m^2) using a 0.65 cc Farmer chamber connected to a Capintec exposure meter. The measurements of *PDD* and output factors were done for 6 MV photon beams with open and 15°, 30°, 45° and 60° nominal wedge filters. Irradiation was repeated using a combination of open and nominal wedge beams, appropriately weighted, to produce isodose curves with an effective wedge angle of 15 ° from a 30° wedge filter, a wedge angle of 30° from a 45° wedge and a wedge angle of 45° from a 60° wedge filter.

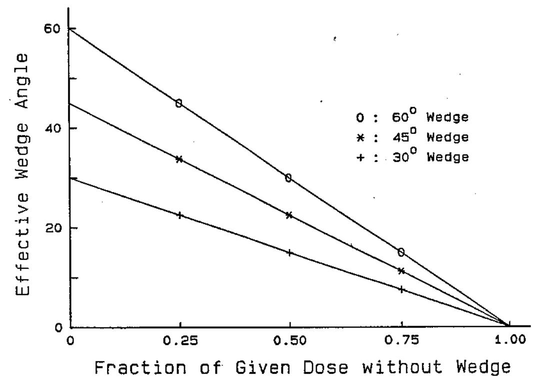

Fig. 1. Variation of effective wedge angle with fraction of total dose given without wedge filter, based on Tatcher's equation. Experimentally veified data points are also shown.

RESULTS AND DISCUSSIONS

There is no general agreement for the choice of a reference depth in definition of wedge angle[3]. We used wedge angle as the angle between the isodose curve at depth 10 cm and the normal to the central axis of the wedge[3].

The effective wedge angles can be obtained from Tatcher's equation by altering the fraction of total dose given without a nominal wedge filter.

Experimental verification was undertaken for combined beams with fraction of total dose given with open beam of 0.25, 0.50 and 0.75, respectively (Fig. 1).

A plot of normalized total scatter correction factors, $S_{c,p}(W)$, and collimator scatter correction factors, $S_c(W)$, for open field as a function of field size, expressed as the ratio of area/perimeter (A/P), are given in Fig. 2a, b, c and d. Vertical bar represent deviation between open field and 15° to 60° nominal or effective wedge fields. These figures show that the deviation of $S_{c,p}(W)$ and $S_c(W)$ between nominal or effective wedge fields and open fields are about 1%. This magnitude will be reflected as differences between *PDD's* and

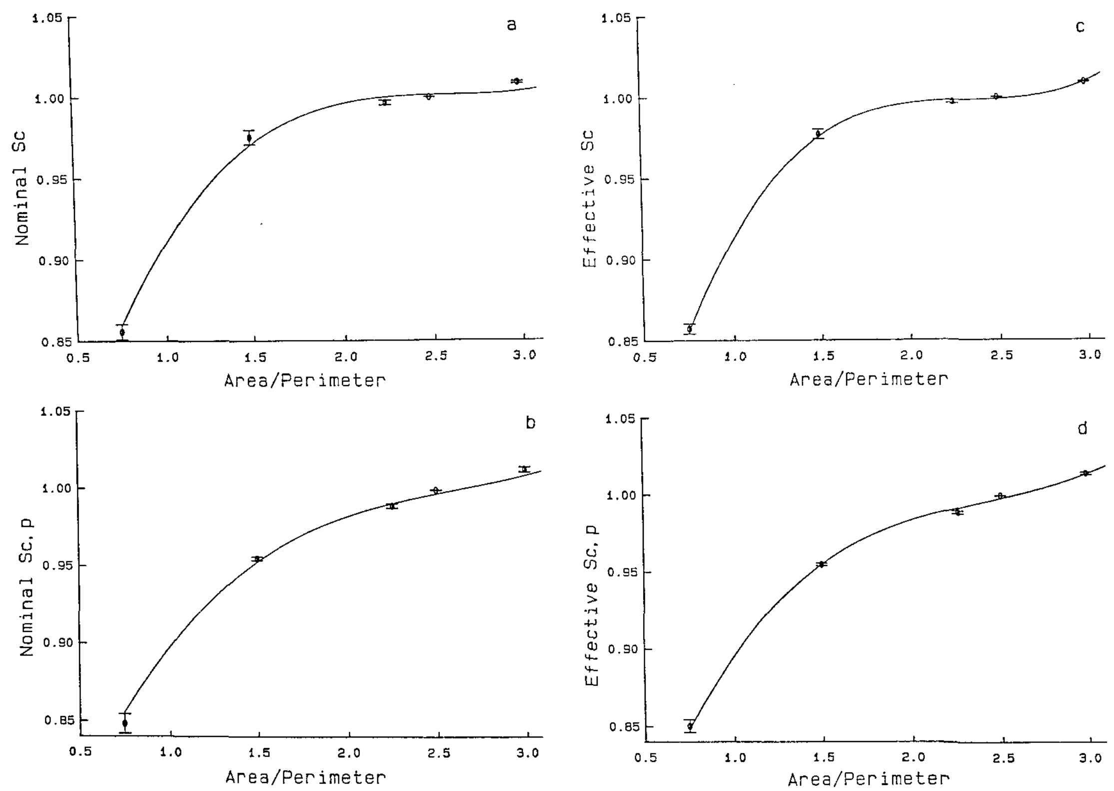

Fig. 2. Normalized scatter correction factors as a function of field size, expressed as a ratio of area/perimeter.
a. Data for collimator scatter correction factor in nominal wedge field.
b. Data for total scatter correction factor in nominal wedge field.
c. Data for collimator scatter correction factor in effective wedge field.
d. Data for total scatter correction factor in effective wedge field.

Table 1a. PDD's for 6cm x 6cm Nominal Wedge Fields

Depth (g/cm^2)	Open Field	15° Wedge	30° Wedge	45° Wedge	60° Wedge
2.0	98.27	99.01 (0.76)	99.18 (0.93)	99.35 (1.10)	99.35 (1.10)
3.0	94.81	95.65 (0.89)	95.70 (0.95)	95.97 (1.23)	96.10 (1.36)
4.0	90.04	91.01 (1.07)	91.10 (1.17)	91.16 (1.24)	91.29 (1.38)
5.0	85.14	86.46 (1.56)	86.59 (1.71)	86.61 (1.73)	87.00 (2.18)
7.0	76.19	77.96 (2.33)	78.10 (2.50)	78.28 (2.75)	78.67 (3.26)
10.0	64.36	65.91 (2.41)	66.02 (2.58)	66.19 (2.85)	66.45 (3.25)
12.0	57.50	59.09 (2.76)	58.96 (2.53)	59.43 (3.35)	60.08 (4.48)

( ) : Percent deviation from open field

TMR's for wedge and open fields (Table 1a, 1b, 2a, 2b, 3a, 3b, 4a and 4b). Thus, it can be deduced from the equation of phantom scatter correction factor calculation that the phatom scatter correction factors for the wedge and the open fields differ by less than 1%.

PDD's measured at various depth for 6 cm×6 cm and 10 cm×10 cm open and various nominal wedge fields are pressented in Table 1a and 1b, respectively. And also 40°, 45°, 50° and 60° effective

Table 1b. PDD's for 10cm x 10cm Nominal Wedge Fields

Depth (g/cm^2)	Open Field	15° Wedge	30° Wedge	45° Wedge	60° Wedge
2.0	98.41	99.53 (1.13)	99.61 (1.22)	99.75 (1.36)	99.87 (1.48)
3.0	95.24	96.40 (1.23)	96.68 (1.51)	96.89 (1.74)	97.08 (1.94)
4.0	90.48	91.67 (1.32)	91.80 (1.46)	92.04 (1.73)	92.31 (2.02)
5.0	86.82	87.80 (1.13)	87.99 (1.35)	88.56 (2.00)	88.86 (2.35)
7.0	79.02	80.13 (1.41)	80.37 (1.71)	81.09 (2.63)	81.83 (3.56)
10.0	66.25	68.02 (2.67)	68.16 (2.89)	68.53 (3.44)	68.83 (3.89)
12.0	59.08	61.21 (3.62)	61.43 (3.98)	61.82 (4.64)	62.20 (5.29)

( ) : Percent deviation from open field

Table 2a. TMR's for 6cm x 6cm Nominal Wedge Fields

Depth (g/cm^2)	Open Field	15° Wedge	30° Wedge	45° Wedge	60° Wedge
2.0	.9874	.9948 (0.75)	.9966 (0.93)	.9982 (1.10)	.9982 (1.10)
3.0	.9614	.9701 (0.91)	.9707 (0.97)	.9733 (1.24)	.9748 (1.38)
4.0	.9215	.9314 (1.08)	.9325 (1.19)	.9331 (1.25)	.9345 (1.41)
5.0	.8790	.8925 (1.53)	.8943 (1.74)	.8945 (1.76)	.8983 (2.20)
7.0	.8002	.8185 (2.29)	.8207 (2.56)	.8224 (2.78)	.8260 (3.23)
10.0	.6921	.7086 (2.38)	.7112 (2.76)	.7128 (2.99)	.7157 (3.40)
12.0	.6280	.6449 (2.69)	.6440 (2.54)	.6491 (3.35)	.6555 (4.38)

( ) : Percent deviation from open field

Table 2b. TMR's for 10cm x 10cm Nominal Wedge Fields

Depth (g/cm^2)	Open Field	15° Wedge	30° Wedge	45° Wedge	60° Wedge
2.0	.9888	.9999 (1.12)	1.0000 (1.13)	1.0000 (1.13)	1.0000 (1.13)
3.0	.9657	.9777 (1.24)	.9801 (1.49)	.9820 (1.69)	.9839 (1.89)
4.0	.9258	.9382 (1.34)	.9402 (1.55)	.9421 (1.76)	.9447 (2.04)
5.0	.8946	.9067 (1.34)	.9096 (1.67)	.9133 (2.09)	.9168 (2.47)
7.0	.8254	.8390 (1.65)	.8419 (2.01)	.8474 (2.67)	.8552 (3.61)
10.0	.7173	.7335 (2.26)	.7360 (2.61)	.7377 (2.85)	.7412 (3.33)
12.0	.6556	.6726 (2.59)	.6747 (2.92)	.6753 (3.01)	.6781 (3.44)

( ) : Percent deviation from open field

wedge fields generated by 60° nominal wedge are presented in Table 3a and 3b, respectively. Data show that the central axis depth for the various wedge fields are normalized to the value obtained at the depth of maximum ionization. The data in Table 1a and 3a show the differences less than 3.26% between nominal or effective wedge fields and open fields for *PDD's* to the depth 7 cm in 6 cm× 6 cm field size. The differences, however, increase as the depth increases. For larger (10 cm×10 cm) field size as shown in Table 1b and 3b, the deviation of *PDD's* between the nominal or the effective wedge fields and the open fields are great dosimetric errors of 3.56% at depth 7 cm and nearly 5.29% at 12 cm. For both field sizes, the deviation from open field *PDD's* are greater for the 60° nominal wedge than for 15° nominal wedge, and the nominal wedge field *PDD's* are greater than the corresponding open field value, indicating some hardening of the beam caused by the wedge.

Table 3a. PDD's for 6cm x 6cm Effective Wedge Fields Generated by 60° Nominal Wedge

Depth (g/cm^2)	Open Field	40° Wedge	45° Wedge	50° Wedge	60° Wedge
2.0	98.27	98.99 (0.73)	99.08 (0.83)	99.17 (0.92)	99.35 (1.10)
3.0	94.81	95.67 (0.91)	95.78 (1.02)	95.88 (1.14)	96.10 (1.36)
4.0	90.04	90.87 (0.92)	90.98 (1.04)	91.08 (1.15)	91.29 (1.38)
5.0	85.14	86.38 (1.46)	86.53 (1.64)	86.69 (1.82)	87.00 (2.18)
7.0	76.19	77.85 (2.17)	78.05 (2.44)	78.26 (2.72)	78.67 (3.26)
10.0	64.36	65.75 (2.17)	65.93 (2.44)	66.10 (2.71)	66.45 (3.25)
12.0	57.50	59.22 (2.98)	59.43 (3.36)	59.65 (3.73)	60.08 (4.48)

( ) : Percent deviation from open field

Table 3b. PDD's for 10cm x 10cm Effective Wedge Fields Generated by 60° Nominal Wedge

Depth (g/cm^2)	Open Field	40° Wedge	45° Wedge	50° Wedge	60° Wedge
2.0	98.41	99.38 (0.99)	99.50 (1.11)	99.62 (1.23)	99.87 (1.48)
3.0	95.24	96.47 (1.29)	96.62 (1.45)	96.77 (1.61)	97.08 (1.94)
4.0	90.48	91.70 (1.35)	91.85 (1.52)	92.00 (1.69)	92.31 (2.02)
5.0	86.82	88.18 (1.57)	88.35 (1.76)	88.52 (1.96)	88.86 (2.35)
7.0	79.02	80.89 (2.37)	81.13 (2.67)	81.36 (2.96)	81.83 (3.56)
10.0	66.25	67.97 (2.60)	68.19 (2.92)	68.40 (3.25)	68.83 (3.89)
12.0	59.08	61.16 (3.53)	61.42 (3.97)	61.68 (4.41)	62.20 (5.29)

( ) : Percent deviation from open field

Table 4a. TMR's for 6cm x 6cm Effective Wedge Fields Generated by 60° Nominal Wedge

Depth (g/cm^2)	Open Field	40° Wedge	45° Wedge	50° Wedge	60° Wedge
2.0	.9874	.9946 (0.73)	.9955 (0.82)	.9964 (0.91)	.9982 (1.10)
3.0	.9614	.9702 (0.92)	.9713 (1.03)	.9724 (1.15)	.9746 (1.38)
4.0	.9215	.9302 (0.94)	.9312 (1.05)	.9323 (1.17)	.9345 (1.41)
5.0	.8790	.8919 (1.47)	.8935 (1.65)	.8951 (1.83)	.8983 (2.20)
7.0	.8002	.8174 (2.15)	.8195 (2.42)	.8217 (2.69)	.8260 (3.23)
10.0	.6921	.7078 (2.27)	.7098 (2.55)	.7117 (2.83)	.7157 (3.40)
12.0	.6280	.6464 (2.92)	.6510 (3.28)	.6487 (3.65)	.6555 (4.38)

( ) : Percent deviation from open field

If field size incease at same depth, the deviation of *PDD's* and *TMR's* from open fields increases because phantom scatter correction factors increase with increasing field size.

In comparision of 45° nominal wedge field with 45° effective wedge field generated by 60° wedge, both S_c and $S_{c,p}$ deviation was 0.30% (Fig. 3a and 3b). This magnitude is negligible compared to the deviation between the open field *PDD's* or *TMR's* and the nominal or effective wedge field *PDD's* or *TMR's*.

When doses delivered to deep seated structures (for example, the dose to the cervical spinal cord from treatment of a parotid tumor) significantly larger errors in dose (about 5%) should be caused by substitution of the open field data for the wedge field treatment. Minimization of these errors can be achieved if appropriate wedge field data are used for dose computations in beam modification by the wedge filters. This is especially recommend-

Table 4b. TMR's for 10cm x 10cm Effective Wedge Fields Generated by 60° Nominal Wedge

Depth (g/cm²)	Open Field	40° Wedge	45° Wedge	50° Wedge	60° Wedge
2.0	.9888	.9963 (0.75)	.9972 (0.85)	.9981 (0.94)	1.0000 (1.13)
3.0	.9657	.9778 (1.26)	.9794 (1.42)	.9809 (1.57)	.9839 (1.89)
4.0	.9258	.9384 (1.36)	.9400 (1.53)	.9416 (1.70)	.9447 (2.04)
5.0	.8946	.9094 (1.65)	.9112 (1.85)	.9131 (2.06)	.9168 (2.47)
7.0	.8254	.8453 (2.41)	.8477 (2.71)	.8502 (3.01)	.8552 (3.61)
10.0	.7173	.7332 (2.22)	.7352 (2.50)	.7372 (2.78)	.7412 (3.33)
12.0	.6556	.6706 (2.29)	.6725 (2.58)	.6744 (2.86)	.6781 (3.44)

( ) : Percent deviation from open field

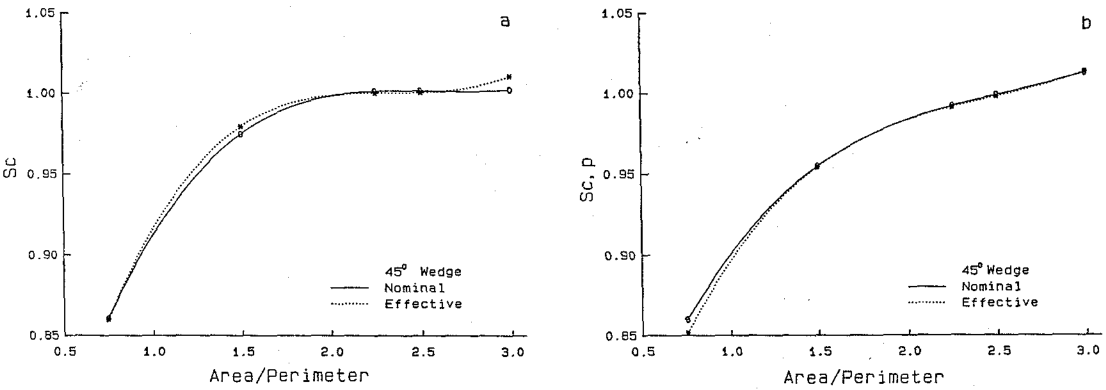

Fig. 3. Comparison of 45° nominal wedge field with 45° effective wedge field generated by 60° nominal wedge as a function of field size, expressed as a ratio of area/perimeter.
a. Data for collimator scatter correction factor.
b. Data for total scatter correction factor.

ed when large wedge fields and thick wedge filters are employed, deep seated tumors are treated, or estimates of dose are required for the critical structures located at greater depths behind the tumor volume.

If wedge field treatments at a fixed source surface distance are planned with the isodose curves of individual wedges and the wedge transmission factors obtained in a phantom at the depth of dose maximum, no additional *PDD* corrections are needed because the differences between the wedge field *PDD's* and the open field data are inherent in the isodose curves for the individual wedges. However, when isocentric treatment planning is performed, since isocentric dose weightings are given in depth and monitor settings for given isocentric doses are computed from *TMR's*, separate tables of *TMR's* for each wedge field and depth are necessary. The *TMR's* for the wedge field readily be derived from the wedge field *PDD's* according to the *TMR* calculation equation.

CONCLUSIONS

Percent depth doses, tissue maximum ratios, and scatter correction factors for the various wedge fields were measured and compared with the values for the corresponding open fields. The validity of Tatcher's equation for the various effective angle of wedge filters were established experimentally by measurements in water phantom.

The use of wedge filter in the external radiation beam caused less than 1% difference in the collimator and phantom scatter factors (S_c and S_p) of the nonwedged fields. Thus, the open field scatter correction factors could readily be used in routine calculations of monitor settings in the wedge field treatment. It would be also inferred that the relation between *PDD's* and *TMR's* given in equation of *TMR* calculation was valid for wedge filters as for open or nonwegde fields.

When Tatcher's equation was applied in clinical situations. eviation of *PDD's* between the effective wedge field and the nominal wedge field were negligible. Thus, a wide range of wedge angle filters smaller than the nominal wedge angle filters could he obtained by irradiating partly with, and without, the wedge filter inserted into the radiation beam.

Data were presented for both commercially available wedge filters and effective wedge filters and two field sizes near the lower and upper limits of clinically useful range of wedge fields. Comparison showed wedge field depth dose data to be different from the data for the corresponding open fields.

The differences obtained from the 60° nominal wedge were consistently higher than for the 15° nominal wedge, indicating a dependence on the thickness of the wedge. Although the differences were less than 3.26% at shallow depth (7 cm or less) for the smaller fields, significantly larger deviations from open field data were obtained at greater depths and generally for the larger wedge field. Generally, the wedge field depth dose data were greater than the corresponding open field values, indicating some hardening of the beam by wedge filter.

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=국문초록=

6 MV X선에 있어서 쐐기형 조사야와 개방 조사야 사이의 깊이 선량률의 차이

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Tatcher식에 의하여 조직최대선량비와 깊이선량을 6 MV X-선의 중심축상에서 측정하였다. 쐐기형 조사야에 있어서 깊이, 조사야 및 쐐기의 두께 등이 증가할수록 깊이선량은 개방 조사야에 비하여 크기가 증가하였다. 그러나 쐐기형 조사야에 있어서 조직산란보정 계수는 개방 조사야에 비하여 그 차이가 1% 미만이었다. 두 조사야에 있어서 중심축상의 깊이선량백분률의 차이가 발생하는 것은 쐐기에 의해서 X-선이 강화됨을 의미한다. 같은 각도의 쐐기에서 깊이선량백분률과 산란보정계수의 명목쐐기형 조사야와 유효쐐기형 조사야 사이의 차이는 없었다. 개방 조사야에서 조사야 6 cm×6 cm, 깊이 7 cm의 깊이선량백분률은 명목 또는 유효쐐기형 조사야 보다 3.26%가 더 컸다. 그러나 조사야(10 cm×10 cm)가 커질수록 깊이선량백분률의 차이는 명목 또는 유효쐐기형 조사야보다 더 증가하였다—선량계측차이는 깊이 7 cm에서 3.56%, 12 cm에서는 5.30%였다.

그러므로 심부종양치료시 선량의 계산이나 모니터세팅은 각 쐐기의 깊이 백분선량률과 투과율을 사용하여야 오차를 줄일 수 있을 것으로 사료된다.