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Electron Dosimetry of Shaped Fields on Mevatron KD 67－7467

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Abstract. A method of making inserts for shaped fields in electron beam therapy on the Mevatron KD 67－7467 Linear Acclerator is introduced. The inserts are made from an alloy called Lipowitz metal. These are designed to fit the inside of the standard Siemens cones. Studies have shown that this method does not adversely affect field flatness. However, if the ratio of shaped field to open field is greater than about 70%, the output dose is significantly changed by the inserts.

Because the cone ratios for the fields do not follow the open cone ratio curves on the Mevatron KD 67－7467, we separated the cone ratio suggested by Biggs into two parts, the insert ratio and the cone factor. The dosimetry for these shaped beams has been investigated extensively.

Introduction

Electron collimation in linear accelerators is usually accomplished by square or circular applicators supplied by the manufacturer. The electron fields are often shaped by lead strips or sheets, placed either directly on the skin surface or at the end of the treatment applicator. Because field size modification can significantly affect the dosimetry, several considerations go into the design and the dosimetry of field blocking.

Biggs et al[1] have devised a technique of obtaining inserts for irregulaly shaped fields on a Clinac 18, manufactured by Varian Associates. They measured extensively the effect of field shaping in energy and cone ratio. The cone ratio was defined as the ratio of central axis dose at the depth of maximum dose by arbitrary shape and size of field to the dose at the depth of maximum dose by an open cone of reference field size (10 cm×10 cm). However, their study was confined only to Clinac 18 and ignored the size of opon cone, this is, without field shaping.

The object of the present investigation was to measure a dosimetric quantities in Mevatron KD 67－7467 (Siemens corporation) linear accelerator. Because this machine is different from Clinac 18 in electron operation and cone design, the quality of electron beams uaries in Mevatron KD 67－7467 compared to Clinac 18.

The Lipowitz metal inserts have been developed to provide shaped fields using the cones supplied and a scheme was found for predicting the insert ratios for various field sizes and cones by measuring output doses and percent depth dose.

Method and Material

Instunmentation

A commercial water scanning system (WP600C, Wellhofer, Inc.) with a 0.147㎤ cylindrical, 6㎜ inner diameter ionization chamber (PTW, Freiburg, Germany) was used for the central axis measurements, beam profiles, and iso-ionization distributions. Surface dose, build-up, and insert ratios were measured with flat chamber according to Marcus. A 6㎜ diameter, 2㎜ gap parallel plate ionization chamber according to Marcus (PTW-Freiburg), with a polyethylene with graphite (area-weight 2.3㎎/㎠) front window, was used.

All the ionzation measurements were converted to dose using the appropriate correction factors for particular chamber, energy, depth, and phantom material. (These were calculated using the collision mass stopping powers given in Table I of ref. 2, and the other correction factors given also in ref. 2.)

Electron beam shaping

Electron shields to be discussed in this work were designed for the Mavatron KD 67－7467, which is capable of producing electron beams with nominal energy of 6, 8, 10, 12, 15, and 18 MeV. Siemens supplies four sizes of cone to be used with the electron beams. They produce square fields with sides of 10, 15, 20, and 25㎝ when the face of the cone is positioned in the patient's surface at 100㎝ of source to surface distance (SSD).

Rub moulds were made for each of the four cones. The moulds were constructed with an aluminum base and four side walls which define the inside of the cone. Each wall has a bottom lip which forms side grooves to fit the cones. To produce inserts, styroform is cut to the desired field size and centered in mould. It is recommended that the styroform be weighted down not to be floated in the high density alloy. The melted alloy is poured into the the mould and quenched. The inserts are mounted on lower aperture by the fixation bolts into supporting bars.

To protect normal tissue, it is necessary to establish the thickness of insert which will produce an acceptable attenuation (95%)[3]. The thickness of insert used in this study was 10㎜. This reduced the incident dose rate to below 5% level in all six energies[3].

The ICRU-35[4] has recommended, in the use of R_{85}, the depth of 85% maximum dose level as therapeutic range in clinical practice. Therefore, transverse scans of the beam, beam profiles, and iso-ionization were made at R_{85} in water for three energies. The cones were modified by square inserts and the resultant fields were scanned. Similar electron beam shaping was described by Biggs et al[1].

Dependence of photon jaws

Four cones were supplied by manufacturer limiting the possible treatment fields to the following sizes at 100cm SSD : 10×10, 15×15, 20×20, and 25×25cm. When electron cones are used with the Mevatron KD 67−7467, the manufacturer recommends that the collimator setting be larger than the cone size. For example, jaws sizes are 19×19cm, 23×23cm, 27×27cm, and 32×32cm for cone sizes 10×10cm, 15×15cm, 20×20cm, and 25×25cm, respectively Collimator settings other than the recommended one cause significant changes in the measured dose. This variation in collimator setting for diffenent cone size seems to cause a rather pronounced effect on the measured doses, particularly for the lower energies. Figure 1 shows the dependence of measured dose to photon jaw size for several electron energies using the 10×10cm open cone and 10×10cm insert in 25×25cm cone. Normally the jaws are set at 19×19cm and 32×32cm for open cone 10×10cm and 25×25cm, respectively. At jaws size 32×32cm, the increase of relative dose in open cone was 13% and the increase in insert was 12%, relative to 19×19cm jaws size, at 6 MeV. If the jaws are set at 10×10cm, just at edge of the field defining aperture, the dose drops by almost 41% and 39% for open cone and insert, respectively, relative to 19×19cm jaws size. As the energy increases, the amount of change in the measured dose for different jaws settings slowly increased, when compared to 6 MeV.

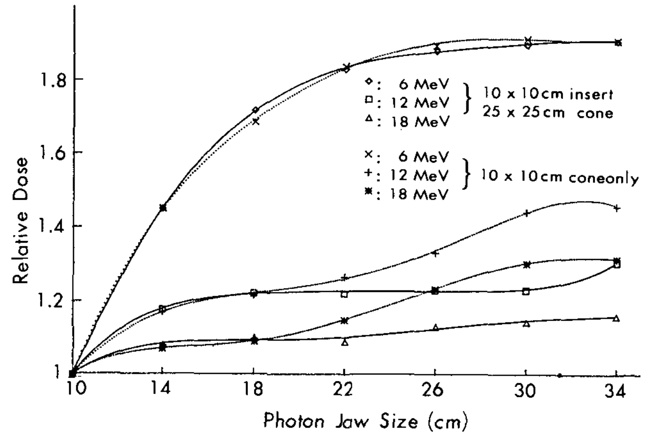

Figure 1. Variation of the relative dose delivered through 10×10cm open cone and 10×10cm insert within 25×25cm cone and various jaws settings according to the energies.

Thereafter, all measurements were made with the recommended photon jaws setting for the particular cone regardless of the size or shape for the insert.

Therapeutic range measurement

A comparision of the therapeutic ranges (R_{85}) for a supplied standard cones was done with various inserts placed on every cones. Measurements were done for all energies. A 48×48×48cm water phantom was placed at the source to surface distance of 100cm. The Wellhofer dosimetry system was used with 0.147㎤ PTW ionization chamber. Percent depth ionizations were corrected for both inverse square and chamber displacement effects. For shaped fields, ionization curves were obtained for length of side of field down to 3㎝ for 10×10㎝ cone and 6㎝ for other cones. These central axis ionization curves were adjusted to percent depth dose distributions by applying the appropriate stopping power ratios and other correction factors for each energy[2]. Figure 2 shows the variation with the depth of the 85% isodose line in central axis for all the energies and cones. For 6 MeV, the 85% depth is essentially constant both field size and cone. At higher energies, the depth of the 85% isodose drops at a certain point with decreasing field size. This transition occurs at even larger field as the energy increases. At 18 MeV, for example, the 85% depth is flat down to 7×7㎝ and then drops rapidly, decreasing from 5.6㎝ to 4.2㎝ over the whole range.

The change of 85% depth was observed when an insert of the same size as open cone is placed into a cone. The magnitude of this effect is the most pronounced at the highest energies and tends in most cases to decrease with increasing field size for each energy. The maximum variation of 85% depth of 18 MeV in 3×3㎝ insert was about 6㎜ in respect to 25×25㎝ open cone. If the size of insert was larger than 12×12㎝, however, the variation of the 85% depth does not significantly change in respect to various open cones.

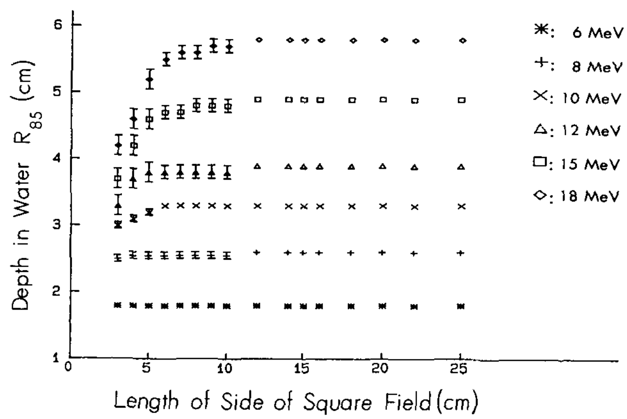

Figure 2. Variation of the depth of 85% isodose on the central axis according to length of side of square field, for all energies. Error bar indicates the variation of the depth in insert fields using the various open cones.

Dosimetry

Biggs[1] has proposed the following equation for dose calculation at a depth d in water for a field size at a given source to surface distance.

$$\text{Dose} = M \times \text{calibration factor} \times \text{cone ratio} \times \% \text{ depth dose} \div 100 \quad (1)$$

where M is the number of monitor unit of a beam delivered. The calibration factor is the number of cGy delivered at d_{max} per monitor unit for reference field size at SSD=100㎝.

When an insert of same size as open cone is placed into a cone, a differenee may be occured in the cone ratio because the contamination of the beam with low energy electrons and photons generated from the insert affects the output dose. The magnitude of this effect is the most pronounced at the highest energies and tend to decrease with increasing field size for each energy[1].

Thus, the cone ratio, previously defined, may be modified and separated by two parts, the insert ratio and the cone factor, because the output and the dose distributions are varied with various open cone sizes and energies(Figure 3).

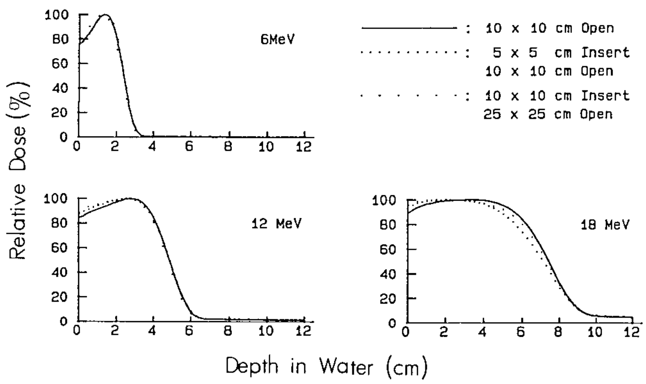

Figure 3. Comparision of central axis percent depth dose for 6, 12, and 18 MeV between open cone and inserts. ______, open cone, 10×10cm ; ……, 5×5cm insert in a 10×10cm cone ; · · · · , 10×10cm insert in 25×25cm cone.

The insert ratio may be defined as the ratio of the dose at d_{max} for a insert field size to the dose at d_{max} for an open field size in the same cone. The cone factor may be defined as the ratio of the output dose at d_{max} for an open cone to the output dose at d_{max} for a reference open cone (10×10cm). Thus, in the equation (1), the cone ratio means the insert ratio multiplied by cone factor. We modified the equation (1) for dose calculation at a depth in a given SSD as following.

$$\text{Dose} = \text{M} \times \text{calibration factor} \times \text{insert ratio} \times \text{cone factor} \times \%\ \text{depth dose} \div 100$$

The dose delivered at a depth d, for a field size A, and cone size C, at SSD could be written as D(d, A, C, SSD). Using this formulation, the above ratios are defined as follows :

$$\%\ \text{depth dose} = \frac{D(d, A, C, SSD)}{D(d_{max}, A, C, SSD)} \times 100$$

$$\text{Insert ratio} = \frac{D(d_{max}, A, C, SSD)}{D(d_{max}, A_o, C, SSD)} \qquad (2)$$

$$\text{Cone factor} = \frac{D(d_{max}, C, SSD)}{D(d_{max}, C_o, SSD)}$$

Calibration factor = D(d_{max}, A_o, C_o, SSD)/M,

were Ao is the reference field size corresponding to open cone, C_o is the reference cone size corresponding to calibration condition. In the current study, A_o and C_o are chosen at 10×10cm field and 10×10cm open cone, respectively.

The cone factor represents the contribution of scattering of photon jaws setting as well as cone because photon jaws setting are different in the same cone.

Result

After introduction of Lipowitz shielding block, the characteristics of the electron beams might have been affected beam energy (practical range, R_p. and the depth of dose maximum, d_{max}), percent depth dose, iso-ionization curves, surface doses, cone factor, insert ratio, field flatness and symmetry, and doses to shielded area.

Field flatness and symmetry

Beam profiles were measured to compare the insert fields with the open fields of the same dimension. Figure 4 shows three examples of transverse scan. Iso-ionization curves were obtained for open and shaped fields of the same width and length at depth of therapeutic range in central axis for three energies. This shows close agreement between each pair of fields. Round-up in 6 MeV and round-down in 12 and 18 MeV are observed at the fields edges compared to the open field but the beam flatness and symmetry for the energies appear to be unaffected by shaping with the inserts. The width of the field with the insert is increased by about 1mm at the 50% level for the 10×10cm field at all energies.

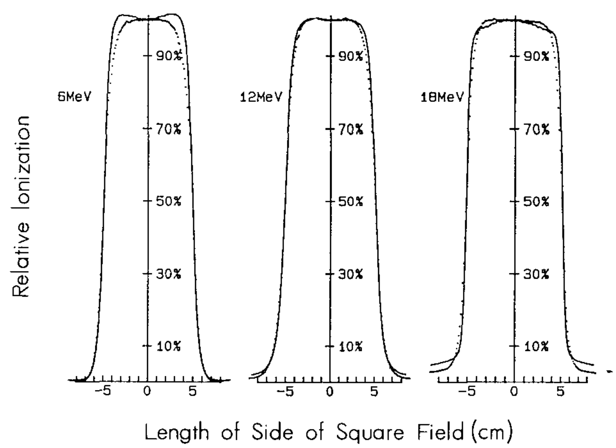

Figure 4. Beam profiles for 6, 12, and 18 MeV measured at each therapeutic range, comparing the beam flatness with an open cone to that with an insert of the same dimension. ______, open cone, 10×10cm ; ·········, 10×10cm insert in 25×25cm cone.

Iso-ionization curves were obtained in a plane perpendicular to the central axis at depth of therapeutic range using the Wellhofer dosimetry system with iso-dose hunting software programs in previously described instrumentations. Comparision of typical curves are shown in Figure 5. These curves are normalized at 85% of maximum dose in central axis. Some shrinkage in 90% iso-ionization is observed at each energy, but the 50% iso-ionization in each energy are not significantly altered. This means that the therapeutic volume of insert field are smaller than that of the open cone and the dose distributions are significantly changed between 90% and 50% iso-ionization line. The homogeneity indices (area of 50% iso-dose line/area of 90% iso-dose line) were 1,366, 1.849, 2.452 in 10×10cm open cone and 1.835, 2.040, 2.689 in 10×10cm within 25×25cm cone for 6,12, and 18 MeV, respectively. This may be the partial transmission of electrons or Bremsstrahlung produced at the shield edge and different scattering by different recommended jaw sizes.

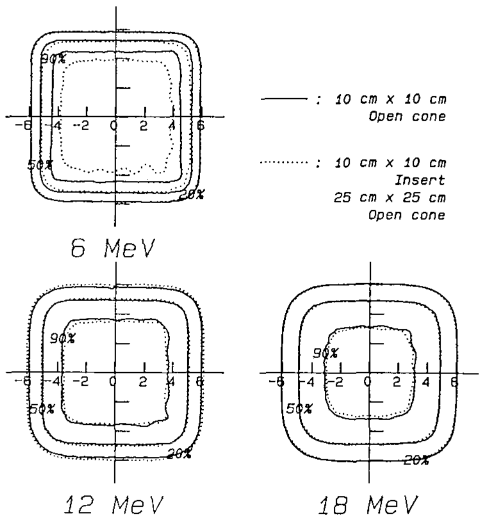

Figure 5. Iso-ionization curves for 6, 12, and 18 MeV in plane perpendicular to central axis measured at each therapeutic range, comparing an open cone to an insert of the same dimension. ______, open cone, 10×10cm ; ·········, 10×10cm insert in 25×25cm cone.

Surface dose

The electron shield has some effects on increasing the surface dose. The surface dose is also influenced by contamination of the beam with low energy electrons and photons, buildup of secondary electrons from materials in front of the phantom surface, and increased angular spread of the beam before entering the phantom[4]. The surface dose in this study was defined at 0.05cm depth in central axis and measured with Marcus chamber in water phantom. Figure 6 shows surface dose at various energies and field sizes. The left margin of error bars indicates the surface dose of open cone and the length of error bars indicates the variation of surface dose in various inserts. Typically, as the shielded area increases, the surface does increases at every energies. If the ratio of the blocked field to open field is greater than 0.7, it appears to be only a few percent at most.

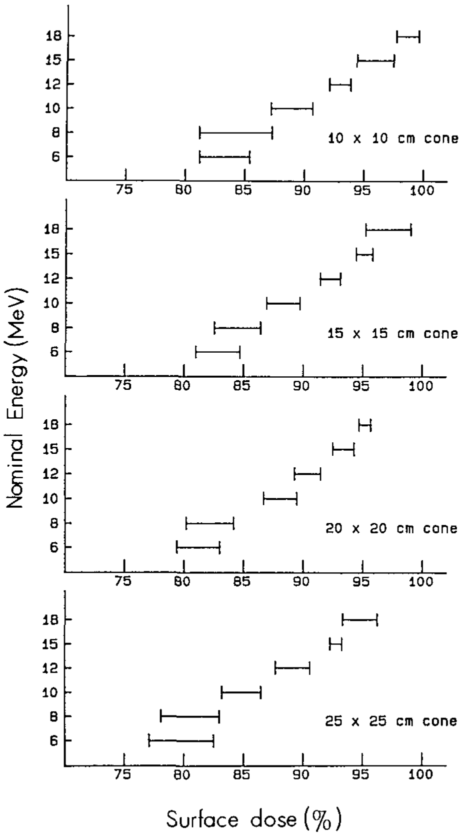

Figure 6. Variation of surface dose (relative to % of maximum dose) with nominal energies. The left margin of error bars indicate the surface dose of open cone and the length of error bars means in the variation of surface dose in various inserts.

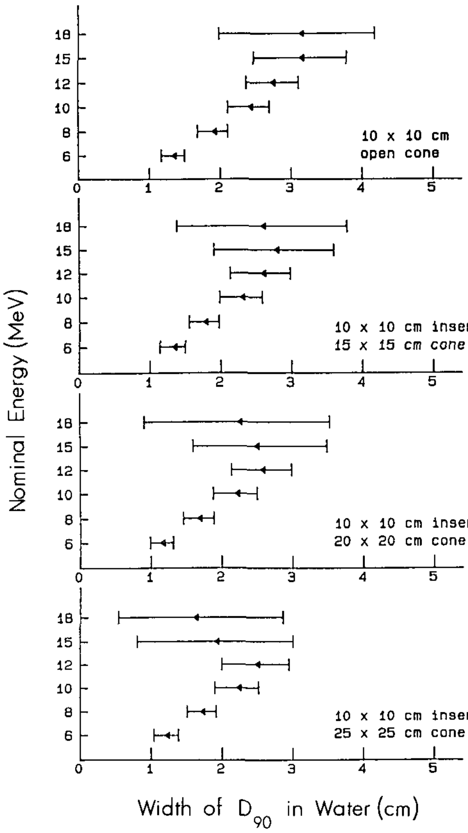

Figure 7. Variation of width (length of error bar) between 99% of maximum dose according to nominal energy. ∴ indicate the estimate of maximum build-up depth.

Shaped beam dosimetry

Build-up measurements for open and shaped fields were made using the Marcus chamber in water phantom described earlier. These measurements include the complete buile-up curve for the most fields. The depth of d_{max} is poorly defined for energies above 10 MeV. This is correlated with the fact that the width of between the 99% of maximum dose is narrow up to 10 MeV, but quite broad between 12 and 18 MeV energies. These are illustrated as the length of error bar in Figure 7.

The width of 99% of maximum dose was not significantly changed in the same field size. The depths of d_{max} were remained the same for the majority of field sizes and energies (Figure 8). However, for small field at above 10 MeV, the position of d_{max} shifted toward the surface by as much as 1.0cm.

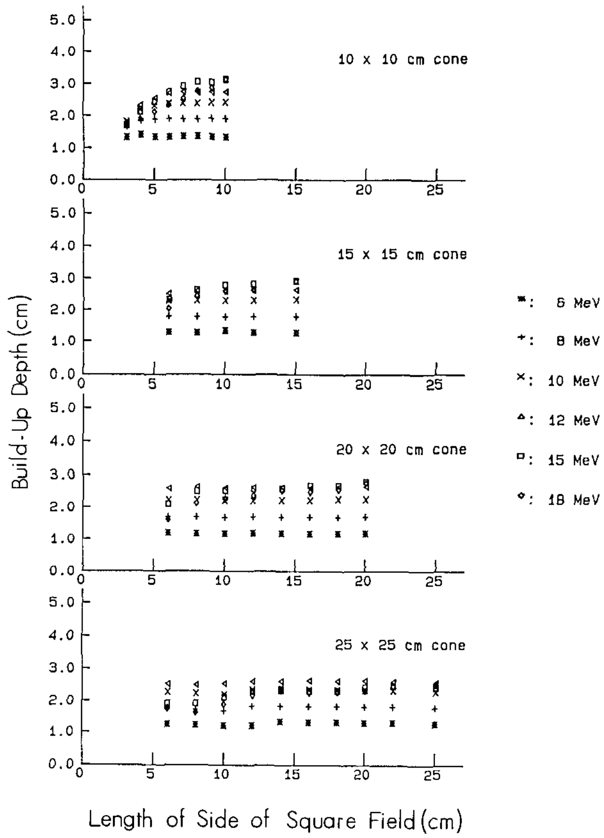

Figure 8. Variation of maximum build-up depth with length of side of square field size.

Cone factors were measured for all the open cones at each energy. Figure 9 shows the cone factors for various energies with the recommended photon jaws size by manufacturer. The cone factors for lower energies are larger than those of higher energies in the same cone size. For example, the cone factors, when normalized to 10×10cm cone cone were 1.006, 1.009, 1.019, 1.026, and 1.056 for 18, 15, 12, 10, 8, and 6 MeV. respectively, in 25×25cm cone. The variation of cone factor with energy depends on photon jaws size and contribution of low energy electrons and scattered photons.

Unfortunately, when inserts are placed in the electron cones, the insert ratios for the fields depend on their own separated cones. The insert ratios were made for each cone and energy. Figure 10 presents the results of four of the cones. The inserts were used to produce

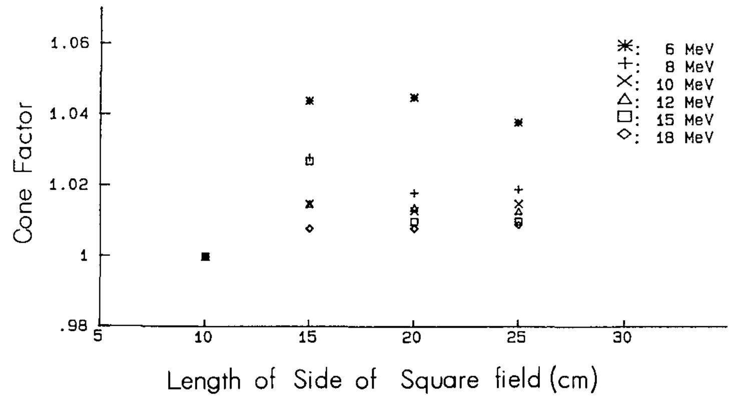

Figure 9. Cone factors in various nominal energies with length of side of open cone.

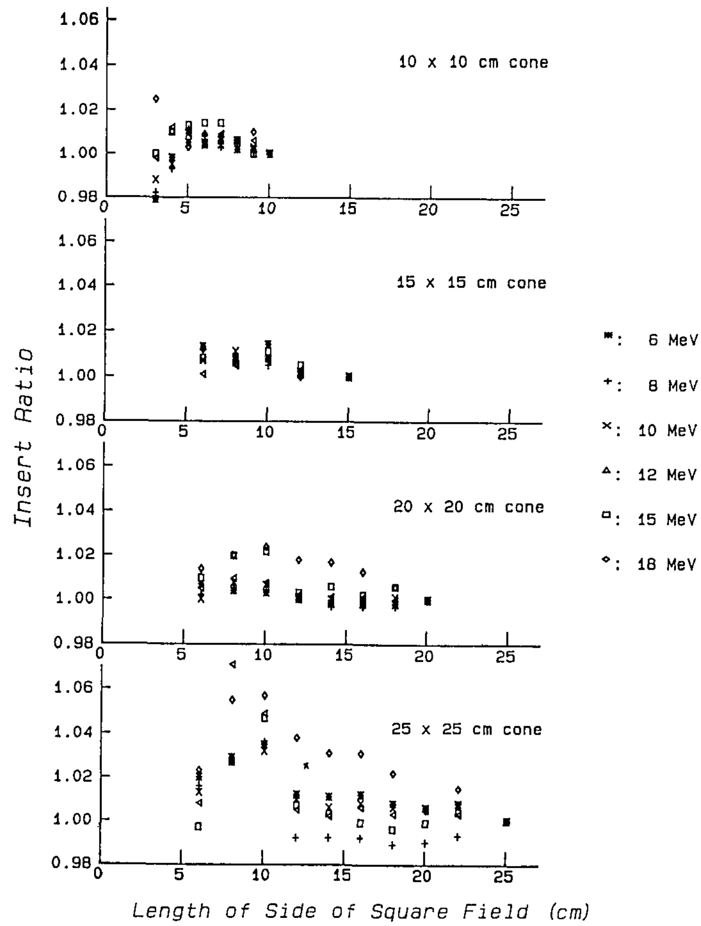

Figure 10. Insert ratio for shaped fields with all energies and cones.

square fields. The insert ratios increase for a given cone at a certain point, and then decrease as the length of side of square field decreases. The difference decreases as energy decreases. A large difference occurs at the 25×25cm cone for 18 MeV. The insert ratios are negligible for the field size which blocked less than 70% of open cone. This represents that the inserts are appropriate when below 7% blocking area were used in electron beam therapy because the outputs of electron beam are not significantly changed by inserts.

The changes by rectangular fields are checked by the square root method. If the change in collimator scatter is not considered, this method is applicable to estimate output factor and depth dose. The depth dose for rectangular field size can be extracted from the square field data by the following relationship[5].

$$D^{x,y}=[D^{x,x}\times D^{y,y}]^{1/2},$$

where D is the central axis depth dose, and x and y are the field dimensions.

Since the collimator scatter is neglected in this model, the applicability of square root method is not valid in those situation where the collimator scatter is significantly changed. Since the variation of insert ratio with cones is small (about 5% between 10×10cm and 25×25cm cone, Figure 10), the root mean square method may be used directly to calculate depth dose distributions and insert ratios. For example, Figure 11, 12 compare central axis depth dose distributions in square and rectangular fields obtained by measurements and calculations. In Figure 11 the measured and calculated percent depth dose data in 6×9cm field show close agreement. In 3×9cm field, however, some differences of the measured values and calculated values are observed in 18 MeV (Figure 12). This means that the difference of percent depth dose increase as the blocking rations or energies increase.

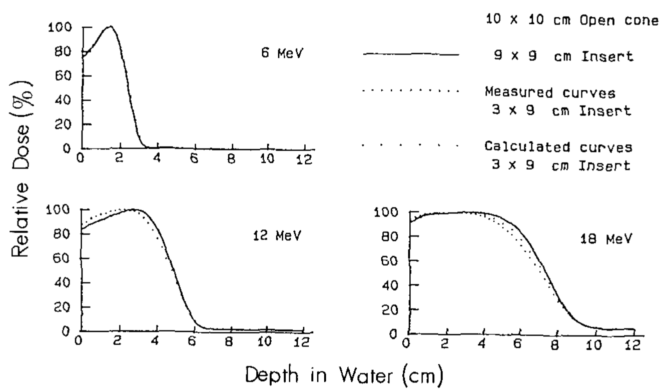

Figure 11. Comparision of central axis percent depth dose for 6, 12, and 18 MeV between 9×9cm square field and 6×9cm rectangular field. All curves are obtained by using 10×10cm open cone. ______, measured value of 9×9cm insert ; ······, measured value of 6×9cm insert ; · · · · , calculated value of 6×9cm insert.

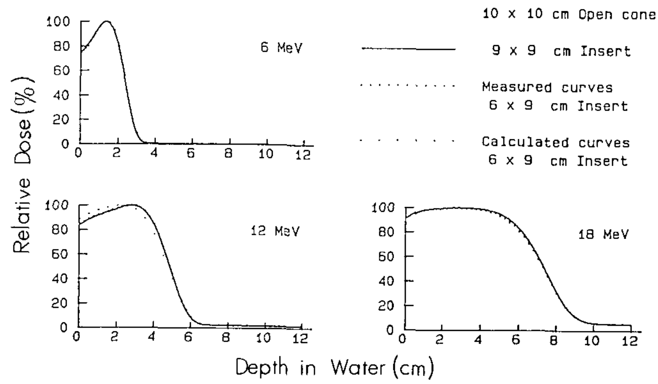

Figure 12. Comparision of central axis percent depth dose for 6, 12, and 18 MeV between 9×9cm square field and 3×9cm rectangular field. All curves are obtained by using 10×10cm open cone. ______, measured valus of 9×9cm insert ; ······, measured value of 3×9cm insert ; · · · ·, calculated value of 3×9cm insert.

In rectangular field, the insert ratios increase as the blocking ratios as well as the energies increase because the collimator scatter is increased by the insert(Table 1). The difference between the measured and calculated value of insert ratios at same energy slowly increase until the blocking ratio reaches 0.5, and then rapidly increase when the blocking ratio is over 0.5. Therefore, the use of root mean square method in rectangular fields are reasonable for the blocking ratio below 0.5.

Table 1. Insert ratios for rectangular shape of fields obtained by the root mean square method (Crossplane width is 9cm).

Length (cm)	Nominal Energy (MeV) 18	15	12	10	8	6
9	1.003 (0.1)	1.000 (0.0)	1.002 (0.1)	1.002 (0.3)	1.001 (0.1)	1.002 (0.2)
8	1.010 (0.4)	1.003 (0.3)	1.004 (0.3)	1.003 (0.4)	1.001 (0.2)	1.004 (0.3)
7	1.009 (0.3)	1.007 (0.4)	1.003 (0.2)	1.003 (0.4)	1.003 (0.4)	1.004 (0.4)
6	1.009 (0.3)	1.007 (0.4)	1.006 (0.5)	1.006 (0.5)	1.004 (0.5)	1.006 (0.5)
5	1.010 (0.5)	1.008 (0.5)	1.007 (0.6)	1.005 (0.4)	1.006 (0.8)	1.008 (0.9)
4	1.010 (0.7)	1.009 (0.6)	1.009 (1.2)	1.009 (1.1)	1.009 (1.0)	1.009 (1.0)
3	1.027 (2.8)	1.025 (2.5)	1.025 (2.5)	1.024 (2.4)	1.021 (2.0)	1.020 (1.8)

Normalized at 10cm×10cm field size.
( ) : absolute percent deviation from measured values

Discusion

When electron cones are used with the Mevatron KD 67-7467, the manufacturer recommends that the collimator setting be larger than the cone size. The variation in collimator setting for diffenent cone size seems to cause a rather pronounced effect on output doses, particularly at the lower energies. In general, changes in the field size or the photon jaws size cause changes in the cone factors, insert ratios, or dose distributions. The cone factor varies most strongly at lower energies (Figure 1) because at those energies more electrons are scattered through the large angles by the scattering foils onto the fixed collimations than at higher energies. If the photon jaws intersect a part of the electron beam, the scattering angles at low energy becomes large. As the insert area decreases, the contribution to the dose from cone scatter becomes larger. The spectrum of this component has a lower effective energy than the primary beam. Electrons scattered from the lower aperature enter the surface obliquely. These two effects would tend to increase the dose close to the surface more than it would at depth, thereby shifting the depth of 85% isodose closer to the surface (Figure 2) as well as increasing the surface dose (Figure 6). The central axis dose distributions are altered if field dimensions are reduced to the extent that a condition of non-equilibrium is created for the laterally scattered electrons.

It is difficult to pridict the change in insert ratio since it changes the field dimension as well as introduces additional effect on scattering off the block. Inserts of blocking ratio less than 0.7 cause little or no adverse affect on beam profiles. It has been possible to find systematic variations in the insert ratio with such field shaping, based on square field tables.

In conlusion, a dosimetry system has been devised, which can be used to facilitate routine use of shaped electron fields. It seems to be prctically advantageous to place the shaped Lipowitz metal insert inside standard electron cones.

The use of these inserts has not been found to be the dominant source of uncertainty in the overall dosimetry system. It is recommended in the use of shaped field that the useful limit of blocking ratio are 0.7 because the difference of the insert ratio and of dose distributions is negligible. In retangular field, the prediction of insert ratio and dose distribution using root mean square method was not significantly different from square field tables. The root mean square method would be reasonable for routine use when the blocking ratio is less than 0.5.

The suggested dosimetry formalism (equation 2) is thought to be valid because the difference of the scattering contribution of photon jaws setting is represented by cone factor.

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국문초록

Mevatron KD 67-7467의 변형조사면에 대한 전자선 선량측정

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전자선 치료에 있어서 조사면을 부분적으로 차폐할 수 있는 차폐체 제작 방법을 제시하였다. Lipowitz 합금으로 만든 차폐체는 표준 Siemens cone에 적합하며, 조사면의 평탄도는 차폐체에 의한 영향을 거의 받지 않았다. 그러나 개방 조사면에 대한 차폐 조사면의 비가 0.7 이상이면 차폐체에 의한 선량의 차이가 있음을 알았다.

Biggs 등이 제안한 Cone ratio는 차폐 조사면의 Cone ratio curve가 개방조사면의 Cone ratio를 따르지 않기 때문에 본 연구에서는 Cone ratio를 Cone factor와 Insert ratio로 나누어 차폐 조사면에 대한 선량 변화를 폭 넓게 측정하였다.