Application of the Equivalent-Field Method for Output Calculation: Is it safe for elongated x-ray fields?

Chang-Seon Kim, Ph.D., Chul-Yong Kim, M.D., Myung-Sun Choi

Department of Radiation Oncology, Korea University Medical Center
Seoul, KOREA

Purpose: When an elongated x-ray field is used for treating a patient, the equivalent- field method is commonly used for the output calculation. This study is intended for investigating potential factors such as, beam quality, field elongation ratio, and depth of measurement, which might effect on the applicability of the equivalent square technique for output calculation. The derivation of a 'rule of thumb' for the application criteria of the equivalent-field method is also aimed.

Materials and Methods: Three x-ray beams, 4-, 6- and 10-MV, were employed for this study. Width of the rectangular field was ranged from 5-40 cm and the elongation ratio (length/width) 1:0 to 10:0. An elongation effect was measured in a water phantom at three different depths, dmax, 5-cm, and 10-cm. For an elongated field and its equivalent square field, the output factor was measured and the difference in the output factor were examined between two fields.

Results and Discussions: As the elongation ratio increases, a larger discrepancy in outputs is observed between the elongated rectangular field and its corresponding equivalent square field. Output was measured larger for an elongated field than for its corresponding equivalent square field and the maximal difference over 10 % was found. The difference was found larger for the smaller field with the same elongation ratio. The effect of the beam quality and the depth of measurement on the output difference was minimal.

Conclusion: Based on the study, there is criteria for the application of the method for output calculation. For the combination of long axis and elongation ratio whose relationship satisfies *Elongation ratio* < *(0.48) (Long axis) - 0.5,* the equivalent-field method is valid for output calculation within 2 % for the field whose long axis < 25-cm. For other combinations, instead of using the equivalent-field method, direct output measurement is recommended. This criteria can be applied for 4-10 MV x-ray beams up to 10-cm depth.

Key Words: equivalent-field method, output factor, elongated field, rule-of-thumb

Introduction

In clinical radiotherapy, the fields most often used are rectangular or irregular in shape and it is customary, for calculation purposes, to find a standard field (usually square) equivalent to these

Reprint requests to:
Chang-Seon Kim, Ph.D.
Department of Radiation Oncology
Korea University Medical Center
Seoul 136-705, KOREA
(phone) 02-920-5516, (FAX) 02-927-1419
(E-mail) ckim@nownuri.net

rectangular fields. The use of the equivalent field is a well-recognized method for obtaining depth-dose parameters [1], such as, percentage depth dose, tissue-air ratio, and tissue-phantom ratio, and dose-determination parameters, such as, peak-scatter factor and output factor for rectangular fields. The equivalent field concept relates to that square (or circular) field which gives at any axial depth the same scatter dose as for a given rectangular field.

Manual calculation of doses from irregularly shaped fields in patients undergoing radiotherapy utilize either scatter summations or square fields which are dosimetrically equivalent to the treatment fields. Equivalent fields are widely used in rectangular-field photon-beam dose calculations, mostly as equivalent squares. Even though several people have been tried to calculate equivalent square fields [2 - 8], a calculation based on a purely geometric basis either by estimation or from the area-perimeter ratio [9 - 12] is known as its rapidity and accuracy. However, for highly elongated fields, highly irregular fields, and fields bisected by blocks, area-perimeter ratio calculations tend to underestimate the sizes of equivalent squares and doses. Two methods are used in practice for determination of equivalent square fields. One is based on tables of equivalent squares which have been calculated by Day [13] from an integration involving the scatter-radius function. The other method has been proposed by Sterling [10] and is based on the assumption that square fields and rectangular fields are equivalent if they have the same area/perimeter ratio.

This purpose of our study was to verify the general validity of the equivalent square field method based on the area/perimeter ratio to predict the output for elongated fields over a range of megavoltage beam qualities. This study was also aimed for deriving a 'rule of thumb' for the application criteria.

Methods and Materials

The study was performed for three x-ray beams, 4-MV (CLINAC 600C) and 6- and 10-MV (CLINAC 1800, Varian, USA), available in the Department of Radiation Oncology of our hospital. Measurements were done in a water phantom because the physical density, effective atomic number, and electron density of water are 1.000 × 10^3 kg/m^3, 7.51, and 3.343 × 10^{29} m^{-3}, respectively, which are close to those of soft tissue, ρ = 1.040 × 10^3 kg/m^3, Z_{eff} = 7.64, and electron density n_0 = 3.480 × 10^{29} m^{-3}. A cylindrical chamber (Type 23343-1473, PTW-Freiburg, Germany), having a 0.3 cm^3 active volume, which was connected to a PTW IQ4 electrometer with 300-V detector bias voltage, was chosen for a dosimetry system. Nominal source-to-chamber distance (SCD) was fixed, 100 cm.

Measurement of the absorbed dose for the elongation effect was done at three different depths, d_{max}, 5-cm, and 10-cm. Width of the upper collimator was changed to make the field size of 5-20 cm at 100 cm SCD and the elongation ratio, which is defined the ratio of length to width of the rectangular fields, of the rectangular fields ranged from 1.0 to 10.0. Even though there is a collimator exchange effect [5, 14] on the output, here the width of the upper collimator was varied to offer different elongation ratio with given field height. For each quality of radiation considered, the smallest field dimension tested was large enough to provide lateral electronic equilibrium and, therefore, some small fields with very large elongation ratio were neglected. For an elongated field and its equivalent square field, the output factor, which is defined the ratio of the absorbed dose at d_{max} for the 10 cm × 10 cm field, was measured and the difference in the output factor were examined for various field sizes and/or elongation factors. The dimension of the equivalent square field could be adequately expressed as four times the area, A, divided by the perimeter, P, of the rectangular field, 4 A/P. To minimize the effect of cable irradiation in highly elongated fields and to minimize the stem effect of the chamber, the chamber axis was always oriented in the direction of the narrower side of the rectangular field.

For each measurement, three consecutive readings were taken. The percent difference in output between the elongated field by direct measurement and its corresponding equivalent square field was determined.

Results and Discussions

Direct measurement of the output of elongated x-ray fields were compared to corresponding equivalent square fields calculated by area-perimeter ratio calculation. In Fig. 1, the output discrepancy are presented at dmax as a function of field size and elongation ratio for three x-ray beams. As the smallest field dimension tested was large enough to provide lateral electronic equilibrium, some small fields with very large elongation ratio was neglected. For the same elongation ratio, the difference was found to be larger for the smaller than for the larger field . For larger fields whose side are larger than 25-cm, output discrepancy between the direct measurement of the elongated field and its equivalent square field can be neglected and the maximum difference was less than 2 %.

No major difference was found between three measurement depths and the difference were within 1.5 percent (Table 1). For a field whose one side of the square field is 7-cm, the percent difference of the output was over 8% for the elongated field, elongation ratio > 4:1. As the elongation ratio of rectangular fields increases, a larger discrepancy in outputs was observed between an elongated rectangular field and their corresponding equivalent square field. Output was

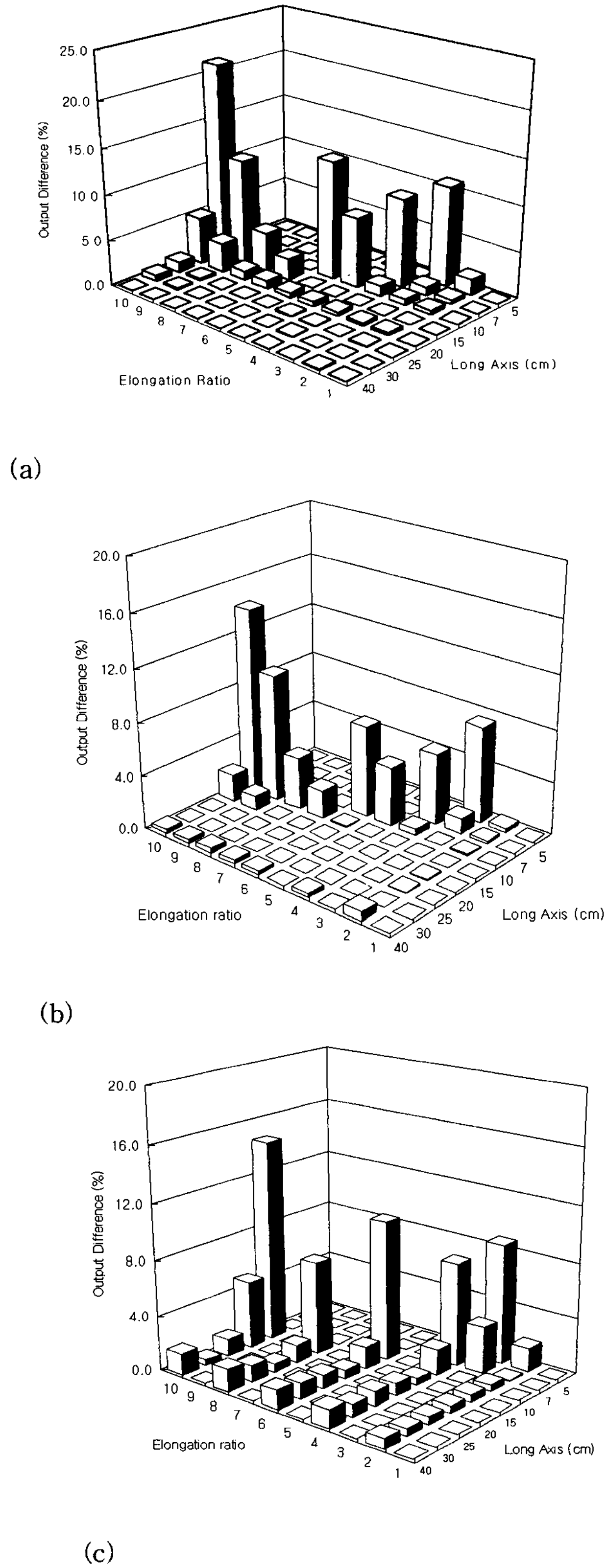

Fig. 1. Percent difference in output between using the equivalent square method and direct measurement for the elongated fields for three x-ray beams at dmax: (a) 4-MV; (b) 6-MV; (c) 10-MV.

Table 1. Percent difference in output between using the equivalent square method and direct measurement Using 4-MV X-ray Beam. Measurements were performed for various field size and elongation ratio at three different depth.; (a) d_{max}; (b) 5-cm depth; (c) 10-cm depth.

(a)

Ratio	Long Axis (cm)							
	5	7	10	15	20	25	30	40
1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2	1.7	0.6	0.4	-0.2	0.3	0.1	0.0	0.1
3	10.9	0.9	0.6	-0.1	0.3	-0.6	0.0	0.0
4	---*	9.6	1.1	-0.1	0.4	0.1	0.1	0.0
6	---	---	12.9	0.0	0.5	0.0	-0.2	0.0
8	---	---	---	4.3	1.0	-0.7	-0.4	-0.2
10	---	---	---	21.3	5.1	1.1	0.6	-0.2

(b)

Ratio	Long Axis (cm)							
	5	7	10	15	20	25	30	40
1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2	0.5	0.0	0.2	0.2	0.1	0.1	0.1	0.0
3	11.4	1.3	0.9	-0.6	0.6	-0.8	0.4	0.0
4	---	9.0	0.9	0.2	0.2	0.1	0.1	0.0
6	---	---	11.7	1.2	0.8	0.1	0.1	0.1
8	---	---	---	6.7	1.4	0.5	0.4	0.2
10	---	---	---	20.5	5.1	1.1	0.7	0.6

(c)

Ratio	Long Axis (cm)							
	5	7	10	15	20	25	30	40
1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2	-0.3	-0.2	-0.2	0.0	0.1	0.1	0.0	0.1
3	9.6	1.6	0.0	0.0	-0.3	0.0	0.5	0.0
4	---	8.1	0.5	0.5	0.1	0.1	0.1	0.0
6	---	---	10.4	0.8	0.0	0.1	0.1	0.1
8	---	---	---	5.6	0.6	0.2	0.1	0.6
10	---	---	---	15.5	3.9	0.5	0.5	0.6

* No measurement

measured larger for an elongated field than that of its equivalent square field and the maximal difference of 10 % was found. The effect of the beam quality on the difference was minimal. For small field with very large elongation ratio, as there is a breakdown of the lateral electronic equilibrium occur, the large output difference was found.

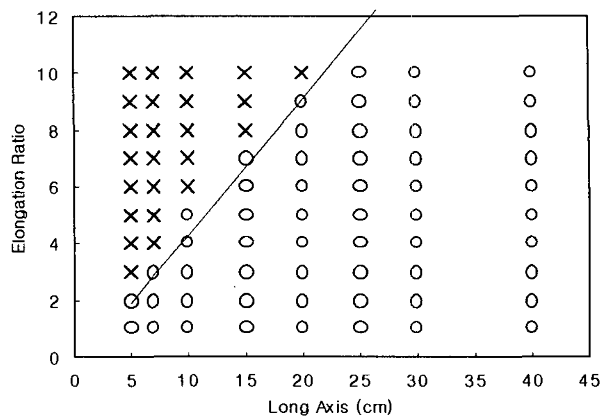

Fig. 2. Scattered plot of lattice points on the *elongation ratio-long axis space*. Here open circle (○) and cross (×) denotes the case of preferred equivalent-field technique and direct measurement, respectively.

Based on the results, Fig. 1 and Table 1, a rule of thumb for the application of the output calculation using the equivalent-square method can be derived easily. The lattice points on the *Elongation ratio-Long axis space* are shown in the Fig. 2. The combinations marked on the scattered plot are the measuring points and all the lattice points are grouped into two categories. If the combination falls in the lower, the equivalent-square method can be applied for the output calculation (marked as ○) but otherwise, instead of using the technique, direct measurement is recommended (the upper group, marked as X). The boundary between two groups can be expressed as a simple equation. For the combination of long axis and elongation ratio whose relationship satisfy $\textit{Elongation ratio} < (0.48)\ (\textit{Long axis}) - 0.5$, the equivalent-field method is valid for output calculation within 2 % for the field whose long axis < 25-cm. For fields with long axis > 25 cm, there is no limitation of the applicability for the equivalent-field method if the short axis of the field is large enough to meet lateral electronic equilibrium. For those points, instead of using the equivalent-field method, direct output measurement is recommended for routine clinical use. This criteria can be applied for 4-10 MV x-ray beams up to 10-cm depth.

Another approach for the output calculation for the rectangular and for irregular shaped field is the Clarkson's method. The comparison of three approaches, i.e., direct measurement, equivalent square method, and Clarkson's method, are on going. The collimator exchange effect is another factor. A study is planned to be answered to the question whether the rule-of-thumb derived here is still varied in that case.

Conclusions

The equivalent-field method should be used carefully for output calculation for fields of large elongation ratio. Based on the study, there are criteria, rule of thumb, for the application of the method for output calculation. For a rectangular field whose long axis < 25-cm, the relationship, *Elongation ratio < (0.48) (Long axis) - 0.5,* can be a criteria whether the application of the equivalent-field method is valid within 2 % output difference. Direct output measurement is recommended for the combinations of elongation ratio and long axis of the elongated field which do not satisfy the relationship. This criteria can be applied for 4-10 MV x-ray beams up to 10-cm depth.

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출력인자 계산에 이용되는 등가면법의 타당성 연구: 장방형 X-선 조사면에 대해서 안전한가?

고려대학교 의과대학, 안암병원, 방사선 종양학과

김 창선 · 김 철용 · 최 명선

연구 목적: 등가면법은 장방형의 X-선 조사면의 출력인자 계산에 널리 이용되고 있다. 본 연구에서는 출력인자 계산시 등가면법의 적용에 영향을 줄 수 있는 선질, 조사면의 두 변의 길이의 비, 측정점의 깊이 등을 조사하였다. 또한 등가면법의 타당성이 유지되는 영역을 밝히는 어림계산법을 제시하였다.

대상 및 방법: 본 연구에 사용된 X-선의 선원은 4-, 6-, 10-MV 이었다. 조사면의 폭을 5-40 cm 까지 변화시키고 각 조사면에서 두 변의 비를 1:1 에서 10:1 까지 변화시켰다. 조사면의 장방효과는 물팬톰을 이용하였으며, dmax, 5-cm, 10-cm 깊이에서 시행하였다. 장방형의 조사면과 각 조사면에 대한 등가정사각형면에서의 출력인자를 구하여 이들 두 방법에서의 차이를 나타냈다.

결과 및 토의: 장방형의 조사면과 이에 대응하는 등가면 간의 출력인자의 차이는 일반적으로 장방비가 커질수록 증가하였다. 장방형의 조사면에 대한 출력인자의 측정값은 일반적으로 각 조사면의 등가정사각형면을 이용하여 계산한 값보다 높게 나타나서 크게는 10%의 차이를 나타냈다. 똑같은 두 변의 비에 대하여 장방형의 조사면과 등가정사각형면에 대한 출력인자의 차이는 조사면의 크기가 작을수록 크게 나타났다. 실험에 사용한 각각에서 선질의 종류와 각각의 선질에서 측정깊이에서 두 값은 큰 차이를 보이지 않았다.

결론: 본 연구결과에 의하여 등가면법을 출력인자 계산에 사용할 경우 이를 판단할 어림계산법을 구할 수 있다. 한 변의 길이가 25-cm 이하인 조사면에 대하여 만일 *장방비 < (0.48) (긴 변의 길이) - 0.5* 를 만족하는 경우에는 출력인자의 오차를 2% 안에서 등가면법을 이용할 수 있다. 이와는 다른 경우에는 출력인자를 직접 측정하여야 한다. 이러한 기준은 4-10MV X-선원에 대하여 10-cm 깊이의 측정점까지 타당하다.

중심 단어: 등가면법, 출력인자, 장방형 조사면, 어림계산