Comparison of four models for calculation of collimator scatter factors of linac photon beams

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Background. *Two approaches for approximation of collimator scatter correction factors of rectangular fields can be found in recent publications. One is based on empirical equations or some more sophisticated physical models using certain parameters which have to be adjusted for a specific machine. The other is based on an earlier proposed idea of decomposition of collimator scatter correction factor function of two variables - into the product of two functions of one variable. In this work four models, based on the decomposition, are compared. All these models are based on the measurement of the output variation while opening one of the two collimator blocks, the other being opened at some fixed value.*
Material and methods. *The measurements were carried out using nominal 6 MV and 15 MV X-ray beams of a Siemens linac and nominal 6 MV and 18 MV X-ray beams of a Varian linac.*
Results and conclusions. *It was shown that better approximation can be achieved with a suitable choice of basic measurements and normalisation of data.*

Key words: radiotherapy dosage; scattering radiation; photons; collimator scatter, rectangular fields

Introduction

From a review of tumor control dose-response curves a standard requirement of 3.5% has been proposed for the accuracy of the dosimetry of radiotehrapy units.[1] In order to provide this level of accuracy it was recommended to separate collimator (head) and phantom scatter. Namely, as shown by several authors,[2-5] the collimator scatter correction factor Sc for rectangular fields and, therefore, the total scatter correction factor Scp will differ if the upper and lower collimator jaws are interchanged. The magnitude of this, so called collimator exchange effect (CEE), depends on the construction of the treatment unit head and will be defined as

$$CEE=Sc(x,y)-Sc(y,x).$$

Then the maximum difference is expected as

$$CEEmax = Sc(x_{max},y_{min})-Sc(x_{min},y_{max}),$$

where indices min and max indicate the largest and the smallest openings, and x is the opening of the upper, y of the lower collimator jaw. Sc is usually normalised so that

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$Sc(x_{ref},y_{ref})=1$, while $x_{ref}=y_{ref}=10$ cm at nominal distance.

Determining a two-dimensional table for Sc factors of rectangular fields is time consuming. Therefore, various models were proposed, based on a significantly smaller amount of data. The application of Sterling's formula can cause even a 3% deviation from real data. The model proposed by Karlsson et al.[6] decomposes the function Sc(x,y) of two independent variables into the product of two one-variable functions

$$Sc(x,y)=Sc(x_{max},y)\cdot Sc(x,y_{max}),$$

when two decomposing functions are normalised so that they are a unity at $y=y_{ref}$ or $x=x_{ref}$, respectively. This model requires measurements for various y's at x_{max}, thus significantly reducing the number of measurements. Using this model we also obtained deviations up to 3% from the actually measured Sc(x,y).

In this work we shall compare three various models also based on the idea of the decomposition of Sc(x,y) into the product of two one-variable functions, trying to get a better approximation using various types of normalisation and limitation.

Materials and methods

The measurements were carried out using nominal 6 MV and 15 MV X-ray beams of a Siemens linac (Mevatron MD installed in Osijek) and nominal 6 MV and 18 MV X-ray beams of a Varian linac (Clinac 1800 installed in Zagreb).

The total scatter correction factor (Scp) is defined as the ratio of the doses at an arbitrary collimator opening and at the reference opening, in the precisely defined reference point at the reference source scin distance (SSD). The reference data in our measurements were: SSD=100cm, reference point is on the central axes at d_{ref} =10 cm and the reference opening was defined as field size 10cmx10cm at SSD=100cm.

Total scatter correction factor is the product of the collimator scatter correction factor Sc and phantom scatter correction factor Sp:

$$Scp= Sc \cdot Sp.$$

Collimator scatter correction factors of rectangular fields were measured using a mini-phantom described in ESTRO booklet No 3. A Farmer tape 0.6 ccm ionization chamber, placed into the mini phantom, was always perpendicular to the elongated field size in order to reduce the cable effect as much as possible. The response of the dosimeter should reflect the change of the photon fluence due to the variation of collimator setting. Sc was determined in the same way as prescribed for Scp, except that the above mentioned mini-phantom was used for the measurements instead of a large water phantom.

For every of the four X-ray beams we measured a table of 8x8 values of $Sc(x_i,y_j)$, where x_i and y_j are discrete openings assuming values x_i,y_j =4,6,8,10,15,20,30,40 cm at indices i,j=1..8. For the sake of clarity let us simplify the notation by using the symbol $Sc(i,j)\equiv Sc(x_i,y_j)$. At our choice of discrete openings, index i,j=4≡ref means reference value of x_i,y_j and similarly i,j=1≡min and i,j=8≡max mean minimum and maximum openings, respectively. The Sc(i,j) values were normalized in the standard way, so that Sc(ref,ref)=Sc(4,4)=1.

We compared four models to calculate $Sc(i,j)_{calc}$ from partial set of measured data Sc(i,j) consisting of one column and one row (models 1 and 2) or two columns and two rows (models 3 and 4):

Model 1

This model was proposed by Karlsson et al.[6] The only measured row and column are Sc(max,j) and Sc(i,max), with i,j=1..8, respectively. In our notation Sc is calculated as

$$Sc(i,j)_{calc} = Sc(i,max) \cdot Sc(max,j) /[Sc(ref,max) \cdot Sc(max,ref)].$$

Model 2

The only measured row and column are Sc(ref,j) and Sc(i,ref), with i,j=1..8, respectively. Sc is calculated as

$$Sc(i,j)calc = Sc(i,ref) \cdot Sc(ref,j).$$

No additional normalization is necessary due to the fact that both, row Sc(i,ref) and column Sc(ref,j) are already normalized by Sc(ref,ref)=1.

Model 3

The two measured rows and columns are Sc(min,j), Sc(max,j) and Sc(i,min), Sc(i,max), with i,j=1..8, respectively. This model of calculation is given with three expressions which define the function $Sc(i,j)_{calc}$ within three separated ranges, namely

for x<y: $Sc(i,j)_{calc} = Sc1 = Sc(min,j) \cdot Sc(i,max) / Sc(min,max)$,

for x>y: $Sc(i,j)_{calc} = Sc2 = Sc(max,j) \cdot Sc(i,min) / Sc(max,min)$,

for x=y: $Sc(i,j)_{calc} = (Sc1 + Sc2)/2$.

It is easy to see that following equations are valid:

$$Sc(min,j)_{calc} = Sc(min,j) \text{ for } j=1..8,$$
$$Sc(i,max)_{calc} = Sc(i,max) \text{ for } i=1..8,$$
$$Sc(max,j)_{calc} = Sc(max,j) \text{ for } j=1..8,$$
$$Sc(i,min)_{calc} = Sc(i,min) \text{ for } i=1..8.$$

These equations express the fact that all calculated values on the border of the table are identical to the measured data. Therefore, the maximum deviations of calculated data could be expected in the middle of the table.

Model 4

The two measured rows and columns are the same as for Model No. 3.

This model of calculation is also given by three expressions, with somewhat different normalization, namely

for x<y: $Sc(i,j)_{calc} = Sc1 = Sc(min,j) \cdot Sc(i,max) / [Sc(min,ref) \cdot Sc(ref,max)]$,

for x>y: $Sc(i,j)_{calc} = Sc2 = Sc(max,j) \cdot Sc(i,min) / [Sc(max,ref) \cdot Sc(ref,min)]$,

for x=y: $Sc(i,j)_{calc} = (Sc1 + Sc2)/2$.

The possibility to calculate other Sc values by linear interpolation is implied for all four models.

Results and discussion

A sample of measured data versus data processed by model 3 and for Clinac 1800 18MV X-rays is shown in Table 1. Similar

Table 1. Measured and calculated data for Clinac 1800 18MV X-rays, according to model 3

lower jaw:	\ upper jaw:	4cm	6cm	8cm	10cm	15cm	20cm	30cm	40cm
	measured	0.950	0.958	0.971	0.977	0.982	0.989	0.994	1.001
4cm	calculated	0.950	0.958	0.971	0.977	0.982	0.989	0.994	1.001
	deviation%	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	measured	0.959	0.973	0.982	0.989	0.997	1.004	1.007	1.016
6cm	calculated	0.959	0.975	0.986	0.992	0.997	1.004	1.009	1.016
	deviation%	0.00	0.21	0.36	0.26	-0.03	-0.02	0.19	0.00
	measured	0.961	0.978	0.991	0.996	1.008	1.012	1.019	1.027
8cm	calculated	0.961	0.980	0.994	1.002	1.008	1.015	1.020	1.027
	deviation%	0.00	0.20	0.31	0.64	-0.05	0.27	0.08	0.00
	measured	0.961	0.980	0.992	1.000	1.010	1.016	1.025	1.032
10cm	calculated	0.961	0.980	0.992	1.005	1.012	1.020	1.025	1.032
	deviation%	0.00	0.00	0.00	0.51	0.24	0.36	-0.02	0.00

lower jaw:	\ upper jaw:	4cm	6cm	8cm	10cm	15cm	20cm	30cm	40cm
	measured	0.962	0.981	0.993	1.001	1.013	1.020	1.030	1.038
15cm	calculated	0.962	0.981	0.993	1.004	1.018	1.026	1.031	1.038
	deviation%	0.00	0.00	0.00	0.30	0.46	0.56	0.07	0.00
	measured	0.962	0.981	0.993	1.002	1.016	1.022	1.032	1.041
20cm	calculated	0.962	0.981	0.993	1.004	1.017	1.026	1.034	1.041
	deviation%	0.00	0.00	0.00	0.20	0.10	0.38	0.17	0.00
	measured	0.962	0.981	0.993	1.003	1.017	1.023	1.033	1.043
30cm	calculated	0.962	0.981	0.993	1.004	1.017	1.023	1.035	1.043
	deviation%	0.00	0.00	0.00	0.10	0.10	0.00	0.19	0.00
	measured	0.962	0.981	0.993	1.004	1.017	1.023	1.034	1.044
40cm	calculated	0.962	0.981	0.993	1.004	1.017	1.023	1.034	1.044
	deviation%	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

RMS= 0.187%
E_{max}=0.64%
CEE_{max} =3.9%

tables, not shown here, were elaborated for various beam qualities and the summarized results are given in Table 2.

The results are shown in Table 2. In addition to other methods the results of Sterling formula are also represented for comparison. From Table 2, following conclusions may be drawn. The first two models are based on the measurement of one row and one column. Better results obtained by model 2 mean that, if we measure only one row and one column, the better choice is to use that column and row which correspond to the fixed reference opening, instead of the row and column

Table 2. The roots of mean squares (RMS's) and the maximum deviations (Emax) obtained for various methods and the maximum collimator exchange effects (CEEmax) for various beams

BEAM	Model 1	Model 2	Model 3	Model 4	Sterling
Mevatron 6MV					
RMS%	0.63	0.68	0.20	0.37	1,11
E_{max} %	2.1	1.1	0.72	0.98	3,03
Mevatron 15MV					
RMS%	0.63	0.61	0.19	0.39	1,14
E_{max} %	2.1	1.14	0.62	0.97	2,95
Mevatron 6MV wedge 30_o					
RMS%	1.33	0.96	0.39	0.61	1,19
E_{max} %	3.33	1.58	1.19	1.69	2,56
Mevatron 15MV wedge 30°					
RMS%	1.15	0.79	0.39	0.53	1,03
E_{max} %	3.32	1.39	1.12	1.53	2,71
Clinac 6MV					
RMS%	1.42	0.33	0.32	0.65	1,26
E_{max} %	2.66	0.56	1.05	2.1	3,00
Clinac 18MV					
RMS%	0.69	0.47	0.19	0.37	1,28
E_{max} %	2.06	0.78	0.64	1.11	3,2

which correspond to the fixed maximum opening of the collimator. Models 3 and 4 are based on measured data of two rows and two columns (i.e. double amount of measured data) and, therefore, superior in results as compared with the first two models. The model 3 is obviously the most accurate in spite of the fact that Sc is not exactly equal to a unity under reference conditions.

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