

Calculation of Equivalent Square Fields in Radiation Therapy by an Improved Vadash Correction Factor for Collimator Exchange Effects

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Abstract

Background and objectives: To determine the head scatter factor, a formalism presented by Vadash and Bjärngard has been employed to assess collimator exchange effects. The aim of this study was to determine the best Vadash correction factor (A) by introducing a new method based on the output factor measured in air for different square and rectangular fields. **Materials and Methods:** A new simple mathematical method based on selection of the best dosimetric data was proposed to obtain the A value for Vadash to predict the equivalent square field size. Measurements were performed with a Farmer chamber 0.6 cc in SSD 100 cm and build up cap of Plexiglas, 1.5 and 3.5 cm equal to water, for 6 and 18 MV, respectively, with a Perimus Plus linear accelerator. The output factor in air (OF_{air}) was measured for square and rectangular fields. MATLAB software (version R2014a) was employed for calculations and curve fitting. **Results:** A power model with a constant value was applied to the output factor in air as a function of square field size. The output factor in air ranged from 0.983 to 1.038 at 6MV and from 0.731 to 1.05 at 18 MV with the Y collimator having a greater effect. Obtained values for A were 1.42 and 1.55 with respect to $\sigma_{min}=0.98$ and 2.3 for 6 and 18 MV energies, respectively. **Conclusion:** The proposed A values minimize the collimator exchange effect in calculating equivalent squares, which plays an important role in patient dose calculation and treatment planning.

Keywords: Equal square field- collimator exchange effect- Vadash formula- Output factors in air

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Introduction

Radiation therapy is currently one of the most important therapeutic methods for cancer treatment. The aim of radiation therapy is to maximize damage to the tumor while protecting of the normal tissues (Shalek, 1977; Van Herk, 2004). An important issue in radiotherapy is dose calculating and treatment planning for cancer patients. Photon beam data, such as percentage depth doses, dose profiles, and output factors (OF) are required for accurate dose calculation in radiation therapy (Miyashita et al., 2013). In order to calculate the dose accurately, collimator scattering factor (S_c) or output factor in air (OF_{air}) for all square and irregular fields with any dimensions should be measured (McKerracher and Thwaites, 2007; Miyashita et al., 2009; Khan and Gibbons, 2014). The output factor (OF) expresses the amount of scattering radiation variations from collimators in the treatment volume and is defined as the ratio of absorbed dose of arbitrary field to that of reference field (10×10 cm²) (McKerracher and Thwaites, 2007). OF_{air} is measured in the air. Hence, it

can be assumed to be equal with the S_c .

The detector system for measuring the S_c , is composed of the ion chamber and appropriate build-up cap that make electronic equilibrium. The build-up cap must be entirely covered by the incident beam for all field sizes to reflect the relative changes of incident fluence (Vadash and Bjärngard, 1993; Miyashita et al., 2009; Iftikhar, 2012; Khan and Gibbons, 2014). To prevent electron contamination for high-energy photon beams, the measuring depth must be sufficiently far away from d_{max} (5 or 10 cm) (Van Gasteren et al., 1991). A mini phantom is used for this purpose.

Output factor in air (S_c) depends on energy and field size (collimator opening) (Huang et al., 1987). For squared fields a small increase in field width and length, will have a small effect on output factor in air. But for rectangular and extremely elongated field shapes, the dependence of OF_{air} on field size variations will be more important (Huang et al., 1987). At first it seems that, the OF_{air} for a rectangular $a \times b$ field must be equal to $b \times a$ one. But, as the positions of the jaws in order to provide the rectangular

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$a \times b$ field is different from $b \times a$ field, collimator scatter and hence OF_{air} will be different for these field sizes (Huang et al., 1987; Vadash and Bjärngard, 1993). The influence of the different jaws opening that make a treatment field, on OF_{air} is called collimator exchange effect, which is related to the construction features of linear accelerator head (Zhu et al., 2009).

Since many treatment fields are irregular and OF_{air} is often measured as a function of the square field size at the isocenter, the equivalent square fields are used in clinic (Kim et al., 1997; Miyashita et al., 2013). An equivalent square field size is originally that which gives the same central-axis depth dose characteristics as that of an irregular or blocked field (Norvill and White, 2008; Thomas et al., 2014).

One formula for calculating equivalent square field is the 4A/P method (Sterling et al., 1964). But, the 4A/P method does not consider the collimator exchange effect. So, this approach does not have enough precision (Zhu and Ahnesjo, 2004). Furthermore, the inaccuracy of this formula is greater for large fields (Day and Aird, 1983; Yu et al., 1995). So, Vadash and Bjärngard presented formula $Eq = \frac{(A+1)XY}{AX+Y}$ for equivalent squares, which takes into account collimator exchange effect. In the presented equation, 'A' is a constant specific for each machine's beams. It can be determined experimentally from head scatter factor measurements, or approximated using machine design. For the square fields, A is equal to 1 (Vadash and Bjärngard, 1993; Kim et al., 1997).

Kim et al., (1998) presented a geometrical weighting factor for calculating A, based on the design of the head linear accelerator.

They proposed that, $A = \left(\frac{D_{s-jx}}{D_{i-jx}} \right) \times \left(\frac{D_{i-ly}}{D_{s-ly}} \right)$. D_{s-j} is the distance from the source plane to the top of the X or Y jaw, and D_{i-j} is the distance from the isocentre plane to the jaw.

Yu et al., (1995) presented the formula $A = \left(\frac{D_{low}}{D_{up}} \right)^2$, that D_{low} and D_{up} are distances from the source plane to the down and up jaws, respectively.

Accurate calculation of equal square field size is so important in radiation therapy. Hence, A factor, in the Vadash equation must be determine precisely by considering collimator exchange effect. Therefore, the purpose of this study was to determine the best A factor, for calculation of equal square field size in treatment planning. In the present study, the correction factor (A) was calculated by introducing a new method based on determining output factor in air for different square and rectangular fields for 6 and 18 MV photon beams of linear accelerator.

Materials and Methods

Analytical method

Output factor is defined as the ratio of the measured dose ($M_{X \times Y}$) in arbitrary field in air on the central axis to reference field ($10 \times 10 \text{ cm}^2$) in same point (usually the isocenter):

$$OF_{X \times Y} = \frac{M_{X \times Y}}{M_{10 \times 10}} \quad (1)$$

Where, X and Y represent the outer (lower) and inner (upper) collimator jaws, respectively. For each field, the measured dose consists of the primary and scattered dose portions. The primary dose which comes directly from the source without interactions with matter is independent of collimator opening amount. However, the scatter radiation that generated by the interaction of primary radiation with several head components depends on collimator exchange effect. Therefore, the measured dose for an arbitrary field in air on the central axis ($M_{X \times Y}$) can be express as follows:

$$M_{X \times Y} = P_{X \times Y} + S_{X \times Y} \quad (2)$$

Which, $P_{X \times Y}$ and $S_{X \times Y}$ represent the primary and scattered doses, respectively. To display the difference between upper and lower jaws on scatter dose (collimator exchange effect), the following notation is applied:

$$S_{a \times b} = S_a^l + S_b^u \quad (3)$$

$$S_{b \times a} = S_b^l + S_a^u \quad (4)$$

The symbols u and l refer to the upper (Y) and lower (X) jaws, respectively. "a" and "b" indices represent field dimensions, which determined with collimator opening amount in each cases. Therefore, with respect to Eq. (1), (2), (3) and (4), equations (5) and (6) achieved as follows:

$$OF_{a \times b} = \frac{M_{a \times b}}{M_{10 \times 10}} = \frac{P_{a \times b} + S_{a \times b}}{M_{10 \times 10}} = \frac{P_{a \times b} + S_a^l + S_b^u}{M_{10 \times 10}} \quad (5)$$

And also,

$$OF_{b \times a} = \frac{M_{b \times a}}{M_{10 \times 10}} = \frac{P_{b \times a} + S_{b \times a}}{M_{10 \times 10}} = \frac{P_{b \times a} + S_b^l + S_a^u}{M_{10 \times 10}} \quad (6)$$

Equation (7) was obtained by combining Eq. (5) and (6):

$$OF_{a \times b} + OF_{b \times a} = \frac{P_{a \times b} + S_a^l + S_b^u + P_{b \times a} + S_b^l + S_a^u}{M_{10 \times 10}} \quad (7)$$

Since, the primary dose is independent of the collimator jaws displacement, it can be deduced:

$$P_{a \times b} + P_{b \times a} = P_{a \times a} + P_{b \times b} \quad (8)$$

$P_{a \times a}$ and $P_{b \times b}$ show the primary doses of square fields with $a \times a$ and $b \times b$ dimensions.

Respect to Eq. (8), the Eq. (7) was rewritten as follows:

$$OF_{a \times b} + OF_{b \times a} = \frac{P_{a \times a} + S_a^l + S_a^u + P_{b \times b} + S_b^l + S_b^u}{M_{10 \times 10}} \quad (9)$$

And as a result:

$$OF_{a \times b} + OF_{b \times a} = OF_{a \times a} + OF_{b \times b} \quad (10)$$

In practical situation, there will be a slight difference (Δ) between two hand sides of Eq. (10), this difference (Δ), determined as:

$$\Delta = |OF_{a \times b} + OF_{b \times a} - OF_{a \times a} - OF_{b \times b}| \neq 0 \quad (11)$$

Measurement

Measurement was performed with a Farmer chamber with 0.6 cc volumes in source-surface distance (SSD) 100cm and build up cap of Plexiglas, 1.5 and 3.5 cm equals water, for 6 and 18 MV, respectively on a Perimus Plus linear accelerator. Output factors in air were measured for square field sizes (5×5, 6×6, 7×7, 8×8, 9×9, 10×10, 12×12, 15×15, 20×20, 25×25, 30×30, 35×35, 40×40 cm²) three times and plotted as a function of the square field size. The relation between output factor and equivalent field size was obtained using MATLAB software (version R2014a) curve fitting toolbox (fitted relation).

In the next step, the output factors were measured for 16 rectangular fields) 5×10, 5×20, 5×30, 5×40, 10×20, 10×30, 10×40, 20×30 cm² and conversely).

Six fields for 6MV and eight fields for 18 were selected. The criteria for selecting these fields, was Δ, smaller than 0.002 for 6MV and 0.01 for 18 MV energies. After determining the equivalent square field sizes for the selected rectangular fields, using the fitted relation, the Vadash coefficients (A) were calculated for the selected fields by means of Vadash formula for both energies 6, 18MV.

For the each calculated -A-, the equivalent square field size for all rectangular fields was determined by the Vadash formula. The difference between calculated and the measured equivalent square field size which obtained from the fitted relation was determined. The standard deviations (σ) were calculated for the mentioned differences and the final coefficient -A- for the each energy was selected with respect to minimum standard deviation (σmin) of the differences.

Results

The measured output factors for 6 and 18MV energies versus square field size are shown in Figure1.

Equation 12 illustrates the fitted power models with

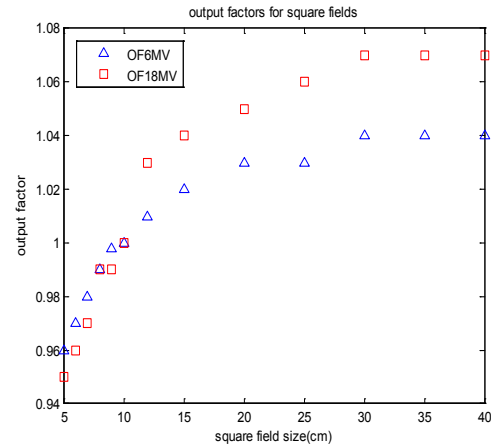


Figure 1. Measured Output Factor for Square Fields in 6 and 18MV

constant value to explain the output factor (OF) as a function of square field size (S_{equi}) in cm, with R²>0.98.

$$OF = \begin{cases} -0.4211S_{equi}^{-0.8814} + 1.058 & \text{for } E=6MV \\ -0.5603S_{equi}^{-0.7432} + 1.112 & \text{for } E=18MV \end{cases} \quad (12)$$

The measured OF_{air} and fitted relations (Eq. 12) are shown in figure 2 as functions of square field size.

The measured output factors for square and rectangular fields with values of Δ in Eq.11 are shown in Table1.

The minimum value of Δ was the selecting criteria to choose the values of the Vadash constant coefficient “A”. Therefore, the equivalent square field sizes were calculated for rectangular fields with the lowest Δ (bold data in Table1) according to Eq.12.

Values of calculated “A”, with replacing calculated equivalent square field sizes in Vadash relation, are shown in Table 2. Also, the standard deviations (σ) of differences between calculated and the measured equivalent square field sizes are illustrated in Table 2.

The final selected coefficient “A” with respect to

Table1. The Values of Δ in Eq.11 for Square and Rectangular Fields in 6 and 18MV Energies

E(MeV)	a×b	OF	b×a	OF	a×a	OF	b×b	OF	Δ
6		0.995		0.98		0.957		1.04	0.025
18	40×5	0.99	5×40	0.75	5×5	0.95	40×40	1.07	0.285
6	40×10	1.023	10×40	1.009	10×10	1	40×40	1.04	0.008
18		1.035		1.025		1		1.07	0.01
6	30×5	1.038	5×30	1.033	5×5	0.957	30×30	1.037	0.024
18		0.996		0.748		0.95		1.068	0.28
6	30×10	1.022	10×30	1.013	10×10	1	30×30	1.037	0.002
18		1.035		1.026		1		1.068	0.006
6	30×20	1.031	20×30	1.031	20×20	1.029	30×30	1.037	0.004
18		1.057		1.05		1.055		1.068	0.015
6	20×5	0.993	5×20	0.98	5×5	0.957	20×20	1.029	0.016
18		0.989		0.746		0.95		1.055	0.269
6	20×10	1.02	10×20	1.011	10×10	1	20×20	1.029	0.002
18		1.031		1.026		1		1.055	0.002
6	10×5	0.983	5×10	0.976	5×5	0.957	10×10	1	0.002
18		0.983		0.731		0.95		1	0.238

Table 2. Calculated "A" for the Fields with the Lowest Δ

6MV				18MV			
Field sizes	Δ	A	σ	Field sizes	Δ	A	Σ
10×5	0.002	1.42	0.98	40×10	0.01	0.72	3.42
5×10	0.002	1.29	1.07	10×40	0.01	3.13	2.75
20×10	0.002	2.25	1.71	20×10	0.002	1.06	2.44
10×20	0.002	1.97	1.37	10×20	0.002	1.55	1.9
30×10	0.002	1.37	1.01	30×10	0.006	0.86	2.93
10×30	0.002	2.2	1.65	10×30	0.006	2.32	2.12
20×30	0.004	1.96	1.36	-	-	-	-
30×20	0.004	0.51	3.6	-	-	-	-

minimum standard deviation (σ_{min}) of the differences for 6 and 18 MV energies are bolded in Table 2.

Discussion

Photon beam data, such as percentage depth doses, dose profiles, and output factors (OF) are required for dose calculation in radiation therapy. The OF_{air} can be determined by energy fluence of primary and scattered photons and backscattered radiation from collimator jaws. Scattered photons generated from primary collimator and flattening filter was account for 90.0 % of total scattered photon fluence. Scattered photons from flattening filter decreased slowly as distance from central axis increases (Miyashita et al., 2013). By increasing the field size, the collimator opening increases and the greater surface is irradiated. The Y collimator also have a greater effect on the OF_{air} which is called collimator exchange effect (Vadash and Bjärngard, 1993).

Collimator exchange effect should be taken into consideration, due to its impact on dose calculation via OF (Jensen, 2003). Besides, "A" value in Vadash formula minimizes the collimator exchange effect, in calculating the equivalent squares which plays an important role in the patient dose calculation and treatment planning. The value of "A" constant depends on head accelerator design and should be calculated for each machine and energy.

In this study, a new simple protocol based on the selection of best dosimetric data was proposed to obtain "A" value in Vadash relation to predict the equivalent square field size for rectangular fields which compensates collimator exchange effect in OF_{air} . Table 1 data shows that the OF_{air} has small variations with field size. For the linear accelerator used in this study the values range from about 0.983 to 1.038 in 6MV and from 0.731 to 1.05 in 18 MV, for the measured fields.

Collimator exchange effect is obviously seen in Table 1 data. For example, the OF_{air} for a 30×5 cm² field in 18 MV is greater than OF_{air} of 5×30 cm² field due to using the upper jaw to build the field length which has the greater effect on scatter. The minimum Δ_{min} was equal to 0.002 for 10×30, 10×20 and 5×10 cm² and the maximum difference was 0.025 for 5×40 cm² for 6MV energy. For 18 MV energy the minimum Δ_{min} was equal to 0.002 for 10×20 cm² and the maximum difference was 0.285 for 5×40 cm².

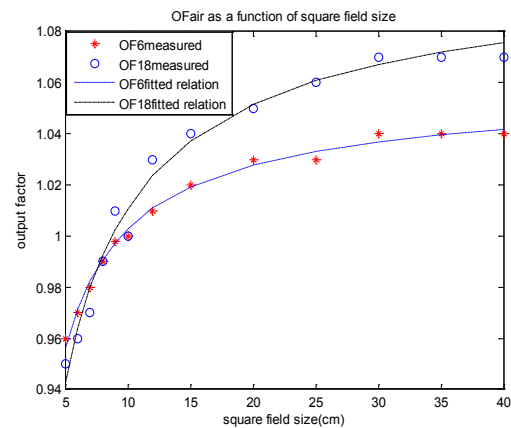


Figure 2. The Measured OF_{air} and Fitted Relations (Eq. 12) are Shown in Figure 2 as Functions of Square Field Size.

As shown in Table 2, the values of "A" =1.42 and 1.55 with respect to σ_{min} =0.98 and 2.3 for 6 and 18 MV energies were selected, respectively among 6 calculated values for "A" constant. Vadash et al (Vadash and Bjärngard, 1993) obtained value of 1.8 for "A" constant for Philips accelerator in 6 and 25MV. M.K.Yu et al (Yu et al., 1995) divided measurements in two groups. In the first group field sizes were defined by X and Y jaws. Field sizes were determined by MLC and Y jaws where X jaw settings were fixed in constant distance from the centerline for the second group. They reported constant value 1.7 for Varian Clinac 600CD and 1.78 and 1.85 for Varian Clinac 2300CD, X and Y jaws in 6 and 15MV respectively and 3.38 for Varian Clinac 2300CD, MLC and Y jaws in 6MV. Kim et al (Kim et al., 1998) represented a function for "A" value which depended on distances of source to every jaws and detector plane. The obtained value for Varian Clinac 2300CD in 8MV was 1.5. Norvill et al (Norvill and White, 2008) calculated OF_{air} for square and rectangular fields in 6 and 18MV and equivalent square values for the rectangular field sizes by fitting interpolation and substituting values of -A- range (1-2.6) in Vadash formula and finally represented A value 1.8 for Siemens Oncor linear accelerator.

In conclusion, a new simple protocol based on dosimetry data was proposed to calculate "A" value in Vadash relation to predict the equivalent square field size for rectangular fields which compensates collimator exchange effect in OF_{air} . The coefficients "A"=1.42 and 1.55 have the minimum standard deviations for differences between calculated and measured equivalent field sizes in 6 and 18 MV energies, respectively. Hence, these values were selected as the final coefficients for equivalent field size assessment in Vadash relation.

The results of proposed protocol presented good agreement with other studies and can be used for calculation of equivalent square field sizes. However, it is necessary to accomplish and complete the study by more dosimetry experiments to expand the results and improve the protocol.

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