THE EXPERIMENTAL ASSESSMENT OF BUILD UP FACTOR AND ATTENUATION COEFFICIENT OF BRASS COMPENSATOR APPLIED IN INTENSITY-MODULATED RADIATION THERAPY (IMRT) FOR 6MV PHOTON BEAM

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ABSTRACT

Introduction: *Recent compensators are commonly applied in IMRT. The precise properties of applied compensators such as thickness, attenuation coefficient and build up factor are intensively important for IMRT calculations.*

Method: *The brass compensator used for 6 MV photon beam was studied to estimate the relative effect of thickness and field size on IMRT calculations. Various field size together with several compensator thicknesses were examined.*

Result: *The average reduction of effective attenuation coefficient (EAC), for the fields of 10×10* cm^2 *to 20×20* cm^2*, was 9.94%. By increasing the field size, EAC was decreased. The major reduction of EAC due to increasing field size was found to be 9.62%. The build up factor was increased by 2% to 21.8% respect to field size and compensator thickness. Also, the build up factor was increased by adding up the thickness. The rate of changes ranged from 24% to 48 %.*

Conclusion: *The compensator thickness and field size are significantly important to calculate the effective attenuation coefficient and build up factor.*

Keywords:*Intensity Modulated Radiation Therapy, Compensators, Brass, Effective Attenuation Coefficient, Build up Factor*

Introduction:

Radiotherapy is one of the effective methods in the treatment of cancer. It is used alone or in combination with surgery or chemotherapy. Half of the cancer patients use radiotherapy as a part of their treatment(1-3). The primary goal of radiotherapy is to deliver the highest dose to cancerous tissue and the lowest to normal organs(2, 4, 5). As the tumor is not isolated, it is not possible to irradiate tumor cells alone. Also, success in removing the tumor depends on technical factors(6). In addition, for an appropriate treatment, accurate definition and description of tumor and treatment volume, high daily repeatability of patient positioning, and accurate dose delivery to the target volume with an appropriate dose of gradient to critical organs and healthy tissues are required. When some of these requirements are not met, a part of tumor may receive lower dose, and eliminate the chance of cancer cell proliferation would happen(7). In the recent methods of radiotherapy, intensity modulated radiotherapy (IMRT) technique is used, which needs very accurate calculations. In IMRT, the output of the beam must be accurately transferred to the depth of interest in tissue, while in different parts of the target volume and under risk organs in the beam path, various intensities of beam should be received. In other words, the uniform intensity of the output beam from the accelerator should be modulated in treatment volume(8, 9). Inverse planning method is used in IMRT to calculate the dose in the treatment volume. Target volume and critical organs are determined by CT scan images of tumors. Then the maximum, minimum, and average permissible doses are determined by TPS. TPS software propose several fields based on the optimization algorithm for which it is defined. In these fields, changes in the relative dose are indicated in each area, which show dose changes relative to the uniform open field. The process is called modulated intensity plan. To reach the dose levels, fields must be planned and implemented in accordance with the specification set via treatment planning software. TPS determines there are two ways to deliver radiation dose in IMRT: multileaf collimator and compensators(8-10). The advantages of using compensators are increasing the efficiency of patient treatment, and providing continuous dose. Other benefits of compensators are faster quality assurance program performance, easier dosimetry data management, less running time, less erosion of the accelerator, and lower requirement of shield in treatment room(11). Recently, tendency to use compensators for IMRT treatment has increased(12). The formula used to calculate the thickness of compensator is as follows(8):

$$x = -\frac{1}{\mu_{eff}} \ln\left(\frac{D}{D_0}\right) \qquad \text{Eq.1}$$

is the relative dose; μ_{eff} is the attenuation coefficient of the compensator, and *x* is the thickness of the compensator(8). The thickness of the treatment planning software (TPS) can be sent to an automatic analysing system (such as, Parscientific, Model ACD-3, Odense, Denmark), and the compensator volume can be exploited(13). In the method of constructing compensators, using automatic analysing machines, the maximum reported error in the beam intensity as compared to the ideal state is ±2.5%, which is the half of acceptable error by ICRU(14).

The exact calculation for the optimal dose delivery with acceptable error level to the desired depth therapy is crucial to fabricate a compensator. therefore, the exact calculation of effective attenuation coefficient of the compensator is an important factor. Effective attenuation coefficient of the compensator is not only dependent on the material and the nominal energy of the accelerator, but also it changes by variations in radiation conditions. The other important factors influence on the attenuation coefficient of the compensator are the sizes of treatment field size and compensator thickness(15, 16). In several studies, μ_{eff} is calculated using various materials by Mont Carlo simulation (MC) (17-19) or experimental measurements(20) in various radiotherapy conditions. But the error rate in providing doses needs to be calculated due to the lack of the consideration of factors affecting attenuation coefficient of brass compensator. In the present research, after studying the changes in the effective attenuation coefficient based on the field size and compensator thickness, the error rate was calculated. The Buildup factor was also studied in this research. Considering to this fact that scattering particles are produced at the presence of compensator, therefore the build up factor which is used for counting the primary and scattered radiations can be applied for any definite geometry(21).

Methods and Materials

The applied brass alloys in this study was commercial brass contains:FCD (Cuzn39pb3) with 3% lead, 61.5% copper, and 35.5% zinc casted and constructed by cold rolling. Using dosimeter MapCHECK 2 model 1177, solid phantom, and SP34 (Solid Phantom 34), the effect of compensator thickness and field size on the effective attenuation coefficient and build up factor of the compensator was assessed by photon 6 MV Elekta SL 75/25 medical linear accelerator. For all irradiations carried out by 100MU, the distance to phantom surface was set to 100cm. The brass compensator of various thicknesses was placed in the tray at the distance of 672 mm from the accelerator. Dose measurements in all conditions were carried out in solid water phantom at the depth of 5cm (equivalent to tissue) by MapCHECK 2 dosimeter. To calculate the effective attenuation coefficient, Eq1. was applied. In this equation, *D* is the measured dose in the field with compensator; D_0 is the measured dose in the field without compensator; μ_{eff} is the effective attenuation coefficient and x is compensator thickness was including 0.5, 1, 1.5, 2, 3, 4, 5, and 6 cm. The compensator was placed 672 mm in front of the head of gantry. In this section, the absorbed dose was measured with and without compensator at the depth of 5 cm in solid water phantom. Then, it was re-measured (D) for each thickness of the same depth. The field size for the thicknesses was ranged from 1×1 cm^2 to 20×20 cm^2. The effective attenuation coefficient of square fields for dimensions of 1, 2, 3, 4, 6, 8, 10, 15, and 20 cm and the thicknesses of 1, 1.5, 2, 3, 4, 5, and 6 cm was calculated by experimental measurements. For the photon beams, from 6MV to 18MV energy, the measurement error of MapCHECK dosimeter for dose values more than 8cGy was less than 1%(22). All the measurements were conducted for the photon beam of 6 MV with the dose of 100 cGy.

Build up Factor Calculations:

The effective attenuation coefficient vs field size was depicted by Excel 2013. The proportional quadrative equation was then found. The linear attenuation coefficient was derived by extrapolation to field size of 0×0. The depth dose at this hypothetical field size results from primary radiation (scattered radiations will not change the depth dose at this field size). The build up factor of square fields for dimensions of 1, 2, 3, 4, 6, 8, 10, 15, and 20 cm and the thicknesses of 1, 1.5, 2, 3, 4, 5, and 6 cm was calculated by experimental measurements.

Uncertainty in dose calculations:

The following formula was used to calculate the error percentage:

$$\%\varepsilon = \left| \frac{e^{-\mu_{eff}(x,F)x} - e^{-\mu_{eff}(x=1\,cm, F=10\times 10\,cm^2)x}}{e^{-\mu_{eff}(x,F)x}} \right| \times 100$$

Eq2.

μ_{eff}, x, F and ε are effective attenuation coefficient, compensator thickness, field size and error level, respectively.

Results:

Figure 1 and Figure 2 show the changes in the effective attenuation coefficient versus compensator thickness and field size.

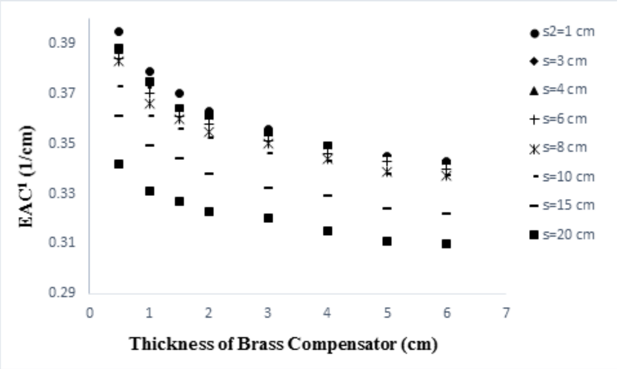

Figure 1. Variation of the μ_{eff} vs. compensator thickness for various field sizes.

[1] Effective Attenuation Coefficient

[2] Side of square field

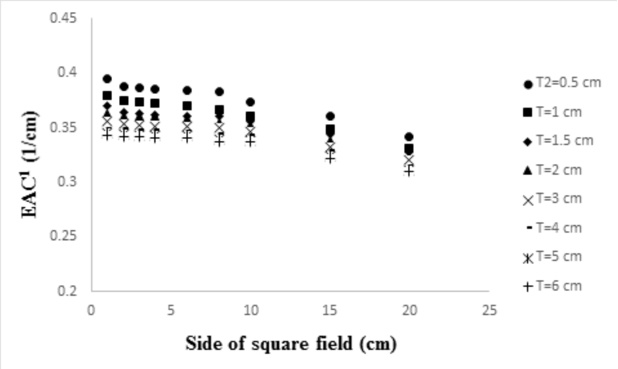

Figure 2. Variation of the μ_{eff} vs. the field size for various thicknesses of brass.

[1] Effective Attenuation Coefficient

[2] Thickness of compensator

The maximum acceptable error in radiotherapy is 5% that 3% of which is because of the error of measurements and dosimeter calculations, and the rest 2% refers to the treatment planning error(22). The error calculations, Table1, indicates that compensator thickness and field size potentially leads to more than 20% error in dose delivery of the treatment volume in the calculation of the effective attenuation coefficient.

Table 1. The error in dose delivery for thickness and field size

		Thickness (cm)							
		0.5 cm	1 cm	1.5 cm	2 cm	3 cm	4 cm	5 cm	6 cm
Field size (cm^2)	1×1 cm^2	1.7	1.8	1.4	0.4	1.5	4.7	7.7	10.2
	2×2 cm^2	1.4	1.4	0.5	0	2.1	4.7	8.1	10.8
	3×3 cm^2	1.3	1.3	0.3	0.2	2.7	53.1	8.6	10.8
	4×4 cm^2	1.2	1.1	0.2	0.2	3	5.1	8.6	11.3
	6×6 cm^2	1.2	1	0	0.6	3	5.8	8.6	11.8
	8×8 cm^2	1.1	0.5	0.2	1.2	3.2	6.6	10.4	13.4
	10×10 cm^2	0.6	0	0.7	1.8	4.4	6.9	10.9	13.4
	15×15 cm^2	0	1.2	2.5	4.5	8.3	12	16.9	20.9
	20×20 cm^2	1	3	5	7.3	11.6	16.8	22.1	26.4

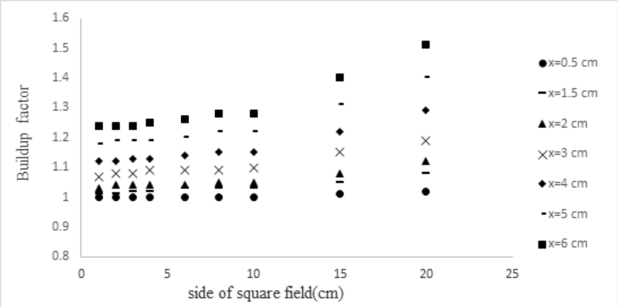

Figure 3. Variation of the buildup factor vs. the field size for various thicknesses of brass.

Build up factor results:

Figure 3 and Figure 4 show the changes of build up factor vs field size and thickness of brass compensator respectively.

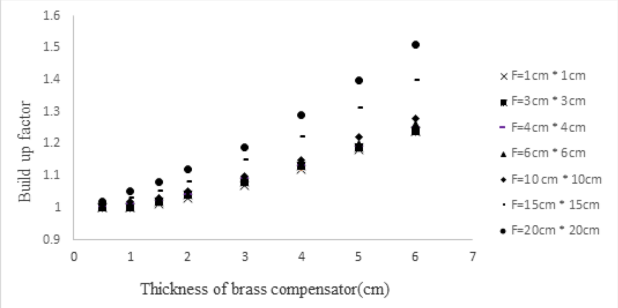

Figure 4. Variation of the buildup factor vs. compensator thickness for various field sizes.

Discussion:

The reduction in the effective attenuation coefficient by increasing thickness relates to the field size. As an average, μeff decreased the effective attenuation coefficient by 11.57%. For the fields of 10×10 cm^2 to 20×20 cm^2, the average reduction of the effective attenuation coefficient was 9.94% in Figure 1. By increasing the field size, the effective attenuation coefficient was decreased. The major reduction of the effective attenuation coefficient due to increasing field size was found to be 9.62%. This results is confirmed by a previous study carried out by T. Bartrum and his team(16). They showed that there is a significant correlation between the effective coefficient of brass and field size for 6 MV beam, so that the effective attenuation coefficient decreases with increasing field size. The results obtained by them show 2.5% disparity with the measurements of this study, which could be due to the difference in depth of measurement. By adding up the thickness from 0.5 cm to 2 cm, the effective attenuation coefficient decreased by 12.18% averagely. By adding up the thickness from 2 to 6 cm, the average decrease of the effective attenuation coefficient was obtained as 10.07 in Figure 2.

As it is illustrated in Figure 3, the build up factor is increased by 2% to 21.8% with field size and compensator thickness. Furthermore, the build up factor was increased by adding up the thickness (Figure 4). The rate of changes ranged from 24% to 48 %. One of the possible reasons for this increase is Compton scattering, considering to this fact that the probability of compton scattering increases with the number of electrons. It must be mentioned that the minimum and maximum values were obtained for the filed sizes of 1×1 and 20×20, respectively.

Conclusion:

In this study, the effect of changes in the thickness of brass compensator and field size on μ_{eff} and build up factor were assessed to be applied in IMRT. The results revealed that by increasing the thickness and field size, μ_{eff} was decreased. This study also demonstrated that the lack of consideration of compensator thickness and field size can lead to more than 20% error rate in dose delivery in the treatment volume. In other words, precise determination of compensator thickness and field size is significantly important for μ_{eff} calculation. The results of this study also showed that the build up factor increases by increasing field size and thickness of brass compensator.

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