Original Article

Interpretation of In-air Output Ratio of Wedged Fields in Different Measurement Conditions

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Abstract

Background: The collimator scatter factor (S_c) is one of the most important parameters in monitor unit (MU) calculation. There are several factors that impact S_c values, including head structures, backscatter in dose monitoring chambers, and wedges. The objective of this study was to investigate the variation of S_c with different buildup cap materials, wall thickness of buildup caps, source-to-chamber distances (SCDs), ionization chambers, and wedge angles in 6 MV photon beam. **Methods:** In this study, copper and Perspex buildup caps were made with two different thicknesses for each buildup cap. Measurements were performed on an Elekta Compact medical linear accelerator (6 MV) using RK dosimeter with a sensitive volume of 0.120 cm^3 and Farmer-type ion chamber with a sensitive volume of 0.65 cm^3. In all measurements, buildup caps and ionization chambers were positioned such as to stand vertically to the beam central axis. It was also investigated the effect of internal wedge with different angles (30° and 60°) different SCDs on S_c. **Results:** It was found in large field sizes, S_c values in Perspex buildup cap were higher than copper. Different SCDs and type of ion chamber and wall thickness of buildup caps had no significant influence on S_c values. The presence of wedge influenced S_c values significantly. Variation of S_c in wedged fields compared to open fields had a maximum deviation of 0.9% and 6.8% in 30° and 60° wedge angles, respectively. **Conclusion:** It was found that the presence of wedges had a significant influence on S_c and increases with wedge angles. As such, it should be taken into account in manual MU calculations.

Keywords: *Buildup cap, collimator scatter factor, ionization chamber, wedge*

Introduction

In radiation therapy, what is of importance is accurate monitor unit (MU) calculation to provide the dose given to the planning target volume and decreasing the doses excessive to the critical organs at risks.[1-3] In general, the absorbed dose at the point inside a phantom or patient involves two components, the primary (original photons released from the source) and scatter radiation (photons and electrons scattered from the linear accelerator treatment head and phantom), to reach the point of interest.[1,4-7] The total scattering factor (S_{cp}) is one of the components that affect MU calculation.[4,8,9] The S_{cp} involves the collimator scatter factor (S_c) and the phantom scatter factor (S_p). The S_c, also known as the head scatter factor or in-air output ratio,[4,10,11] is defined as the ratio of collision with water kinetic energy released per unit mass in the free space of an arbitrary field to that of a reference field size (10 cm × 10 cm).[10] According to the American Association of Physics in Medicine (AAPM) Task Group number 74 (TG74) recommendations, the S_c can be determined in air using miniphantoms in cylindrical shapes (buildup caps) with usually the ionization chamber located at 10 g/cm^2 water equivalent depth.[10] This depth is enough to stop contaminating electrons from getting the detector volume. In general, S_c measurements using low-Z miniphantom materials (with atomic number close to water) for large field sizes and high-Z miniphantom materials for small field sizes are recommended.[6,10] Several factors influence S_c values such as primary collimator, flattening filter, secondary collimator, tertiary collimators (MLCs), and beam-modifying devices such as wedges.[7,11,12] The wedges are generally used as beam modifier devices, to optimize the distribution of target volume dose in radiation therapy.[4,13] When placed in the path of radiation beam, the wedges

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decrease the intensity of the beam.[13] Usually, a single S_c value is used for the patients' MU calculations, which are usually measured for open-beam fields, whereas the presence of the wedge changes S_c value; if this variation of S_c value is not taken into account in MU calculations, it may ultimately lead to major tumor dose differences for the patient, especially for MU calculation of palliative cases which dose calculation is performed manually.[5,11,14] To conduct S_c measurements, the standard solid-state drive (SSD) (100 cm) is used, but in small field sizes, to ensure that the buildup cap is completely covered by small fields and electron equilibrium condition, the extended SSD should be used.[15] Several studies have investigated the variation of S_c in different conditions. Jun *et al*. studied the variation of S_c with different miniphantom materials and reported that the total correction factor increased with increases in field size and miniphantom longitudinal thickness.[16] In another study, Jun *et al*. showed that at small longitudinal thicknesses, the in-air output ratio correction factors for polymethyl methacrylate (PMMA) and graphite are close to 1. The maximum magnitudes of the in-air output ratio correction factors occur at the largest collimator setting (40 cm × 40 cm) and the largest miniphantom longitudinal thickness (30 g/cm^2): 1.008 ± 0.001 for 6 MV and 1.012 ± 0.001 for 15 MV, respectively.[8] Iftikhar assessed the output factors using different ionization chambers and miniphantoms and reported that the use of miniphantoms with Z_{eff} close to water and ionization chamber is the best choice for S_c measurements for large field sizes.[6] Appasamy *et al*. studied S_c using indigenously designed columnar miniphantom. They found that S_c at 1.5 cm depth is >10 cm, and the miniphantom material, chamber volume, and difference of SSD had no significant impact on S_c, whereas the existence of internal wedge has a significant effect on S_c. They suggested the use of PMMA miniphantom for greater field sizes and brass for smaller field sizes.[5,11,14] Chegeni *et al*. studied S_c using Electronic Benefits Transfer (EBT2) film dosimeter with water and Cerrobend buildup caps and Farmer-type ionization chamber with polystyrene miniphantom. They found that EBT2 film with water buildup cap can be a good substitute for the ionization chamber.[17] Jomehzadeh *et al*.[1] studied the effect of material and wall thickness of miniphantoms on S_c measurements in irregular fields shielded by Cerrobend. They reported that using brass compared to copper and Perspex is a good choice for the measurement of S_c.[1] In most treatment planning systems, entering S_{cp}, S_c, and S_p are necessary.[9] What is important is measuring S_c in different conditions with and without wedges to calculate the accurate MU and reduce the error in achieving the desired dose to the target volume. This study aimed to design miniphantoms and investigate the variation of S_c with different miniphantom materials, wall thickness, SSDs, ionization chambers, and S_c variation with wedges in 6 MV photon beam.

Materials and Methods

Photon beam, chambers, and miniphantom design

In this study, 6 MV photon beam of Elekta Compact Linac is used. The Farmer-type ion chamber FC65-P (Scanditronix, Wellhofer) with a sensitive volume of 0.65 cm^3, outer diameter of 7 mm, inner diameter of 6.2 mm, and total active length of 23.1 mm with an inner electrode of aluminum was used. The second chamber was RK ionization chamber (Scanditronix, Wellhofer) with an active volume of 0.12 cm^3, inner diameter of 4 mm, outer diameter of 7 mm, and air cavity length of 10 mm; the material for the central electrode and inner wall was a mixture of graphite and epoxy resin, and the material for the outer wall was PMMA. To investigate the influence of miniphantom material and wall thickness on S_c measurement, copper and Perspex were fabricated. The copper homemade buildup cap was designed with a wall thickness of 6.5 mm and 8 mm for farmer ion chamber and a wall thickness of 12 mm and 16 mm for RK ion chamber. Homemade Perspex buildup cap was designed with wall thicknesses of 15 mm and 18 mm for Farmer ion chamber and wall thicknesses of 14 mm and 19 mm for RK ionization chamber.

Head scatter factor (S_c) measurement

To measure S_c, the fabricated miniphantoms were fixed, using a stand, perpendicular to the beam central axis and the measurements were carried out for (5 cm × 5 cm, 10 cm × 10 cm, 15 cm × 15 cm, 20 cm × 20 cm, and 25 cm × 25 cm) field sizes. The S_c measurements were conducted at a source-to-chamber distance (SCD) of 100 cm and 120 cm. Due to different wall thicknesses, the SCD sets (distance from source to central electrode of chamber) varied for each miniphantom. Figure 1 shows the S_c measurement setup in different materials and wall thicknesses of miniphantoms in open and wedged fields.

The field size in each measurement was large enough to cover the buildup cap. All the readings were done three

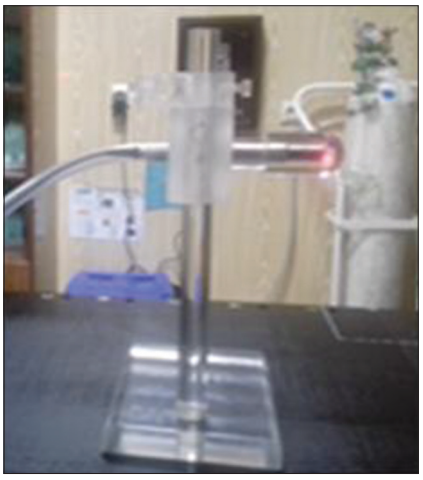

Figure 1: The S_c measurement setup in different materials and wall thickness of miniphantoms in open and wedged fields

times with 100 MU at 200 MU/min dose rate, and then, the average of the readings was obtained. To calculate S_c, the average of all the readings was normalized to the reference open-field (10 cm × 10 cm) readings average.[1,4,10] All the measurements were conducted in a wedged angle of 30° and 60°.

Results

Effect of miniphantom material and ionization chambers

Table 1 shows S_c in-air values measured for open fields (5 cm × 5 cm–25 cm × 25 cm) using Perspex, copper miniphantoms, and Farmer, RK ionization chambers at SCD = 100 cm. In Farmer ionization chamber measurements, the maximum and minimum deviation of S_c values using two miniphantoms were 0.294% and 0.099%, respectively. The S_c value in copper miniphantom compared to Perspex was higher for field sizes smaller than 10 cm × 10 cm and lower for field sizes larger than 10 cm × 10 cm. In RK ionization chamber measurements, the maximum and minimum deviation of S_c values using two miniphantoms were 0.296% and 0.196%, respectively.

To assess the effect of ionization chamber on S_c measurements, Farmer and RK ion chambers using Perspex and copper miniphantoms were utilized. An average deviation of 0.371% was observed [Table 1].

Effect of miniphantom thickness

Figure 2 shows that the variation of S_c for 6 MV open fields measured using Perspex and copper miniphantoms with different wall thicknesses and RK and Farmer ionization chambers at SCD = 100 cm. In Perspex cap measurements, with increases in wall thickness, S_c values decreased in field sizes larger than 10 cm × 10 cm for both ionization chambers. In case of Farmer chamber measurements, the percentage of deviation in S_c values measured in Perspex with different wall thicknesses varies from 0.097% to 0.103%; in RK chamber, it varies from 0.098% to 0.390%.

In copper miniphantom measurements, S_c value increased with increases in wall thickness in field sizes larger than 10 cm × 10 cm in both ion chambers. A maximum deviation of 0.393% was observed in 25 cm × 25 cm field size, between different thicknesses compared to 6.5 mm.

Effect of source-to-chamber distance

Figure 3 shows a plot of S_c variation for 6 MV open fields with different SCD. From the data, it was observed that the impact of SCD on S_c, in small field sizes, was negligible but was noticeable in large field sizes. It was found that with SCD increasing, the output factor decreased in RK ion chamber, while it increased in the Farmer.

Impact of beam-modifying devices on S_c

The S_c values measured in wedged fields compared to open fields are shown in Table 2. Measurements were carried out using Perspex miniphantom with 15 mm wall thickness and Farmer-type ionization chamber at SCD = 100 cm. Results demonstrated that the S_c value measured in open fields compared to the S_c value measured in wedged fields had a maximum and minimum deviation of 0.876% and 0.395% for 30°, and 6.628% and 2.664% for 60° angles of wedge, respectively. Table 3 presents the comparison of the measured data.

Figure 4 presents S_c values using Perspex miniphantom with 14 and 15 mm thicknesses and Farmer, RK ion chambers at SCD = 100 cm. The data led to the conclusion that the S_c value in wedged beam is greater than open beam in field sizes larger than 10 cm × 10 cm. Furthermore, all

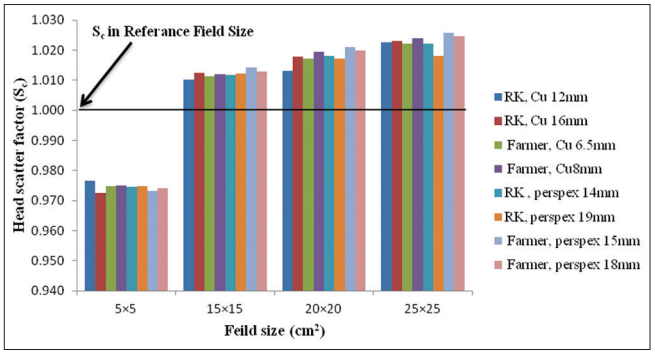

Figure 2: Variations of S_c in Perspex and copper miniphantoms with different wall thickness in open fields using RK ionization chamber including 12 and 16 mm of copper (cu) and 14 and 19 mm of Perspex and Farmer ionization chamber including 6.5 and 8 mm of copper (cu) and 15 and 18 mm of Perspex. (Source-to-chamber distance = 100 cm)

Table 1: Variation of S_c using Perspex, copper miniphantoms, and Farmer, RK ionization chambers (source-to-chamber distances=100 cm)

Field size (cm^2)	Farmer chamber (0.65 cm^3)		RK chamber (0.12 cm^3)		Percentage of deviation		
	Perspex 15 mm (A)	Copper 8 mm (B)	Perspex 14 mm (C)	Copper 12 mm (D)	(B-A) × 100/A	(C-A) × 100/A	(D-C) × 100/C
5	0.972	0.974	0.975	0.977	0.206	0.309	0.205
10	1	1	1	1	0	0	0
15	1.013	1.012	1.012	1.009	−0.099	−0.099	−0.296
20	1.021	1.018	1.015	1.012	−0.294	−0.588	−0.296
25	1.026	1.023	1.021	1.023	−0.291	−0.486	0.196

Table 2: The variation of S_c with field size for open and wedged fields in 30 and 60 angles

Field size (cm^2)	Open field (A)	Wedge 30° (B)	Wedge 60° (C)	Percentage deviation	
				(A-B)/A×100	(A-C)/A×100
5	0.972	0.968	0.944	0.411	2.881
10	1	1	1	0	0
15	1.013	1.017	1.040	−0.395	−2.664
20	1.021	1.028	1.072	−0.686	−4.994
25	1.026	1.035	1.094	−0.876	−6.628

Table 3: This study measured S_c for open square fields with Perspex (15 mm) and Farmer chamber (0.65 cm^3) in source-to-chamber distances=100 cm compared with published data

Field size (cm^2)	Our study (A)	TG-74 (B)*	Appasamy *et al*. (C)	Percentage deviation	
				(A-B) × 100/B	(A-C) × 100/C
5	0.972	0.971	0.972	0.103	0
10	1	1	1	0	0
15	1.013	1.015	1.014	-0.196	-0.099
20	1.021	1.022	1.027	-0.099	-0.583
25	1.026	-	1.032	-	-0.580

*AAPM TG74: American Association Physics in Medicine Task Group number 74

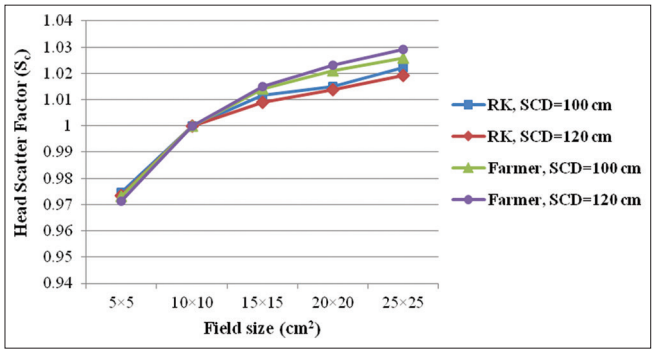

Figure 3: Variation of S_c in open square fields using Perspex (14 and 15 mm) at different source-to-chamber distances and ionization chambers

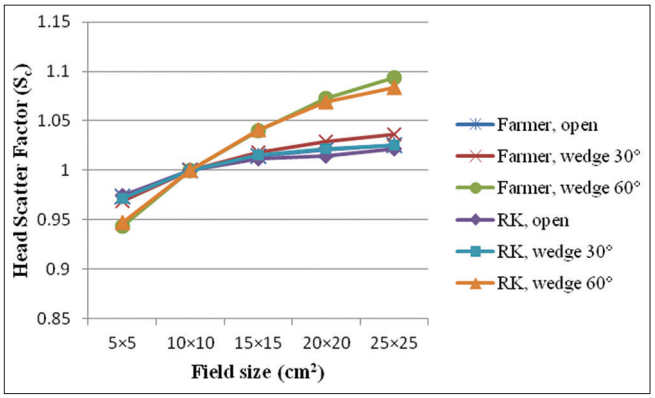

Figure 4: Variation of S_c in open and wedged fields using Perspex (14 and 15 mm) miniphantoms and RK, Farmer ionization chambers. (source-to-chamber distance = 100 cm)

in all, S_c in wedged beam is lower than open beam in field sizes lower than 10 cm × 10 cm.

Discussion

The characteristics of an ideal miniphantom are as follows: (a) the overall width of the miniphantom should be physically smaller than the high-dose region, (b) miniphantom should be sufficiently thick to eliminate electron contamination, and (c) should be able to be situated exactly and reproducibly.[18] Furthermore, in S_c measurement, lateral electron equilibrium is necessary, and the miniphantom must be fully covered by the radiation beam without the penumbra region.[10] For small field measurements, high *Z* materials, extended SSD, and detectors with small sensitive volume are recommended.[10,17,19] Based on the data [Table 1], the type of miniphantom materials has no significant impact on S_c measurements in 6 MV and is in good agreement with the findings by Iftikhar[6] and Appasamy *et al*.[14] In higher energies with increasing field size, instances of large scatter and reductions in mean energy of the beam occur, which interact differentially with different buildup cap materials and cause variation in S_c measurements. However, in low energies, this behavior may be reversed and no differential impact with buildup cap materials is occurred. Miniphantoms with wall thicknesses equal to d_{max} might allow electron contamination to reach the detector sensitive volume and wrongly increase the reading principally in larger field sizes.[10] Increasing field size alters the effective energy of the beam and as a consequence, changes the scatter, transmission, and buildup in the miniphantom.[19] Using a miniphantom with a smaller wall thickness still stops all contamination in the electrons, reducing the amount of scatter and attenuation in the miniphantom.[10] Jursinic suggested that miniphantoms with wall thicknesses <10 cm can be useful for photon energies of 6 and 15 MV.[19] Figure 2 demonstrated that S_c values at wall thicknesses larger than d_{max}, in copper miniphantom, are greater than those of d_{max} (in agreement with Li *et al*.[8,16] findings). In Perspex

buildup cap, with increases in wall thickness beyond the d_{max}, the S_c decreases (in agreement with the findings by Appasamy *et al*.[5] and AAPM TG-74[10]). Table 2 depicted that the ionization chamber type had no significant impact on S_c; these results are in good agreement with those by Iftikhar.[6] Chen *et al*. reported that for the radiation fields of ≥4 cm × 4 cm, no differences were observed in S_c measurements by three ionization chambers (0.6, 0.13, and 0.01 cm^3 sensitive volume).[15] However, for small field sizes, particularly for fields as small as 1 cm × 1 cm, great alterations were found in S_c values, even though the CC01 (0.01 cm^3) and CC13 (0.13 cm^3) chambers have small active volumes.[15] The standard SSD (SSD = 100 cm) setup is usually used to measure S_c for large fields, but extended SSD should be used for small fields to ensure that the fields completely cover the buildup cap and electron equilibrium is established; otherwise, great errors would arise.[15] The impact of SSD on S_c was studied by measuring S_c at different SSD (100 and 120 cm) in Perspex buildup cap and RK, Farmer ionization chambers [Figure 4]. These results show that SSD has no impact on S_c; this is in good agreement with the data in the study by Appasamy *et al*.[5,14] In the present study, the influence of wedge on S_c [Figure 4 and Table 2] demonstrated that in field sizes larger than 10 cm × 10 cm, S_c increases in wedged fields compared to open fields. S_c also increases as the wedge angle does. This is due to increased scattering photons from the wedge filter, which increases in proportion to increases in field sizes above 10 cm × 10 cm. This is in agreement with the results of the studies by Appasamy *et al*.[5,11,14] and Ashokkumar.[7,12]

The published data concerned S_c with Perspex at 15 mm wall thickness and Farmer chamber.[10,14] Compared with Appasamy *et al*.[14] and AAPM TG-74,[10] the present study showed a maximum deviation of 0.580% and 0.196% for a field size of 25 cm × 25 cm, respectively. This deviation may be due to what Appasamy *et al*.[14] and AAPM TG-74[10] have measured S_c in 10 cm, but the present study was carried out in 1.5 cm wall thickness.

Conclusions

S_c measurements were carried out in 6 MV square fields using low and high *Z* buildup caps with different wall thicknesses and ionization chambers. The results revealed that the effect of copper and Perspex buildup cap as well as that of wall thickness in Farmer or RK ionization chambers (with different active volume) on S_c measurements in 6 MV Elekta Linac are not significant; also, different SCDs had no significant impact on S_c measurement in large field sizes. However, it was found that the presence of wedge has significant influence on S_c measurement, increasing as the wedge angle does. Therefore, it should be taken into account in manual MU calculations.

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Conflicts of interest

There are no conflicts of interest.

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