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## Measurement of Head Scatter Factor for Linear Accelerators using Indigenously Designed Columnar Mini Phantom

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A columnar mini phantom is designed as recommended by ESTRO to measure the Head Scatter Factor ( $S_C$ ) for 6 MV beam of two linear accelerators. The measurement of  $S_C$  at different orientations of the chamber, parallel and perpendicular at 1.5 cm depth predicts the deviation of 2.05% and 1.9% for Elekta and Siemens linear accelerators respectively. The measurement of  $S_C$  at 1.5 cm is higher compared to 10 cm depth for both the linear accelerators suggesting the electron contamination at 1.5 cm depth. The effect of wedges on  $S_C$  yields a significant contribution of 3.5% and 5% for Siemens and Elekta linear accelerators respectively. The collimator exchange effect reveals the opening of upper jaw increases the  $S_C$  irrespective of the linear accelerator. The result emphasizes the need of  $S_C$  measurement at 10 cm. The presence of wedge influences the  $S_C$  value and the SSD has no influence on  $S_C$ . The measured  $S_C$  values are in good agreement with the published data.

**Key Words:** Head Scatter Factor, Columnar Mini Phantom, Collimator exchange effect, ion chamber, linear accelerator.

### Introduction

The output of a medical linear accelerator for a given field size is calculated from the output measured for a reference field size under a reference condition by applying the total scatter correction factor ( $S_T$ ) or output factor. All the dosimetric systems [8, 7, 10, 3, 15] used in linear

accelerator calculations require, that dose to a point in a phantom, be separated into a primary component arising from photon and electron fluence from the head of the accelerator and a secondary component arising from scatter in the phantom. This separation of accelerator-head-scatter and phantom-scatter components is necessary since the linear accelerator collimators, external blocks and the missing tissues modulate these two scatter components differently. The basic method for separating these components of dose involves the measurement of the total scatter factor in a phantom ( $S_T$ ), and either the head scatter factor ( $S_C$ ) or the phantom scatter factor ( $S_P$ ) individually [7, 11]. Direct measurement of  $S_P$  is difficult and it involve measurements at extended distances [7] or use of many different sizes of phantoms or blocks [11]. Hence the direct measurement of  $S_C$  is usually done as an in-air measurement with an ion chamber covered with a build-up cap. A number of studies has been reported in the literature Biggs P. J. et al [1,2], Mackie T. R. [14], Luxton G. [12,13], Tatcher M. [17], Heukelom S. [6], Sjogren R. [16], Venselaar J. [19] on the characteristics of  $S_C$  such as, the effect of contaminating electrons, collimator exchange effect, impact of introduction of beam modifying wedges etc, and measurement techniques of head scatter correction factor for high energy X-ray beams. For many years, measurements were made with a cylindrical build-up cap of wall thickness equivalent to  $d_{max}$ , the depth of maximum dose in a water phantom. The combination of  $d_{max}$  build-up cap and ion chamber is not strict photo fluence detection system, since contamination electrons generated in the head of the accelerator can penetrate the ion chamber. The  $S_C$  measured reflects the relative change of photon and electron fluence per monitor unit as a function of collimator opening. The recent ESTRO, literatures [5, 18] recommend the use of build-up caps of square or cylindrical shapes with long axis parallel with beam central axis, and the ion chamber is placed at 5 or 10 cm depth. These build-up caps are generally called as columnar miniphantoms and the 5 or 10 cm depth completely avoids dose from contamination electrons depending on energy. Although a depth of 5 cm is sufficient for most beam energies in clinical use, a standard depth of 10 cm has been recommended for all energies up to 40 MV. Therefore the combination of ion chamber with a columnar miniphantoms will act effectively as a photon-fluence detector system.

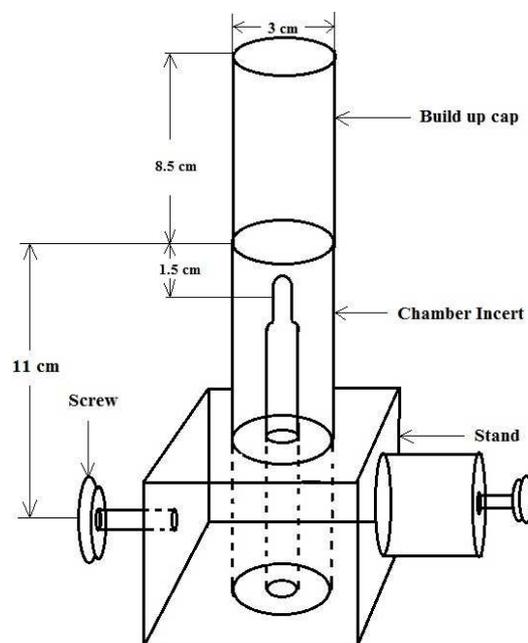
In this study an attempt has been made to design a columnar mini-phantom to meet both the ESTRO recommendations as well as the earlier method. The designed mini-phantom is used to study the head scatter factor in two linear accelerators and the effect of depth, field size, Source to Skin Distance (SSD) and wedges are analyzed for 6 MV photon energy.

## Materials and Methods

In this study 6 MV photon beams of Primus (Siemens Medicals Systems, USA) and Synergy (Elekta Medical Systems, UK) linear accelerators were used. The output factors and  $S_C$  were measured in-air with a farmer type ion chamber FG65C (Scanditronix- Wellhofer, USA) with Dose 1(Scanditronix- Wellhofer, USA) electrometer.

## Design of mini-phantom

In this study the PMMA (Poly Methyl Metha Acrylate) is used for the fabrication of the mini phantom which is a water equivalent polymer material  $(C_2O_2H_8)_n$ . The mini phantom has three parts namely stand, chamber insert and build up cap as shown in figure 1. The stand is used to position the chamber insert with buildup cap. Screws are provided to fix the chamber as well as the stand in the couch. The chamber insert is 11 cm length; with 3 cm diameter having a buildup of 1.5 cm when the chamber is used in perpendicular and parallel orientation without the buildup cap, suitable to insert 0.6 cc ion chamber. The buildup cap has the dimension of 8.5 cm length; 3 cm diameter. It can be attached with the chamber insert when ever measurements are made at 10 cm at parallel orientation.

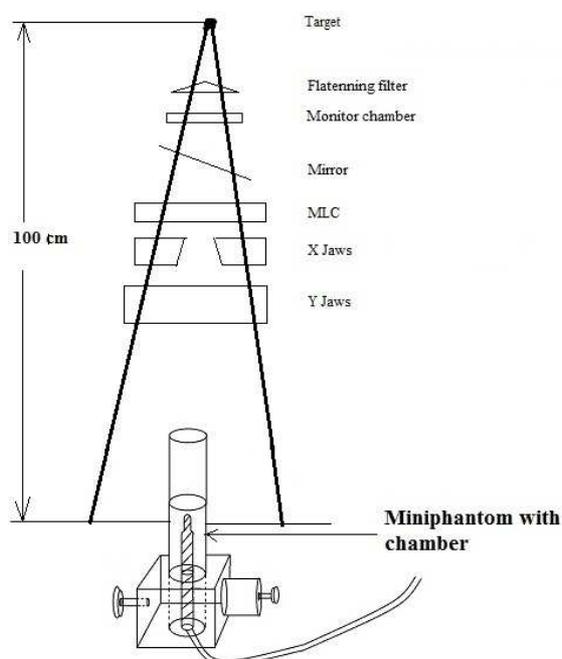


**Figure 1.** Line diagram of the designed miniphantom

## Head scatter factor measurement

To measure the head scatter factor the designed mini-phantom is positioned as shown in the figure 3. The mini phantom is positioned with stand and chamber insert without buildup cap. This will facilitate the measurement at 1.5 cm depth. After calibration of the linear accelerator, the readings were taken for the field sizes starting from  $3 \times 3 \text{ cm}^2$  to  $40 \times 40 \text{ cm}^2$  for the depth of 1.5 cm, with parallel and perpendicular orientations for both linear accelerators.

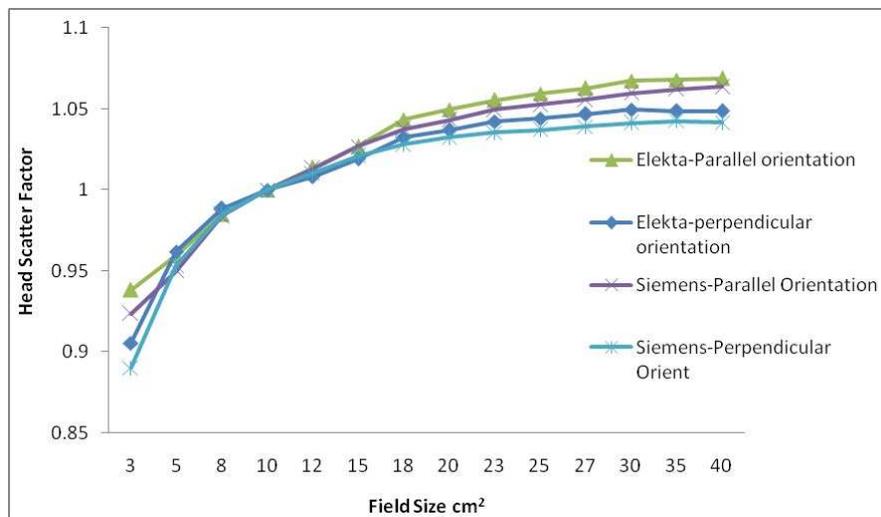
The mini phantom is repositioned with buildup cap, parallel to the beam, so that the longitudinal dimension is sufficient to prevent electron contamination. This will make setup for measurement at 10 cm depth. Sc measurements are made for various square field sizes from  $3 \times 3 \text{ cm}$  to  $40 \times 40 \text{ cm}$ . The cross section of the mini phantom is fully covered by the radiation beam, to provide sufficient lateral thickness, to eliminate electron contamination. Measurements are made at the depth of 10 cm, with parallel orientation with Source to Chamber Distance (SCD) of 100 cm for both Siemens and Elekta linear Accelerators. The measurements were also carried out with different Source to Surface Distance (SSD), wedged beams; and with extended SSD's for both the linear accelerators. All the readings were measured for 100 MU at the depth of 10 cm columnar miniphantom unless otherwise stated.



**Figure 2.** Experimental setup for the measurement of Head Scatter Factor

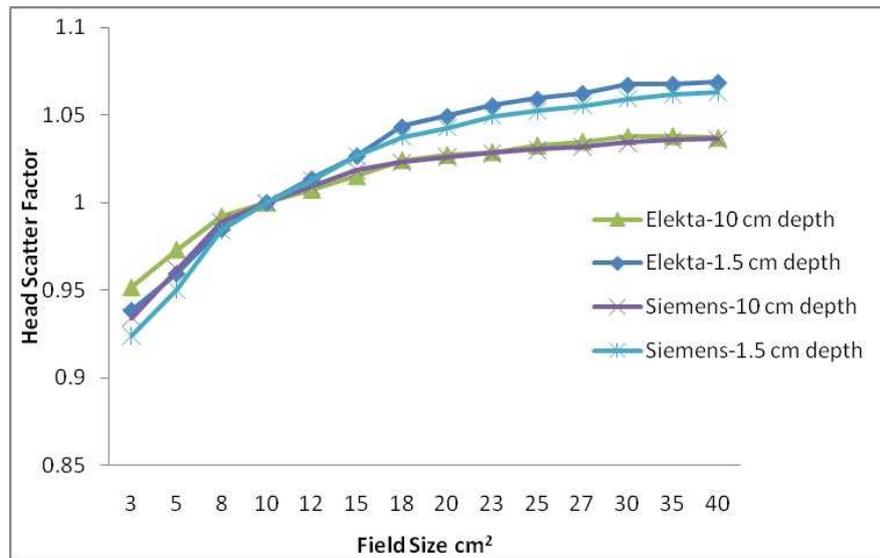
## Results

The measured Head Scatter Factor (HSF) for the 6 MV photon beam for various field sizes with the designed columnar miniphantom parallel and perpendicular orientation at 1.5 cm depth for Siemens and Elekta machines, are given in figure 3. A maximum deviation of 2.05% and 1.9% is observed in larger field size ( $40 \times 40 \text{ cm}^2$ ) for Siemens and Elekta respectively. No significant deviations were found for the fields sizes of  $5 \times 5 \text{ cm}^2$  to  $15 \times 15 \text{ cm}^2$ . The  $S_C$  is higher in parallel orientation than in the perpendicular orientation for larger field sizes.



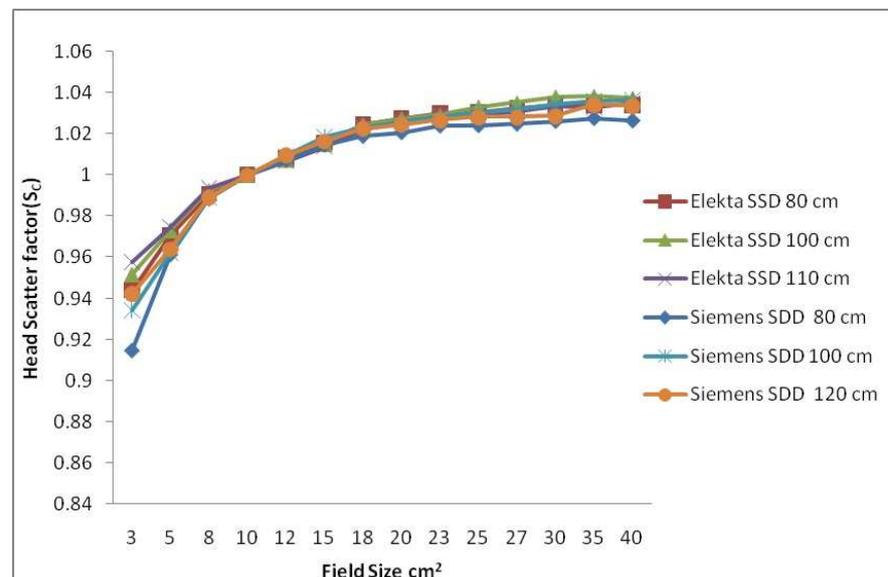
**Figure 3.** Variations of  $S_C$  with field size for parallel and perpendicular orientation with 1.5 cm depth of miniphantom for Siemens and Elekta

The figure 4 shows a plot of  $S_C$  for both Elekta and Siemens, at 1.5 cm and 10 cm for different field sizes. The  $S_C$  measured with 10 cm depth is less compared with the 1.5 cm depth for the larger field sizes for both the accelerators. A maximum deviation of 2.5% and 2.9% is observed in case of Siemens and Elekta at  $40 \times 40 \text{ cm}^2$  field sizes.



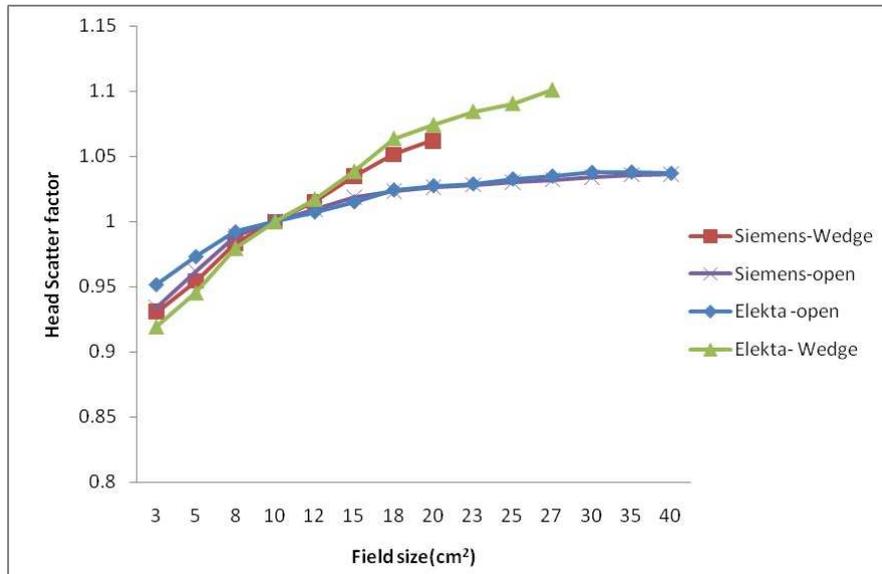
**Figure 4.** Variations of  $S_c$  with field size with 1.5 cm and 10 cm depth of miniphantom for Elekta and Siemens

The variation in  $S_c$  for different field sizes with different SSD is analyzed for the 6 MV photon beam for 80, 100 and 120 cm SSD in Siemens and Elekta accelerators. The columnar miniphantom of 10 cm measurement depth is used for this study. There is no significant variation of  $S_c$  for different SSD's for both linear accelerators (Figure 5).



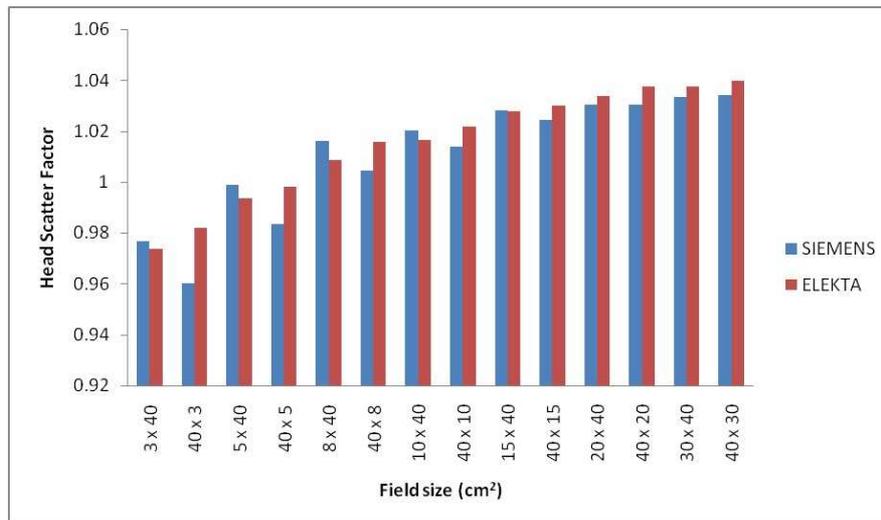
**Figure 5.** Variation of  $S_c$  with field size for different SSD for Elekta and Siemens

The miniphantom (at 10 cm) is used to study the effect of wedges on  $S_C$ . It is compared with that of open fields, given in the figure 6. The  $S_C$  values of with and without the wedge is compared in PMMA, the  $S_C$  reduces to 3.3% in smaller fields and increases up to 5% in larger fields.



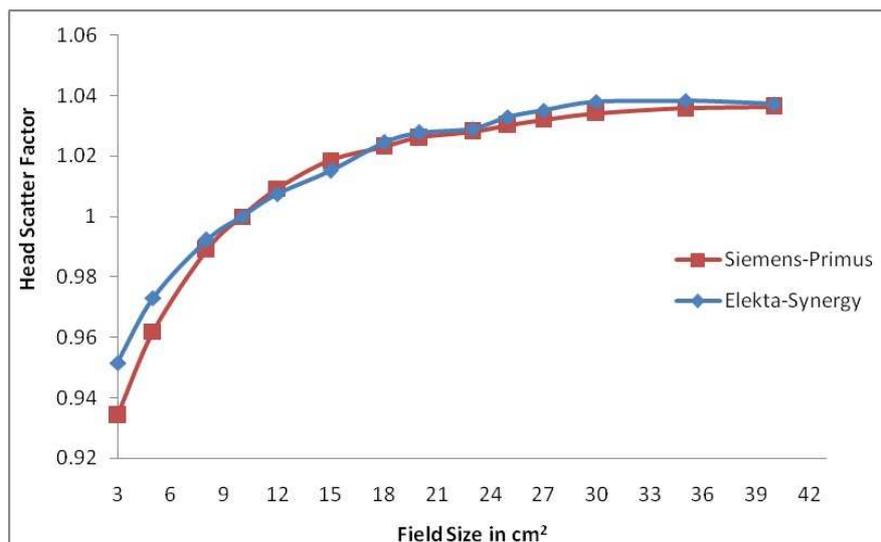
**Figure 6.** Variation of  $S_C$  with field size for wedge and open beams in Elekta and Siemens

The  $S_C$  is measured for the rectangular field sizes to check the collimator exchange effect and the readings for both linear accelerators are shown in figure 7. Here the upper jaw is y and the lower jaw is x in siemens, where as, it is reverse in Elekta.  $S_C$  is more, if the asymmetry is more (e.g 40 fi 3 cm<sup>2</sup>) and becomes negligible for larger field sizes (e.g. 40 x 30 cm<sup>2</sup>). In case of Siemens, it varies from 0.23 % to 0.85%, and in Elekta it varies from 0.06% to 1.5%.



**Figure 7.** Variation of  $S_C$  for rectangular fields with X and Y jaws exchanged in Elekta and Siemens

The  $S_C$  for the two linear accelerators (Siemens and Elekta) was measured for square field sizes from  $3 \times 3 \text{ cm}^2$  to  $40 \times 40 \text{ cm}^2$  with the designed columnar miniphantom of 10 cm depth. A maximum deviation of 1.85% is found in smaller field sizes. The  $S_C$  for Elekta is higher than the Siemens in small field sizes; it may be because of the additional scattering from the MLC in the collimator. No significant difference is absorbed from 10 to  $40 \text{ cm}^2$  field sizes, though these two accelerators differ in their collimator design. The  $S_C$  of the linear accelerators is shown in the table 1 and in figure 8.



**Figure 8.**  $S_C$  for different field sizes for Primus-Siemens and Synergy-Elekta linear accelerators

**Table 1.** The measured  $S_c$  at 10 cm depth for Primus -Siemens and Synergy-Elekta linear accelerators at 100 cm SSD

<b>Field Size cm<sup>2</sup></b>	<b>Siemens Primus</b>	<b>Elekta Synergy</b>
<b>3</b>	<b>0.9342</b>	<b>0.9515</b>
<b>5</b>	<b>0.9619</b>	<b>0.9731</b>
<b>8</b>	<b>0.9889</b>	<b>0.9922</b>
<b>10</b>	<b>1</b>	<b>1</b>
<b>12</b>	<b>1.0092</b>	<b>1.0074</b>
<b>15</b>	<b>1.0185</b>	<b>1.0152</b>
<b>18</b>	<b>1.0231</b>	<b>1.0244</b>
<b>20</b>	<b>1.026</b>	<b>1.0276</b>
<b>23</b>	<b>1.0281</b>	<b>1.029</b>
<b>25</b>	<b>1.0302</b>	<b>1.0329</b>
<b>27</b>	<b>1.032</b>	<b>1.035</b>
<b>30</b>	<b>1.0341</b>	<b>1.0379</b>
<b>35</b>	<b>1.0357</b>	<b>1.0382</b>
<b>40</b>	<b>1.0363</b>	<b>1.0372</b>

## Discussion

The head scatter factor plays a major role in output measurements of mega voltage radiation beams as well as in beam modelling of treatment planning systems. The  $S_c$  is caused by (i) source obscuring, (ii) head scattering, (iii) monitor chamber back scattering. The type of phantom and depth of measurement are the topics of interest and it has been reported by several authors [1, 2, 6, 12, 13, 14, 17, 16, 19]. The ESTRO has recommended a columnar mini phantom for the measurement of Head Scatter Factor [5]. The present study reports the design of a similar phantom and its measurements in 6 MV photon beam.

The measurement of  $S_c$  at 1.5 cm, both parallel and perpendicular orientations of the mini phantom for different linear accelerators are yielding slightly higher value for larger field sizes at parallel orientations (fig. 3) and are agreeing with that of Paul A. Jursinic [9] results. The maximum deviation observed is 2.05% for Siemens and 1.9% for Elekta 6 MV beams, suggesting that parallel orientation predicts higher  $S_c$  than perpendicular orientation. When the

measurements are made at 1.5 cm, the chamber is influenced by electron contamination and it is more in the parallel orientation.

Measurement of  $S_C$  increases with field sizes and also higher at 1.5 cm depth compared with 10 cm measurements suggesting the electron contamination at 1.5 cm, when the chamber is at 10cm, the longitudinal dimension is sufficient to prevent electron contamination (Fig.4). The present study emphasizes the need of  $S_C$  measurements at 10 cm for 6 MV photon beam. This is in agreement with that of Venselaar et al [19] and who has recommended  $S_C$  measurements at 10 cm depth. The measured  $S_C$  at 10 cm is compared with that of AAPM, TG-74 [21] data for both Siemens and Elekta Linear accelerators (Table 2). The present data is in good agreement with that of TG-74 reports.

**Table 2.** Comparison of Measured Head Scatter value with that of TG-74 data, at 10 cm depth

Field Size cm <sup>2</sup>	Siemens Primus	TG- 74	% of Deviation	Elekta Synergy	TG-74	% of deviation
3	0.9342	0.935	0.08	0.9515	0.958	-0.68
5	0.9619	0.961	0.09	0.9731	0.971	0.21
10	1	1	0	1	1	0
15	1.0185	1.017	0.08	1.0152	1.015	0.02
20	1.026	1.027	-0.09	1.0276	1.022	0.54
30	1.0341	1.032	0.2	1.0379	1.032	0.56
40	1.0363	1.032	0.41	1.0372	1.034	0.32

The electron contamination scatter correction factor ( $S_{cel}$ ) has been calculated as suggested by Venselaar et al [19] and it ranges from 0.9704 to 1.014 for the field sizes of  $40 \times 40$  cm<sup>2</sup> to  $3 \times 3$  cm<sup>2</sup>.

The role of SSD on the  $S_C$  has been evaluated by measuring the  $S_C$  at different SSD (80, 100, 110 cm) at 10 cm depth as shown in figure 5. The results suggest that the SSD has no influence on head scatter for both Siemens and Elekta linear accelerators.

The impact of beam modifying devices such as wedge was studied for the designed miniphantom. The measurement is compared with that of open beam, for both Siemens and Elekta linear accelerators (Fig 6). The maximum field sizes used is 20 x 20 cm for Siemens and 30 x 30 cm for Elekta linear accelerators. With wedges, significant deviation is observed

between open and wedge beam measurements especially at larger field sizes, greater than 10 x 10 cm. The maximum deviation is found to be 5% for larger fields in Elekta linear accelerator. The corresponding value for Siemens accelerator is 3.5%, which is less than that of Elekta. The increase in  $S_C$  with wedged beams may be due to increased photon scattering from the wedge filter, which increases with increase of field sizes above 10 x 10 cm. This is in agreement with that of Heukelom et al [6] and Zhu et al [21].

The collimator exchange effect is studied for both linear accelerators as shown in fig 7. The collimator is exchanged from 3 x 40 cm to 30 x 40 cm field sizes. The maximum deviation observed is 1.6% for Siemens and 0.85% for Elekta linear accelerator suggesting that the collimator exchange effect is lower in Elekta linear accelerator compared to Siemens. It may be due to the design of the collimator of the given linear accelerator. In Siemens, the Y- jaw is the upper jaw, closer to the beam monitoring chamber.

The results also reveal that the  $S_C$  is higher, whenever Y- jaw is set for higher field sizes in Siemens linac. Reverse is the trend in Elekta linac, in which the  $S_C$  higher, whenever X-jaw dimension is higher. This implies that the upper jaws of Siemens and Elekta are Y and X respectively. The opening of the upper jaws contributes to the head scatter. This may be due to the back scatter from the dose monitor chambers. George X Ding [4] has studied the collimator exchange effect and reported that backscatter to the beam monitor chamber is the cause for collimator exchange effect. He reported a 50% contribution of backscatter to the beam monitor chamber to the collimator exchange effect. The deviation observed in Siemens and Elekta linear accelerators are 1.6 and 0.85% suggesting significant reduction of  $S_C$  in Elekta. This may be attributed due to the difference in design of linear accelerator head. The Elekta linear accelerator has the MLC (40 pairs, 1cm width at 100 cm) above the upper jaw (X- jaw) which may perturb the back scatter to the beam monitoring chamber and reduces the collimator exchange effect. This may be the reason for the lower  $S_C$  in Elekta compared to that of Siemens linear accelerator.

## **Conclusion**

A columnar mini phantom is designed with PMMA material as per the ESTRO recommendation. It is used to measure the  $S_C$  at 1.5 cm and 10 cm depth for 6 MV photon beams of Siemens and Elekta linear accelerators. The measurement of  $S_C$  at different orientations of the chamber, parallel and perpendicular at 1.5 cm depth predicts the deviation

of 2.05% and 1.9% for Elekta and Siemens linear accelerators respectively. The measurement of  $S_C$  at 1.5 cm is higher compared to 10 cm depth for both the linear accelerators suggesting the electron contamination at 1.5 cm depth. This emphasizes the need of  $S_C$  measurement at 10cm with columnar mini phantom. The effect of SSD is studied and has no influence on  $S_C$  for both the linear accelerators.

The effect of wedges on  $S_C$  yields a significant contribution of 3.5% and 5% for Siemens and Elekta linear accelerators respectively. The collimator exchange effect reveals the opening of upper jaw increases the  $S_C$  irrespective of the linear accelerator. However,  $S_C$  is lower for Elekta compared to Siemens which may be due to the design of linear accelerator, especially the presence of MLC in Elekta linear accelerator.

## Reference

- [1]. Biggs P. J, Ling C. C. Electron as the cause of the observe  $d_{max}$  shift with field size in high energy beams. *Med Phys.* 1979; 6: 291-295.
- [2]. Biggs P J, Russell M. D. An investigation into the presence of secondary electrons in megavoltage photon beams. *Phys Med Biol.* 1983; 28: 1033-1043.
- [3]. Bjarngard B. E, Vadash P. Analysis of central-axis doses for high energy x-rays. *Med Phys.* 1995; 22: 1191–1195.
- [4]. Ding G. X. An investigations of accelerator head scatter and output factor in air. *Med Phys.* 2004; 31: 2527-2533.
- [5]. Dutreix A, Bjarngard B. E, Bridier A, Mijnheer B, Shaw J.E, Svensson H. . Monitor unit calculation for high energy photon beams. The Netherlands, ESTRO and Garant Publishers, 1997: 101-104.
- [6]. Heukelom S, Lanson J. H, Mijnheer B. J. Wedge factor constituents of higher-energy photon beams: head and phantom scatter dose components. *Radiother Oncol.* 1994; 32: 73-83.
- [7]. Holt J. G, Laughlin J. S, Moroney J. P. The extension of the concept of tissue-air ratios (TAR) to high-energy x-ray beams. *Radiology.* 1970; 96: 437–446
- [8]. Johns H. E, Cunningham J. R. *The Physics of Radiology.* 4<sup>th</sup> edition. Charles C. Thomas, Springfield. 1983: 336–381.
- [9]. Jursinic P A, Measurement of head scatter factors of linear accelerators with columnar miniphantoms. *Med Phys.* 2006; 33: 1720-1728.

- [10]. Karzmark C J, Deubert A, Loevinger R. Tissue-phantom ratios—An aid to treatment planning. *Brit J Radiol.* 1965; 38: 158–159.
- [11]. Khan F M, Sewchand W, Lee J, Williamson J F. Revision of tissue-maximum ratio and scatter-maximum ratio concepts for cobalt 60 and higher energy x-ray beams. *Med Phys.* 1980; 7: 230–237.
- [12]. Luxton G, Astrahan M A. Characteristics of high energy photon beam of a 25 MV accelerator. *Med Phys.* 1988; 15: 82-87.
- [13]. Luxton G, Astrahan M A, Output factor constituents of a high energy photon beam. *Med Phys.* 1988; 15: 88-91.
- [14]. Mackie T R, Scrimger J W. Contamination of a 15-MV photon beam by electrons and scattered photons. *Radiology.* 1982; 144: 403-409.
- [15]. McKenzie A L, Stevens P H. Twenty-five years of MTRP—A theoretical and experimental analysis. *Phys Med Biol.* 1995; 40: 17–29.
- [16]. Sjogren R, Karlsson M. Electron contamination in clinical high energy photon beams. *Med Phys.* 1996; 23: 1873-1881.
- [17]. Tatcher M, Bjarngard B E. Head-scatter factors in rectangular photon fields. *Med Phys.* 1993; 20: 205-206.
- [18]. Van Gasteren J J M, Heukelom S, Jager H N, Mijnheer B J, van Kleffens H J, van der Laarse R. et al. Determination and use of scatter correction factors of megavoltage photon beams. Netherlands Commission on Radiation Dosimetry. NCS Report No. 12. 1998.
- [19]. Venselaar J, Heukelom S, Jager N, Mijnheer B, van der Laarse R, van Gasteren H, et al. Effect of electron contamination on scatter correction factors for photon beam dosimetry. *Med Phys.* 1999; 26: 2099-2106.
- [20]. Weber L, Nilsson P, Ahnesjo A. Build-up cap materials for measurements of photon head-scatter factors, *Phys Med Biol.* 1997; 42: 1875-1886.
- [21]. Zhu T C, Lam K L, Li X A, Charlie Ma C-M, Palta J R, et al. Report of AAPM Therapy Physic Committee task Group 74: In-air output ratio,  $S_c$ , for megavoltage photon beams. *Med Phys.* 2009; 36: 5261-5291.