VOLUME - 9, ISSUE - 9, September - 2020 • PRINT ISSN No. 2277 - 8160 • DOI : 10.36106/gjra

Original Research Paper

Oncology

COLLIMATOR EXCHANGE EFFECT OF MEGAVOLTAGE PHOTON BEAMS AND ITS IMPACT ON CLINICAL DOSIMETRY

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ABSTRACT

AIM: To determine the Collimator Exchange Effect (CEE) for telecobalt unit (Bhabhatron -II TAW) and Linear accelerator unit (Varian Trilogy).

MATERIALS AND METHOD: The study was carried out in Bhabhatron-II TAW Telecobalt machine and Varian Trilogy Linear Accelerator. The study was done to find the collimator scatter factor (Sc) for rectangular fields at 5 and 10gm/cm2 depths using indigenously designed mini phantom. Three sets of electrometer reading were noted for the irradiation of each field size and the average was taken for calculation. Sc values for different rectangular fields were then calculated from these data sets and the CEE at two depths (5 and 10 gm/cm2) for the 6MV and 15MV photon and Co-60 gamma beam were calculated.

RESULTS: The values of Sc obtained for the rectangular fields as alternatively defined by X & Y jaws are different for high energy photon beams indicating CEE. The maximum percentage difference between the Sc of the corresponding collimator settings for the Bhabhatron-II TAW unit for depths 5 and 10gm/cm2 were found to be 0.42% and 0.5% respectively. Sc values for 6MV and 15MV photon beams were found to be higher when Y-jaw (upper jaw) acts as the longer side of the rectangular field. The maximum percentage difference between the Sc values of the corresponding collimator settings for 6MV at depths 5 and 10gm/cm2 were 2.74% and 2.87% respectively whereas for 15 MV the differences were 3% and 2.99%.

CONCLUSION: The CEE of Cobalt Teletherapy units can be ignored in clinical dosimetry. However, the CEE of Linear Accelerators having energies 6MV & 15MV should be taken into consideration. A two dimensional table of Sc should be generated for rectangular fields during MU calculations in Linear Accelerators. For TPS based calculations, the generated data should be incorporated during beam modeling for accurate dose delivery in clinical dosimetry.

KEYWORDS : Collimator Exchange Effect, Bhabhatron-II TAW, Varian Trilogy, Mini-phantom

INTRODUCTION:

The effective radiation dose used in treatment of cancer is measured from the output factors generated from megavoltage teletherapy machines under reference conditions. It can be expressed as the sum of two components-primary dose and scattered dose. The output factor is the total scatter correction factor ($S_{c,p}$) at d_{max} . [1] Holt *et al* and subsequently several other authors used the concept of separation of the total scatter correction factor ($S_{c,p}$) into collimator scatter factor (S_c) and phantom scatter factor (S_p).[1-5] For rectangular fields, the interchange of upper and lower collimator jaws causes variation in the collimator scatter factor which is commonly termed as the Collimator Exchange Effect (CEE). [6-13] This effect is due to (a) the photons scattered from the flattening filter reaching to the point of measurement and (b) photons scattered backward from the upper and lower collimator jaws into the beam monitor chamber.[7,12,13,14] The magnitude of CEE, therefore depends on the configuration of the head of the treatment machine including factors such as the dimensions and material of the flattening filter, the distance between the upper collimator parts and the monitor chamber, and the presence of shielding material in the accelerator head. Megavoltage teletherapy machines have different treatment head design and hence are expected to show different CEE values.[15]

During radiation therapy of patients, different field sizes and shapes are used. It is necessary to establish the change in scattered radiation with change of irradiated area so that it can be taken into account to correct the uncertainties in treatment time/Monitor Unit (MU) calculations. van Gasteren *et al* measured $S_{c,p}$ at depth of 5cm for photon beams with a quality index (QI) up to and including 0.75 and at depth of 10cm with QI larger than 0.75 in order to exclude the influence of contaminant electrons.[1,16,17] Sjögren *et al* recommended 10cm as both reference and normalization depth for all megavoltage photon beam qualities, i.e. ^{60}Co and X-rays accelerators up to 50 MV. [18] ESTRO (European Society for Radiotherapy and Oncology) and AAPM (American Association of Physicists in Medicine) Task group report 74 recommends that CEE should be measured at 10 g/cm^2 depth to avoid electron contamination and the diameter of the phantom should be at least 4 g/cm^2 to achieve lateral electronic equilibrium.[14,19] Till date, the CEE of Bhabhatron -II TAW (telecobalt unit) and Varian Trilogy (linear accelerator unit) has not been reported. In this study, we have investigated the CEE for Bhabhatron -II TAW and Varian Trilogy using a indigenously designed mini phantom.

MATERIALS AND METHOD:

The study was carried out in two megavoltage teletherapy units. One of the teletherapy machines was Bhabhatron-II TAW Telecobalt machine (Panacea Medical Technologies, Bangalore, India) and the other was Varian Trilogy Linear

Accelerator (Varian Medical Systems, Palo Alto, California, United States).

The Bhabhatron-II TAW telecobalt unit has a radioisotope (Co-60) loaded with average gamma photon energy of 1.25 MeV. The secondary collimator of this machine defines field sizes from (0×0) cm^2 to (35×35) cm^2 at 80 cm SSD. The secondary collimator consists of a pair of asymmetric Y-jaws (Y1 & Y2) and a pair of symmetric X-jaws (X1& X2). Each pair of jaws is parallel, square and symmetrical about the collimator axis of rotation. The distance of the lower surface of X-jaw and Y-jaw from the source are 44.52 cm and 37.02 cm respectively. Below both these jaws trimmers are attached.

The Varian Trilogy linear accelerator used in the study has two photon energies, 6MV and 15MV. The collimator system of the unit comprises of two pairs of jaws – Y jaw being the upper jaw and X jaw is the lower jaw with a tertiary multileaf collimator (MLC) below the jaws. The field size can be varied from (0.5×0.5) cm^2 to (40×40) cm^2 as measured at 100cm target to surface distance (TSD). It has 60 pairs of Millennium MLC leaves. The central 20 cm have 5 mm leaf width and outer 20 cm have 10 mm leaf width at isocentre.

The collimator scatter factor (S_c) is defined as the ratio of dose rate in a mini phantom for a given field size to that of a reference field size (10 cm × 10 cm) and it counts the in air variation of output with the variation of field size of megavoltage photon beam.[9] The study was done to find the collimator scatter factor for open rectangular fields in Linear Accelerator (Varian Trilogy) for 6MV and 15MV photon beams and in Bhabhatron-II TAW (Telecobalt unit) Co-60 gamma beam at 5 and 10 gm/cm^2 depths. To measure the collimator scatter factor (S_c), a calibrated 0.125cc ion chamber (Make: PTW Freiburg Model: 31010 Semiflex) along with PC Electrometer (Sun Nuclear Corporation) and indigenously designed cylindrical wax mini phantom was used. The chamber has nominal response of 3.3 nC/Gy and long term stability of ≤ 1% per year. The dimension of the wax mini-phantom was as per ESTRO recommendation. [14] The mini-phantom was prepared using dental wax of density 0.85 gm/cm^3. The dental wax sheets were melted and fabricated in cylindrical shape with diameter 4gm/cm^2. The chamber slot was made to mimic the jig of any commercially available water phantom such that the distance from the surface of the phantom to its centre is 5gm/cm^2.The centre of the active volume of the ion chamber in the jig was determined in the Computed Tomography (CT) simulator. The CT number for the phantom ranged from -90 to -105 HU. The phantom thickness beyond the centre of the chamber slot was kept 5gm/cm^2 inclusive of the base of the phantom. A buildup of another 5gm/cm^2 height was made in the same design for performing measurement at 10gm/cm^2 depth.

For all the measurements, the long axis of the ion chamber was set parallel to the gantry axis of rotation in such a way that the central axis of the beam passes through the centre of the active volume of the chamber. Six sets of data were collected, two each for 6 MV and 15 MV photon beams and two for Co-60 photon beam. The measurements were carried out at two depths - 5 gm/cm^2 and at 10 gm/cm^2 for all the energies. Three sets of electrometer readings were recorded delivering 100MU for a reference field size (10×10) cm^2 at 5gm/cm^2 depth using 6MV photon beam.

First, reference square field size (10×10 cm^2) was opened and the ion chamber was irradiated at the depth of 5gm/cm^2 for 100 MU using the 6MV photon beam and the three sets of electrometer readings were recorded. Then X-jaw of the secondary collimator was fixed at 5 cm and the Y-jaw was varied from 5 cm to 35 cm. For each field size the chamber was irradiated for 100 MU and the electrometer readings were recorded. In the next step the Y-jaw was fixed at 5 cm while the X-jaw was varied from 5 cm to 35 cm and the electrometer readings were recorded. The same procedure was repeated at depth of 10gm/cm^2, by putting additional buildup thickness of 5gm/ cm^2.

Measurements of S_c for 15 MV photon beam were carried out repeating the above steps. For Co-60 beam, the same procedure was repeated keeping source to chamber distance (SCD) 80 cm and chamber was irradiated for 0.50 minute for all the measurements. Three sets of electrometer reading were noted for the irradiation of each field sizes and the average was taken for calculation. S_c values for different rectangular fields were then calculated from these data sets and the CEE at two depths (5gm/cm^2 and 10 gm/cm^2) for the 6 MV and 15 MV photon and Co-60 gamma beam were calculated.

RESULTS:

The variation of S_c with longer side of the rectangular field for the different beam qualities are shown in the figure1, figure2 and figure3. Table 1, Table 2 and Table 3 represent the values of collimator scatter factor for 1.25 MeV Co-60, 6 MV and 15 MV photon beams respectively. S_c (X,Y) represents the values of S_c when the X-jaw was kept fixed at 5cm at isocenter and Y-jaw was varied from 5 cm to 35 cm. While S_c (Y,X) represents the values of S_c when Y-jaw was kept fixed at 5cm at isocenter and the X-jaw was varied from 5cm to 35cm. The figures 1-3 represent the variations of S_c with the longer side of the rectangular field at the depth of 5 and 10 gm/cm^2 for Co-60 beam, 6 MV and 15 MV photon beams respectively. Results from the tables and graphs show that the values of S_c for the rectangular fields as alternatively defined by X & Y jaws are different for high energy photon beams. This indicates that the secondary collimator of Bhabhatron-II TAW and Varian Trilogy units exhibits collimator exchange effect (CEE). The maximum percentage difference between the S_c of the corresponding collimator settings for the Bhabhatron-II TAW unit for depths 5gm/cm^2 and 10 gm/cm^2 are found to be 0.42% and 0.5% respectively.

S_c values for 6 MV and 15 MV photon beams were found to be higher when Y-jaw (upper jaw) acts as the longer side of the rectangular field. The S_c values initially increase with increasing field size but plateau off for larger field sizes. The difference in S_c values between the two corresponding rectangular fields also increases as the ratio of length to width of the rectangular fields increases. The maximum percentage difference between the S_c values of the corresponding collimator settings for 6 MV photon beam from Varian Trilogy at depths 5gm/cm^2 and 10 gm/cm^2 are 2.74% and 2.87% respectively. For 15 MV photon beam the differences are 3% and 2.99% for 5gm/cm^2 and 10 gm/cm^2 depth respectively.

DISCUSSION:

In this study, CEE of Bhabhatron-II TAW and Varian Trilogy photon beams were determined. The measurements were done using an indigenously designed mini-phantom at 5 and 10 gm/cm^2 depths for 1.25MeV, 6MV and 15MV photons. The CEE of Bhabhatron-II TAW at depth 5 and 10 gm/cm^2 was within 0.5% in this study. Senthilkumar *et al* found the CEE of Theratron Phoenix Co-60 Teletherapy machine to be less than 0.5% using two mini-phantoms (PMMA and Bee's Wax). [10] ESTRO (Booklet No. 6) mentioned CEE for cobalt unit (MDS Nordion Theratron 780, ^{60}Co) of about 0.5%. [15] Therefore, the CEE of Bhabhatron-II TAW can be ignored during clinical dosimetry.

The CEE of Varian Trilogy for 6MV photon beams at 5 gm/cm^2 depth was 2.74% and at 10 gm/cm^2 depth was 2.87%. The CEE for 15MV photon beams at 5 gm/cm^2 depth was found to be 3% and at 10 gm/cm^2 depth it was 2.99%. These results indicate that Varian Trilogy exhibits CEE when using 6MV and 15MV photon beams. Murugan Appasamy *et al* reported the CEE for 6MV photon beams of Elekta Synergy and Siemens Primus Linear Accelerator to be 0.85% and 1.6% respectively using a columnar mini-phantom. [11] Sudhir Kumar *et al* also reported CEE of 1.66%, 1.44% and 1.19% for 1.5 cm, 5.0 cm and 10 cm depths respectively using 6MV photon beam in Siemens Primus Linear Accelerator. [9] For 15 MV photon beams, they found CEE of 1.74% and 1.38% at 3 cm and 10 cm depths respectively. ESTRO (Booklet No. 6) mentioned CEE of 1% for the EOS SL20 (MLC) using 18MV photon beam and 2.4% for the Siemens Primus (MLC) using 6MV photon beams. [15]

We also found that the value of S_C for rectangular fields when the longer side is defined by Y-jaws are higher than the corresponding rectangular field when the longer side is defined by X-jaws. The difference in S_C values between the two corresponding rectangular fields gradually increases as the elongation ratio of rectangular field increases. The reason for CEE of the Varian Trilogy collimator system therefore can be attributed to the backscattered radiation to the monitor chamber by the Y-jaws (upper jaws) of the secondary collimator.

CONCLUSION:

This study further confirms the CEE of megavoltage teletherapy machines used in clinics. The CEE of Cobalt Teletherapy units can be ignored in clinical dosimetry. However, the CEE of Linear Accelerators having energies 6 MV & 15 MV should be taken into consideration during clinical dosimetry. This study found that CEE for 15 MV photon beam has minimal difference at 5 gm/cm^2 and 10 gm/cm^2 depths of measurement. Therefore, a two dimensional table of Collimator Scatter Factor should be generated for rectangular fields during MU calculations in Linear Accelerators. For TPS based calculations the generated data should be incorporated during beam modeling for accurate dose delivery in clinical dosimetry.

TABLE 1 :Collimator Scatter Factor (S_c) of Co-60 beam at 5 an d 10gm/cm^2 depths.

^{60}Co, Bhabhatron-II TAW						
Longer side of the field (cm)	Depth = 5 gm/cm^2			Depth = 10 gm/cm^2		
	S_C (X,Y)	S_C (Y,X)	Difference (%)	S_C (X,Y)	S_C (Y,X)	Difference (%)
5	0.94671	0.94671	0.00	0.94714	0.94714	0.00
6	0.95830	0.95978	0.15	0.95892	0.96235	0.36
7	0.96644	0.96842	0.20	0.96648	0.96898	0.26
8	0.96768	0.97261	0.51	0.97024	0.97211	0.19
9	0.97261	0.97409	0.15	0.97141	0.97580	0.45
10	0.97508	0.97533	0.03	0.97464	0.97793	0.34
11	0.97730	0.97681	0.05	0.97733	0.97797	0.06
12	0.97755	0.97853	0.10	0.97773	0.98043	0.28
13	0.97903	0.98224	0.33	0.98199	0.98416	0.22
14	0.98100	0.98248	0.15	0.98186	0.98576	0.40
15	0.98248	0.98544	0.30	0.98363	0.98679	0.32
16	0.98520	0.98470	0.05	0.98722	0.98722	0.00
17	0.98544	0.98495	0.05	0.98519	0.98775	0.26
18	0.98840	0.98569	0.28	0.98715	0.98922	0.21
19	0.98865	0.98544	0.33	0.98869	0.98948	0.08
20	0.99062	0.98692	0.37	0.99045	0.99155	0.11
22	0.99087	0.98766	0.32	0.99158	0.99075	0.08
24	0.99161	0.98890	0.27	0.99248	0.99388	0.14
26	0.99087	0.99062	0.02	0.99451	0.99318	0.13
28	0.99210	0.98840	0.37	0.99321	0.99401	0.08
30	0.99334	0.98865	0.47	0.99554	0.99378	0.18
32	0.99433	0.98964	0.47	0.99488	0.99135	0.36
35	0.99358	0.98939	0.42	0.99647	0.99151	0.50

TABLE 2 : Collimator Scatter Factor (S_c) of 6MV at 5 and 10gm/cm^2 depths.

Varian Trilogy (6 MV)						
Longer side of the field (cm)	Depth = 5 gm/cm^2			Depth = 10 gm/cm^2		
	S_C (X,Y)	S_C (Y,X)	Difference (%)	S_C (X,Y)	S_C (Y,X)	Difference (%)
5	0.96357	0.96357	0.00	0.96309	0.96309	0.00
6	0.97002	0.97387	0.01	0.97022	0.96659	0.38
7	0.97477	0.97715	0.06	0.97484	0.96911	0.59
8	0.97930	0.97896	0.03	0.97861	0.97036	0.85
9	0.98246	0.98043	0.21	0.98155	0.97190	0.99
10	0.98620	0.98122	0.51	0.98420	0.97204	1.25
11	0.98823	0.98190	0.65	0.98658	0.97316	1.38
12	0.99072	0.98269	0.82	0.98854	0.97456	1.43
13	0.99310	0.98394	0.93	0.98966	0.97400	1.61
14	0.99468	0.98394	1.09	0.99063	0.97442	1.66
15	0.99593	0.98461	1.15	0.99287	0.97512	1.82
16	0.99796	0.98518	1.30	0.99413	0.97484	1.98
17	1.00000	0.98484	1.54	0.99483	0.97484	2.05
18	1.00113	0.98541	1.60	0.99567	0.97568	2.05
19	1.00215	0.98518	1.72	0.99623	0.97540	2.14
20	1.00328	0.98631	1.72	0.99916	0.97498	2.48
22	1.00532	0.98654	1.90	1.00042	0.97526	2.58
24	1.00701	0.98654	2.08	1.00042	0.97568	2.54

26	1.00803	0.98665	2.17	1.00112	0.97610	2.56
28	1.00984	0.98665	2.35	1.00210	0.97665	2.61
30	1.01142	0.98688	2.49	1.00420	0.97749	2.73
32	1.01301	0.98778	2.55	1.00559	0.97777	2.85
35	1.01493	0.98789	2.74	1.00713	0.97903	2.87

TABLE 3 : Collimator Scatter Factor (S_c) of 15MV at 5 and 10gm/cm^2 depths.

Varian Trilogy (15 MV)						
Longer side of the field (cm)	Depth = 5 gm/cm^2			Depth = 10 gm/cm^2		
	S_C (X,Y)	S_C (Y,X)	Difference (%)	S_C (X,Y)	S_C (Y,X)	Difference (%)
5	0.97029	0.97029	0.00	0.97038	0.97038	0.00
6	0.97581	0.97350	0.24	0.97668	0.97353	0.32
7	0.97952	0.97511	0.45	0.98041	0.97574	0.48
8	0.98364	0.97722	0.66	0.98402	0.97644	0.78
9	0.98605	0.97742	0.88	0.98647	0.97738	0.93
10	0.98866	0.97812	1.08	0.98881	0.97796	1.11
11	0.99006	0.97842	1.19	0.99032	0.97843	1.22
12	0.99167	0.97852	1.34	0.99207	0.97878	1.36
13	0.99338	0.97942	1.42	0.99324	0.97866	1.49
14	0.99438	0.97932	1.54	0.99440	0.97913	1.56
15	0.99528	0.97983	1.58	0.99522	0.97948	1.61
16	0.99588	0.97983	1.64	0.99662	0.97983	1.71
17	0.99689	0.97993	1.73	0.99709	0.97971	1.77
18	0.99759	0.98003	1.79	0.99779	0.97983	1.83
19	0.99859	0.98023	1.87	0.99860	0.98006	1.89
20	0.99990	0.98033	2.00	0.99988	0.98041	1.99
22	1.00171	0.98043	2.17	1.00152	0.98064	2.13
24	1.00281	0.98103	2.22	1.00268	0.98088	2.22
26	1.00442	0.98093	2.39	1.00385	0.98111	2.32
28	1.00582	0.98113	2.52	1.00525	0.98134	2.44
30	1.00773	0.98173	2.65	1.00700	0.98123	2.63
32	1.00883	0.98173	2.76	1.00921	0.98193	2.78
35	1.01154	0.98203	3.00	1.01096	0.98158	2.99

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