Original Article

Estimation of Skin doses for Retrofit Prototype Multileaf Collimators Designed for Telecobalt Therapy Machine

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Abstract

Aim: The objective of this study was to evaluate skin dose based on retrofit prototype multileaf collimators (MLCs), designed for cobalt-60 teletherapy machine. Since patient's skin is sensitive to radiation, evaluation of skin dose is of utmost importance for investigating the risk of late effects. **Materials and Methods:** Measurements were performed with a Phoenix cobalt-60 teletherapy machine and the detector used was EBT3 radiochromic film. The experiments were performed in a solid water phantom with two prototype MLCs mounted to the machine. Dose readings were taken by placing the films at source-to-surface distance (SSD) of 60 cm, 65 cm, 70 cm, 75 cm, 80 cm, 85 cm, and 90 cm for various MLC-generated field sizes starting from 2 cm × 2 cm to 14 cm × 14 cm. The films were analyzed using custom made programs. The measured doses were normalized to the dose at dmax for that particular measurement of SSD. **Results:** The skin dose is expressed as a percentage of dose at dose maximum. In general, the skin dose increases with field size and decreases with SSD. The measurements indicate surface doses within 20%–60% for the investigated SSD range. Furthermore, there is no significant difference between the surface doses of two prototype MLCs studied. **Conclusions:** From the measurements, it can be concluded that there is good skin sparing even at close distance to the MLCs. The skin dose is <50% for SSDs >65 cm. A minimum gap of 5 cm is required to produce acceptable skin dose.

Keywords: Cobalt-60 teletherapy machine, multileaf collimators, radiochromic films, surface dose

Received on: 09-04-2020 **Review completed on: 12-10-2020** **Accepted on: 13-10-2020** **Published on: 02-02-2021**

INTRODUCTION

In recent times, interest has increased in the modernization of telecobalt units to meet the growing needs in developing countries[1] regarding availability of cost-effective radiation therapy facilities with a tele-cobalt machine along with the treatment planning accessories. In view of above, an add-on prototype multileaf collimators (MLCs) was developed for existing telecobalt machines without making any changes to the machine.[2-4]

Earlier, a number of studies have been performed on various beam modifiers to evaluate surface dose for high energy photon beams.[5-7] The aim of the present study is to investigate surface doses for cobalt-60 energy when a retrofit multileaf collimator is attached to telecobalt machine.

It is known that more than 50% of people with cancer will receive radiation therapy during their cancer treatment. External beam therapy delivers radiation from a machine outside the body. About 2–3 weeks after the first radiation treatment, the over exposure of the skin may lead from acute skin reactions most commonly called radiation dermatitis, which appears as a mild, red rash (erythema) and dry desquamation involving itchy, peeling, or flaking skin to delayed effects with more severe reaction with blisters and wet, peeling skin often called moist desquamation.[8,9]

Estimation of surface dose in radiation therapy is important in cases where the patient skin is dose-limiting tissue, or with part of the target volume in the treatment area. The surface dose is defined as the dose deposited at the interface between the air and the phantom. Determination of surface dose (usually referred as skin dose) is practically impossible but can be interpreted carefully from clinical point of view.

Access this article online	
Quick Response Code:	**Website:** www.jmp.org.in
	DOI: 10.4103/jmp.JMP_25_20

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How to cite this article: Rani AR, Ayyangar K, Reddy AR, Kumar AA, Reddy PR. Estimation of skin doses for retrofit prototype multileaf collimators designed for telecobalt therapy machine. J Med Phys 2020;45:215-20.

Skin is composed of three layers: the epidermis, the dermis, and the hypodermis (subcutaneous fat). As per the International Commission on Radiation Units and Measurements and the International Commission on Radiological Protection recommendations, skin dose should be assessed at a depth of 0.07 mm that generally corresponds to basal cell layer of epidermis, which is the most radiosensitive layer.[10,11] However, clinically, the relevant depth for skin dose determination should be defined by radiation oncologist based on the treatment site as the epidermis thickness varies throughout the human body.

During the course of radiotherapy, several clinical factors that increase the risk and severity of skin reactions include high daily and cumulative radiation doses, the type of beam used to deliver the radiation, a large treatment field (such as pelvis, head and neck), treatment to areas with skin folds (such as the head and neck, the groin or under the breast), and whether it is delivered in conjunction with certain chemotherapy drugs. For appropriate treatment decisions, it is essential for one to know the dose at the skin surface of a patient, which if not managed properly can interrupt the treatment.

The use of megavoltage photon beams adds the advantage of skin sparing effect depending on several clinical setup parameters. The summation of dose from contaminant electrons originating from the treatment head; which is dependent on the setup parameters such as field size, source-to-surface distance (SSD), manual or motorized wedges, tray, blocks, and MLCs[12,13] with the dose from secondary electrons produced in the irradiated patient; which is dependent on the field size and curvature of the irradiated material contribute to the dose at the skin surface.[14-16]

In dosimetric context, usually, skin dose is referred to as surface dose. For accurate determination of surface doses, one has to emphasize on selection of appropriate dosimetric tool and the correct measurement depth for the chosen surface dose dosimeter. Every dosimeter owing to its specific physical property may have different effective point of measurements. As a result, surface dose measurements may vary. However, the choice of suitable dosimeter is of utmost importance.

A number of dosimeters are available for estimation of surface doses, such as extrapolation chambers,[17,18] fixed-separation parallel-plate chambers,[19,20] thermoluminiscent detectors (TLDs),[21,22] diodes,[23] metal oxide semiconductor field effect transistor (MOSFET) devices,[24] and gel dosimeters.[25] First, the availability of extrapolation chambers is limited to only some institutions and time consuming. Second, the fixed-separation thin entrance window parallel-plate ionization chambers shows over-response in the buildup region, which can be overcome by applying suitable correction factors for accurate results. Due to their size and physical geometry, parallel-plate chambers are only suitable for in-phantom measurements. Third, the TLDs, diodes, and MOSFETs may be used for low-resolution surface dose distributions.

On the other hand, radiochromic films have emerged as an essential dosimeter for quantification of two-dimensional surface doses. The films are tissue equivalent possessing minimal energy dependence offering high spatial resolution and can be self-developed. A number of studies performed using radiochromic films have alleviated most of the problems faced with conventional dosimetry.[26,27] Devic *et al*.[28] reported the surface doses for 6 MV photon beam with different Gafchromic film models (HD-810, EBT, HS and XR) taking into account their effective depth of measurement. Bilge *et al*.[29] in their study used EBT2 film for surface dose evaluation and compared the results to those from a parallel-plate chamber. They found that the difference between EBT film and ionization chamber to be within 5% for 6 MV and 3% for 18 MV. In a paper, Butson *et al*.[30] presented surface dose results for 6 MV using Gafchromic film, which served as a useful extrapolation device due its high spatial resolution. Novotny *et al*.[31] have used Gafchromic film as the primary modality to measure dose output and profile of 4 mm collimator of Gamma Knife.

The present study also employs Gafchromic EBT3 films for carrying out measurements at source-to-surface distances (SSDs) of 60–90 cm, for MLCs defined field sizes ranging from 2 cm × 2 cm to 14 cm × 14 cm as defined at 80 cm SSD.

MATERIALS AND METHODS

In this experimental study, two in-house developed add-on prototype MLCs designated prototype-1 and prototype-2 MLCs with different leaf designs were investigated. The prototype-1 MLC has nondivergent 14 leaf pairs with a 2 cm × 2 mm tongue and groove construction with rounded edge. It can define a maximum field size of 14 cm × 14 cm at the isocenter. The design and radiation characteristic study of prototype MLCs were presented in conferences[2-4] and reported.[32] It has been previously[33] demonstrated that the designed MLCs can be successfully used for conformal therapy. Due to intensive use of multi-leaf collimators (MLCs) in clinics, it is important to find an optimum design for the leaves. In view of this necessity, a second prototype was designed consisting of divergent 16 leaf pairs with 155 mm length, 40 mm height with 6.5 mm width on top and 7 mm width at the bottom to follow the divergence of the cobalt radiation with a step design for leaf sides and leaf end rounded edge. It can define a maximum field size of 14 cm × 16 cm at the isocenter. Both the prototype MLCs were positioned onto Theratron 780E Phoenix telecobalt machine at 45 cm from the cobalt-60 source with top of the leaves at 52 cm and bottom at 56 cm, fitting in the tray slot with projected leaf width of 1 cm at the isocenter. When the MLCs are mounted onto the machine, an air gap of 24 cm is left between the MLCs and the isocenter. The cross-sectional view of the prototype MLCs leaves is shown in the Figure 1.

The Gafchromic® EBT3 film (International Specialty Product, NJ, US) finds wide applications in clinical dosimetry which covers a dose range of 0.1 Gy to 20 Gy.[34-36] These are readily available as 25 sheets pack with dimensions 8 inch x 10 inch and also in dimensions of 12 inch × 16 inch to cater to large radiation fields. It comprises an active layer, nominally 28 µm thick, sandwiched between two 125 µm thick matte-polyester substrates to prevent formation of newton's rings. This symmetric structure allows the user for scanning either side. The effective point of measurement for the EBT3 film was essentially taken as 0 mm depth for cobalt-60 beam.

All the films used for the investigation of surface dose were used from same lot since the thickness of active layer varies from one batch to another. Before starting the measurements, a proper calibration curve was created for accurate evaluation. The films were cut into small pieces of 5 cm × 5 cm size and placed between the solid water phantom slabs without any air gaps at the depth of 5 cm at source-to-axis distance (SAD) of 80 cm with 20 cm of backscatter thickness to account for phantom scatter equilibrium. The films were irradiated with a dose range from 0 to 500 cGy for 5 cm × 5 cm field size. An unirradiated (0 cGy) film was used for background dose. The exposed films were scanned and digitized using an Epson Expression 11000XL scanner (Epson America, Long Beach, CA, USA) with 72 dpi resolution in 48-bit RGB mode with no color correction, after an irradiation period of 24 h. After the scanning process, each film was analyzed with a user defined program for obtaining the optical densities (ODs) of film pieces by averaging the readings over the central 2 cm x 2 cm region of the exposed field size. The net optical densities were obtained by subtracting the average background reading from each irradiated film piece. The corrected ODs were used to create the calibration curve against the known doses. This calibration curve was applied to all subsequent measurements for converting the net ODs to the dose.

After obtaining calibration curve, the prototype-1 MLC was attached to the tray holder slot. The machine collimator was adjusted to its maximum opening. The measurements were carried out at 80 cm SSD, with different MLC defined field sizes, 2 cm × 2 cm, 4 cm × 4 cm, 6 cm × 6 cm, 8 cm × 8 cm, 10 cm × 10 cm, 12 cm × 12 cm, and 14 cm × 14 cm for the zero depth, and then buildup of 5 mm thickness solid water phantom slab was placed above the films for irradiation at depth of maximum dose (dmax) for all the above-mentioned field sizes. Later the SSDs were changed to 60 cm, 65 cm, 70 cm, 75 cm, 85 cm, and 90 cm. The measurements with prototype-2 MLCs were made under the same setup conditions of prototype-1 MLCs measurement. Similarly, the machine collimator was to set 5 cm × 5 cm, 10 cm × 10 cm, 15 cm × 15 cm field sizes and the data was taken for at different SSDs. The measured doses were normalized to the dose at dmax for that measurement SSD. The experimental setup is shown in the Figure 2.

RESULTS

The skin or surface dose is usually expressed as a percentage of dose at dose maximum. Figure 3 shows the percentage skin dose values for open fields 5 cm × 5 cm, 10 cm × 10 cm, and 15 cm × 15 cm at 80 cm SSD. The surface doses for respective field sizes were as 25.81%, 31.98%, and 42.99%. It is evident from the result that as the field size is increased, skin dose increases.

Figure 4 shows the impact of SSD on the skin doses, for prototype-1 MLCs defined square fields. The straight line represents the linear fit to measured data points. Skin doses

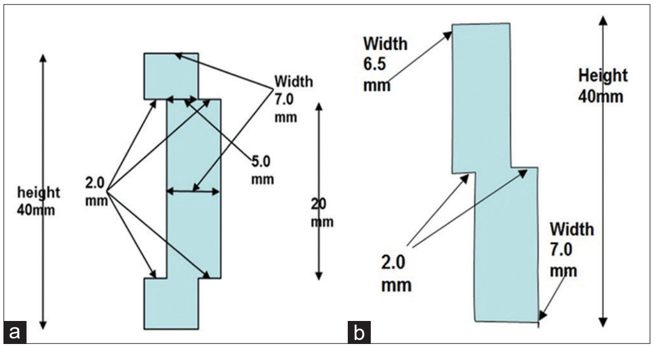

Figure 1: Leaf cross-sectional diagram of (a) prototype-1 (b) prototype-2 multileaf collimators system

Figure 2: A typical experimental setup with prototype multileaf collimators attached to the telecobalt machine

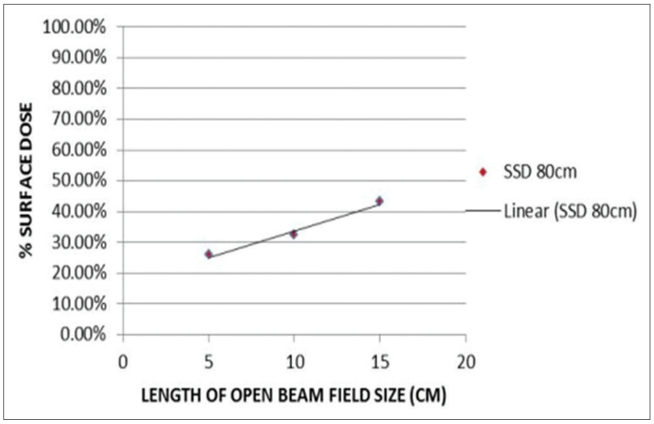

Figure 3: Surface dose (as a percentage of the dmax dose) from open cobalt fields as a function of the size of the edge of the equivalent square field

at 90 cm SSD were slightly greater than at 80 cm SSD for fields >10 cm × 10 cm and much less for fields below 6 cm × 6 cm. The maximum deviation was 4.7% for the 14 cm × 14 cm field. Skin doses at 80 cm SSD were greater than at 85 cm SSD for all measured fields (deviations were <1%) except for 6 cm × 6 cm, there was no deviation.

Percentage skin dose values at 60 cm SSD were greater than at 80 cm SSD for all measured fields and maximum percentage skin dose deviation was 45.2% for a 14 cm × 14 cm field size. It may be concluded that the effects of the prototype-1 MLC on skin doses at low SSD were much more significant and increased with increased field size.

The skin surface doses expressed in percentage for different SSDs for prototype-1 MLC are shown in Table 1.

Figure 5 shows the effect of SSD on the skin doses, for prototype-2 MLCs defined square fields. Skin doses at 90 cm SSD were mostly equal to at 80 cm SSD for fields >10 cm × 10 cm and much less for fields below 6 cm × 6 cm. For the maximum field size of 14 cm × 14 cm, there was no significant deviation. Skin doses at 80 cm SSD were greater than at 85 cm SSD except for 8 cm × 8 cm and 12 cm × 12 cm; the deviations were 9.6% and 5.1%.

Percentage skin dose values at 60 cm SSD were greater than at 80 cm SSD for all measured fields and maximum percentage skin dose deviation was 53.48% for a 14 cm × 14 cm field size. The skin dose, however, increased rapidly at 60 cm SSD. This is because the source of electrons is mostly from the MLCs and as we go closer, the surface dose increases. The skin doses expressed in percentage for different SSDs for prototype-2 MLCs are shown in Table 2.

DISCUSSION

Kry *et al*.[37] mentioned that cobalt beams produce a higher surface dose with increasing field size, ranging between 20%–85% of the dmax dose for open square fields. They also studied the impact of block tray on skin dose. On introduction of block tray, there was no increase in surface dose for small fields whereas for large fields it showed decrease in surface dose due to attenuation of electrons in the block tray. In this paper, the block tray was replaced by prototype MLCs acting as tertiary collimator to the machine.

In general, the skin dose increases with field size and decreases with SSD. The skin dose values for prototype-1 and prototype-2 MLCs fields were higher than for the open fields. According to IEC-60601-2-11 recommendations,[38] the relative surface dose

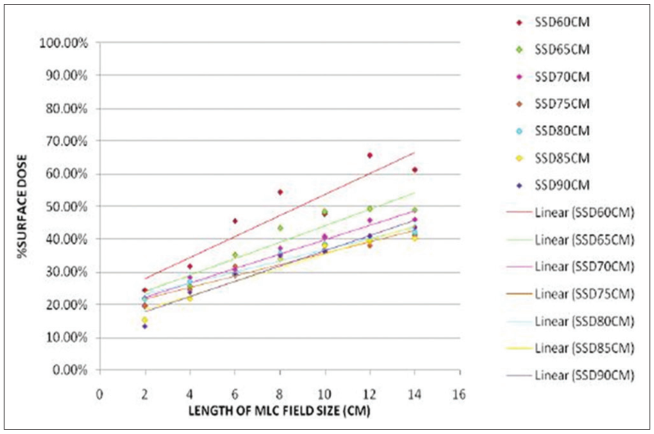

Figure 4: Surface dose (as a percentage of the dmax dose) from prototype-1 multileaf collimator fields as a function of the size of the edge of the equivalent square field

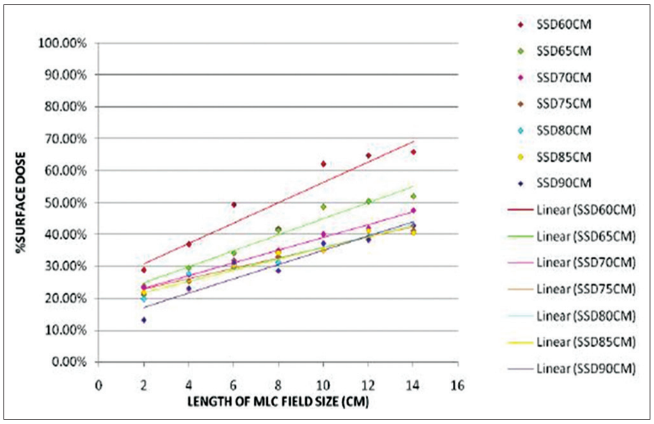

Figure 5: Surface dose (as a percentage of the dmax dose) from prototype-2 multileaf collimator fields as a function of the size of the edge of the equivalent square field

Table 1: Skin dose from cobalt-60 beam influenced by the presence of add-on prototype-1 multileaf collimator for field sizes ranging from 2×2 cm² to 14×14 cm² defined by the multileaf collimators

	Percentage surface dose						
Field size (cm²)	**SSD 60 cm**	**SSD 65cm**	**SSD 70 cm**	**SSD 75 cm**	**SSD 80 cm**	**SSD 85 cm**	**SSD 90 cm**
2	24	22	20	20	22	15	13
4	32	26	28	25	27	22	24
6	46	35	31	32	29	29	29
8	54	43	37	34	36	34	35
10	48	48	41	37	39	38	36
12	66	49	46	38	40	39	41
14	61	49	46	41	42	40	44

SSD: Source-to-surface distance

Table 2: Skin dose from cobalt-60 beam influenced by the presence of add-on prototype-2 multileaf collimators for field sizes ranging from 2×2 cm² to 14×14 cm² defined by multileaf collimators

	Percentage surface dose						
Field size (cm²)	**SSD 60 cm**	**SSD 65cm**	**SSD 70 cm**	**SSD 75 cm**	**SSD 80 cm**	**SSD 85 cm**	**SSD 90 cm**
2	29	24	23	21	20	22	13
4	37	30	27	25	28	23	23
6	49	34	31	32	30	30	31
8	42	41	35	33	31	34	29
10	62	49	40	37	37	35	37
12	65	50	42	39	39	41	38
14	66	52	48	41	43	41	43

SSD: Source-to-surface distance

on the central axis with normal treatment distance 80 cm for 10 cm × 10 cm field size should not exceed 70% of absorbed dose at 5 mm depth for 10 cm × 10 cm irradiation field size, and 90% of absorbed dose at 5 mm depth for the maximum irradiation field size available. The measurements indicate 32.0% for 10 cm × 10 cm open field, 39.0% for prototype-1 and 37.0% for prototype-2 MLC defined 10 cm × 10 cm fields. With the addition of prototype MLCs, the surface dose deviations were 22.0% for prototype-1 and 15.7% for prototype-2 from open field skin dose. The prototype 1 has straight edged leaves whereas the prototype 2 has focused leaves on one direction. In the case of prototype-1, the gradient surface of the leaves could have resulted in more number of scatter electrons. This could explain the additional 6% increase in surface dose compared to open field. Besides, the difference between prototype-1 and prototype-2 is only 2%.

It can be seen from above that 60 cm SSD is as close as 5 cm to the skin. Usually we require 15 cm between MLC and patient skin to avoid electrons generated by any beam defining aperture. However, at 60 cm we find that the skin dose is close to 70% for large fields bigger than 10 cm × 10 cm. In general, the surface doses for both the prototype MLCs are between 20%–60% and are in compliance with the IEC requirements. Furthermore, there is no significant difference between surface doses due to prototype-1 and prototype-2 MLCs.

CONCLUSIONS

Clinically, since the use of single field dose does not exceed 45-50 Gy, the increase in skin dose due to use of the MLC is not a problem. Additionally, the use of multiple beams reduces this restriction further. From this study, it has been found that the skin dose is <50% for SSDs >65 cm. Skin dose values increase with decreasing SSD. This result implies that a gap more than 5 cm from the MLC bottom to the patient's skin have to be maintained for cobalt therapy using the MLC. Hence, we can conclude that the skin dose produced from conformal plans using the prototype MLC systems are acceptable and within tolerance limits.

Financial support and sponsorship

This work is done as a part of the BRNS grant, "Development and implementation of automated multi-leaf collimator with treatment planning system as an add-on for telecobalt machine." It is a social impact project sanctioned by BRNS in April 2011.

Conflicts of interest

There are no conflicts of interest.

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