Dosimetry and evaluating the effect of treatment parameters on the leakage of multi leaf collimators in ONCOR linear accelerators

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Abstract

Background: One of the standard equipment in medical linear accelerators is multi-leaf collimators (MLCs); which is used as a replacement for lead shielding. MLC's advantages are a reduction of the treatment time, the simplicity of treatment, and better dose distribution. The main disadvantage of MLC is the radiation leakages from the edges and between the leaves. The purpose of this study was to determine the effect of various treatment parameters in the magnitude of MLC leakage in linear accelerators.

Materials and Methods: This project was performed with ONCOR Siemens linear accelerators. The amount of radiation leakage was determined by film dosimetry method. The films were Kodak-extended dose range-2, and the beams were 6 MV and 18 MV photons. In another part of the experiment, the fluctuation of the leakage was measured at various depths and fields.

Results: The amount of leakage was generally up to 1.5 ± 0.2% for both energies. The results showed that the level of the leakage and the amount of dose fluctuation depends on the field size and depth of measurement. The amount of the leakage fluctuations in all energies was decreased with increasing of field size. The variation of the leakage versus field size was similar to the inverse of scattering collimator factor.

Conclusions: The amount of leakage was more for 18 MV compare to 6 MV The percentage of the leakage for both energies is less than the 5% value which is recommended by protocols. The fluctuation of the MLC leakage reduced by increasing the field size and depth.

Key Words: Dosimetry, multi-leaf collimators leakage and film dosimetry, radiation therapy

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INTRODUCTION

The main goal of radiation therapy is reducing the amount of dose to surrounding healthy tissue and critical structures. One of the standard equipment for this purpose is medical linear accelerators used with multi-leaf collimators (MLCs).[1-5] MLC is used as a substitute for lead shielding and in accordance with the geometry of the tumor, for the beam formation.[6-13]

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The general structure of the MLC system consists of a two sets of leaves of tungsten alloy which are placed on each side of the field.[4,9,14-16]

An advantage of MLC over the lead shielding is simple treatment set up, reducing treatment time and better dose distribution around the tumor. One of the disadvantages of MLC is radiation leakage from the edges and between the leaves.[17,18] MLC leakage consists of two parts, the first part, is a direct leakage from the edges and sides of the MLC, and the other one is the output of leakage after interaction with MLC inside the field as illustrated in Figure 1.[6,19-21] MLC must have an acceptable leakage, and it has to be below a certain amount which is usually 5% of the total dose. MLC is used in three-dimensional conformal radiation therapy, and the computer is used to target tumors with proper margins.[6,22,23]

The amount of leakage is different in various accelerators, and this value must be measured in each particular machine. Arnfield *et al*. measured the leakage rate for the Varian linear accelerator with 40 pairs of MLC by Kodak XV-2 film. For 10 cm × 10 cm treatment field, depth 5 cm, source to surface distance (SSD) =100 cm and for photons of 18 MV and 6 MV, the measured leakage percentage were 1.68%.[24] Jordan and Williams measured leakage for Phillips MLC system for the 6 MV and 20 MV photons by the Farmer ionization chamber and the film. Leakage were reported 4.1% and 4.3% for 6 MV and 20 MV, respectively.[7] For the Varian accelerator, Galvin *et al*. measured 1.5–2% leakage by radio chromic film for the energy of 6 MV, and 2% for 15 MV energy.[6,19] Average leakage of 1.8% between the leaves has been reported by Cosgrove *et al*. and Siochi for Siemens ONCOR linear accelerator and miniature MLC (MMLC).[8,10,25]

In general, the amount of leakage is varied between 0.5% and 4% for different systems and energies and its magnitude is less with for lower energies.[17,19,26,27]

In this paper, MLC leakage is measured by 41 pairs MLC ONCOR accelerator with two 6 MV and 18 MV photons. To measure the leakage, different methods have been used such as film dosimetry and Pinpoint ionization chamber.

MATERIALS AND METHODS

In this experiment, the extended dose range-2 (EDR-2) film from Kodak is used for film dosimetry. The use of radiotherapy, film dosimetry is used to measure the relative dose. This film should be calibrated before the experiment. EDR-2 film calibration is done as recommended by Zhu *et al*.[28] and Childress *et al*.[29,30] to prevent measurement errors. According to the protocols, for calibration of an EDR-2 film, the radiation is given as 2 cm × 10 cm strips, by multiple beam fields. The amount of radiation varies in each strip, and it changes between 50 and 1000 cGy. This calibration is done with 6 MV photons and for the experiment, a 1.5 cm layer of water phantom is placed on film as a buildup. The relative brightness values film, along with the dose is used to create a calibration curve. Calibration curve is illustrated in Figure 2 and the dose can be obtained from optical density each point.

To check the amount of leakage from the leaves of the MLC, for both 6 MV and 18 MV, the film were irradiated with 1000 monitor unit (MU) by closed MLCs. For this experiment, all MLCs were closed, and the primary collimators were placed in the fully open position. One problem in ONCOR lilacs is that if all of the MLCs are in a closed position, exposure was not possible. The reason is that the primary collimators are closed when the filed size is zero. For this problem, the last MLC placed in the open position with 1 cm gap as illustrated in Figure 3. This gap will have no effect on the measurement of leakage because the open area outside the field size is used.

The film was positioned between solid RW3 slabs; at the depth of 1.5 cm to photon 6 MV and a depth of 3 cm for photon 18 MV and the field size of was 40 cm × 40 cm irradiated 1000 MU. After the film processing, it was scanned by the Mircotek scanner. The scanned images were saved in TIF format. Leakage was measured by using the film calibration curve and MATLAB (The MathWorks, Inc., MA) software.

In the second part of the experiment, the water phantom RW3 filled with water and were placed under the accelerator in SSD = 98.5 cm for 6 MV and the SSD = 97 cm for 18 MV.

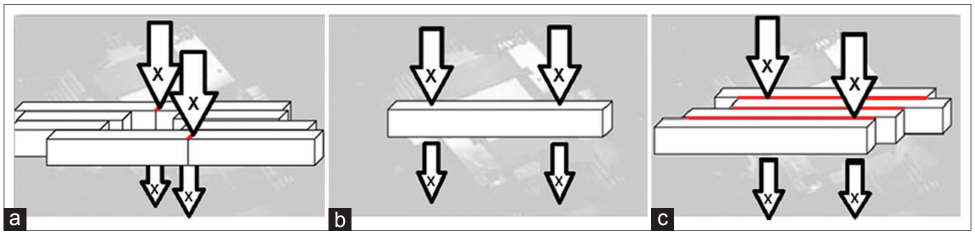

Figure 1: Illustration of (a) end leaf transmission, (b) leaf transmission and (c) interleaf transmission

Pinpoint and Semiflex dosimeters from PTW were used, respectively, as the main and reference dosimeter. The sensitive volume of Pinpoint dosimeter is very small and it has very high resolution. Leaf number 41 was opened 1 cm and the reference dosimeter was placed on the MLC gap.

The main dosimeter, Pinpoint, was adjusted into the water at the depth of 1.5 cm and distance of 5 cm from the match line of the MLC ends.

In order to, move the Pinpoint perpendicular to the length of the leaves; the accelerator was rotated 270°. The movement direction of Pinpoint dosimeter to measure the relative amount for leakage is shown in Figure 4. Finally, the 800 MU radiations were given during the movement of the dosimeter. This gives enough time to scan the entire path of the length. Reading values by reference and the main dosimeter is automatically saved by PTW program.

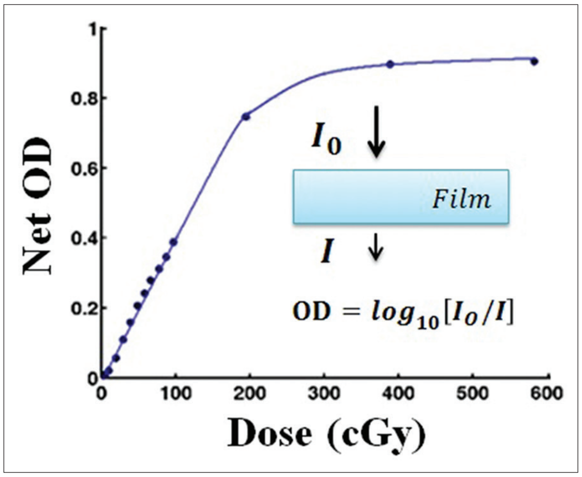

Figure 2: Calibration curve for extended dose range-2 Kodak film which is irradiated with 6 MV photons

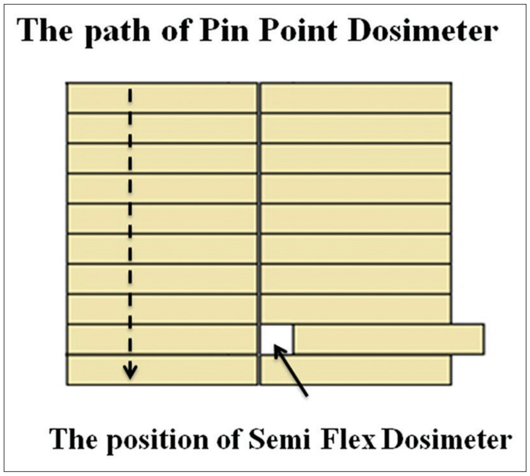

Figure 4: The location of the reference dosimeter and the direction of the main dosimeter in a water phantom at a depth of 1.5 cm and 3 cm for energies of 6 MV and 18 MV, respectively

RESULTS

In one part of the film dosimetry, the amount of the leakage for two sets of the leaves in both side of the field size is compared. The values are related to the left and right set of the leaves. For 18 MV, the average leakage was the same value of 1.5 ± 0.1%. For 6 MV photons, the left side had 1.3 ± 0.2%, and the right side has 1.2 ± 0.2% leakages. The in-heterogeneity of the leakage from MLC is noticeable for 6 MV beam.

In addition, for the leakage each of leaf, the amount was between 0.98 ± 0.2% and 1.48 ± 0.2% for 6 MV and 1.2 ± 0.1% to 1.7 ± 0.1% for 18 MV. These facts suggest that for specified field size, all areas of the field do not have the same leakage. This difference can be due to a slight difference in the average density of MLC components even though they have the same design. In Figure 5, the average amount of leakage from the gap between the left and right and

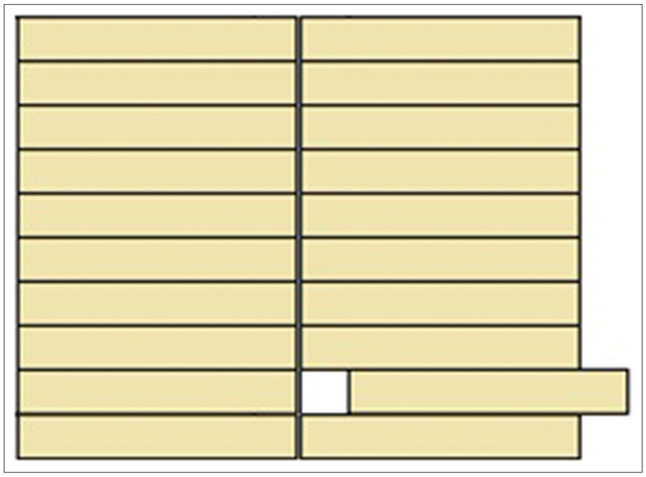

Figure 3: Illustration of multi-leaf collimator set up for film dosimetry. One leaf at the end with 1 cm gap is open to prevent the closure of the primary collimators

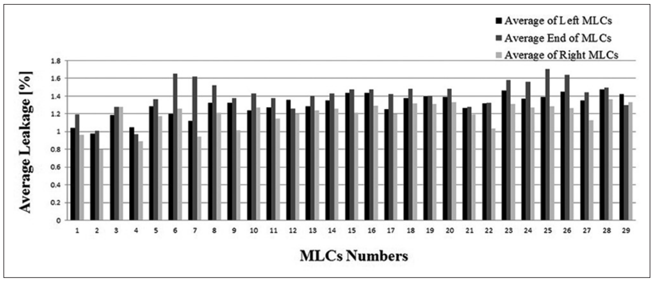

Figure 5: The leakage of 6 MV photons using film dosimetry. The amount of leakage is related to the left and right multi-leaf collimator and also the ends of opposed leaves

end points of each MLC for energy 6 MV is plotted as percent of dose.

The average amount of radiation leakage, for left MLCs, is equal to 1.3 ± 0.2% and for the right MLC is 1.2 ± 0.2%. MLC leakage from the end of them which is called MLC end leakage; is equal to 1.4 ± 0.2% and its amount is about 13% higher than the leakage of the gap between them.

In Figure 6, the average amount of leakage from the gap between the left and right MLCs and the endpoints of each of them in 18 MV radiation leakage is illustrated. Average values of the left and right MLC leakage dose is 1.5 ± 0.1%. The leakage for ends of opposed leaves is 1.6 ± 0.1% which this amount is about 7% higher than the leakage gap.

In another step, the transmitted leakage of the MLC leaves was measured for both of energies. In Figure 7, the results of beam transmission percentage of 6 MV leaves for energy are plotted. Average percentage of photons leaking for 6 MV is about 0.98 ± 0.2%. In Figure 8, the average percentage leakage for photon 18 MV is plotted, and the average value is 1.3 ± 0.1%.

As illustrated in Figures 5-8, the amount of leakage is different for each individual leaf. For all cases, a similar pattern is observed. According to the Figures 5-8, left MLCs had lower leakage and in central MLCs, the leakage is increased.

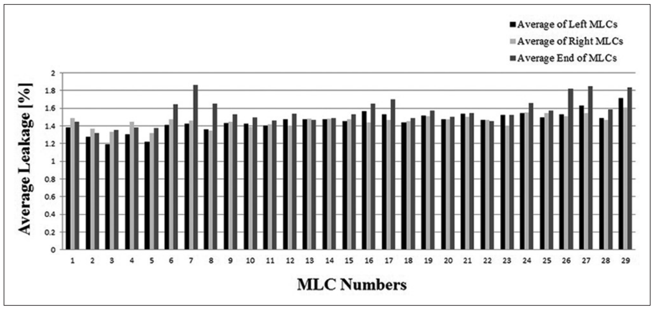

Figure 6: The leakage of radiation for 18 MV. The amount of leakage from the left and right multi-leaf collimators and also their ends of opposed leaves

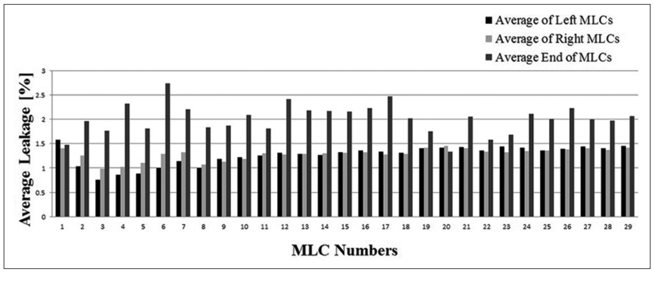

Figure 8: The beam transmission through the leaves for energy 18 MV

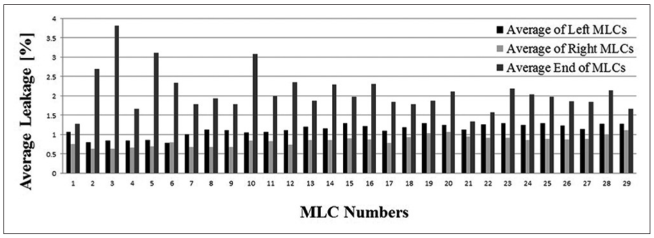

Figure 7: The beam transmission through the leaves for energy 6 MV using film dosimetry

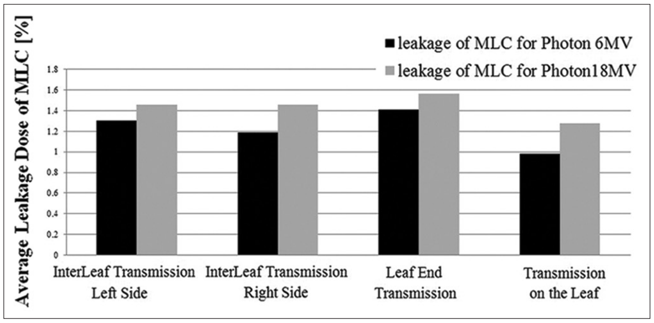

Figure 9: Average leakage of multi-leaf collimator for 6 MV and 18 MV from film dosimetry

The comparison of the leakage in right and left leaves of the MLC is also illustrated in Figure 9 for 6 MV and 18 MV beams. As it is illustrated, the difference of the leakage for 6 MV is considerable but it is the same for 18 MV.

This result of this study is consistent with results of Siochi and Jordan and Williams[7,8] Siochi measured 1.5% and 3.8% leakage for interleaf and leaf end, respectively. Jordan and Williams obtained 4.1% and 1.8% leakage for interleaf and through the MLC. The energy range for these works is from 6 to 20 MV.

The results of the Pinpoint dosimetry are illustrated in Figures 10-16. In Figure 10, the leakage fluctuations of the 6 MV and 18 MV are illustrated. The amount of the leakage fluctuation for 6 MV energy is more than18 MV. This is due to the higher amount of scattering and attenuation of 6 MV photons in the beam path.

The fluctuations of leakage for 6 MV photons for all MLCs are illustrated in Figure 11. On the top of the figure, the path of profile to determine the leakage by a red line is shown on EDR-2 film. In Figure 11 the maximum is related to the gap between the adjacent leaves and minimum is related to be related to point the middle of the leaf width.

The leakage of MLC in the intensity modulated radiating therapy (IMRT) treatments is more important than the three-dimensional conformal

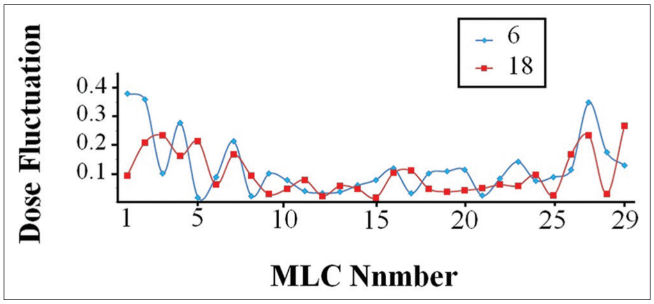

Figure 10: Graph leakage fluctuations for 6 MV and 18 MV measured with Pinpoint

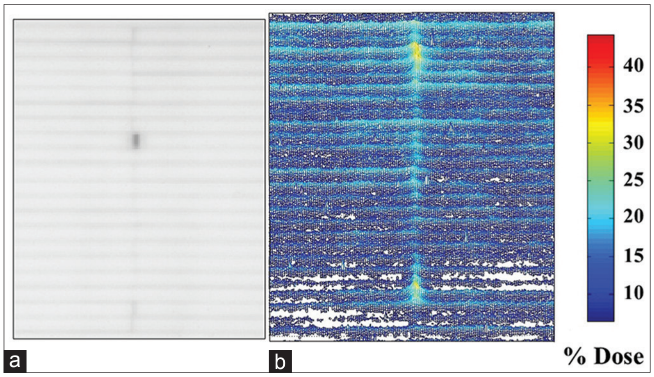

Figure 12: (a) The image of the film that is irradiated by 6 MV photons. (b) Planar dose map illustrating fluctuations of leakage by film dosimetry

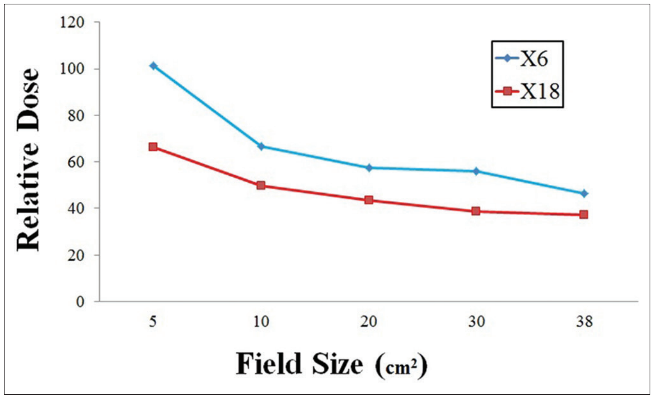

Figure 14: Relative dose versus the various depths, for 6 MV and 18 MV photons. The field size for this experiment is 10 cm × 10 cm

radiation therapy since the typical MU in IMRT is much more and it is in the order of 1000 MU.[31]

The leakage dose profile of film dosimetry is demonstrated for photon 6 MV in Figure 12. By film scanning, isodoses of radiation leakage was plotted by MATLAB program. Horizontal bright region represents the amount of leakage from the MLC's. A relatively higher leakage is observed at the end of the leaves which are not fully closed.

Another point of interest on the film is the end of leaves as illustrated in Figure 13. For fully closed leaves, a number of the leaves remain slightly open. For this reason, there is very high leakage at these points. This effect is seen when the position of MLC leaves are not calibrated for a long time. In this part, the amount of leakage is significant about 20 ± 0.2% to 30 ± 0.2%. An example of isodoses lines for this case is illustrated in Figure 13.

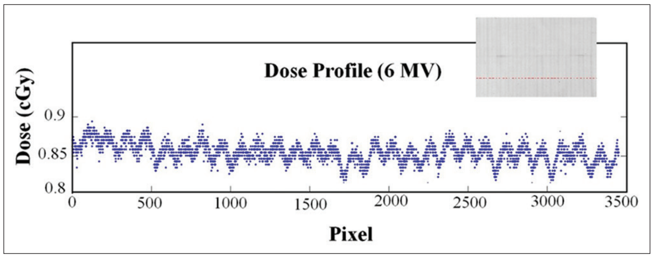

Figure 11: The fluctuations of leakage for each leaf. The path of the profile to determine the leakage is shown by a line on the image

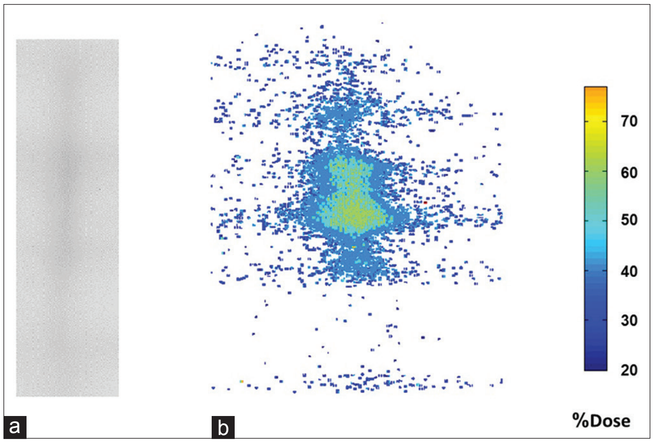

Figure 13: (a) The scan of the partial film that irradiated by photon 6 MV and (b) planar dose map illustrating fluctuations of leakage for end of the leaves

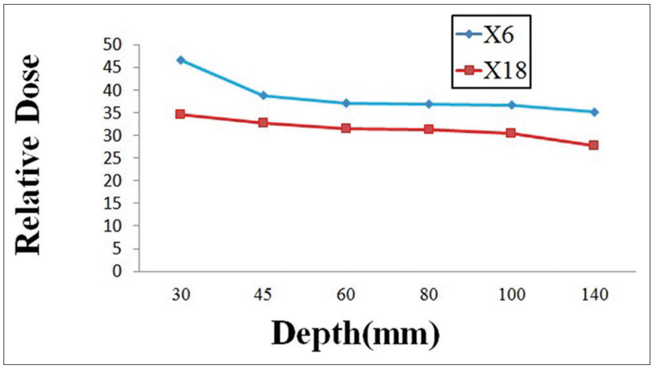

Figure 15: Relative leakage fluctuation dose versus the 10 × 10 field size, for 6 MV and 18 MV photons

As mentioned before, in IMRT technique, it is possible to have 1000 MU on each day of treatment, while this order of MU in three-dimensional conformal radiation therapy is unlikely. In realistic cases of IMRT, these

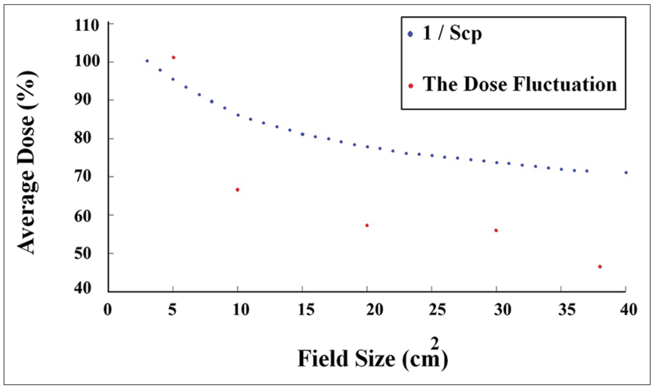

Figure 16: The inverse quantity Scp and dose fluctuation to the field size

1000 MU and related leakage is distributed over the entire treated area from various angles. In the worth case, all the leakages overlap and all the above results can be used for evaluation of the dose consequences. As it was illustrated in Figures 12 and 13, the amount of the interleaf leakage was up to 1.5 ± 0.2% which equal to approximately 15 cGy in 1000 MU. The worth case was about 20 ± 0.2% of leakage for the leaf end, and this happens for not fully calibrated MLC. This percentage of the leakage gives approximately 200 cGy for 1000 MU, which is quite considerable. The possible solution is very accurate and frequent checkup and regular MLC calibration by a physicist.

In the another step of experiment, the Pinpoint dosimeter are moved during the path of –5 cm to 5 cm distance with 0.3 steps, with field size 10 cm × 10 cm and in depth of 30 mm. About 10 leaves exist in this field size, and 1500 MU irradiation was delivered. The entire process was repeated for depths up to of 45 mm, 60 mm, 80 mm, 100 mm, and 140 mm. Average leakage for each depth by MATLAB program was calculated, and the graph is illustrated in Figure 14. It is clearly illustrated that with increasing of depth, the amount of leakage is reduced.

All the above steps are repeated for 18 MV with 2000 MU delivery. The only difference was that at a depth of 1.5 cm calculations was removed because of build up the photons 18 MV located at 3 cm depth. The impact of changes of the leakage versus field size is illustrated in Figure 15. To change the field size, the primary collimator is changed while the MLC was in fully closed position. The field sizes were 5 cm × 5 cm, 10 cm × 10 cm, 20 cm × 20 cm, 30 cm × 30 cm, and 38 cm × 38 cm. In Figure 15, the horizontal axis and vertical axis indicates field size and the amount of leakage, respectively. As it is illustrated, with increasing the field size, the amount of leakage is reduced. According to Figure 15, the amount of leakage is greater for 6 MV. This phenomenon is because of the greater distance between maximum and minimum of the leakage in 6 MV respect to 18 MV.

If the inverse quantity of Sc versus the field size is plotted, similar behavior can be seen as it is illustrated in this Figure 16. Both quantities Sc and fluctuation are decreased with increasing the field size.

DISCUSSIONS

The total average of MLC leakages, for both 6 MV and 18 MV photons was 1.3 ± 0.2% and 1.5 ± 0.1% respectively. Our results were in the range of the other studies. Klüter *et al*.[32] measured the leakage of a dual energy linear accelerator Siemens ARTIST on 6 MV and 18 MV photon energies. They investigated and obtained approximately, the same dose for intra-leaf leakage amounted for 6 and for 18 MV. A much higher interleaf leakage for 6 MV was measured.[32] Jordan and Williams used a Farmer-type ionization chamber and film to investigate the transmission properties of a Philips MLC system at 6 and 20 MV. Their results showed a maximum transmission of 4.1% at 6 MV and 4.3% at 20 MV between the leaves and 1.8% at 6 MV and 2% at 20 MV averaged over the leaves.[7] It should be noted that besides all the fluctuations, the amount of leakage is acceptable for standard clinical treatments. The numerical value of leakage that is measured for the energy 18 MV is more with respect to 6 MV that is due to the less scattering and more penetrating power of the 18 MV.

The amount of leakage through MLC is less than the amount of leakage from the gap between the MLCs and the endpoints of MLCs; this phenomenon is because the amount of beam when passing through the MLCs is weakened. This attenuation of the MLCs depends on the alloy materials that used in the construction of MLCs and the design of leaves. Siochi used the ModuLeaf (MMLC) for the Siemens ONCOR linear accelerator and the average interleaf and crack leakage between closed leaf ends were respectively, 1.50% and 3.76% at 6 MV.[8]

In the evaluation of variation of the leakage, it was illustrated that with increasing of the depth, the amount of leakage was reduced. The depth of the measurement in this part was varied between 4 and 16 cm. As it was illustrated in Figure 16, for changes of the leakage versus field size it was observed that the changes of the leakage have a behavior similar to 1/Scp. The reason is that the increased scattering in the entire volume increases the total dose and decreases the relative fluctuation between minimum and maximum.

With increasing the field size, the number of leafs inside the field is increased and this leads to higher scattering into leakage region, and leakage fluctuation is reduced. This was observed on both 6 MV and 18 MV photons.

CONCLUSIONS

The aim of this work was to study the variation of radiation leakage from MLC for Siemens linear accelerator. The alloy density can be different among individual leaves. Thus, it is important to measure the transmission of any particular MLC. The direct transmission is related to the average thickness of the individual leaves. The amount of the leakage in all cases was acceptable for standard clinical treatments (less than the 5% specified in the protocols), and it could be important for IMRT treatment. The important results of this test were evaluating the leakage and nonuniformity of leakage fluctuations versus depth and field size. The amount of fluctuations for leakage at all energies was decreased with increasing field size and depth.

In this study for film dosimetry, high number of MU is irradiated. This situation is similar to IMRT technique in which a high amount of MU is used. In terms of energy, the amount of leakage was higher for 18 MV compare to 6 MV.

There are three types of leakage in MLC. Transmission directly through the MLC thickness, leakage between the opposite leaf end, and leakage between the adjacent leaves also called interleaf transmission. Comparing these three cases, the leakage between the ends and transmission was more than interleaf transmission. The amount of the transmitted radiation through the MLC leaf was less compared to other leakages as expected.

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Nil.

Conflicts of interest

There are no conflicts of interest.

REFERENCES

1. Sadjadi A, Nouraie M, Mohagheghi MA, Mousavi-Jarrahi A, Malekezadeh R, Parkin DM. Cancer occurrence in Iran in 2002, an international perspective. Asian Pac J Cancer Prev 2005;6:359-63.
2. Jemal A, Siegel R, Ward E, Hao Y, Xu J, Murray T, *et al*. Cancer statistics. CA Cancer J Clin 2008;58:71-96.
3. Suit H, Goldberg S, Niemierko A, Ancukiewicz M, Hall E, Goitein M, *et al*. Secondary carcinogenesis in patients treated with radiation: A review of data on radiation-induced cancers in human, non-human primate, canine and rodent subjects. Radiat Res 2007;167:12-42.
4. Taylor ML, Kron T. Consideration of the radiation dose delivered away from the treatment field to patients in radiotherapy. J Med Phys 2011;36:59-71.
5. Yavari P, Hislop TG, Bajdik C, Sadjadi A, Nouraie M, Babai M, *et al*. Comparison of cancer incidence in Iran and Iranian immigrants to British Columbia, Canada. Asian Pac J Cancer Prev 2006;7:86-90.
6. Galvin JM, Smith AR, Lally B. Characterization of a multileaf collimator system. Int J Radiat Oncol Biol Phys 1993;25:181-92.
7. Jordan TJ, Williams PC. The design and performance characteristics of a multileaf collimator. Phys Med Biol 1994;39:231-51.
8. Siochi RA. Leakage reduction for the Siemens Moduleaf. J Appl Clin Med Phys 2009;10:2894.
9. Committee ART, Boyer A. Basic applications of multileaf collimators: American Association of Physicists in Medicine Madison; 2001.
10. Cosgrove VP, Jahn U, Pfaender M, Bauer S, Budach V, Wurm RE. Commissioning of a micro multi-leaf collimator and planning system for stereotactic radiosurgery. Radiother Oncol 1999;50:325-36.
11. Du MN, Yu CX, Symons M, Yan D, Taylor R, Matter RC, *et al*. A multifeaf collimator field prescription preparation system for conventional radiotherapy. Inte J Radiat Oncol Biol Phys 1995;32:513-20.
12. Hariri S, Shahriari M. Suggesting a new design for multileaf collimator leaves based on Monte Carlo simulation of two commercial systems. J Appl Clin Med Phys 2010;11:3101.
13. Jeraj M, Robar V. Multileaf collimator in radiotherapy. Radiology and Oncology. 2004;38(3).
14. Rassiah-Szegedi P, Szegedi M, Sarkar V, Streitmatter S, Huang YJ, Zhao H, *et al*. Dosimetric impact of the 160 MLC on head and neck IMRT treatments. J Appl Clin Med Phys 2014;15:4770.
15. Lonski P, Taylor ML, Franich RD, Harty P, Kron T. Assessment of leakage doses around the treatment heads of different linear accelerators. Radiat Prot Dosimetry 2012;152:304-12.
16. Thompson CM, Weston SJ, Cosgrove VC, Thwaites DI. A dosimetric characterization of a novel linear accelerator collimator. Med Phys 2014;41:031713.
17. Klein EE, Harms WB, Low DA, Willcut V, Purdy JA. Clinical implementation of a commercial multileaf collimator: Dosimetry, networking, simulation, and quality assurance. Int J Radiat Oncol Biol Phys 1995;33:1195-208.
18. Powers WE, Kinzie JJ, Demidecki AJ, Bradfield JS, Feldman A. A New System of Field Shaping for External-Beam Radiation Therapy 1. Radiology. 1973;108:407-11.
19. Galvin JM, editor The multileaf collimator: A complete guide. Proc AAPM annual meeting; 1999.
20. Deng J, Pawlicki T, Chen Y, Li J, Jiang SB, Ma CM. The MLC tongue-and-groove effect on IMRT dose distributions. Phys Med Biol 2001;46:1039-60.
21. Xu XG, Bednarz B, Paganetti H. A review of dosimetry studies on external-beam radiation treatment with respect to second cancer induction. Phys Med Biol 2008;53:R193-241.
22. Podgorsak MB, Kubsad SS, Paliwal BR. Dosimetry of large wedged high-energy photon beams. Med Phys 1993;20(2 Pt 1):369-73.
23. Tailor RC, Followill DS, Hanson WF. A first order approximation of field-size and depth dependence of wedge transmission. Med Phys 1998;25:241-4.
24. Arnfield MR, Siebers JV, Kim JO, Wu Q, Keall PJ, Mohan R. A method for determining multileaf collimator transmission and scatter for dynamic intensity modulated radiotherapy. Med Phys 2000;27:2231-41.
25. Faddegon BA, O'Brien P, Mason DL. The flatness of Siemens linear accelerator x-ray fields. Med Phys 1999;26:220-8.
26. Takahashi S. Conformation radiotherapy. Rotation techniques as applied to radiography and radiotherapy of cancer. Acta Radiol Diagn (Stockh) 1965:Suppl 242:1.
27. Tubiana M. Can we reduce the incidence of second primary malignancies occurring after radiotherapy? A critical review. Radiother Oncol 2009;91:4-15.
28. Zhu XR, Jursinic PA, Grimm DF, Lopez F, Rownd JJ, Gillin MT. Evaluation

of Kodak EDR2 film for dose verification of intensity modulated radiation therapy delivered by a static multileaf collimator. Med Phys 2002;29:1687-92.
29. Childress NL, Rosen II. Effect of processing time delay on the dose response of Kodak EDR2 film. Med Phys 2004;31:2284-8.
30. Childress NL, Salehpour M, Dong L, Bloch C, White RA, Rosen II. Dosimetric accuracy of Kodak EDR2 film for IMRT verifications. Med Phys 2005;32:539-48.
31. Ma CM, Pawlicki T, Jiang SB, Li JS, Deng J, Mok E, *et al*. Monte Carlo verification of IMRT dose distributions from a commercial treatment planning optimization system. Phys Med Biol 2000;45:2483-95.
32. Klüter S, Sroka-Perez G, Schubert K, Debus Jr. Leakage of the Siemens 160 MLC multileaf collimator on a dual energy linear accelerator. Phys Med Biol 2011;56:N29-37.