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Dosimetric Evaluation of the Multileaf Collimator for Irregular Shaped Radiation Fields

KEYWORDS: radiotherapy, multileaf collimator, quality assurance, IMRT

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ABSTRACT *The three-dimensional planned conformal radiotherapy (3D-CRT), intensity-modulated radiotherapy (IMRT), and image-guided radiotherapy (IGRT) are the most advanced techniques in radiotherapy, which use irregular fields–using multileaf collimators (MLC) in a linear accelerator. The accuracy of these techniques depends on dosimetric characteristics of the multileaf collimators. There is an option for optimizing the jaws to the irregular MLC field to reduce the scattered radiation and intra- and inter-leaf radiation leakage beyond the field. In this study, 80 leaf MLC system has been taken to compare and differentiate their characteristics with 6 and 10 MV photon beams.The MLC system in Elekta linear accelerator is used as a separate unit , that is, The dosimetric characteristics include dose rates, percentage depth doses, surface dose, dose in the build-up region, penumbra, and width of 50% dose levels*

INTRODUCTION

Early implementations of multileaf collimation5–6 were limited to tests and tolerance recommendations for early Varian MLC machines. Soon afterward, Jordan and Williams8 published a paper for Elekta machines and Das etal.9 for Siemens machines. Mubata et al.2 published a paper dedicated to quality assurance (QA) for Varian machines following these initial papers. In 1998, the AAPM formed a task group (AAPM TG-504) to address multileaf collimation, including extensive sections on multileaf collimator QA. This publication recommended a scope limited QA program. Although the task group report was published during initial IMRT implementations using multileaf collimation, it did not make recommendations specific for MLCs as used for IMRT. Subsequent publications,1,3,10–15 particularly those by Cosgrove et al.16 and Chang et al.,17 pointed to tests for MLC QA along with tools for such tests. With regards to the impact of MLC on IMRT, publications have documented the impact of leaf positioning accuracy and interleaf or abutted leaf transmission on the accuracy of delivered IMRT fields.18–20Therefore additional tests of multileaf collimators that are used for IMRT are recommended. Some of the leaf parameters that affect dose delivery for IMRT include leaf positional accuracy and transmission values. Simple tests, such as the picket fence test described by LoSasso,20 can assess positional accuracy qualitatively (by the matching of sequential segments and leaf transmission, particularly interleaf) .We recommend the picket fence test be performed with a careful examination of the image acquired by static film. On the other hand, we recommend expansion of the leaf position accuracy test to account for gantry rotation which may affect leaf motion due to gravitational effects imposed on the leaf carriage system. Loss of travel speed can result in increased beam holds or gap width errors.20 MLC travel speed is evaluated with OmniPro-IMRT software. Leaf position repeatability, MLC spoke shot, and coincidence of light field and x-ray field all are tests intended to check the alignment of the MLCs. Therefore physicists must be aware of the replacement schedule as post-testing is required. All tests should reflect the types of treatments delivered in the department. The method of testing film, solid state detectors, software, EPID shall be sensitive enough to detect errors less than the tolerance level and have the ability to analyze all MLC leaves.

Over the past years, the field-shaping technique has been widely implemented to upgrade conventional radiotherapy to a three-dimensional conformal radiation treatment. The benefits of dose conformity to the target volume while sparing dose to normal tissues and improving target dose uniformity have been discussed in several publications.7,21-24 The technique is based on adjusting the beam aperture to match the shape of the target at various gantry angles. This was performed initially with a few conformal static beams through the use of a number of custom-molded blocks made of lead alloy.21-23 with the development of the intensity modulation radiotherapy (IMRT), the field shape can be dynamically conformed to the target during beam on. Thus, further improvement in dose conformity can be achieved through a series of conformal dynamic arcs. In the case of the intensity modulation radiotherapy treatment (IMRT), the change of the field shape is accompanied by the beam on, a certain amount of leaf position error has to be accepted in order to make the treatment deliverable.25 Therefore, to ensure that the treatment is delivered accurately, it is essential that an efficient and effective quality assurance program can be applied on a routine basis.

In current paper the Static test provide a quantitative information about the leaves locations based on well defined radiation-centre crossed lines, using analysis software for Matrix for Iba company as it is a powerful image analysis tool allowed us to analysis images with high resolution, up fraction of millimeters, and Comparing the measured MLC' s A and B values with the expected value listed in MLC file to get the positional errors for each leave over A and B banks.

2. Materials and Methods:

All the following equipment was from Elekta Systeme, A linear accelerator Elekta Synergy Platform, equipped with an 80-leaf MLCi, and was used for IMRT Therapy. The treatment energy used was 6 and 10 MV photons beam. The MLC consists of 40 pairs of leaves of 1 cm covering fields up to 40 x 40 cm2. The MLC is a computer controlled device consists of set of opposing leave pairs moving in the X jaws direction (perpendicular to the beam direction) and fixed below it on two opposing carriages (banks). All these systems were interfaced with Mosaiq (Radiation Oncology information system).

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ISOCHECK; Isocenter and Iba Blue 3D water phantom and and RW3 slab phantom, is tissue-equivalent with a density of 1.04 g/cm3; its dimensions are 30 × 30 × 30 cm3 , and a Pinpoint ion chamber .All equipment used is produced by Iba (Iba dosimetry company)

All position of leaves tips and also dose distributions measured using Matrix software and ready pack film. The criterion used to evaluate the accuracy of the tests was the gamma index, with individual acceptance criteria of 2% dose difference (DD) and 2- mm distance to agreement (DTA). A quantitative analysis of the dose distribution comparison based on gamma reports was performed to show the percentage pixels in a scanned area 10 × 10 cm2 that exceeded the acceptance criteria (percentage failed pixels).

2.1. Generating and running the "MLC machine" file:
The "MLC machine" files are created by using Microsoft Office Excel program to view and easily editing the file such as field name, index, collimator angle, the position of every leaf in the MLC at each fraction of irradiation dose increment… etc. When completed (finished), and before loading the machine file to the MLC console, it is good practice to open the file on the Xio program to check and simulate the "irradiated" field. It can be loaded to the MLC console of the LINAC for irradiation by imported it to the Mosaiq program which the user can then modify the field properties and change the calibration conditions and dose rate according to his or her need.

2.2. Dosimetric characteristics of MLC:
In current paper the dosimetric characteristics of multileaf collimators (MLCs) were evaluated for 6 and 10 MV photon beams. The percentage depth dose, surface dose, dose in the build-up region, beam profile, flatness, symmetry, and penumbra width were measured using three field-defining methods: (i) 'Jaw only', (ii) 'MLC only, and (iii) 'MLC+Jaw'. Analysis of dose rate shows that the dose rate for 'MLC only' field was higher than that for 'Jaw only" and 'MLC+Jaw' fields in both the energies.

2.3. MLC positions:
To create MLC fields of leaf position with different location that covers a wide range of clinical use, so that separate this wide range into four quarter films of fields to study it individually and take the advantage of MLC repetition in this separation for the study of reproducibility of the MLC.

3. RESULTS AND DISCUSSION
3.1 Collimator Rotation Isocenter:
The mechanical rotational isocenter for the collimator axis should be confined to a sphere of ≤1.0 mm radius. Rotation of the collimator from 90° to 270° while observing the pointer run-out that verify the worst case run-out meets specification.

Beam Profile for small field Size: for MLc$_i$ with Jaws and Jaws only:
relative
dose

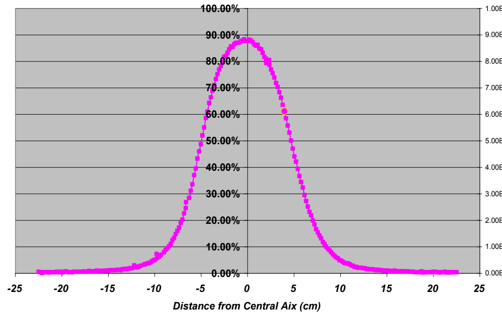

Fig (1) : Beam Profile for field size 1x1 cm 2 for MLCi with Jaws(Blue Curve) and Jaws Only(Pink Curve)

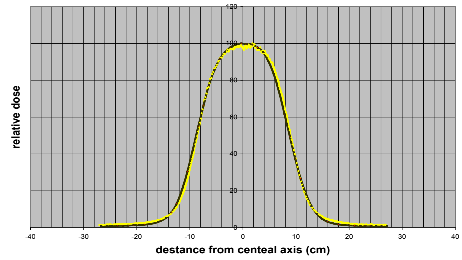

Fig. (2): Beam Profile for field size 2x2 cm 2 for MLCi with Jaws (Blue Curve) and Jaws Only (Yellow Curve)
The beam profiles were measured using 80 -leaf MLC system, for the square field sizes 1×1 cm², 2×2 cm², 10×10 cm², and 20×20 cm² at dmax and 10 cm in the cross-plane orientation for the three field-defining methods mentioned in section 2.2. Within 2.7% for both energies. The flatness and symmetry of the beam profiles were determined for the fields defined above; it was found that the flatness and symmetry were within 2.7% for both energies. The width of 50% dose level' was measured and analyzed; it was observed that the width of the 'MLC only' field was higher by 2 to 3 mm for 6 MV and 2 to 2.5 mm for 10MV photon when compared with 'Jaw only' and/or 'MLC+ Jaw'.

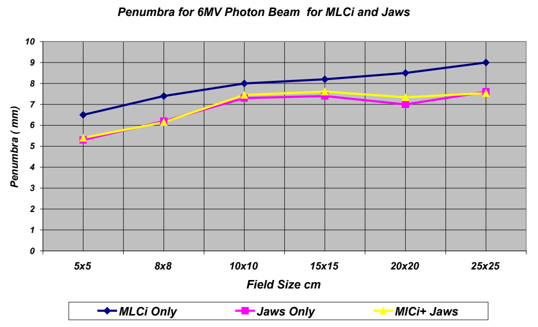

Fig . (3) : Penumbra Comparison Between MLCi and Jaws for 6 MV photon Beam

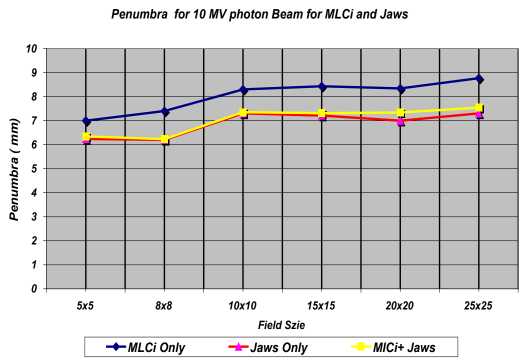

Fig . (4) : Penumbra Comparison Between MLCi and Jaws for 10 MV photon Beam

The penumbra was measured at depth dmax from the 80 to 20% isodose lines. Penumbra of 'MLC only' field was more than that of 'Jaw only' and 'MLC+ Jaw' by 1.7to 2.7 mm for 6 MV and 2.3 to 3 mm for 10 MV photon beam. Figures 3 and 4 show the penumbra at depth dmax for 6 and 10 MV respectively.

3.2. MLC positions:
New Matlab files appear in a working directory after calculation. These files are the measured and expected A and B

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values in each case so it can be used them easily for analysis and plotting the differences. For example AUR and ATUR are the measure and expected A values from the upper right image respectively, BUR and BTUR for the B side and the same for the other images.

First of all, the new function DrawBank 1.m was used here. Simply you give this function the measured and expected A or B values, and it gives a nice graph including the mean position error for each leave over the six fields of an image with an error bar to show the range of the errors. The data for every leave appears in green unless one of its errors exceeds the tolerance.

3.2.1. Stability of the dMLC

The initial adjustment of the MLC is crucial in producing the reference values that will allow the detection of future MLC errors. Picket fence and garden fence tests were designed to accurately detect leaf position errors. The results observed for stability of MLC test intensity patterns for their positional accuracy of match line are listed in [Table 1]. The qualitative analysis of standard MLC patterns shows that the match lines between different intensity segments are straight, approximately equal in intensity, and lying within the positional error of ±0.1 cm [fig. (5)].This implies that there is no leaf and carriage positional error occurring during the MLC movement. Match-line accuracy in Picket and Garden Fence test patterns also confirms the same.

Table (1): Percent Dose Difference (DD) / Distance To Agreement (DTA) comparison between different dMLC of Garden Fence Test in all fixed gantry angles & Arc modes for nine analysis criteria.

Garden fence test				
(%DD/DTA)	Average (%)	Range (%)	# of Plans	# of comparison
3%-3mm	96.47	90.12 – 99.84	6	15
3%-2mm	93.00	83.39 – 99.06	6	15
3%-1mm	76.98	62.04 – 87.63	6	15
2%-3mm	93.70	82.56 – 99.42	6	15
2%-2mm	88.96	73.78 – 98.35	6	15
2%-1mm	69.53	53.28 – 82.41	6	15
1%-3mm	88.38	53.39 – 98.79	6	15
1%-2mm	84.35	66.69 – 96.77	6	15
1%-1mm	61.68	46.93 – 76.01	6	15

One of the superposition of dose profile (along the direction of leaf movement) for Garden Fence test at 0°, 90°, 180°,270° fixed gantry angles, and cw, ccw for arc is shown in [fig. 6 (a)] 3% dose difference (DD) and 3 mm distance to agreement (DTA), and its gamma index report in [fig. 6 (b)].The gamma index analysis results with various tolerance levels, the average fraction of passed gamma values using 2% and 2mm criteria was 88.96% for all films. Shrinking the tolerance to 2% and 2mm, the average pass-rate for all films was above 83.55 % to 98.35 %, but two gamma comparison tests are lowers 76.91% and 73.78 % for 0° with 270° and 90° with 270° respectively.

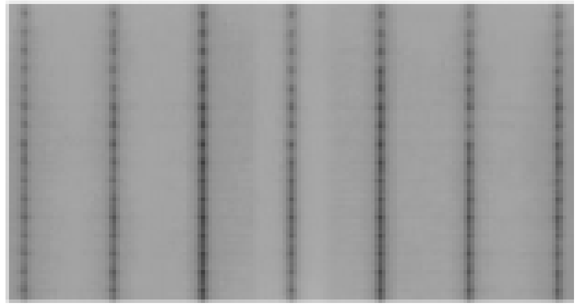
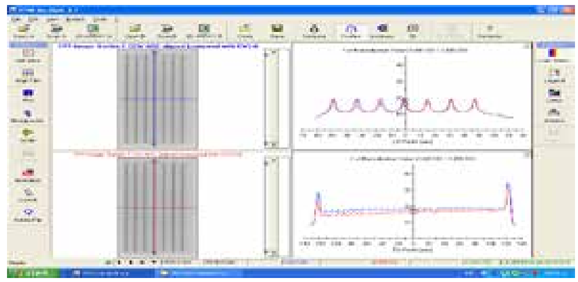
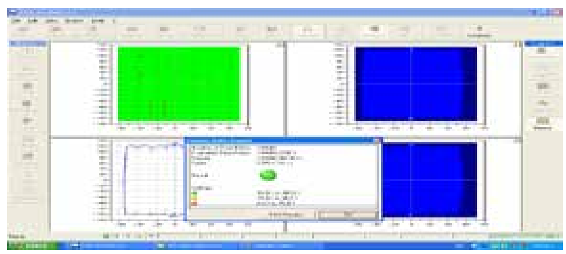


Fig . (5) : The recorded intensity pattern film.



a



b

Fig.[6.a]: The Garden fence test at cw & ccw arcs and its pattern in the direction parallel to the leaf motion(LR-Profile) the upper one & and in a perpendicular direction (TG-Profile) the lower one. (b) The gamma index report showed evaluated dose points passed 98.35% and failed 1.65%.

3.2.2. Leaf speed and stability test with and without beam interruptions (Multi-travel test):

The stability of leaf speed was verified using a Multi-travel test field that requires the leaf pair to move at several constant speeds, generating a stepwise homogeneous dose delivery of well-defined intensity. The stability of the different speed levels was analyzed, comparing the uniformity of each profile in fixed gantry angle to the arc mode. Qualitative analysis of dose profiles for leaf speed and stability test with and without beam interruptions showed that they were identical and well within the uncertainty of film dosimetry. This is demonstrated in [fig. 7 (a)], showing the dose profiles for 8 ways of the multi-travel test parallel and perpendicular to the leaf motions. Thus it was observed after the gamma comparison (2% DD & 2 mm DTA) that leaf speed remained constant and dose delivered was not affected by the interruptions [fig. (7 b)]. The gamma index analysis results with various tolerance levels are shown in [Table 2], the average fraction of passed gamma values using 2% and 2mm criteria was above 97.30 % for all films except for the comparison between them and the absolute one (14×14 cm2) due to the cross calibration of the dose measured located in a middle of two machine unit values which yield the comparison between values 81.21% and 89.45% for the same criteria.

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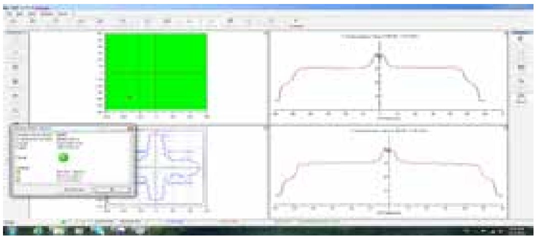
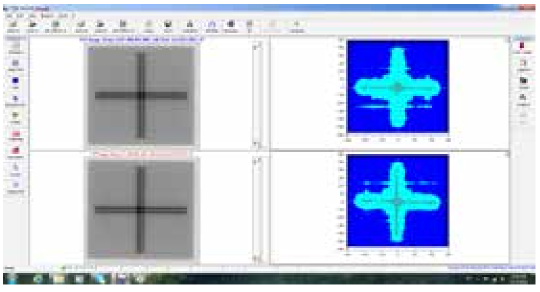
Table (2): Percent Dose Difference (DD) / Distance To Agreement (DTA) comparison between different dMLC of Multi-Travel Test in all fixed gantry angles & Arc modes for nine analysis criteria.

Multi-travel test				
(%DD/DTA)	Average (%)	Range (%)	# of Plans	# of comparison
3%-3mm	99.82	99.14 – 100	8	4
3%-2mm	99.70	98.88 – 99.99	8	4
3%-1mm	98.27	95.42 – 99.97	8	4
2%-3mm	99.53	98.44 – 99.99	8	4
2%-2mm	98.91	97.30 – 99.97	8	4
2%-1mm	95.68	90.66 – 99.85	8	4
1%-3mm	97.89	95.23 – 99.92	8	4
1%-2mm	95.91	91.66 – 99.65	8	4
1%-1mm	88.52	81.59 – 79.92	8	4



a



b

Fig. (7.a) An example of the Multi-travels test (8 travels) for ccw arc (the upper film), and it fixed gantry angle (the lower film) and their color wash in the right side. (7.b) 2% DD & 2 mm DTA gamma index report showed evaluated dose points passed 98.18% and failed 1.82%. The pattern in the direction parallel to the leaf motion (LR-Profile) the upper one & and in a perpendicular direction (TG-Profile) the lower one.

4. CONCLUSIONS

This protocol was describing our initial experience of quality assurance (QA) tests on the multileaf collimator (MLC) for IMRT techniques. Novel QA tests were designed and used to simultaneously determine uncertainties associated with MLC for dose delivery erros (gantry angle leaf positional deviation) not only in still linac gantry but also in dynamic arc therapy.

The dosimetric characteristics of the Elekta 80-leaf MLCi system were measured, compared, and analyzed using 6 and 10 MV photon beams. It was found that its characteristics were quite similar to those of the standard collimator (jaws) system and penumbra. Dose rate for 6 and 10 MV photon beams was higher for 'MLC only' field than that for the other two field-defining methods. The PDD comparison shows that the surface dose and dose in the build-up region were more for 'MLC only' fields. Beam profile analysis shows that the flatness and symmetry for both the systems were within 2.6%; the 'width of 50% dose level' and penumbra were slightly higher for 'MLC only' fields in both energies. The results of this study suggest that standard collimator jaws should be optimized to the irregular MLC field (i.e., MLC+Jaw) to minimize the surface dose, dose rate, penumbra, and dose in the build-up region.

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