Iranian Journal of Medical Physics
ijmp.mums.ac.ir

The Dosimetric Effects of Different Multileaf Collimator Widths on Physical Dose Distributions

Ehab M. Attalla[1, 2*] , Ismail Eldesoky [1]

1. Cairo; National Cancer Institute, Children's Cancer Hospital
2. Cairo University, Cairo, Egypt

ARTICLE INFO

Article type:
Original Article

Article history:
Received: Nov 10, 2016
Accepted: Sep 12, 2017

Keywords:
Multileaf Collimator
Intensity-Modulated Radiation Therapy
Dose Distribution

ABSTRACT

Introduction: Geometric changes in the multileaf collimator (MLC) led to dosimetric considerations in intensity-modulated radiation therapy (IMRT) due to the number and size of the pixels in the intensity map, which are determined by the MLC leaf width. In this study, we evaluated the dosimetric effects of different MLC widths on physical dose distributions for IMRT plans.
Materials and Methods: Forty-two IMRT plans based on different MLC devices were generated and analyzed to study the effect of MLC width on plan quality.
Results: Improvements in IMRT plan quality using 0.4 cm leaf width in comparison with 1 cm leaf width were evaluated. The 0.4 cm leaf-based plans resulted in significantly higher D_{mean}, $D_{98\%}$, $D_{95\%}$, $D_{5\%}$, and V_{95} (58.86 Gy, 95.11%, 96.57%, 104%, and 97.92%, respectively) compared to the 1 cm leaf plans (58.66 Gy, 92.56%, 94.56%, 104.14%, and 95.72%, respectively). Conformation number (CN) for planning target volume in 0.4 cm leaf plans was significantly higher than the 1 cm leaf plans (0.74 vs. 0.67; $P<0.05$). In addition, the 0.4 cm leaf plans significantly improved dose homogeneity compared to the 1 cm leaf plans (1.08 vs. 1.10; $P<0.05$). We found that 0.4 cm leaf width significantly decreased the integral dose to normal tissue compared to the 1 cm leaf width (from 56.09 to 49.46 Gy.Kg $P<0.05$).
Conclusion: No significant clinical differences were observed between the two plans for a serially functioning tissue, while the differences in mean doses were statistically significant for parallel functioning normal tissues.

► *Please cite this article as:*
Attalla E, Eldesoky I. The Dosimetric Effects of Different Multileaf Collimator Widths on Physical Dose Distributions. Iran J Med Phys 2018; 15:12-18. 10.22038/ijmp.2017.20058.1190.

Introduction

The geometric changes in multileaf collimator (MLC) imply dosimetric considerations in intensity-modulated radiation therapy (IMRT) because the number and size of the pixels in the intensity map are determined by MLC leaf width. In addition, MLCs influence both field size and resolution [1]. Intensity maps for each MLC field are modulated by first overlaying a grid of square pixels on the planning target volume (PTV) in the beam's eye view to shape the area of interest while protecting the normal tissue (size of these squares given by the MLC leaf width). The inverse treatment planning system then proceeds to optimize the pixel intensities and achieve the planning goals [2].

The whole body dose received by the patient from leakage radiation is determined based on the total number of monitor units and the total treatment time, which depends on the number of segments required for delivering the calculated intensity pattern.

We aimed to determine the effect of leaf size on the optimization of IMRT treatment plans for different tumors that were adjacent to a radiosensitive critical structure (serially functioning and parallel functioning normal structures) to determine the cases requiring fine resolution.

Materials and Methods

Patient data

Forty-two plans were retrospectively evaluated to assess the impact of MLC leaf width on the optimization of IMRT treatment plans for the prostate (for rectum and bladder preservation strategies) and different brain cases (next to the brainstem, optic chiasm, and eyes) by comparison of the quality and complexity of each plan.

Mean target volumes of the lesions were 72.19 cc (range: 15.1-182.4 cc) and 169.38 cc (range: 72.96-351.9 cc) for the brain and prostate groups, respectively. The chosen volumes were intended to represent the ranges of the target volumes typically encountered in these sites.

*Corresponding Author: National Cancer Institute, cairo university & Children Cancer Hospital , Egypt. Tel: 01005373359; Email: attalla.ehab@gmail.com

Target Definition and Plan Preparation

The patients underwent helical computed tomography (Siemens CT scanner Somatom Sensation version syngo CT 2007S from Germany) with 2-mm slice intervals in the supine position. The patients were immobilized with head and neck thermoplastic masks and/or with vacuum-locked cradles. All the acquired CT images were transferred to and registered in the Treatment planning System (TPS). For each case, the target volumes, normal structures, and organs at risk (OARs) were contoured according to International Commission on Radiation Units and Measurements (ICRU) 50 and 62 reports by a same physician who evaluated the final plan. The expansion of the clinical target volume to planning target volume (PTV) sometimes results in some overlaps with the OARs [3, 4]. The overlap between PTV and OARs may be used to accurately guide physicians in the use of interventions to limit the extent of the overlap region prior to optimization. Table 1 shows the diagnoses, prescription doses at the isocenter, PTV volumes, and patient volumes for the investigated cases.

Table 1. The diagnoses, prescription doses, planning target volumes, and patient volumes for the cases used to study the effect of multileaf collimator width on the quality of intensity-modulated radiation therapy plans

Diagnosis	Prescribed dose (Gy)	Planning target volume (CC)	Patient volume (CC)
Craniopharyngioma	50.4	15.3	2108
Craniopharyngioma	50.4	82.8	1786
Craniopharyngioma	54.0	81.5	2195
Craniopharyngioma	54.0	89.3	4402
Craniopharyngioma	54.0	41.9	2439
Craniopharyngioma	54.0	63.1	1879
Craniopharyngioma	54.0	27.9	1815
Craniopharyngioma	54.0	64.7	1917
Craniopharyngioma	54.0	162.1	3238
LT cerebellopontine angle ependymoma	54.0	115.2	2282
Posterior fossa ependymoma	55.8	91.1	2030
Brain	50.4	182.4	1536
Brainstem	54.0	20.7	1939
Retinoblastoma	41.4	29.7	1315
Base of skull	64.8	15.1	2078
Prostate	50.4	351.9	2598
Prostate	76.0	143.3	10686
Prostate	77.7	151.4	9837
Prostate	76.0	72.9	8792
Prostate	76.0	129.7	13584
Prostate	76.0	167.1	9237

Treatment Planning

Treatment plans were designed and evaluated using Siemens Medical Solutions (Malvern, PA Germany), which uses the KonRad (MRC Systems GmbH, Heidelberg, Germany) inverse planning software release 2.2.23 for IMRT planning [5]. We utilized 6 MV photons from Siemens ONCOR Expression linear accelerator for all the IMRT fields.

The MLC delivery system replaces the lower movable jaws inside the linear accelerator head. The OPTIFOCUS MLC for the ONCOR linear accelerators has 39 pairs of inner leaves 10 mm in width and two pairs of outer leaves 5 mm in width, which provides coverage of a full 40 cm IMRT field length. Each leaf can travel a maximum distance of 15 cm over the beam's central axis, which may limit the IMRT field width to 27 cm in some cases.

Once beam data for the corresponding MLC are collected and commissioned, the TPS also allows treatment planning for delivery using the Siemens ModuLeaf Mini Multileaf Collimator (MMLC) with a leaf width of 2.5 mm. The Siemens mini-MLC is called the MMLC and has 40 pairs of leaves with 10 x 12 cm maximum field size at the isocenter. The leaf geometry of the MMLC is divergent lock-and-key to minimize leakage and transmission characteristics critical for IMRT. The MMLC device is attached to the head of the linear accelerator prior to use.

The physical parameters of the MLC and MMLC, such as head scatter, leaf leakage, and tongue-and-groove effect, are implemented and modeled in the treatment planning system. In spite of the fact that the MLC tongue-and-groove effect on IMRT dose distribution is known to be clinically negligible for the composite plan [6]. The leaf offsets have the same effect for both MLC and MMLC, in addition to no significant mechanical limitations except for the leaf width.

The plans were performed based on nine equally spaced axial beam arrangements (0, 40, 80, 120, 160, 200, 240, 280, and 320^0) to minimize doses to the critical structures and to achieve high dose fall-off around the target at the same time. IMRT plan optimization based on two MLC devices was

generated using the same treatment geometry and dose constrain parameters to produce an acceptable plan satisfying the OAR tolerance criteria established in our department. These dose constraints cover the maximum and minimum doses for the target and critical organs, in addition to the penalty functions for breaking each. The plan specification parameters as a compromise between target coverage and protection of the OARs for each individual patient are optimized manually.

The output of the optimization process was an idealized intensity-modulated fluence distribution for each beam. The theoretically optimized intensity profiles were converted into an actual deliverable fluence map by the built-in leaf sequencer based on the number of intensity modulation levels. Higher number of modulation levels was associated with greater number of monitor units and segments required for delivery. The number of intensity levels used to discretize individual beam fluence was determined manually in order to achieve the clinical goals with the fewest number of segments. The beamlet size used by the treatment planning system is not user configurable.

The final dose calculations were performed based on pencil beam algorithm measurement with inhomogeneity correction. For plan comparison, 2-mm dose-grid resolutions are used to construct dose–volume histograms (DVHs). All the plans were accepted based on the criterion that 95% of the prescription dose covered at least 95% of the PTV without any hot spots above 107%.

Dosimetric Evaluation Parameters And Statistical Analysis

Plan quality was evaluated according to DVHs and dose statistics with respect to the target coverage criteria and OAR sparing criteria. For the targets, the mean and maximum doses to the PTVs and several physical indices ($D_{98\%}$ [cGy] , $D_{95\%}$ [cGy], $D_{5\%}$ [cGy], $V_{95\%}$ [%], and $V_{107\%}$ [%]) were compared, where D_n is the minimum dose delivered by n% of the PTV. Homogeneity of dose within PTV has been evaluated by using homogeneity index (HI) as defined by HI = $D_{5\%}$ / $D_{95\%}$, where $D_{5\%}$ and $D_{95\%}$ denote the dose levels on the DVH curve corresponding to 5% and 95% of the target volume, respectively. The more D_5 and D_{95} approach each other, the steeper the target's curve in DVHs. The optimal HI value is 1.

Van't Riet et al. summarized that the conformity of high doses around the target has been evaluated by conformation number (CN) [7], just because it takes into account irradiation of the target volume and irradiation of healthy tissues.

The CN was defined as in the following equation:

$$CN = TV_{RI}/ TV*TV_{RI}/V_{RI} \quad (1)$$

where CN is conformation number, TV_{RI} denotes the target volume covered by the reference isodose, TV indicates target volume, and V_{RI} is the volume of the reference isodose; according to the ICRU, the used reference isodose was 95%.

For OARs, the dose–volume parameters were analyzed for MMLC and the standard MLC by comparing several physical indices. In the prostate cases, the irradiated volumes that received at least 70, 66.6, 50, 40, and 20 Gy (V_{70} Gy, $V_{66.6}$ Gy, V_{50} Gy, V_{40} Gy, and V_{20} Gy), the mean doses (D_{mean}), and $D_{50\%}$ were calculated. D_{mean} and $D_{50\%}$ to the rectal wall, bladder, and femoral heads were quantified. On the other hand, in the brain cases, the irradiated volumes receiving doses higher than 5, 10, and 15 Gy (V_5 Gy, V_{10} Gy, and V_{15} Gy) were measured. In the rest of OARs, the mean doses were calculated for the eyes and lenses. Plan complexity was assessed by comparing the number of segments and monitoring the units required to deliver the plan.

Further, low dose distribution in healthy tissue was evaluated by comparing the percentage volumes of each patient receiving 2 and 5 Gy for the two plans. In this study, the integral dose (ID) was described as the product of the mean dose in Gy for the external contour and the mass of the external contour in Kg [8]. In addition, the mass of the external contour was considered as the product of its volume with a tissue density of 1 g/cm^3. The integral dose was defined for n voxels by the following equation:

$$ID= \sum^{n_i} D_i m_i = \sum^{n_i} D_i V_i \rho_i \quad (2)$$

where D_i, mi, V_i, ρ_i are the dose, mass, volume, and density of voxel i.

Statistical Analysis

To analyze the data descriptive statistics (mean±SD) and paired t-test were used in SPSS. The significance threshold was set at 0.05.

Results

Conformity and Homogeneity of the Target

Figure 1 demonstrates the DVHs and dose distributions for the MMLC and standard MLC (82 MLC) plans for a brainstem case. In total, 42 plans based on different MLC devices were generated and analyzed. The evaluation of the DVH-based parameters of the targets is shown in Table 2. The MMLC-based plans result in significantly higher D_{mean}, $D_{98\%}$, $D_{95\%}$, $D_{5\%}$, and V_{95} (58.86 Gy, 95.11%, 96.57%, 104%, and 97.92%, respectively) compared to the standard MLC plans (58.66 Gy, 92.56%, 94.56%, 104.14%, and 95.72%, respectively) .

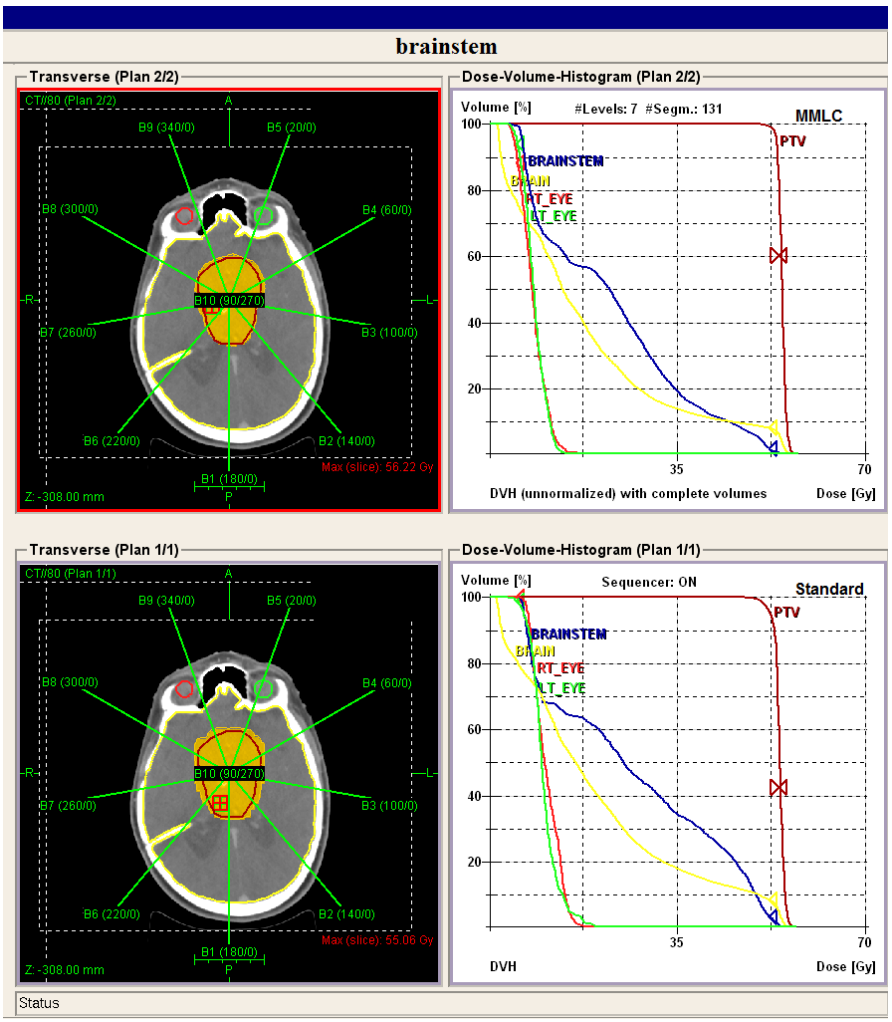

Figure 1. The dose distribution and dose–volume histograms for the ModuLeaf Mini Multileaf Collimator and standard multileaf collimator (82 MLC) treatment plans for a brainstem case

Table 2. D_{max} (Gy), D_{mean} (Gy), $D_{95\%}$ (%), $D_{98\%}$ (%), $D_{5\%}$ (%), $V_{95\%}$ (%), and $V_{107\%}$ (%) for planning target volumes in the ModuLeaf Mini Multileaf Collimator and standard multileaf collimator plans

Parameter	D_{max} (Gy)		D_{mean} (Gy)		$D_{95\%}$ (%)		$D_{98\%}$ (%)	
	MMLC	82 MLC	MMLC	82 MLC	MMLC	82 MLC	MMLC	82 MLC
Mean±SD	64.2 ±11.3	63.2 ±11.8	58.9 ±10.8	58.7 ±10.8	96.6± 1.2	94.7 ± 1.5	95.1 ± 2.4	92.7 ± 2.3
P-value	0.006		0.004		0.001		0.001	
Parameter	$D_{5\%}$ (%)		$V_{95\%}$ (%)		$V_{107\%}$ (%)			
	MMLC	82 MLC	MMLC	82 MLC	MMLC	82 MLC		
Mean±SD	104.0 ±1.2	104.1 ±1.5	97.9 ± 1.5	95.7 ± 1.8	0.8 ± 1.1	1.3 ± 2.1		
P-value	0.49		0.0001		0.163			

*P-values < 0.05 are presented in bold numbers.
MMLC: ModuLeaf Mini Multileaf Collimator
MLC: multileaf collimator
D_{max}: maximum dose to organ, D_{mean}: mean dose to organ, $D_{n\%}$: the percentage dose received by the n% volume of the target volume, $V_{n\%}$: the percentage volume irradiated by n% of the prescribed dose

Table 3 presents a comparison of the number of segments and the delivering MUs between MMLC and standard MLC plans, hence providing a measure of relative plan complexity. The average number of MUs with MMLC was significantly higher than that with the standard MLC (1076.43 vs. 372.28; P<0.05). The standard MLC required 54.8% fewer segments than MMLC. The mean number of segments was reduced from 111.33 to 50.33.

Table 3. The homogeneity index, conformation number, monitor units, and the number of segments in both ModuLeaf Mini Multileaf Collimator and Standard multileaf collimator plans

Parameter	Homogeneity index		Conformation number		Monitor units		Segments	
	MMLC	82 MLC	MMLC	82 MLC	MMLC	82 MLC	MMLC	82 MLC
Mean±SD	1.08 ±0.02	1.10 ±0.03	0.74 ±0.11	0.67 ±0.12	1076.4 ±437.4	372.3 ±121.4	111.3 ±29.7	50.3 ±17.6
P-value	**0.0001**		**0.0001**		**0.001**		**0.001**	

*P-values < 0.05 are presented in bold numbers.
MMLC: ModuLeaf Mini Multileaf Collimator
MLC: multileaf collimator

Dose Sparing of the Oars

Table 4 exhibits a comparison of the DVH-based parameters of the OARs for different cases. Compared to the plans calculated using the standard MLC, most of the plans with MMLC had significant advantages in dose sparing of the brain, rectum, bladder, both eyes, and RT lens (P<0.05). MMLC and standard MLC were not significantly different between LT and RT heads of femur, brainstem, optic chiasm, and LT lens. The significant dosimetric improvements in the rectal dose volume parameters may diminish late rectal toxicity, which is significantly correlated with the absolute/percentage volume of the rectum receiving all dose ranges [9].

Table 4. The dose–volume parameters for different organs at risk for both ModuLeaf Mini Multileaf Collimator and standard multileaf collimator plans

Organs at risk	DVH parameter	MMLC	82 MLC	P-value
Brain	V_{5Gy} (%)	56.8 ± 14.9	62.8 ± 14.9	0.001
	V_{10Gy} (%)	47.6 ± 11.2	55.6 ± 10.2	0.0001
	V_{15Gy} (%)	37.2 ± 13.5	44.9 ± 13.0	0.0001
Rectum	D_{mean} (Gy)	31.8 ± 7.3	37.9 ± 8.9	0.009
	V_{20Gy} (%)	70.7 ± 16.5	79.5 ± 18.6	0.005
	V_{40Gy} (%)	33.4 ± 19.2	45.5 ± 20.7	0.038
	V_{50Gy} (%)	19.5 ± 14.4	30.9 ± 19.1	0.022
	$V_{66.6Gy}$ (%)	6.6 ± 7.6	10.7 ± 7.5	0.050
	V_{70Gy} (%)	5.2 ± 6.8	6.9 ± 5.8	0.080
	$D_{50\%}$(Gy)	31.3 ± 10.6	37.9 ± 13.2	0.013
Bladder	D_{mean} (Gy)	33.1 ± 7	40.3 ± 6.4	0.0001
	V_{20Gy} (%)	65.5 ± 18.9	76.8 ± 14.6	0.016
	V_{40Gy} (%)	35.0 ± 11.1	50.0 ± 13.2	0.016
	V_{50Gy} (%)	25.6 ± 10.3	36.0 ± 11.7	0.004
	$V_{66.6Gy}$ (%)	15.1 ± 8.9	19.3 ± 9.4	0.014
	V_{70Gy} (%)	13.5 ± 8.9	14.9 ± 9.2	0.087
	$D_{50\%}$(Gy)	27.4 ± 9.9	39.5 ± 8.8	0.002
LT head of femur	D_{mean} (Gy)	12.6 ± 2.6	12.6 ± 2.3	0.997
	$D_{5\%}$(Gy)	22.5 ± 4.0	21.3 ± 1.8	0.415
RT head of femur	D_{mean} (Gy)	12.9 ± 2.8	13.4 ± 3.2	0.251
	$D_{5\%}$(Gy)	23.3 ± 2.7	23.3 ± 1.4	0.984
Brain stem	Max 1cm^3	49.7 ± 9.8	51.0 ± 6.6	0.286
optic chaism	Max (Gy)	35.6± 20.5	37.4 ± 15.6	0.372
RT eye	D_{mean} (Gy)	8.5 ± 2.7	11.2 ± 3.8	0.0001
LT eye	D_{mean} (Gy)	7.1 ± 3.7	9.7 ± 4.5	0.0001
RT lens	D_{mean} (Gy)	5.7 ± 1.6	9.4 ± 3.1	0.032
LT lens	D_{mean} (Gy)	4.2 ± 2.0	6.1 ± 3.8	0.119

*P-values < 0.05 are presented in bold numbers
MMLC: ModuLeaf Mini Multileaf Collimator
MLC: multileaf collimator
DVH: dose–volume histogram
D_{mean}: mean dose to organ, $D_{n\%}$: the dose received by n% volume of the organ volume, V_{nGy}: the percentage volume irradiated by n Gy or more of a certain structure

Integral Dose and Dose to Normal Tissue

Evaluation of the effect of the type of MLC on ID showed that using MMLC significantly decreased ID to normal tissue compared to standard MLC (from 56.09 to 49.46 Gy/Kg; P<0.05; Table 5).

Several paradigms of radiation carcinogenesis suggest that the dose-response relationship is linear

up to a dose of 6 Gy, where it then reaches a plateau [10]. In this case, the percentage volumes of each patient receiving 2 Gy and 5 Gy may be important. Subsequently, the present study reported that the percentage volumes of patients receiving 2 Gy and 5 Gy for comparison between MMLC and standard MLC plans. The percentage volume of eachpatient receiving 5 Gy (V_{5Gy}) was significantly lower for MMLC compared to standard MLC (51.56 vs. 57.47; P<0.05). The $D_{1\%}$, $D_{2\%}$, $D_{5\%}$, and V_{2Gy} parameters showed insignificant differences between both MLCs.

Table 5. Integral dose and low dose distribution in healthy tissues

Parameter	Integral dose		$D_{1\%}$(Gy)		$D_{2\%}$(Gy)	
	MMLC	82 MLC	MMLC	82 MLC	MMLC	82 MLC
Mean	49.5	56.1	59.5	59.4	54.9	55.9
SD	42.9	47.2	10.2	10.1	8.4	8.0
P-value	**0.0001**		0.176		0.101	
Parameter	$D_{5\%}$(Gy)		V_{2Gy} (%)		V_{5Gy} (%)	
	MMLC	82 MLC	MMLC	82 MLC	MMLC	82 MLC
Mean	39.4	43.4	74.1	74.9	51.6	57.5
SD	11.5	9.2	15.2	8.9	9.8	8.7
P-value	0.124		0.634		**0.0001**	

*P-values < 0.05 are presented in bold numbers
MMLC: ModuLeaf Mini Multileaf Collimator
MLC: multileaf collimator
$D_{n\%}$: the dose received by the n% volume of the organ volume, V_{nGy}: the percentage volume irradiated by n Gy or more of a healthy tissue

Discussion

The average CN for PTV in MMLC plans was significantly higher than that for standard MLC plans (0.74 vs. 0.67). In addition, the MMLC significantly improved DH (HI =1.08 for MMLC vs. 1.10 for standard MLC).

The absence of a significant clinical difference between the two plans for the brainstem and optic chiasm is related to their nature as serially functioning normal structures, where the maximum dose is the most important predictor of biological response. On the other hand, the differences in D_{mean} were statistically significant for the rectum, bladder, and both eyes, which are parallel functioning normal tissues where the biological response is most closely associated with D_{mean}. These results may contribute to the clinical preference of MMLC plans considering the nature of OARs.

MMLC also has some minor disadvantages including the need for greater number of segments to deliver the prescribed dose, which consequently, requires increased total number of monitor units for the treatment. The number of segments is reduced by an average of 45.20% using the standard MLC compared to MMLC. In addition, the standard MLC plans require 34.58% fewer monitor units compared to MMLC plans. Moreover, the mounting of MMLC (as an add-on tertiary MLC) not only prolongs the treatment procedure, but also reduces the clearance between the gantry and couch, hence limiting the freedom to select certain beam angles.

Nevertheless, the use of a small leaf width in MLC may improve the therapeutic ratio by reducing toxicity to the surrounding normal tissue during IMRT delivery [11].

Conclusion

Treatment of small lesions in cases involving complex targets and OAR geometries will especially benefit from the use of MMLC. There was no significant clinical difference between the two plans for a serially functioning normal structure, while the differences in mean doses were statistically significant for parallel functioning normal tissues. These results may contribute to the clinical preference of 2.5-mm leaf plans considering the nature of OAR. This would require one to decide whether to allow a greater number of segments and MUs for a better quality plan in spite of the accompanying increase in both treatment time and whole body dose.

References

1. Fiveash JB, Murshed H, Duan J, Hyatt M, Caranto J, Bonner JA, Popple RA. Effect of multileaf collimator leaf width on physical dose distributions in the treatment of CNS and head and neck neoplasms with intensity modulated radiation therapy. Medical physics. 2002 Jun 1;29(6):1116-9.

2. Burmeister J, Mc Dermott PN, Bossen berger T, Ben Josef E, Levin K, Forman JD. Effect of MLC leaf width on the planning and delivery of SMLC IMRT using the CORVUS inverse treatment planning system. Medical physics. 2004 Dec 1;31(12):3187-93.
3. International Commission on Radiation Units and Measurements ICRU report 50: prescribing, recording, and reporting photon beam therapy. Bethesda: ICRU, 1993.
4. International Commission on Radiation Units and measurements ICRU report 62: prescribing, recording, and reporting photon beam therapy (supplement to ICRU report 50). Bethesda: ICRU, 1999.
5. Deshpande S, Sathiyanarayanan VK, Bhangle J, Swamy K, Basu S. Dosimetric and QA aspects of Konrad inverse planning system for commissioning intensity-modulated radiation therapy. Journal of Medical Physics/Association of Medical Physicists of India. 2007 Apr;32(2):51.
6. Kim HJ, Kim S, Park YK, Kim JI, Park JM, Ye SJ. Multileaf collimator tongue-and-groove effect on depth and off-axis doses: A comparison of treatment planning data with measurements and Monte Carlo calculations. Medical Dosimetry. 2015 Dec 1;40(4):271-8.
7. Van't Riet A, Mak AC, Moerland MA. A conformation number to quantify the degree of conformality in brachytherapy and external beam irradiation: Application to the prostate. International Journal of Radiation Oncology* Biology* Physics. 1997 Feb 1;37(3):731-6.
8. Aoyama H, Westerly DC, Mackie TR, Olivera GH, Bentzen SM, et al. Integral radiation dose to normal structures with conformal external beam radiation. International Journal of Radiation Oncology* Biology* Physics. 2006 Mar 1;64(3):962-7.
9. Huang EH, Pollack A, Levy L, Starkschall G, Dong L, Rosen I, Kuban DA. Late rectal toxicity: dose–volume effects of conformal radiotherapy for prostate cancer. International Journal of Radiation Oncology* Biology* Physics. 2002 Dec 1;54(5):1314-21.
10. Hall EJ, Wuu CS. Radiation-induced second cancer: the impact of 3D-CRT and IMRT. International Journal of Radiation Oncology* Biology* Physics. 2003 May 1;56(1):83-8.
11. Gong Y, Wang S, Zhou L, Liu Y, Xu Y, Lu Y, et al. Dosimetric comparison using different multileaf collimeters in intensity-modulated radiotherapy for upper thoracic esophageal cancer. Radiation Oncology. 2010 Jul 15;5(1):65.