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Dosimetric impact of different multileaf collimators on prostate intensity modulated treatment planning

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ABSTRACT

Aim: The main purpose of this study is to perform a dosimetric comparison on target volumes and organs at risks (OARs) between prostate intensity modulated treatment plans (IMRT) optimized with different multileaf collimators (MLCs).
Background: The use of MLCs with a small leaf width in the IMRT optimization may improve conformity around the tumor target whilst reducing the dose to normal tissues.
Materials and methods: Two linacs mounting MLCs with 5 and 10 mm leaf-width, respectively, implemented in Pinnacle^3 treatment planning system were used for this work. Nineteen patients with prostate carcinoma undergoing a radiotherapy treatment were enrolled. Treatment planning with different setup arrangements (7 and 5 beams) were performed for each patient and each machine. Dose volume histograms (DVHs) cut-off points were used in the treatment planning comparison.
Results: Comparable planning target volume (PTV) coverage was obtained with 7- and 5-beam configuration (both with 5 and 10 mm MLC leaf-width). The comparison of bladder and rectum DVH cut-off points for the 5-beam arrangement shows that 52.6% of the plans optimized with a larger leaf-width did not satisfy at least one of the OARs' constraints. This percentage is reduced to 10.5% for the smaller leaf-width. If a 7-beam arrangement is used the value of 52.6% decreases to 21.1% while the value of 10.5% remains unchanged.
Conclusion: MLCs collimators with different widths and number of leaves lead to a comparable prostate treatment planning if a proper adjustment is made of the number of gantry angles.

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1. Background

Intensity modulated radiation therapy (IMRT) is an advanced form of external beam radiation therapy involving the delivery of multiple beams at different angles around the patient. This technique has the ability to improve dose distributions in a way that results in a higher conformity around the tumor target whilst reducing the dose to normal tissues. The clinical evidence for the effectiveness of IMRT is encouraging.[1] IMRT treatment delivery requires the use of multileaf collimators (MLC). Over the years, linear accelerator vendors have not only improved the reliability of MLCs but also made the leaf-width smaller. Smaller leaf-width allows the treatment planning system to use a finer beamlet size during optimization achieving a better plan quality.

The IMRT planning process involves two steps: the first one consists in an idealized pencil beam dose calculation and dose optimization; the other one in the final dose calculation based on the actual physical beam apertures. Consequently there are differences between the pencil beam calculation and optimization and the corresponding dose distribution that takes into account collimator-specific effects. The purpose of this work was a dosimetric comparison of prostate IMRT plans optimized for two linacs having different multileaf collimators. The plan optimization was carried out using the same parameters. The treatment delivery accuracy of the different plans was validated by performing patient specific intensity modulated radiation therapy quality assurance (IMRT QA) using a two dimensional (2D) ion chamber array.[2]

2. Materials and methods

2.1. Machines characterization

In our department, Siemens Medical Solutions (Erlangen, Germany) machines are available, namely an Artiste™ and an Oncor™ Impression linear accelerator, mounting respectively a 160 and a 82 OPTIFOCUS MLCs. The dosimetric characteristics of both MLCs have been previously described.[3,4]

The 160 MLC™ has 160 leaves (80 on each side) with a leaf-width of 5 mm over the full field of 400 mm × 400 mm. The divergent jaws allow an automatic focus to the field edge (single focused); the leaves are mounted in the two leaf banks, each in a moveable carriage that allows the leaves to extend horizontally 200 mm from the carriage so that, in combination with the carriage movement, a displacement across the entire field from −200 to +200 mm is possible. To reduce the interleaf leakage, the leaf ends are shaped with curved upper and lower portions and with a sinusoidal central portion allowing a slight overlap of both sides. As tongue- and groove system, the leaves are slightly tilted in order to avoid a straight open air gap for central rays of the beam. Upper leaves are shifted slightly upwards to lead to a different length of the overlap region between two neighboring leaves.

The OPTIFOCUS™ MLC collimator is equipped with 82 leaves of projected width of 10 mm for the entire field. A double-focus leaf design follows the beam divergence so that the end and side of the leaves follow the beam divergence in both directions. The movement of the leaves across the entire field is from −100 to 100 mm. The physical properties of the two different collimators are summarized in Table 1; some accelerator beam data measured according to the IAEA code of practice,[5] used for the linacs commissioning and for the implementation of the treatment planning system, were reported in Table 2. In Fig. 1 the percentage depth doses and the profiles for the reference field were reported for the 5-mm and 10-mm MLC linac, respectively.

Table 1 – Physical properties of the 160 MLC™ and the OPTIFOCUS 82MLC™ mounted respectively on Artiste and Oncor linacs.

	160 MLC™	82 MLC™
Number of leaves	160	82
Leaves design	Single focused	Double focused
Leaf width (mm)	5	10
Maximum leaf speed (mm/s)	40	20
Maximum leaf movement of a single leaf (cm)	20	10
Leaf movement gap (mm)	400	300

2.2. Clinical cases

Nineteen patients with prostate carcinoma undergoing either a radical or an adjuvant postoperative prostate treatment, routinely treated with IMRT, were selected for this study. All patients were treated according to our protocols and received a prescribed dose of 80 Gy and 70 Gy, respectively, for radical and adjuvant treatment, in 2 Gy daily fractions. The CTV included the prostate and vesicles or the prostatic lodge for the radical or adjuvant treatment, respectively. The PTV was obtained by adding 5 mm margin to the CTV, except 4 mm posteriorly to limit the rectal dose. If lymph nodes were included in the CTV, the same margin was adopted. Patients were instructed to maintain an empty rectum and a full bladder for the planning CT and for the treatment. All patients were treated with 6 MV photons and underwent a daily IGRT using a megavoltage cone-beam CT (MV-CBCT). The daily CBCT doses were included in the DVHs presented in this study and approved by the radiation oncologist.

2.3. Treatment techniques and planning optimization

For each clinical case, a Step & Shoot IMRT treatment plan was performed both with the Artiste and with the Oncor model, using identical procedures and beam setup arrangement. Pinnacle[3] treatment planning system (P[3]IMRT, Version 9.0, Philips Medical Division, Madison, WI) using the direct machine parameters optimization (DMPO) approach was used for this purpose. For each plan, both 5- and 7-beam configuration was studied. Equally spaced gantry angles were set for the 7-beam configuration, while 180°, 250°, 315°, 100°, 45° gantry angles were used for the 5-beam configuration. No distinction on gantry angles was used for radical or adjuvant treatments. The number of segments was set to 10 per beam for every plan and the minimum number of monitor units (MUs) for segment

Table 2 – Tissue Phantom Ratio ($TPR^{20}{}_{10}$), depth of maximum dose (D_{max}), absolute output (cGy/MU) for a reference field for Siemens Artiste and Oncor linacs.

	ARTISTE		ONCOR	
	6 MV	18 MV	6 MV	18 MV
$TPR^{20}{}_{10}$	0.674	0.775	0.674	0.771
D_{max} (cm)	1.51	3.01	1.50	3.00
Absolute calibration (cGy/MU), SSD 100, $d = 10$ cm, 10 cm × 10 cm	0.666	0.761	0.667	0.759

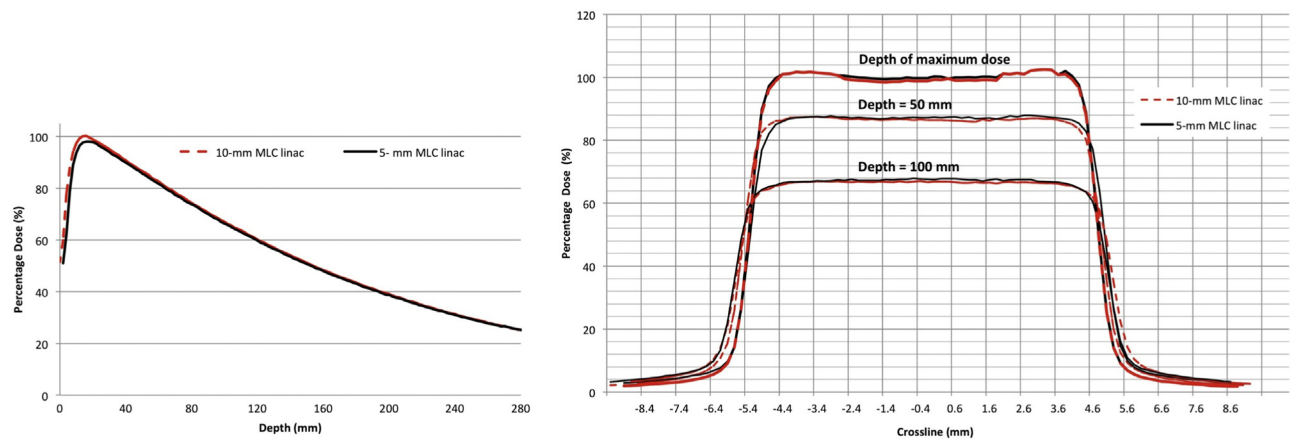

Fig. 1 – The percentage depth doses (PDDs) and the profiles for the reference field were reported for the 5-mm and 10-mm MLC's linac.

Table 3 – Prostate IMRT protocol with dose-volume constraints used for IMRT planning. All constraints are based on a 2 Gy/fraction.

Organ	Dose (Gy)	% volume
Bladder	65	50
Bladder	70	35
Bladder	75	20
Rectum	40	60
Rectum	50	50
Rectum	70	20
Femoral heads	30	50
Femoral heads	50	35
Small bowel	15	120cc
Small bowel	45	195cc

equal to 2 (according to our quality assurance protocol, the dose linearity is better than 0.5% for 2 MUs delivered); the dose grid resolution was set to 0.2 cm × 0.2 cm × 0.2 cm and the cone convolution algorithm was used for the dose calculation. The 100% of the dose was prescribed to the mean PTV volume. The plan optimization was based on dose volume objectives for planning target volumes (PTVs) and on the OAR constraints commonly adopted in clinical practice[6,7] (Table 3). We strived to reach a final plan delivering 100% of the prescription dose to at least 95% of the tumor volume, no more than 105% of the prescription dose to no more than 1% of the tumor volume, while ensuring OAR dose as low as achievable. Optimization was considered completed when PTV was adequately covered with the prescription dose, when the optimization reached a plateau in the cost function and when it was determined (increasing the weight or setting a lower OAR constraint in the optimization) that no further gain could be achieved in sparing OARs without compromising target coverage. To avoid operator-dependent errors, the plan optimization was carried out always by the same experienced medical physicist. Every plan was first optimized with Artiste MLC and, secondly, with the Oncor MLC model maintaining exactly the same configuration and optimization parameters. For plan QA verification the dose distribution of each IMRT plan was recalculated on the CT scan of an IBA MatriXX Evolution phantom[8–9] sandwiched between 5.5 and 7.0 cm of a 30 cm × 30 cm × 1 cm phantom slabs at a zero gantry angle. Measured and calculated planar dose distributions were compared using gamma evaluation with 3 mm distance-to-agreement and 3% dose difference end points.[10–12]

2.4. *Criteria for treatment plan evaluation and comparison*

To compare the treatment plans derived from the two different optimizations, DVH cut-off points and maximum dose received D_{max}, global conformity index (GCI) were used for target evaluation, while only DVH cut-off points were used for the OAR sparing comparison. We defined the DVH cut-off points D_x (or $D_{x\%}$) as the dose expressed in gray (Gy) received by *x* volume in cc (or *x*% of the total volume). We defined D_{max} as the dose received by 1 cm^3 of the target volume. $D_{98\%}$, $D_{95\%}$ and D_{max} cut-off points were used for the PTV dose coverage comparison; for critical structures, clinically relevant DVH cut-off points depend on the dose delivered. For the bladder we used $D_{50\%}$, $D_{35\%}$, $D_{20\%}$, while for the rectum we used $D_{60\%}$,

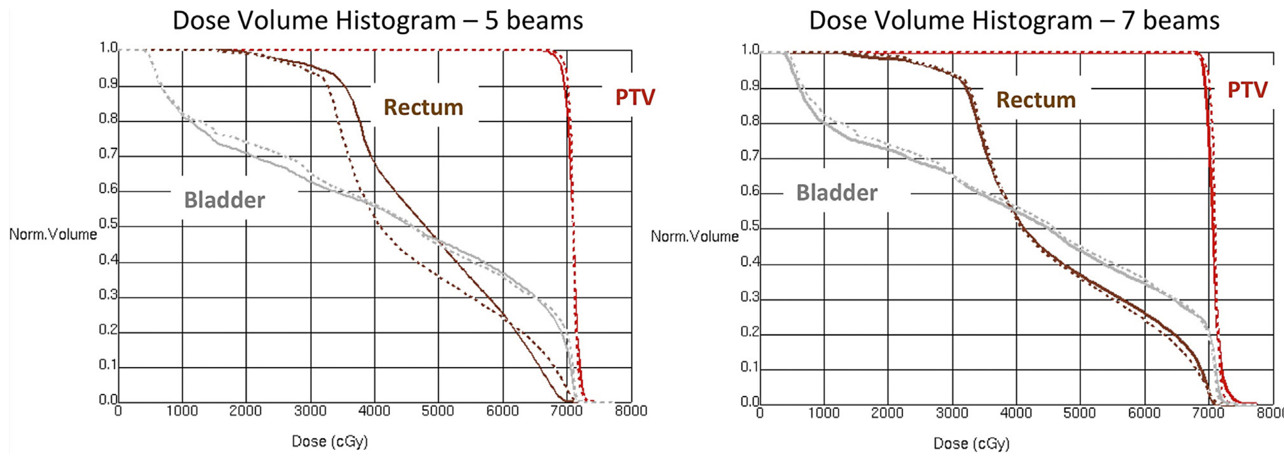

Fig. 2 – Dose volume histogram for an exemplary patient. The DVHs for 7 (on the right) and 5 beams configuration (on the left) were illustrated. The 5-mm MLC (dotted line) and 10-mm MLC (continuous line) results were shown.

$D_{50\%}$, $D_{20\%}$. The cut-off points for the OARs were evaluated individually, but also together for the overall acceptance criteria of the patient; a treatment planning will be considered to respect the overall OAR constraints if each single cut-off point for the rectum and bladder was respected. The GCI provides a score expressing the relationship between irradiated tumor tissue and non-irradiated healthy tissues, and is defined as

$$\mathrm{GCI} = \frac{\mathrm{TV}_{98\%}}{\mathrm{TV}} \cdot \frac{\mathrm{TV}_{98\%}}{\mathrm{V}_{98\%}} \qquad (1)$$

where TV, $\mathrm{TV}_{98\%}$ represent the target volume and the target volume covered by 98% of the prescription dose, respectively, while $\mathrm{V}_{98\%}$ the generic volume covered by 98% of the prescription dose. The $\mathrm{TV}_{98\%}$ to $\mathrm{V}_{98\%}$ ratio is a measure of the coverage quality; it represents the fraction of the volume of healthy tissue receiving a dose greater than or equal to the prescribed reference dose; it takes into account exclusively the irradiation of healthy tissues and it measures the proportion of the volume receiving 98% of the prescription dose that covers indirectly the volume of healthy tissue. The GCI index can help to evaluate the protection of healthy tissues. The GCI ranges from 0 to 1, where 1 is the ideal value. A value close to 0 indicates either total absence of conformation, i.e. the target volume is not irradiated, or a very large irradiation volume compared to the target volume; irradiation was considered to be conformal if and only if the GCI was greater than 0.6.

Treatment plans were compared based on the relative percentage differences (%diff D) at above mentioned DVH cut points for the PTV, bladder and rectum;

$$\%\mathrm{diff}\, D = 100 * \frac{D_{x\%5\text{-mm}} - D_{x\%\text{-mm}}}{D_{x\%5\text{-mm}}}$$

where $D_{x\%\ 5\text{-mm}}$ is the dose expressed in Gy received by x% of the volume when the 5-mm collimator optimization is performed. A negative percentage difference indicates for 5-mm MLC optimization, a lower dose as compared to the ones performed with the 10-mm MLC; and vice versa, a positive value of the percentage difference indicates a greater dose received at this point for the 5-mm MLC optimization.

3. Results

3.1. *PTV coverage*

The two linacs, regardless of the MLCs leaf-width, provided plans with satisfactory target coverage both with the 5- and 7-beam configuration. In Fig. 2, the DVH of an exemplary patient for the 7 and 5 beam configuration was reported both with the 5-mm MLC and 10-mm MLC plan optimization. The difference on the OAR cut-off points are less evident in the 7-beam configuration. In both cases the 5 mm-MLC collimator present a lower maximum dose. This result was expected considering that IMRT optimization has maximum priority over the volume to be treated. In order to highlight possible dosimetric differences obtained by optimizing the IMRT planning with the 5-mm vs. 10-mm MLC, in Table 4 the PTV dose percentage differences for $D_{98\%}$, $D_{95\%}$ and $D_{\max}$ were reported for both 5- and 7-beam arrangement.

As can be observed, almost every $D_{98\%}$ and $D_{95\%}$ percentage difference had a positive value (70 positive points out of 76). This indicates that 5-mm MLC optimization leads to a better PTV coverage than 10-mm MLC, regardless of the number of beams used for the treatment planning. The average percentage target volume covered by the prescription dose is 97% and 95% for the 5-mm and 10-mm MLCs plans, respectively.

Both in the case of 5- and 7-beam arrangement, the 5-mm MLC optimization always leads to a maximum dose lower than in 10-mm MLC one. This is outlined by the $D_{\max}$ column which shows 100% of the values with a negative percentage difference. These percentage differences correspond to a maximum dose difference ranging between 1 and 1.5 Gy, with a mean value of 1.1 Gy. Those results were expected due to the difference between 10-mm and 5-mm MLCs leakage effect. The analysis performed separately on the radical and adjuvant treatments leads to the same results.

With regard to GCI, the mean, minimum and maximum values obtained for the 5-mm-MLC optimization were 0.89, 0.85, 0.92 versus 0.86, 0.83, 0.89, respectively, for the 10-mm MLC optimization. The GCI obtained for the 5-mm MLC width were superior than the 10-mm MLC, while no difference

Table 4 – Percentage difference in PTV coverage for the cut off points $D_{98\%}$, $D_{95\%}$ and D_{max} obtained for the 5-mm MLCs (Artiste) vs 10-mm MLCs (Oncor) optimization in the five beams (5b) and seven beams (7b) arrangement. The percentage difference was defined as %diff $D = 100 * (D_{x\%\ 5\text{-mm}} - D_{x\%\ 10\text{-mm}})/D_{x\%\ 5\text{-mm}}$). Cases from 1 to 9 and 10 to 19 were referred to radical and adjuvant treatments respectively.

Case	Volume (cc)	$D_{98\%}$ 5b (7b)	$D_{95\%}$ 5b (7b)	D_{max} 5b (7b)
1	125	1.3 (2.1)	0.7 (0.5)	−0.1 (−1.3)
2	178	0.9 (0.3)	0.9 (−0.1)	−0.1 (−1.1)
3	171	−0.3 (2.3)	0.8 (1.2)	−0.8 (−0.6)
4	223	2.9 (0.0)	−0.4 (0.3)	−1.8 (−0.3)
5	229	1.4 (0.2)	0.9 (0.5)	−5.2 (−0.9)
6	151	0.6 (0.7)	0.5 (0.6)	0.0 (−0.8)
7	167	0.5 (0.6)	0.1 (0.1)	−1.0 (−0.5)
8	221	0.8 (1.0)	0.5 (0.7)	−1.3 (−1.3)
9	208	−0.1 (−0.3)	0.0 (−0.2)	−0.7 (−0.6)
10	148	1.9 (2.2)	1.3 (1.1)	−0.8 (−0.3)
11	126	1.0 (0.0)	1.0 (0.1)	−0.6 (−0.8)
12	147	2.5 (1.9)	0.4 (0.9)	−1.3 (0.0)
13	144	0.4 (0.3)	0.0 (0.3)	−2.8 (−0.4)
14	167	0.2 (0.6)	0.3 (0.2)	−0.2 (−0.3)
15	204	1.0 (0.5)	0.6 (0.2)	−0.3 (−0.9)
16	157	0.9 (1.1)	0.3 (1.2)	−2.1 (−1.7)
17	173	0.8 (1.1)	0.3 (0.7)	−2.3 (−3.4)
18	216	2.3 (2.2)	1.2 (1.5)	−0.7 (−1.9)
19	170	0.2 (0.3)	0.4 (0.4)	0.0 (0.0)
Mean	175	1.0 (0.9)	0.5 (0.5)	−1.2 (−0.9)
Std-dev	33	0.9 (0.8)	0.4 (0.5)	1.3 (0.8)

may be outlined for configurations with different numbers of beams. These high values obtained came from the priority given in the optimization to PTV coverage and conformation stressed using ring regions of interest (ROIs) around the PTV.

3.2. *OAR dose constraints*

Table 5 shows, for each beam configuration (5 vs. 7 beams) and MLC optimization (10 vs. 5-mm MLC), the percentage of patients failing the single OAR DVH cut-off point for the bladder and rectum adopted in our center and reported in Table 3, and in the last column the overall failing criteria in terms of the failure ratio. If the five-beam arrangement was combined with the 10-mm MLC optimization, only 47.4% (overall) of the IMRT planning met the constraints; this percentage raises up to 89.5% for the 5-mm MLC. These results suggest the need to re-optimize the IMRT planning. The new optimization coming from an increase in the overall number of beam entries (from 5 to 7) resulted in an improvement of the respected cut-off point constraints; in particular, overall percentages of failure cases obtained in the worst case were decreased from 52.6% to 21.1%, while the failure percentage of 10.5% for the 5-mm MLC remains unchanged. This can be explained by the particular conformation of the bladder and rectum, respectively, of two of the nineteen patients of this study that made it impossible to fulfill all OAR constraints to keep a good PTV coverage. These two patients did not satisfy 2 out of 4 reference constraints, in particular the rectum cut-off point $D_{60\%}$ and $D_{50\%}$ for one patient, and the bladder $D_{50\%}$ and $D_{35\%}$ cut-off points for the other one.

If we now focus our analysis on the values obtained for the rectum and bladder, we can state that every plan performed with the 7-beam configuration, independently from the MLC characteristics, respects the single constraints of the OARs (except for two patients as discussed above). In general the results related to the bladder and rectum are quite similar; for convenience, in Table 6 we reported only the details obtained for bladder cut-off points.

It can be observed that every value, except one, in Table 6 is less or equal to zero; this outlines that with a 5-mm MLC optimization, the doses received by the bladder at the DVH cut-off points investigated were in general lower (113 points out of 114), independently from the beam arrangement; the same may be observed for the rectum. The high difference obtained for the case 19 is due to a very low dose value of the $D_{50\%}$ obtained: 6 Gy vs. 8 Gy for 5-mm and 10-mm MLCs optimization, respectively. This result implies that the conclusions of a recent work about the usage of a box 3D Conformal Radiotherapy technique in treating prostate cancer[14] may be extended to include IMRT.

It is also important to highlight that the differences in the treatment optimization resulting from the two different MLCs were reduced by switching from 5- to 7-beam arrangement. In Table 6, this difference was smoother in 49 out of 57 cut-off points, meaning a better bladder DVH agreement. Similar are the findings for the rectum.

In the OAR analysis, no particular distinction was observed between radical or adjuvant treatments, nor evidence of different behavior connected with the OAR volumes.

3.3. *Treatment plan verification*

As stated before, measured dose data from delivering the treatment fluence map on the IMRT phantom and calculated planar dose distributions were compared using gamma evaluation with 3 mm distance-to-agreement and 3% dose difference end points. According to gamma evaluation, the comparison performed showed an excellent conformity. The agreement between the two dose distribution data was expressed by the percentage of the measured points in

Table 5 – Percentage of patients failing the single OAR constraints for bladder and rectum. In the last column the overall failing criteria is also reported (in bracket) in term of failure patient ratio.

		Bladder		Rectum		OARs		Overall
		$D_{50\%}$	$D_{35\%}$	$D_{20\%}$	$D_{60\%}$	$D_{50\%}$	$D_{20\%}$	
5 Beams	10-mm MLC	5.3%	26.3%	5.3%	15.8%	10.5%	15.8%	52.6% (10/19)
	5-mm MLC	5.3%	5.3%	0.0%	5.3%	5.3%	0.0%	10.5% (2/19)
7 Beams	10-mm MLC	5.3%	5.3%	0.0%	10.5%	5.3%	0.0%	21.1% (4/19)
	5-mm MLC	5.3%	5.3%	0.0%	5.3%	5.3%	0.0%	10.5% (2/19)

Table 6 – Percentage difference for bladder DVHs cut off points $D_{50\%}$, $D_{35\%}$, $D_{20\%}$, resulting from 5-mm MLC (Artiste) vs. 10-mm MLC (Oncor) optimization in the five beams (5b) and seven beams (7b) arrangement. The percentage difference was defined as %diff $D = 100 * (D_{x\%\ 5\text{-mm}} - D_{x\%\ 10\text{-mm}})/D_{x\%\ 5\text{-mm}}$). Cases from 1 to 9 and 10 to 19 were referred to radical and adjuvant treatments respectively. Positive values are highlighted in bold.

Case		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	Mean
$D_{50\%}$	5b	−8.7	0.0	−9.1	−2.0	−7.0	−5.3	−24.0	−2.6	0.0	0.0	0.0	−11.4	0.0	0.0	0.0	−10.3	−3.6	0.0	−33.3	−6.2
	7b	−7.7	0.0	0.0	0.0	**2.0**	−2.1	0.0	−6.7	0.0	−3.4	−3.2	−7.7	0.0	−0.9	−5.3	−9.5	−5.7	0.0	−33.3	−4.4
$D_{35\%}$	5b	0.0	−0.7	−4.8	−5.1	−9.1	−9.6	−4.5	−2.2	0.0	−7.0	−2.2	−8.0	−2.9	−4.4	0.0	0.0	−2.9	**3.4**	−25.0	−4.4
	7b	0.0	−0.7	−2.4	0.0	−1.6	−7.1	0.0	0.0	0.0	−6.0	0.0	−1.8	0.0	0.0	0.0	−10.7	0.0	0.0	−22.7	−2.8
$D_{20\%}$	5b	−6.8	−4.0	−11.1	0.0	−1.4	−2.9	−1.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	−1.4	−4.0	−1.7
	7b	−6.0	0.0	−3.5	0.0	−1.4	−2.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	−1.9	−0.7
Vol	(cc)	195	58	254	118	223	104	223	207	124	174	53	174	114	112	379	186	151	68	291	168.8

accordance with the calculated ones inside the area defined by 20% and 90% dose level. These percentages give a gamma distribution in the 20% dose level[13] area always higher than 95%, with mean value of 96% and in the 90% dose level area always higher than 97% with mean value of 98.5%.

4. Conclusions

The present work outlines that the use of the two different MLC delivery techniques considered in prostate IMRT planning resulted both in a good PTV coverage and sparing of the OARs. The use of 10-mm leaf-width collimator may require an increase in the total number of beamlets and beam entries in order to fulfill OAR constraints maintaining a good PTV coverage. The 7-beam arrangement allows a comparable DVH for the two different MLC optimizations, even if a higher maximum dose persists for the 10-mm MLC. The clinical relevance of these results should be assessed on patient base; the number of patients involved in this study was too small to achieve reliable results but enough to share the possibility to achieve good clinical results even with a minor technology.

Conflict of interest

None declared.

Financial disclosure

None declared.

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