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Dosimetric sensitivity of leaf width on volumetric modulated arc therapy plan quality: an objective approach

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ABSTRACT

Background: Several authors investigated a dosimetric impact of leaf width on radiotherapy plan quality subjectively, and concluded that thinner leaf-width multileaf collimators (MLC) are beneficial because of their better coverage of clinically relevant structures. Study aimed to investigate the dosimetric effect of MLC leaf width on volumetric modulated arc therapy plan quality by objective approach.

Materials and methods: Twelve of each prostate and head-and-neck patients were planned for volumetric modulated arc therapy (VMAT) treatments for MLC leaf widths of 4 mm and 10 mm. Three different VMAT schemes single-arc, dual-arc and two combined independent single-arcs were optimized. Dose volume histogram and Isodose distribution were used for quantitative and qualitative comparison of the treatment plan, respectively. Dose-volume-indices of the planning target volume, organs at risk and number of delivered monitor units were compared. The 4 mm leaf width being reference over 10 mm and results were noted as statistically significant if $p \leq 0.05$ using student t-test.

Results: All VMAT schemes for both tumor sites showed a gain in target coverage, similar organs at risk doses and higher monitor units to be delivered, when changing leaf width from 10 mm to 4 mm. The p-values were significant for majority of head-and-neck dose indices.

Conclusion: The thinner-leaf MLCs, owing to their better spatial resolution, result in an overall gain for target coverage, while maintaining permissible doses to the organs at risk.

Key words: VMAT; treatment planning; MLC leaf width

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Introduction

In the modern multidisciplinary approach, radiotherapy is one of the mainstream modalities in the treatment of different cancers. In standard radiotherapy treatments 3-dimensional conformal radiotherapy (3DCRT) and intensity modulated radiotherapy (IMRT) are used to provide optimum target coverage to the planning target volume (PTV), while sparing organs at risk (OAR) by maintaining permissible doses [1, 2]. Otto [3] proposed delivery of IMRT in a single gantry arc as volumetric modulated arc therapy (VMAT), an efficient dose delivery technique with comparable dose distributions to standard IMRT.

Since the inception of multileaf collimators (MLCs) and the concept of intensity modula-

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tion in radiotherapy planning in the early 1990s, the MLC leaf width has been a point of interest for researchers [4–6]. Several authors reported the effect of MLC leaf width on plan quality for standard IMRT plans optimized for radiotherapy and radiosurgery, including clinically delivered and Monte-Carlo studies [7–14]. These studies revealed that reduction in MLC leaf width resulted in statistically significantly better results for target coverage and OAR sparing, particularly for anatomical sites where OARs are very close or partly encompassed by the target volume [7, 12]. However, outcome in terms of clinical benefit is not unequivocal yet, though thinner MLC leaves resulted in improved sparing of OARs, and these plans were delivered with more monitor units and increased number of segments [15]. Instead, Burmeister et al. [8] were especially skeptic about efficacy due to increased whole body dose, as longer delivery time and extra monitor units to be delivered to the patient might outweigh the benefit of better target coverage and conformity shaped by thinner MLC leaves. Previous authors have reported the impact of leaf width on VMAT plan quality, whilst treatment plans were optimized for each MLC-machine individually by considering a well optimized set of individual "dose volume objective" (DVO) functions for each tumor site [15–21].

It is very challenging to compare different MLC hardware using the same planning technique because the objective functions used for inverse planning are ideally tailored to the chosen MLC. Possibly, there are two strategies that can be adopted: i) comparing plans with identical objective functions and ii) comparing plans with different objective functions, each tailored to their own MLC-machine hardware and beam specifications [15]. The second strategy is not objective at all, as the planning physicist/dosimetrist may adopt different parametric choices per plan optimization. The first strategy allows a fair comparison by eliminating the arbitrariness of subjective physicist/dosimetrist choices. However, definitely, it is not utilizing the full potential of at least one MLC-machine. In this study the effect of MLC leaf width on VMAT plan quality is assessed objectively using identical DVO functions for all treatment plans to reflect head-to-head MLC properties, which makes it different from above studies.

Materials and methods

Patient selection, contouring and collimators specification

Patients from two tumor sites were selected in order to evaluate the effect of MLC leaf width on VMAT plan quality. Twelve prostate and twelve head and neck cases previously treated with standard IMRT were selected retrospectively for study. For prostate, the prescribed dose (PD) was 78 Gy in 39 fractions set to the PTV. The CTV comprised the prostate gland plus half of the seminal vesicles, while the rectum and bladder were delineated as OARs. The PTV78 was contoured by adding a standard margin of 0.7 cm transverse and 0.9 cm in craniocaudal directions to respective clinical target volume (CTV). For head-and-neck, a heterogeneous group of twelve patients with different dose prescription and target geometries reflecting the complexity of lesions (oropharynx, hypopharynx, oral-cavity and larynx) were selected and planned with simultaneous integrated boost (SIB) in 35/30 equal treatment fractions. The gross tumor volume (GTV) + 5 mm margins for microscopic spread of disease were the CTV and, finally, CTV + 3 mm margins were the PTV. Appropriate OAR (mandible, larynx, parotid glands, oral cavity, spinal cord and brainstem) were identified on every CT scan slice [22]. Eight treatments were planned for three dose levels 70/60/56 Gy (2/1.71/1.6 Gy/fraction), while four post operative treatments were planned for two dose levels 60/54 Gy (2/1.8 Gy/fraction) per PTV_{boost} / $PTV_{elective(s)}$, respectively.

The VMAT plans were optimized and calculated for two Elekta multileaf collimators; MLCi2™ mounted on a Synergy® and Beam Modulator™ (BM) mounted on a SynergyS® (Elekta Ltd., Stockholm, Sweden) medical linear accelerators (Linac). A summary of physical properties of both MLCs is noted in Table 1, and the detailed physical and dosimetric features are described elsewhere [16, 23, 24].

Treatment planning, evaluation criteria and statistical analysis

Plans were optimized using the SmartArc™ module (Pinnacle^3 TPS (version 9.2, Philips Health-care)) for a 6MV photon beam. To obtain optimum dose distribution a template of separate DVOs was optimized for each tumor site (prostate and head-and-neck) using SynergyS Linac parameters.

Table 1. Summary of physical properties of the multileaf collimators (MLCs — MLCi2™ and Beam Modulator™) mounted respectively in Synergy and SynergyS Linacs

Typical feature name	MLCi2™	BM™	Typical feature name	MLCi2™	BM™
Maximum field size [cm^2]	40 × 40	21 × 16	Mid-leaf transmission for (%)	1.8	1.0
Number of leaves (40 pairs)	80	80	Inter-leaf transmission (%)	2.0	1.7
Maximum leaf speed [cm/sec]	2.0	3.0	Over travel central axis [cm]	12.5	Full field
Minimum opposite leaf gap [cm]	0.5	0.5	Leaf material	Tungsten	Tungsten
Leaf width (at isocentre) [mm]	10.0	4.0	Rounded leaf tip and flat side	Yes	Yes
Motion Range (at isocentre) [cm]	32.5	21.0	Focalized	Single	Single
Leaf height [cm]	7.5	7.5	Interdigitation	Yes	Yes
Maximum allowed field along leaf travel direction [cm]	40.0	21.0	Auto tracking backup jaw/Diaphragms	Yes	No
Maximum allowed field across leaf bank [cm]	40.0	16.0	Penumbra	< 7 mm (5 × 5 cm^2 to 15 × 15 cm^2) < 8 mm (> 15 × 15 cm^2)	< 4 mm (up to 5 × 5 cm^2) < 5 mm (up to 10 × 10 cm^2) < 6mm (>10×10 cm^2)

In order to make an objective comparison of the impact of different MLC leaf widths, the (template) same set of DVO functions well optimized for SynergyS (4 mm leaf width MLC) Linac was also used for Synergy (10 mm leaf width MLC) Linac. Using these templates, all corresponding VMAT plans were created for both MLCs. During the optimizing process, the objectives or weights were kept constant to exclude a subjective influence of the planner. It allowed an independent and objective evaluation of the dose distribution obtained for both MLCs.

Three VMAT plans; single-arc (SA), dual-arc (DA) and two combined independent single-arcs (ISAs) were optimized for each of the 12-prostate and 12-head-and-neck cases. Therefore, a total of 72-plans (36-MLCi2; 36-BM) were generated for each tumor site (72-prostate; 72-H&N). Prostate arc length (181–179° clockwise), head-and-neck arc length (185–175° clockwise), gantry space (GS) resolution 4°, collimator angle (C) 45° for SA, DA and 0–270° for ISAs (C0° for 1st arc and C270° for 2nd arc), maximum delivery time (MDT) 90 sec for prostate and 110 sec for head-and-neck were selected [25, 26]. The clinical dose volume objectives (target dose coverage and sparing of OAR) [27, 28] mentioned in the data tables were pursued for PTV_{boost} and critical OARs, however, were not strictly followed for $PTV_{elective(s)}$.

The ability of each MLC to achieve defined clinical objectives was examined in terms of plan quality based on the following dosimetric variables; PTV: target coverage ($D_{95\%}$), dose near-maximum ($D_{2\%}$), conformity index (CI), homogeneity index (HI) [27]. OAR: volume of an organ receiving x-dose (V_{xGy}) and D_{mean} for parotid and D_{1cc} for the spine and MUs were noted. Ideally, CI and HI should be 1 and 0, respectively [27]. The QUANTEC constraints were adopted for quantitative analysis of normal tissue rectum and bladder [28].

The quantitative and qualitative treatment plan quality obtained with 4 mm leaf width MLC was taken as reference while comparing and/or calculating percentage (%) increment or reduction in gain. The two-sided student t-test assuming unequal variances was used to analyze the influence of MLC leaf width on plan quality. The analysis was considered statistically significant if p value was ≤ 0.05. It was a treatment planning analysis; therefore, dosimetric validation between TPS calculated and phantom measured doses was not performed.

Results

Table 2 and 3 summarizes the normalized dose indices (DIs) for prostate and head-and-neck PTVs and OAR. Conformity index in percentage, homoge-

Table 2: The summary of dose-volume indices average ± standard deviation (min-max) of prostate planning target volume (PTV) and organs at risk (OARs) for three volumetric modulated arc therapy (VMAT) schemes optimized for SynergyS and Synergy Linacs (average over 12 patients)

Treatment machine	Arc type	PTV				Rectum				Bladder			MUs
		$D_{95\%}$ (≥ 95% PD)	$D_{2\%}$ (≤ 107% PD)	CI (%)	HI	$V_{25\ Gy}$	$V_{35\ Gy}$	$V_{6\ 5Gy}$ (≤ 25% V)	$V_{70\ Gy}$ (≤ 20% V)	D_{1cc}Gy	$V_{40\ Gy}$	$V_{65\ Gy}$ (≤ 50% V)	
SynergyS (MLC 4 mm)	SA	96.5 ± 0.81 (94.9–97.3)	104.0 ± 1.57 (100.6–106.5)	98.4 ± 1.65 (94.8–100)	0.086 ± 0.026 (0.032–0.133)	76.8 (58.6–97.7)	45.9 (38.3–58.9)	9.2 (6.4–13.3)	5.6 (3.9–7.7)	94.3 (91.9–98.1)	27.1 (10.2–42.3)	13.5 (5.1–22.0)	427 ± 29
	DA	96.8 ± 0.60 (96.0–98.0)	103.7 ± 2.10 (98.3–106.4)	99.5 ± 0.54 (98.6–100)	0.076 ± 0.026 (0.022–0.110)	77.9 (57.1–98.8	44.1 (37.7–56.8)	8.4 (5.0 -11.7)	5.2 (2.8–7.4)	94.4 (89.7–97.7)	26.5 (9.6–41.6)	12.9 (4.7–22.3)	494 ± 50
	ISAs	97.0 ± 0.71 (96.1–98.3)	103.4 ± 1.18 (101.8- 105.3)	99.5 ± 0.58 (99.2–100)	0.072 ± 0.016 (0.047–0.098)	72.6 (56.1–86.6)	44.3 (35.5–53.2)	8.6 (6.0–12.3)	5.3 (3.0–8.2)	94.4 (89.7–97.8)	25.2 (8.8–41.9)	13.0 (4.7–22.5)	476 ± 45
Synergy (MLC 10 mm)	SA	95.9 ± 1.05 (93.9–97.4)	102.7 ± 1.59 (100.5- 105.9)	97.3 ± 2.37 (92.3–99.8)	0.079 ± 0.029 (0.042–0.142)	70.7 (54.7–96.1	40.9 (35.6–60.8)	8.9 (6.5–14.3)	5.1 (2.8–9.3)	93.9 (89.4–98.0)	25.6 (9.7–41.5)	12.4 (4.4–22.2)	397 ± 22
	DA	96.5 ± 0.96 (93.9–97.5)	102.7 ± 1.65 (100.6–105.7)	98.2 ± 2.00 (92.5–99.6)	0.074 ± 0.028 (0.043–0.129)	71.5 (55.7–92.0	40.8 (34.4–50.5)	8.0 (5.4–11.5)	4.6 (1.9–7.4)	93.6 (87.8–98.5)	25.8 (9.2–41.3)	12.3 (4.1–22.3)	439 ± 38
	ISAs	95.7 ± 0.75 (93.8–96.7)	102.0 ± 1.60 (99.8–105.1)	96.8 ± 2.26 (92.1–99.2)	0.074 ± 0.024 (0.048–0.139)	66.3 (51.5 -83.5	39.7 (34.4–52.0)	8.3 (4.9–11.7)	4.6 (1.9–7.6)	93.2 (87.2–97.9)	24.1 (8.5–39.0)	11.8 (3.9–22.1)	419 ± 36

MLC — multileaf collimator; SA — single-arc; DA — dual-arc; ISAs — two combined independent single-arcs; PD — prescribed dose; CI — confidence interval; HI — homogeneity index; MU — monitor unit

Table 3. Summary of dose-volume indices average ± standard deviation (min-max) of head a neck planning target volumes (PTVs) and organs at risk (OARs) for three volumetric modulated arc therapy (VMAT) schemes optimized for SynergyS and Synergy Linacs (average over 12 patients)

Treatment machine	Arc type	Dose indices (PTV_{boost})				Dose indices ($PTV_{elective1}$)		Parotid (right)*		Parotid (left)**		Spine dose	MUs
		$D_{95\%}$ (≥ 95% PD)	$D_{2\%}$ (%) (≤ 107% PD)	CI (%)	HI	$D_{95\%V}$ (%)	CI (%)	V_{30Gy} (%) (≤ 50% V)	D_{mean} (≤ 27 Gy)	V_{30Gy} (%) (≤ 50% V)	Dmean (≤ 27 Gy)	D_{1cc} (≤ 45 Gy)	
Synergy S (MLC 4 mm)	SA	94.6 ± 1.25 (92.6–96.4)	109.1 ± 2.07 (105.7–112.3)	94.7 ± 1.75 (91.7–97.5)	0.168 ± 0.038 (0.110–0.253)	95.1 ± 1.49 (93.2–98.4)	95.2 ± 1.96 (92.9–99.2)	27.3 (6.8–50.4)	20.9 (9.1–27.4)	31.3 (18.3–46.6)	24.5 (13.5–29.7)	35.0 (32.0–37.7)	469 ± 40
	DA	96.1 ± 0.73 (95.0–97.6)	107.3 ± 1.49 (104.7–109.3)	96.7 ± 1.28 (95.1–98.7)	0.135 ± 0.020 (0.096–0.174)	96.8 ± 1.08 (95.1–99.2)	97.4 ± 1.48 (95.2–99.9)	25.7 (4.0–50.9)	20.7 (7.6–27.4)	31.9 (17.7–42.9)	24.3 (12.9–28.7)	33.3 (30.5–35.6)	544 ± 56
	ISAs	96.1 ± 0.70 (95.2–97.1)	107.3 ± 1.69 (104.2–110.1)	96.7 ± 1.24 (95.0–98.6)	0.139 ± 0.034 (0.098–0.217)	96.2 ± 0.86 (95.0–98.1)	96.8 ± 1.25 (95.0–99.2)	29.2 (4.5–50.4)	20.9 (7.9–27.2)	31.5 (16.3–45.4)	23.9 (12.0–29.0)	34.7 (31.2–38.6)	505 ± 53
Synergy (MLC 10 mm)	SA	92.5 ± 1.51 (90.3–95.6)	105.1 ± 1.16 (104.0–107.6)	88.8 ± 5.42 (80.4–98.5)	0.141 ± 0.048 (0.016–0.217)	92.7 ± 2.16 (89.0–96.9)	89.5 ± 5.00 (82.2–99.1)	26.2 (5.1–41.6)	20.3 (8.4–26.8)	33.0 (18.9–46.3)	24.2 (13.1–29.7)	34.6 (31.3–38.4)	434 ± 39
	DA	93.6 ± 1.40 (90.1–95.8)	105.3 ± 1.01 (103.7–107.3)	92.0 ± 4.40 (81.3–99.2)	0.140 ± 0.022 (0.108–0.186)	94.0 ± 2.11 (89.7–97.5)	92.5 ± 4.10 (85.9–98.5)	26.8 (3.7–47.0)	20.5 (8.2–27.0)	31.8 (17.1–43.8)	24.2 (12.7–27.6)	34.0 (31.1–36.8)	487 ± 39
	ISAs	93.1 ± 2.57 (86.2–95.9)	105.7 ± 2.39 (103.6–112.1)	91.6 ± 5.22 (81.5–98.8)	0.149 ± 0.057 (0.091–0.317)	93.1 ± 2.45 (89.1–97.1)	90.6 ± 5.22 (81.8–98.6)	26.7 (3.5–44.9)	20.1 (7.0–26.7)	32.3 (11.4–52.9)	23.9 (10.3–30.2)	35.7 (31.7–40.8)	452 ± 41

*Right parotid average and Dmean over 9 patients; **Left parotid average and Dmean over 10 patients; MLC — multileaf collimator; SA — single-arc; DA — dual-arc; ISAs — two combined independent single-arcs; PD — prescribed dose; CI — confidence interval; HI — homogeneity index; MU — monitor unit

Table 4. Summary of calculated p-values between 4 mm and 10 mm leaf width [single-arc (SA), dual-arc (DA) and two combined independent single-arcs (ISAs) volumetric modulated arc therapy (VMAT) schemes] for prostate and head and neck plans optimized for SynergyS (4 mm) and Synergy (10 mm) Linacs

Tumor location	MLC leaf width (arc type)	Dose indices [PTV_{boost}]				Dose indices [$PTV_{elective1}$]	
		D95%	D2%	CI	HI	D95%	CI
Prostate	4 mm *vs.* 10 mm (SA)	0.181	0.057	0.184	0.557	–	–
	4 mm *vs.* 10 mm (DA)	0.294	0.210	0.051	0.932	–	–
	4 mm *vs.* 10 mm (ISAs)	0.000	0.021	0.002	0.829	–	–
Head and neck	4 mm *vs.* 10 mm (SA)	0.001	0.000	0.003	0.150	0.005	0.002
	4 mm *vs.* 10 mm (DA)	0.000	0.000	0.004	0.506	0.000	0.001
	4 mm *vs.* 10 mm (ISAs)	0.002	0.073	0.006	0.597	0.000	0.001

PTV — planning target volume; ; CI — confidence interval; HI — homogeneity index

neity index and MUs were used for the comparison. The calculated p-values for DIs between 4 mm and 10mm leaf width MLCs were noted in Table 4. The OAR doses (like brainstem, oralc avity, mandible and larynx, etc.) were well below and acceptable per defined clinical constraints, and are not reported.

Prostate

Majority of (SA,DA, ISAs) VMAT plans optimized for the prostate achieved satisfactory target coverage and sparing of OARs for both 4 mm and 10 mm leaf width, except for one patient plans (SA D_{95} = 93.9%; DA D_{95} = 93.9%; ISAs D_{95} = 93.8%) for 10 mm Table 2. For prostate plans percentage of target coverage ($D_{95\%}$), dose maximum ($D_{2\%}$) and CI were higher with 4mm compared to 10 mm leaf width. The volume of OARs (rectum and bladder) at particular dose level (V_{xGy}) have higher values for 4 mm compared to 10 mm leaf width, both from Table 2 [average (min–max)] and individual patient data set (not presented here). However, the obtained OAR V_{xGy} values for both MLC plans were well below the QUANTEC[27] defined dose limits.

Head-and-Neck

All DA and ISAs VMAT plans optimized for head-and-neck achieved adequate target coverage and CI (PTV_{boost}) for 4mm leaf width, whereas SA achieved both indices only for 3-plans. For 10 mm leaf width, 1 plan for SA, 1 plan for DA and 2 plans for ISAs achieved the target coverage and CI, the rest of all plans remained well below the defined clinical dose volume objectives. The percentage of target coverage ($D_{95\%}$), dose near-maximum ($D_{2\%}$) and CI values were higher for 4mm than 10mm leaf width, both from Table 3 [average (min-max)] and individual patient data set (not presented). Similar trend(s) of target coverage was noted for $PTV_{elective(s)}$ for both 4 mm and 10 mm leaf width MLCs. Sparing of OARs; V_{xGy}, D_{mean}(parotids), D_{1cc} (spine dose) values were acceptable for both MLCs.

Similarly, for both tumor sites (prostate and head-and-neck) MUs have higher values for 4mm than 10 mm leaf width, both from Tables 2, 3 (average) and individual patient data sets (not presented). The p-values were not significant for prostate dose indices for SA and DA; however; for ISAs target coverage, dose near-maximum and conformity index were significant (Tab. 4). The p-values were significant for majority of head-and-neck dose indices (D95%, D2% and CI) for both PTV_{boost} and $PTV_{elective(s)}$ mentioned in Table 4.

The individual patient data of target coverage, CI and for both tumor sites are compared in Figure 1 as a representative scheme (ISAs) for both MLCs 4mm and 10mm leaf width. Figure 2 shows a dose volume histogram (DVH) in row1 and typical transverse CT slice dose distribution in row2 for a representative prostate treatment, where dotted lines stand for 10 mm leaf width and solid line for 4mm leaf width DVH doses. The blue isodose line stands for $D_{95\%}$ which encompassed PTV_{boost} and the yellow isodose line, for prescribed dose of 78 Gy. Figure 3 shows a dose volume histogram (DVH) in row 1 and typical transverse CT slice dose distribution in row2 for a representative head-and-neck treatment, where dotted lines stand for 10mm leaf width and solid line for 4mm leaf width DVH doses. The blue isodose line stands for $D_{95\%}$ which encompassed PTV_{boost} (red), whereas $PTV_{elective1}$ (green) and $PTV_{elective2}$ (blue) are also shown with appropriate OARs.

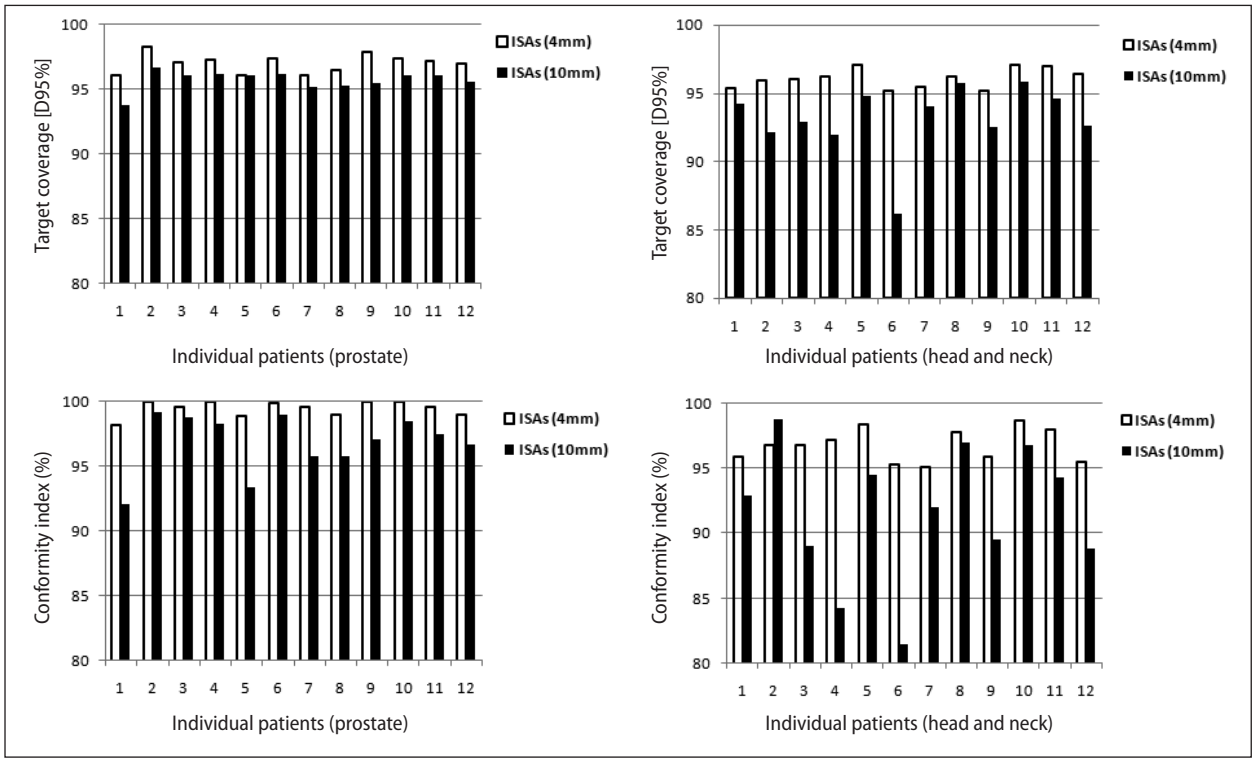

Figure 1. Individual patient data sets comparing planning target volume (PTV) dose-volume indices (D95%, CI) for prostate (left column) and head and neck (right column) for selected case of two combined independent single-arcs (ISAs) optimized for 4 mm and 10 mm leaf width multileaf collimators (MLCs)

Discussion

In this study we have compared the performance of two different types of MLCs for VMAT planning using quantitative and qualitative methods. The plans were generated for two different tumor sites with the SmartArc module of Pinnacle TPS for MLC leaf widths of 4mm and 10mm. In order to highlight possible dosimetric differences, the strategy of three distinct VMAT arcs was adopted using the same DVCs to compare a possible modulation potential of both MLCs objectively. Majority of the previous studies [4, 5, 7–21] have reported the effect of MLC leaf width using subjective approaches, except van Kesteren et al. [15] that compared the Pareto fronts. Theoretically, MLCs with finer leaf width allow more precise beam shaping and high resolution photon beam optimization, which ultimately provides a better match of the beam aperture to the target projection [14]. Consequently, a gain in clinically relevant dose volume indices (like PTV coverage, CI, HI) and reduction of doses to OARs is expected with finer MLCs compared to conventional MLCs (10 mm).

The DVO function(s) well optimized for 4mm leaf width provided clinically acceptable VMAT plans for both tumor sites, except SA for head and neck. Intuitively, one expects that they might work well for 10mm leaf width as well. For the same DVO function, the 10 mm leaf width could not provide satisfactory treatment plan quality for complex cases like head-and-neck. However, for prostate comparable results to 4mm leaf width were noted because of relatively simple prostate tumor shape and site geometry.

From average (min–max) values (Tab. 2, 3) and Figure 1, every dose volume index (PTV_{boost}) had higher values for 4 mm over 10 mm leaf width. A similar trend of gain for dose volume indices was noted for $PTV_{elective(s)}$. Significant p-values for PTV dose indices were noted for both prostate and head-and-neck in Table 4. This indicates that beam optimization with thinner leaves lead to a better PTV coverage, regardless of the type and number of VMAT arcs used. In previous studies, some authors have reported the gain for PTV dose volume indices of IMRT plans and VMAT plans when moving from thicker to thinner MLC leaves [7, 12, 14–16, 19].

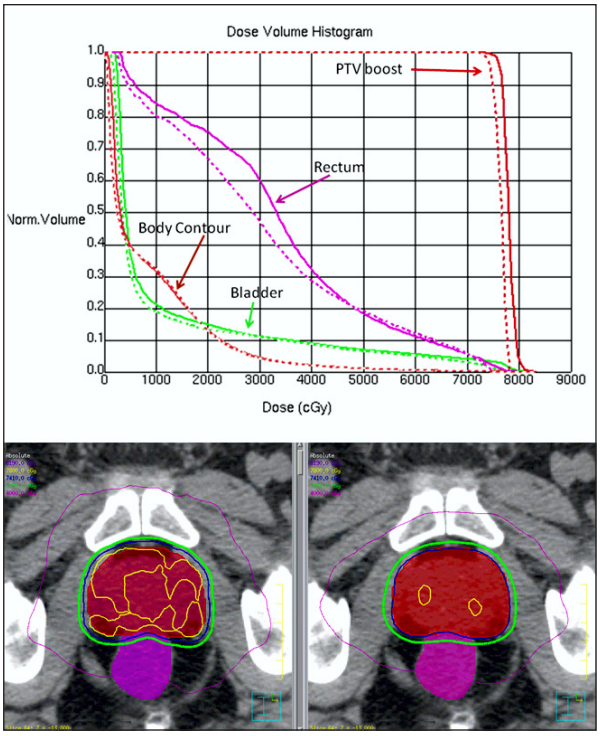

Figure 2. Prostate dose volume histogram (row 1) and dose distribution in a typical transverse CT slice (row2) for two combined independent single-arcs (ISA0s). The PTV78 (red), rectum (pink) and bladder (green) are shown. On dose volume histogram (DVH) solid-line and left CT slice image is for 4 mm leaf width, while dotted-line and right CT slice image is for 10 mm leaf width multileaf collimators (MLCs)

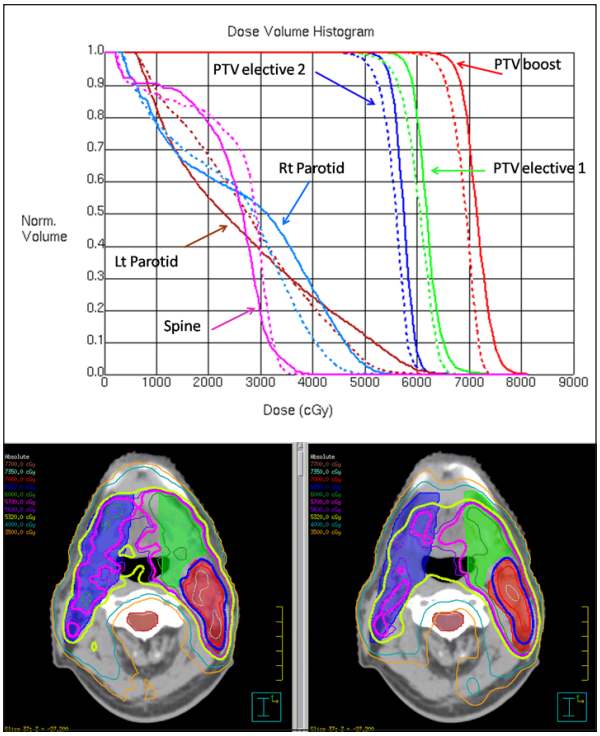

Figure 3. Head-and-neck dose volume histogram (DVH) (row 1) and dose distribution in a typical transverse CT slice (row 2) for two combined independent single-arcs (ISAs). The PTV70 (red), PTV60 (green) and PTV56 (blue) are shown. On DVH solid-line and left CT slice image is for 4 mm leaf width, while dotted-line and right CT slice image is for 10 mm leaf width multileaf collimators (MLCs)

A trend of higher OARs doses for MLC leaf width 4mm was noted because a set (template) of DVOs was well optimized for MLC leaf width 4mm, where the optimizer was forced to achieve defined clinical objectives for target volume coverage and adequate sparing of OARs. Therefore, the optimum target dose coverage will ultimately increase the doses in surrounding normal tissues and OARs. Whereas in case of MLC leaf width, 10mm poor target volume coverage will retain lower doses in the surrounding normal tissues and OARs. However, for both MLC leaf widths of 4mm and 10mm the OAR doses were well below the defined clinical dose volume limits.

The summary of relative percentage reduction (decrease) in gain for dose volume indices and MUs for both tumor sites is noted in Table 5. The dose indices percentage reduction is smaller for prostate and larger for head-and-neck treatments, with the MLC leaf width changed from 4 mm to 10 mm, because head-and-neck cases keep more complex tumor target and OARs site geometry compared to prostate.

The thinner MLC leaves (4 mm) portrays smaller dose delivery segments (segment-area) compared to thicker MLC leaves (10 mm) for both tumor sites. This will not only impact the target coverage, dose conformity but also the number of MUs. The standard deviation for target coverage and dose conformity is smaller for 4 mm and larger for 10mm MLC leaves.

Smaller dose delivery segments will use more MUs compared to larger segments [29] standard deviation is higher for 4 mm compared to 10mm MLC leaves. In this study, higher number of MUs for thinner MLCs were delivered, which is consistent with previous reports [8, 16].

The finer-leaf MLC appears to have more potential for the effective use of user defined dose constraints during dose optimization to produce high resolution treatment plans. In all cases for both tumor sites, it has been consistently noted, both quan-

Table 5. Summary of percentage reduction (decrease) in gain for dose indices (PTV_{boost}) and monitor units (MUs) for prostate and head-and-neck planning, when changing MLC leaf width from 4 mm to 10 mm

Tumor location	Arc type	Dose indices [PTV_{boost}]			Others
		D95%	D2%	CI	MUs
Prostate	SA	0.62	1.25	1.12	7.03
	DA	0.31	0.96	1.31	11.13
	ISAs	1.34	1.35	2.71	11.97
Head & neck	SA	2.22	3.67	6.23	7.46
	DA	2.60	1.86	4.86	10.48
	ISAs	3.12	1.49	5.27	10.50

PTV — planning target volume; SA — single-arc; DA — dual-arc; ISAs — two combined independent single-arcs; CI — confidence interval; MU — monitor unit

titatively (Tab. 2–5) and qualitatively (Fig. 1–3), that treatment plan quality resulted in improved target volume dose indices, when changing the MLC leaf width from 10 mm to 4 mm.

Owing to increased modulation capability of thinner leaves a trend of higher prescribed dose (prostate; PD 78 Gy, head-and-neck; PD 70 Gy) per unit volume towards the centre of PTV was noted for 4 mm than for 10 mm (Fig. 2, 3; yellow isodose line for prostate and red isodose line for head and neck). Therefore, thinner leaves might be a good option for stereotactic radiosurgery (SRS) and stereotactic body radiotherapy (SBRT) treatments, where larger doses are planned with few fractions and the treatments should be delivered as accurately as possible [17, 18, 20, 30–32]. Furthermore, the clinical efficacy of dosimetric advantages of thinner leaf MLC is yet to be determined and further investigation is required.

Conclusion

In an objective approach, since arbitrariness of subjective physicist/dosimetrist choices was eliminated, the results provided an overview of gain or reduction for clinically important dose volume indices. The finer leaves MLC treatment plans lead to a better PTV coverage and higher target conformity irrespective of the type and number of VMAT arcs used. The results showed a trend of higher percentage of prescribed dose per unit volume of PTV. The delivery efficiency of VMAT plans in terms of MUs was better with thicker leaves (MLCi2) but at the cost reduced gain for clinically relevant dose volume indices.

Conflict of interest statement

Authors have nothing to disclose.

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Ethical approval

All procedures performed in studies involving human participants, if any, were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

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