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The Influence of the Minimum Dynamic Leaf Gap on VMAT Plans Quality

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Abstract

The aim of the present work is to investigate the influence of dynamic minimum leaf gap into Pinnacle[3] on VMAT plans quality. Three treatment machines were modeled in our TPS with a different value of dynamic minimum leaf gap of 5, 10 and 20 mm. VMAT plans of AAPM TG-119 phantom and twenty clinical real cases were planned on each machine. Based on AAPM TG-119 guidelines, we compared the machine on their ability to fulfill the dose goals; the pretreatment quality assurance was done with COMPASS QA system (IBA dosimetry, Germany). In order to evaluate how the measured and the planned data from each machine are closed. The monitor units' numbers for each site and machine were also compared. For simple plans, all the three machines easily meet the goals; however, for complex shape case, only the 5 and 10 mm minimum leaf gap machines allow the user to reach the goals. Otherwise, the 20 mm minimum leaf gap machine presents lower difference between planned and measured dose and the best gamma scores than the two others machines. It also has the lower MUs per clinical site. Based on this investigation, 10 mm is the best compromise value for the dynamic minimum leaf gap into Pinnacle. It allows the planner to reach high complex goals during planning process and in another hand gives good agreement between planned and measured doses.

Subject Areas

Radiology

Keywords

COMPASS, Leaf Gap, VMAT

1. Introduction

Formally defined as Intensity Modulated Arc Therapy (IMAT), VMAT was first brought up by Yu *et al.* [1] in 1995. It is a rotational intensity modulated radiation therapy delivered by conventional linear accelerators with conventional multileaf collimators (MLC). The radiation beam is on when gantry is rotating with MLC leaves moving continuously. The user is then able to create a conformal dose distribution. Based on constraints, objectives and optimization algorithm, a fluence profile is generated at every control point. That takes into account some mechanical parameters of the linear accelerator. In order to avoid mechanical collisions between the MLC leaves, Elekta (Elekta Corporation, Stockholm, Sweden) has defined a minimum distance of 5 mm separating two opposite leaves. To have a good conformal dose distribution and protect the healthy organs, the user can sometimes generate smaller segments on some control points.

For static IMRT, Pinnacle (Philips Radiation Oncology Systems, Fitchburg, WI) allows during planning, the planner to set the minimum segment area; it's advice to set it as 4 cm^2. This allows having a large distance between two opposite leaves; In VMAT planning, minimum segment area is not setting but minimum dynamic leaf gap can define the gap of opposite leaves during dynamic treatments planning. The aim of the present work is to investigate the influence of the minimum dynamic minimum leaf gap on VMAT plans quality. Three different machines were modeled in our treatment planning system (TPS) with 5, 10 and 20 mm of minimum dynamic leaf gap respectively. Esophagus, H&N and prostate VMAT plans were planned with Pinnacle's Auto-Planning module and measured in our clinical pretreatment quality assurance process with COMPASS (IBA dosimetry, Germany). Plans were evaluated in terms of estimated delivered time, MUs, HDV and Gamma scores of organs.

2. Materials and Methods

2.1. The Treatment Unit

The testing VMAT plans were delivered on an Elekta synergy dual energy linac. All were planned on 6 MV beam. The system is equipped with agility MLC. Each of the 160 leaves has a projected width of 5.0 mm at the isocenter. A strong MLC quality assurance program is established is on our clinic based on LoSasso et al. work [2].

2.2. The Treatment Planning System

The 9.8 version of Pinnacle (Philips Radiation Oncology Systems, Fitchburg, WI) was the treatment planning system used in the present investigation. The beam and the agility model were based on previous works [3] [4] [5] [6]. Three different machines were modeled were in the TPS. **Figure 1** shows how the parameter is setting into Pinnacle. The minimum dynamic leaf gap values of each machine were 5, 10 and 20 mm respectively. Calculation on Pinnacle is based on a collapse cone convolution/superposition dose engine and our system was already validated for a clinical use on VMAT mode.

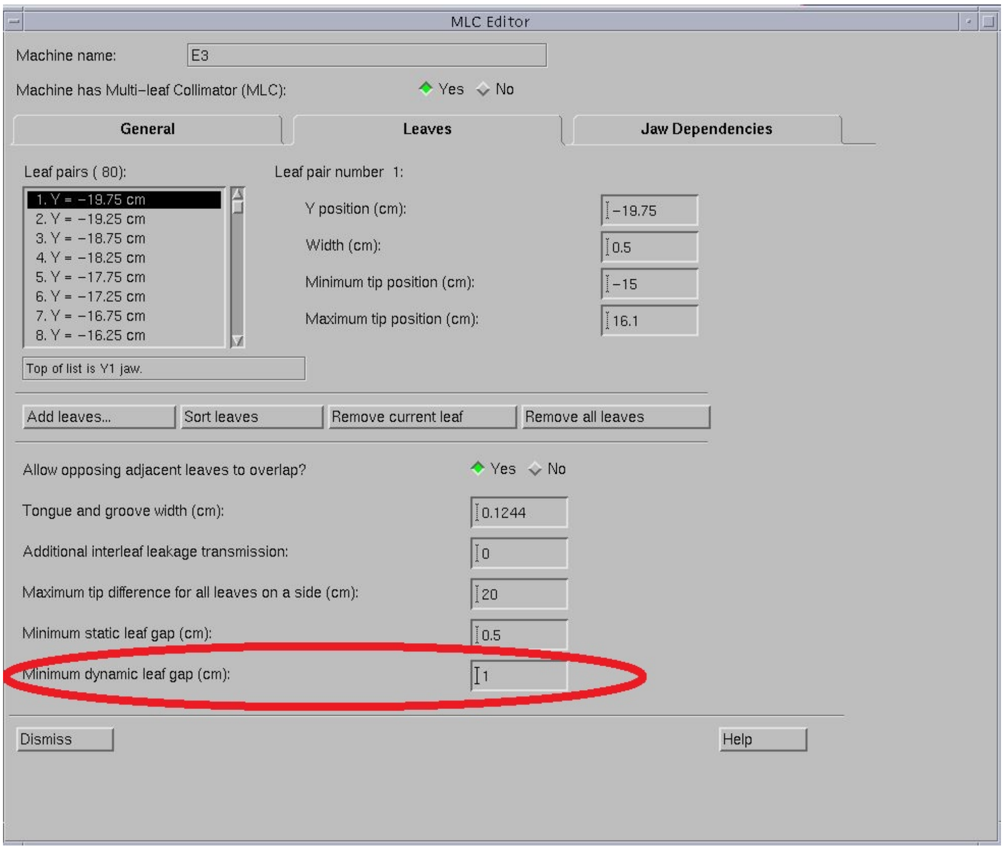

Figure 1. Linac's characteristics required when defining a machine into Pinnacle. In red is where the minimum dynamic leaf gap is setting.

2.3. The COMPASS Quality Assurance System

The system used for the pretreatment quality assurance is COMPASS (IBA Dosimetry, Schwarzenbruck, Germany). The system aims to reconstruct the dose on patient CT based on the measurements taken with the MatriXX 2D array detectors. The system consists of:

- The COMPASS V3.1b software: An independent collapse cone convolution/superposition dose calculation engine used to compare it with the TPS calculated dose (isodose, DVH, 2D and 3D gamma).
- The 2D MatriXX array detector: it consists of a 1020 parallel plane of ion chambers of 0.125 cc with an active area of 24.4 × 24.4 cm^2. It is mounted on the linac head and associated with a gantry angle sensor for data collection.

The beam model in COMPASS is based on the measured data from linac and its geometrical characteristics. Boggula *et al.* [7] validated the clinical use of COMPASS as pretreatment tool and our system was also validated in clinic before starting the study.

2.4. Methods

As previously mentioned, three machines were modeled in the TPS with each leave's dynamic minimum gap of 5, 10, 20 mm. In addition, these machines were read here as E5, E10 and E20 respectively.

2.4.1. The TG-119 Test Plans

The DICOM-RT data of phantom were downloaded and planned in each machine model following the guidelines of AAPM TG-119 [8]. For the C1, C2, C3 and C4 plans of AAPM TG-119, evaluation was done on each machine model to correspond each on a to a specific minimum dynamic leaf gap will easily let the planner to reach the dose goals as stated in the AAPM TG-119 guidelines. These cases were also measured in the QA pretreatment process and compared with the planned RT-dose in terms of DVH and gamma.

2.4.2. Testing with Real Patients Plans

Five esophagus, eight H&N and seven prostate VMAT plans were planned with Pinnacle's Auto-Planning module and validated by a senior medical physicist. The final dose calculation was performed using a 3 mm grid resolution and an adaptive convolve algorithm. The plans were measured with our COMPASS QA system and the reconstructed DVH compared to the planned DVH on the ICRU point dose. Comparison of some 3D gamma volumes and MUs of each machine model was also done.

3. Results and Discussion

3.1. The TG-119 Plans

For the each machine (E5, E10 and E20), dose obtained with planning process were compared to dose goals established in AAPM TG-119 guidelines (Tables 1-4). The COMPASS reconstructed DVH was also compared to the planned one for each of the C1, C2, C3 and C4 cases.

Tables 5-8 present the results of gamma index passing rate and gamma average values of different structures with each linac model. The analysis was done in the local mode with on the 3%/3mm criteria and 15% of dose threshold (gamma < 1).

Table 1. C1-AAPM TG-119's structures planned dose on different modeled machine compared to dose goals. Diff is the difference of between the TPS and COMPASS reconstructed dose.

Structures	Parameters	Goal (Gy)	Planned (Gy)			Diff (%)		
			E5	E10	E20	E5	E10	E20
Center	D99	>50.0	51.0	50.8	50.5	−6.7	−6.3	−6.0
	D10	<53.0	52.6	52.6	52.5	−0.3	−0.2	−0.1
Superior	D99	>25.0	27.0	27.0	27.2	1.4	1.2	1.0
	D10	<35.0	33.9	33.9	33.5	−1.5	−1.4	−1.2
Inferior	D99	>12.5	14.3	14.0	14.2	1.5	0.2	0.5
	D10	<25.0	22.9	24.6	24.2	−1.4	−1.0	−0.1

Table 2. C2-AAPM TG-119's structures planned dose on different modeled machine compared to dose goals. Diff is the difference between the TPS and COMPASS reconstructed dose.

Structures	Parameters	Goal (Gy)	Planned (Gy)			Diff (%)		
			E5	E10	E20	E5	E10	E20
PTV	D95	>75.6	76.1	75.9	75.7	−0.9	−0.7	−0.5
	D5	<83.0	80.8	80.5	80.4	−0.6	−0.3	−0.1
Rectum	D30	>70.0	56.8	57.9	64.1	−2.5	−1.5	−1.0
	D10	<75.0	70.2	70.1	71.7	−1.5	−0.7	−1.5
Bladder	D30	>70.0	21.2	24.3	33.2	7.6	5.3	3.9
	D10	<75.0	40.7	44.1	51.9	9.6	5.6	5.3

Table 3. C3-AAPM TG-119's structures planned dose on different modeled machine compared to dose goals. Diff is the difference between the TPS and COMPASS reconstructed dose.

Structures	Parameters	Goal (Gy)	Planned (Gy)			Diff (%)		
			E5	E10	E20	E5	E10	E20
PTV	D90	>50.0	53.5	53.1	51.9	−1.8	−1.7	−1.2
	D99	>46.5	48.6	49.8	44.7	−2.5	−1.7	−1.3
	D20	<55.0	55.0	54.6	54.7	−1.0	−0.7	−0.3
Cord	Max	<40.0	36.3	33.6	35.8	−7.5	−5.5	−1.0
Parotid	D50 (LT)	<20.0	17.0	16.2	14.2	4.9	3.2	2.1
	D50 (RT)	<20.0	17.6	17.7	15.2	1.8	0.9	0.4

Table 4. C4-AAPM TG-119's structures planned dose on different modeled machine compared to dose goals. Diff is the difference between the TPS and COMPASS reconstructed dose.

Structures	Parameters	Goal (Gy)	Planned (Gy)			Diff (%)		
			E5	E10	E20	E5	E10	E20
PTV	D95	>50.0	51.8	51.1	46.3	−1.2	−0.7	−0.2
	D10	>55.0	54.7	54.8	55.0	1.8	0.9	0.2
Core	Max	<25.0	21.6	21.5	21.2	4.3	3.7	2.5

Table 5. Gamma analysis of AAPM TG-119' C2 case. Gamma-index pass-rates and average gamma values for structures (analysis is in local mode, 3%/3mm, gamma < 1).

Structures	Gamma scores (%)			Average gamma		
	E5	E10	E20	E5	E10	E20
Body	99.43	99.44	99.51	0.22	0.22	0.19
Center	98.61	99.00	99.83	0.22	0.22	0.18
Superior	97.55	100.0	99.66	0.33	0.33	0.31
Inferior	99.52	99.95	100.0	0.28	0.27	0.22

Table 6. Gamma analysis of AAPM TG-119' C2 case. Gamma-index passing rates and average gamma values for structures (analysis is in local mode, 3%/3mm, gamma < 1).

Structures	Gamma scores (%)			Average gamma		
	E5	E10	E20	E5	E10	E20
Body	99.84	99.90	99.94	0.19	0.18	0.16
PTV	99.80	100.0	100.0	0.24	0.19	0.17
Rectum	99.70	100.0	100.0	0.31	0.27	0.27
Bladder	100.0	100.0	100.0	0.27	0.27	0.26

Table 7. Gamma analysis of AAPM TG-119' C3 case. Gamma-index pass-rates and average gamma values for structures (analysis is in local mode, 3%/3mm, gamma < 1).

Structures	Gamma scores (%)			Average gamma		
	E5	E10	E20	E5	E10	E20
Body	98.02	98.81	99.16	0.28	0.28	0.25
PTV	97.65	98.72	99.05	0.39	0.35	0.30
Cord	94.75	96.05	98.94	0.46	0.40	0.33
Parotid LT	100.0	100.0	100.0	0.28	0.27	0.28
Parotid RT	100.0	100.0	100.0	0.24	0.24	0.20

Table 8. Gamma analysis of AAPM TG-119' C4 case. Gamma-index pass-rates and average gamma values for structures (analysis is in local mode, 3%/3mm, gamma < 1).

Structures	Gamma scores (%)			Average gamma		
	E5	E10	E20	E5	E10	E20
Body	99.27	99.40	99.43	0.24	0.23	0.23
PTV	96.93	99.32	99.84	0.39	0.31	0.25
Core	99.00	99.25	99.67	0.29	0.26	0.23

3.2. Cases Studies

Prostate, H&N and esophagus real patient's clinical cases were studied. The analysis was based on dose difference between COMPASS's reconstructed dose and TPS dose at ICRU point.

Prostate cases consist of 3 dose levels planned in a simultaneous integrated boost (SIB) mode with 74, 62.9 and 51.8 Gy of patient dose delivered on each level with 2 arcs in 37 fractions. The mean gamma and gamma scores were also registered as presented in **Tables 9-11**.

Esophagus cases consist of one dose level of 50 Gy planned with 2 arcs in 25 fractions. The mean gamma and gamma scores were also registered as presented in **Tables 12-14**.

Head and Neck case consist of 3 dose levels planned in a simultaneous integrated boost mode with 70, 63 and 56 Gy of dose delivered on each level with 2 arcs in 35 fractions. The mean gamma and gamma scores were also registered as presented in Tables 15-17.

The mean MUs values were calculated for each clinical site on each machine modeled to see how far the leave's minimum leave gap could influence the amount of MUs in clinical planning. The results are represented on the Table 18.

Table 9. Prostate case structures mean dose difference between the TPS and COMPASS reconstructed dose on ICRU point for each machine modeled in the TPS with leave's dynamic minimum gap of 5, 10 and 20 mm.

Structures		E5		E10		E20	
		Mean (%)	SD	Mean (%)	SD	Mean (%)	SD
PTV 74	D50	−0.98	0.41	−0.93	0.35	−0.80	0.36
	D95	−1.66	0.58	−1.47	0.27	−1.41	0.35
	D2	−0.66	0.45	−0.56	0.49	−0.54	0.28
PTV 62.9	D50	−2.09	0.34	−2.06	0.39	−1.89	0.38
	D95	−3.10	0.49	−2.81	0.39	−2.54	0.53
	D2	−1.39	0.47	−1.40	0.26	−1.19	0.35
PTV 51.8	D50	−2.66	0.41	−2.59	0.39	−2.37	0.42
	D95	−3.31	0.39	−3.27	0.44	−2.89	0.47
	D2	−1.57	0.63	−1.31	0.41	−1.24	0.47
Rectum	V50	−2.58	0.49	−2.50	0.67	−1.38	0.32
	V65	−1.73	0.44	−1.51	0.54	−1.42	0.59
	V74	−0.61	0.64	−0.52	0.60	−0.37	0.51
Bladder	V50	−2.01	1.54	−1.86	1.69	−1.64	1.24
	V65	−0.74	0.35	−0.52	0.18	−0.46	0.25
	V74	−1.04	0.74	−0.90	0.66	−0.73	0.47

Table 10. Average gamma score of some prostate organs case (analysis in local mode, 3%/3mm, gamma < 1, 15% dose threshold).

Structures	E5		E10		E20	
	Average gamma	SD	Average gamma	SD	Average gamma	SD
PTV 74	0.36	0.04	0.34	0.05	0.28	0.06
PTV 62.9	0.49	0.09	0.47	0.09	0.43	0.09
PTV 51.8	0.53	0.05	0.50	0.08	0.48	0.09
Rectum	0.45	0.08	0.44	0.10	0.42	0.11
Bladder	0.40	0.04	0.39	0.05	0.35	0.04

Table 11. The gamma passing rate scores of prostate case for PTVs and some OARs (analysis in local mode, 3%/3mm, gamma < 1, 15% dose threshold).

Structures	E5		E10		E20	
	Gamma (%)	SD	Gamma (%)	SD	Gamma (%)	SD
PTV 74	98.83	1.01	98.96	1.13	99.91	0.08
PTV 62.9	95.98	1.33	96.87	1.6	99.03	1.34
PTV 51.8	95.65	1.67	96.8	1.19	98.28	1.92
Rectum	98.19	1.38	98.50	1.49	98.99	1.25
Bladder	99.18	0.98	99.30	0.77	99.70	0.30

Table 12. Esophagus cases structures mean dose difference between the TPS and COMPASS reconstructed dose on ICRU point for each machine modeled in the TPS with the minimum dynamic leaf gap of 5, 10 and 20 mm.

Structures		E5		E10		E20	
		Mean (%)	SD	Mean (%)	SD	Mean (%)	SD
PTV	D50	−0.75	0.22	−0.58	0.10	−0.35	0.28
	D95	−1.43	0.30	−1.08	0.36	−0.80	0.37
	D2	−0.76	0.75	−0.50	0.37	0.22	0.32
Cord	Dmax	−3.35	0.79	−2.50	1.15	−2.02	1.82
Heart	V40	−0.55	0.12	−0.7	0.14	0.04	0.11
	V20	−1.37	0.36	−1.26	0.27	−1.13	0.32
Total Lung	V30	−0.20	0.14	−0.17	0.14	−0.16	0.18
	V10	−1.60	0.35	−1.21	0.42	−1.14	0.52

Table 13. Average gamma values for organs of esophagus case (analysis in local mode, 3%/3mm, gamma < 1, 15% dose threshold).

Structures	E5		E10		E20	
	Average gamma	SD	Average gamma	SD	Average gamma	SD
PTV	0.35	0.07	0.33	0.08	0.30	0.09
Cord	0.26	0.06	0.25	0.08	0.24	0.07
Heart	0.29	0.12	0.28	0.12	0.26	0.11
Total lung	0.26	0.08	0.26	0.07	0.24	0.07

Table 14. The gamma analysis of esophagus case for PTVs and some OARs. (local mode, 3%/3mm, gamma < 1, 15% dose threshold).

Structures	E5		E10		E20	
	Gamma (%)	SD	Gamma (%)	SD	Gamma (%)	SD
PTV	98.01	1.75	98.14	1.86	98.87	0.99
Cord	98.00	1.21	98.69	0.17	99.98	0.02
Heart	98.50	0.88	99.00	0.34	99.93	0.10
Total lung	99.10	0.14	99.60	0.08	99.99	0.01

Table 15. Head and neck cases structures mean dose difference between the TPS and COMPASS reconstructed dose on ICRU point for each machine modeled in the TPS with minimum dynamic leaf gap of 5, 10 and 20 mm.

Structures		E5		E10		E20	
		Mean (%)	SD	Mean (%)	SD	Mean (%)	SD
PTV 70	D50	−0.98	0.61	−0.61	0.85	−0.38	0.92
	D95	−1.70	0.75	−1.18	0.63	−0.95	1.01
	D2	−1.25	0.99	−0.05	1.19	0.04	1.04
PTV 63	D50	−1.66	0.53	−1.41	0.82	−1.24	0.60
	D95	−1.84	0.58	−1.79	0.85	−1.59	0.66
	D2	−1.20	0.75	−0.95	1.10	−0.86	0.93
PTV 56	D50	−1.94	0.47	−1.51	0.45	−1.35	0.33
	D95	−2.12	0.48	−2.01	0.33	−1.76	0.20
	D2	−1.75	0.81	−1.33	0.89	−1.20	0.86
Cord	Dmax	−4.90	2.59	−4.84	2.07	−4.35	1.94
Parotid L	Dmean	−3.26	2.51	−1.77	2.10	−1.31	2.15
Parotid R	Dmean	−3.50	2.10	−3.08	1.81	−2.62	2.06

Table 16. Average gamma values of head and neck case. Organs average gamma values are in local mode, 3%/3mm, gamma < 1, 15% dose threshold.

Structures	E5		E10		E20	
	Average gamma	SD	Average gamma	SD	Average gamma	SD
PTV 70	0.47	0.10	0.38	0.09	0.33	0.07
PTV 63	0.49	0.11	0.42	0.15	0.38	0.12
PTV 56	0.53	0.07	0.40	0.05	0.36	0.04
Cord	0.45	0.11	0.44	0.08	0.41	0.08
Parotid L	0.32	0.11	0.32	0.07	0.30	0.07
Parotid R	0.32	0.08	0.32	0.08	0.30	0.08

Table 17. The analysis passing rate scores of head and neck case for PTVs and some OARs (analysis in local mode, 3%/3mm, gamma < 1, 15% dose threshold.

Structures	E5		E10		E20	
	Gamma (%)	SD	Gamma (%)	SD	Gamma (%)	SD
PTV 70	97.00	5.36	97.56	3.30	98.56	2.26
PTV 63	97.43	2.68	98.66	1.31	99.04	2.66
PTV 56	97.88	2.17	98.12	1.07	99.27	0.56
Cord	96.69	0.08	97.57	2.96	98.62	1.16
Parotid L	100.0	0.01	99.90	0.48	98.83	0.41
Parotid R	99.94	0.11	99.70	0.02	99.99	0.03

Table 18. The MUs average numbers per clinical case and for each machine modeled in the treatment planning system with minimum dynamic leaf gap of 5, 10 and 20 mm.

	E5		E10		E20	
	Mean	SD	Mean	SD	Mean	SD
Prostate	543	70	476	68	384	37
H&N	467	66	441	47	372	34
Esophagus	413	62	378	53	315	37

3.3. Discussion

For plans C1 and C2, the three machines easily fulfill the planned dose goals. The difference between measured and planned dose are almost of the same magnitude as well as organs gamma passing rate scores are closed. On the other hand, plans C3 and C4 show that machine E5 make it possible to fulfill the dose goals easily, unlike the machine E20. The machine E10 has results closed to E5 in terms of dose goals. However, the differences between the measured and the planned dose are smaller for the machine E20 than the E5 one. The machine E20 also has the best gamma passing rate scores and average values that the two others machines E5 and E10. Nonetheless, E10's scores are closer to E20 one.

The planning of the AAPM TG-119 plans clearly shows that the dynamic minimum leaf gap has a real influence on the ability to easily meet the dose goals. The smallest gap (5 mm) gives to the operator more ability to produce a high level of dose conformity to less and more complex volumes shapes. This has a great influence on the coverage of target volumes but no visible influence on the spare of critical volumes. However, our COMPASS pretreatment quality assurance system, both on the AAPM TG-119 phantom and clinical patients shows the better adequacy of the planned dose with the measured one in the case of the 20 mm's modeled machine. This adequacy is also observed in the gamma passing rates scores and the average gamma of organs. In the case of high modulation, a machine modeled with a minimum leave dynamic gap of 5 mm will generate a large number of small segments that could be an issue for the measurements. The spatial resolution of the detector can be a limitation in such case in the way that it enables it to handle small fields' sizes accurately.

For clinical cases, the machine E20 also has the best results in terms of dose difference and gamma scores than E5 and E10. This confirms the influence of the small segments in the quality of the dose measured during pretreatment QA process. Obviously this influence is minimized for high-resolution detector (EPID and film). The dose differences are greater for PTVs of lover dose levels than it is for the main PTV. Since the planning is done in SIB mode, a part of the modulation is done on these intermediate and lower dose levels PTVs and the size of the segments is the reason of that difference. Since all the three machines were modeled with the same leaf transmission, the dose differences observed on the OARs are related to the fact that they share some voxels with the target volumes. All those effects are smaller on the machine E20 and high on the E5. The machine E10 looks close to the E20 in most of the case than the E5.

It is known that for the same dose to be delivered, the smaller the field size will be, larger the number of monitor units needed will. Thus the 5 mm machine modeled generated treatments with high numbers of MUs compared to 10 and 20mm. This is also due to the influence of small fields in the fluence. The differences of the mean MUs between E5 and E20 for prostate, H&N and esophagus are 159, 95 and 98 respectively. That shows the amount of scattering bean generated in machines E5 plans compare to others machine. The machine E10 once again looks close to E20 in terms of MUs.

4. Conclusion

For high quality radiation therapy, it is critical that planned and delivered dose measurement should be closed as much possible. Small segments in treatments plans can bring big issues in the pretreatment quality assurance process due the presence of small field and detectors spatial resolution limitation although they allow the planner to design high complex shape during planning process. To avoid such situation, treatment machine in the planning system should be modeled in a way to minimize small segments occurrence during dose optimization. In Pinnacle[3] the adequate choice of the minimum dynamic leaf gap is for a great importance. The present study shows that 10 mm is an appropriate value of minimum dynamic leaf gap that allows the operator to fulfill complex dose goals while obtaining a good agreement between planned and measured dose. The results obtained in the present work show that 10 mm is the best compromise of minimum dynamic leaf gap.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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