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Performance of the eclipse monitor unit objective tool utilizing volumetric modulated arc therapy for rectal cancer

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ABSTRACT

Aim: To assess the performance of the monitor unit (MU) Objective tool in Eclipse treatment planning system (TPS) utilizing volumetric modulated arc therapy (VMAT) for rectal cancer.
Background: Eclipse VMAT planning module includes a tool to control the number of MUs delivered: the MU Objective tool. This tool could be utilized to reduce the total number of MUs in rectal cancer treatments.
Materials and methods: 20 rectal cancer patients were retrospectively studied using VMAT and the MU Objective tool. The baseline plan for each patient was selected as the one with no usage of the MU Objective tool. The number of MUs of this plan was set to be the reference number of MUs (MU_{ref}). Five plans were re-optimized for each patient only varying the Max MU parameter. The selected values were 30%, 60%, 90%, 120% and 150% of MU_{ref} for each patient. Differences with respect to the baseline plan were evaluated regarding MU number and parameters for PTVs coverage evaluation, PTVs homogeneity and OARs doses assessment. A two-tailed, paired-samples *t*-test was used to quantify these differences.
Results: Average relative differences in MU number obtained was 10% for Max MU values of 30% and 60% of MU_{ref}, respectively ($p < 0.03$). PTVs coverage and homogeneity were not compromised and discrepancies obtained with respect to baseline plans were not significant. Furthermore, maximum OARs doses deviations were also not significant.
Conclusions: A 10% reduction in the MU number could be obtained without an alteration of PTV coverage and OARs doses for rectal cancer.

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1. Background

In recent years modern technologies in radiotherapy based upon intensity modulation, such as intensity modulated radiation therapy (IMRT), helical tomotherapy (Tomotherapy) or volumetric modulated arc therapy (VMAT), have improved dose distributions delivered to the target volumes (PTVs), reducing the dose received by adjacent normal tissue and organs at risk (OARs). Advantages of these new techniques have been compared and evaluated by several authors in the literature.[1–8] VMAT is a radiotherapy technique based on a simultaneous variation of dose rate, gantry angle and MLC position with the aim of improving dose sparing and to significantly reduce treatment time.[9,10] However, intensity modulation implies an increase in the total number of monitor units (MU) with respect to 3D-CRT,[11] mainly due to the delivery patterns created by multi-leaf collimators (MLCs) and the variation in dose rate and gantry angle. This increment in the MU number implies a higher secondary radiation dose, which may entail an increased risk of developing secondary cancers.[12–14] In modulated techniques the number of MUs is not linearly related to the prescribed dose because of the effect of several factors, such as dose rate variation, MLC segmentation or gantry speed.

Eclipse treatment planning system v.11 (Varian Medical Systems, Palo Alto, CA) employs the Progressive Resolution Optimizer (PRO3) algorithm for VMAT optimization, in which one of the different tools available is the MU Objective tool. This tool aims to control MU required for the delivery of the prescribed dose. It is comprised of three parameters, namely Minimum MU (Min MU), Maximum MU (Max MU) and Strength (S). Min MU and Max MU are parameters in charge of defining the MU goal, while S defines the priority enforced by the MU reduction goal. Min MU increases MU (addition of modulation in the optimization process), while Max MU tends to reduce MU (reduction of modulation in the optimization process). Objective tool S values range from 0 to 100 and its scale differs from that of the Dose–Volume Histogram (DVH) objective function priorities. Although there are some publications which describe the use of these parameters,[15] users may not be familiar with how these parameters influence PRO3 results. Besides, the use of the MU Objective tool is not mandatory in Eclipse. The working of these parameters strictly correlate with the modulation factor appearing in tomotherapy treatment planning.[16] In this context, it is imperative to assess the task of limiting MU for several pathologies. For this purpose, some authors have investigated the use of the MU Objective tool for the prostate,[17–19] head and neck,[18,20] gynecological locations,[17] lung SBRT[21] or breast.[22]

2. Aim

This paper aims to investigate the behavior of the MU Objective tool for rectal cancer and to assess whether a considerable reduction in MU entails an alteration in PTV coverage and an increase in OARs dose or not.

3. Materials and methods

For this study 20 rectal cancer patients were retrospectively studied. The radiation oncologist prescribed 45 Gy to the lymph pelvic nodes and 50 Gy to the rectum in a concomitant treatment comprised of 25 fractions. A supine position was considered for all patients. For optimization purposes, an additional volume was created for the lymph pelvic nodes volume which is not contained in the PTV 50 volume, called $PTV45_{Opt}$. This region was created by subtracting the 50 Gy PTV plus a 5 mm margin to the 45 Gy PTV. OARs considered were the bladder, small bowel and both femoral heads. Fig. 1 depicts three views (craniocaudal, lateral and anterior–posterior) showing both PTV structures of a representative case (PTV45 in blue and PTV50 in red).

Apart from Fig. 1, a full description of both PTV dimensions and volumes is given in Table 1.

The plans were created in the Eclipse v11 treatment planning system (Varian Medical System, Palo Alto, CA), utilizing the Progressive Resolution Optimizer (PRO3) algorithm. Two VMAT full arcs were employed using collimator angles of 30° and 330° so as to reduce the tongue and groove effect. To minimize the time delay between arcs, the first one was clockwise and the second counter-clockwise. All plans were optimized on a Varian Clinac iX linac with a Millennium 120 MLC with a 5 mm leaf width at the isocenter. Dose was calculated by means of the Analytical Anisotropic Algorithm (AAA) using a 2.5 mm resolution grid. Beams of 6 MV were utilized and a maximum dose rate of 600 MU/min was employed. Following the manufacturer's recommendations with respect to the S value, it was decided to set it to 80 for all plans reported (recommendations range from 50 to 100). To reduce the MU number Min MU was kept to 0 and Max MU was varied. For each patient a baseline plan was created. This baseline plan was optimized without utilizing the MU Objective tool. The MU

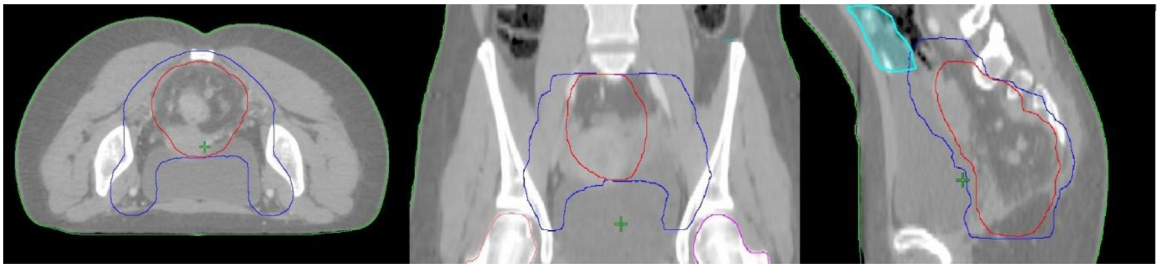

Fig. 1 – Craniocaudal, lateral and anterior–posterior views of a representative case showing PTV45 (blue line) and PTV50 (red line).

Table 1 – Craniocaudal (cc), lateral (lat) and anterior–posterior (ap) lengths and PTVs volume obtained as averages from all patients considered for PTV45 and PTV50. The standard deviation (Std) is also provided.

	PTV45 dimensions			
	cc (cm)	lat (cm)	ap (cm)	Volume (cm^3)
Average	14.5	12.7	9.8	1355.4
Std	3.7	0.5	1.6	264.8
	PTV50 dimensions			
	cc (cm)	lat (cm)	ap (cm)	Volume (cm^3)
Average	12.5	8.4	8.6	621.2
Std	3.8	0.9	0.9	186.1

number obtained was considered as the reference MU (MU_{ref}) for the patient. Five more plans were created for each patient by considering different percentages of MU_{ref}, namely 30%, 60%, 90%, 120% and 150%. In these plans all parameters regarding the cost function (DVH priorities, dose objectives and dose constraints) were kept the same as in the baseline plan so as to evaluate the influence of the MU Objective tool in the final MU number and plan quality and also to minimize any possible dependence on individual planner's skill. For the MU variation evaluation, relative percentage values with respect to MU_{ref} were obtained for each patient. To evaluate the plan quality, several indexes and metrics were utilized. For PTV evaluation, $D_{2\%}$, $D_{98\%}$ and D_{avg} were used. In order to assess variations in homogeneity, the homogeneity index (HI)[23] was also considered. For OARs D_{avg} (bladder, femoral heads and small bowel), $D_{2\%}$ (femoral heads) and $V_{40\,Gy}$ (small bowel) were considered. Differences obtained in the cumulative DVH were analyzed using a paired samples *t*-test ($\alpha = 0.05$). Mean values and standard deviations were also calculated.

Pretreatment quality assurance was performed to observe the influence of MU number reduction on gamma results. For this purpose, all plans were measured using the EPID from the unit (Portal Vision, Varian Medical Systems, Palo Alto, CA). A 2%–2 mm gamma analysis was performed with low dose cut-off (LDCO) of 10%, 5% and 0%, respectively. Percentage points with $\gamma > 0.8$ and $\gamma < 1$ were considered.

4. Results

Fig. 2 depicts the average relative MU difference (ΔMU_{avg}) as a function of the MU_{ref} percentage considered for obtaining the Max MU parameter. Bars length was set to one standard deviation around the average value. A positive value of ΔMU_{avg} implies a reduction in the total number of MU while a negative value means an increase in the MU number with respect to the baseline plan. It can be seen that a MU reduction could be achieved when the Max MU parameter is set to values which are lower than MU_{ref} ($p < 0.03$ for 30% and 60% plans when compared to baseline plans). On the contrary, for Max MU higher than the reference MU value an increase in the total MU number is observed, although these results did not reach statistical significance ($p > 0.52$). Percentage reduction in the MU number for the first two cases is almost 10%.

For both PTVs, average percentage deviations with respect to baseline plan for $D_{2\%}$, $D_{98\%}$, $D_{50\%}$, D_{avg} and HI are reported in Table 2. From the table, it can be seen that differences are quite small and have no statistical significance ($p \gg 0.05$). No substantial variations are observed in PTVs coverage as well as in average doses or $D_{2\%}$. Regarding homogeneity indexes, maximum differences of 2.8% and 2.3% are seen for $PTV45_{Opt}$ and PTV50, respectively. Although *p* values are higher than 0.05 in all cases, it is worth mentioning that *p*-values obtained when considering the 30% and 90% Max MU plans for $PTV45_{Opt}$ HI are very close to statistical significance ($p = 0.054$).

With respect to the OARs considered, results obtained for the percentage deviations are shown in Table 3. For femoral heads, differences of 5.3% and −5.9% are observed in D_{avg} and $D_{2\%}$, respectively. However, no significant variations are found ($p > 0.11$ and $p > 0.27$, respectively). For small bowel D_{avg} and $V_{40\,Gy}$, discrepancies of 3.9% and 2.6% are obtained, but they did not reach statistical significance ($p > 0.32$ and $p > 0.51$, respectively). For the bladder, a maximum difference of 2.3%

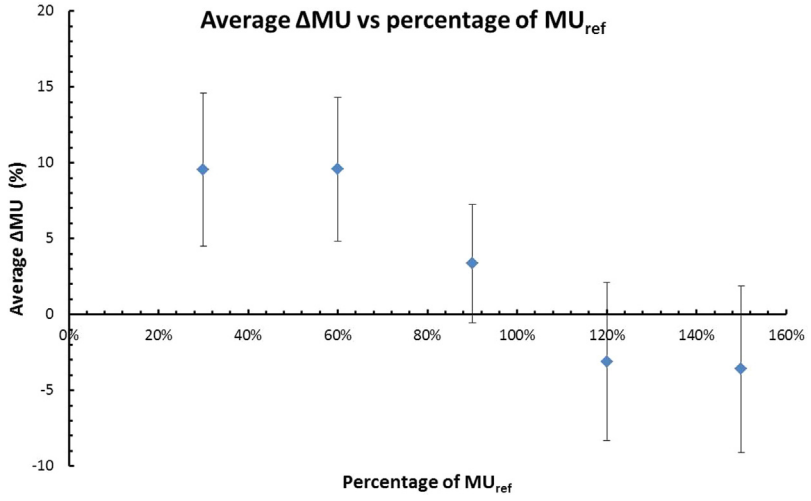

Fig. 2 – Average relative MU difference (ΔMU_{avg}) as a function of the percentage of the reference MU number (MU_{ref}) considered. Error bars length was set to one standard deviation.

Table 2 – Average percentage deviations with respect to the average baseline plan for different percentages of the reference MU number (MU_{ref}). For both PTVs, deviations for doses to 2%, 98% and 50% of the volume are shown. Also average doses and homogeneity indexes results are displayed.

	Deviations with respect to baseline plan (%)									
Plan	$PTV45_{Opt}$					PTV50				
	$D_{2\%}$	$D_{98\%}$	$D_{50\%}$	D_{avg}	HI	$D_{2\%}$	$D_{98\%}$	$D_{50\%}$	D_{avg}	HI
30%	0.2	0.3	0.3	0.2	−0.9	0.3	0.3	0.3	0.3	1.6
60%	0.2	0.2	0.4	0.3	−0.6	0.4	0.3	0.2	0.2	2.0
90%	0.4	0.2	0.4	0.3	2.8	0.4	0.2	0.3	0.3	2.3
120%	0.4	0.2	0.4	0.3	2.3	0.3	0.2	0.3	0.3	2.3
150%	0.3	0.2	0.4	0.3	2.0	0.3	0.2	0.3	0.3	1.0

Table 3 – Average deviations with respect to the average baseline plan for different percentages of the reference MU number (MU_{ref}). Deviations from the baseline plan for doses to 2% of the volume, average doses and the volume irradiated with 40 Gy are shown.

	Deviations with respect to baseline plan (%)						
Plan	Left femoral head		Right femoral head		Small Bowel		Bladder
	D_{avg}	$D_{2\%}$	D_{avg}	$D_{2\%}$	D_{avg}	$V_{40\,Gy}$ (%)	D_{avg}
30%	1.9	1.3	1.9	−1.3	3.8	2.1	1.3
60%	−0.4	−0.4	−0.6	−2.5	3.9	2.6	0.7
90%	5.3	−4.1	3.3	−5.9	3.0	−0.3	0.1
120%	−2.9	−0.1	−3.2	−2.7	3.3	−0.2	1.4
150%	−2.4	−1.2	−0.8	−0.8	2.9	−0.1	2.3

Table 4 – Average percentage values obtained from the gamma analysis results for baseline and MU reduced plans. LDCO stands for low dose cut off.

Plan	LDCO = 0%		LDCO = 5%		LDCO = 10%	
	$\gamma < 1$ (%)	$\gamma > 0.8$ (%)	$\gamma < 1$ (%)	$\gamma > 0.8$ (%)	$\gamma < 1$ (%)	$\gamma > 0.8$ (%)
Baseline	99.95	0.3	99.95	0.3	99.95	0.35
30%	95.05	27.3	97	8.9	99.65	1.75
60%	99.7	4.1	99.35	3.35	99.95	0.2
90%	99.75	2.6	99.7	1.6	99.85	0.3
120%	98.3	9.6	98.1	5.05	99.5	1.9
150%	97.9	14.45	97.85	5.4	99.45	1.35

is reported in D_{avg}, although no statistical significance is observed ($p > 0.09$).

Table 4 shows the average results of the pretreatment quality assurance measurements. For all plans, the percentage of points with gamma greater than 0.8 and lesser than 1 were considered. Also, the influence of LDCO during gamma analysis was reported.

5. Discussion

Results obtained indicate that the maximum MU reduction is obtained for plans in which the Max MU parameter is set to 30% and 60% of MU_{ref} ($p < 0.03$). This reduction is about 10% for these cases. The average value of the Max MU parameter obtained in these two cases (maximum MU reduction) is 388 ± 49 (30% of MU_{ref}) and 389 ± 51 (60% of MU_{ref}) MU, which concurs with results obtained by other authors.[18] The 90% case offers a smaller reduction (3.4% average value), although this difference is not statistically significant ($p > 0.5$). A quite curious behavior appears when Max MU parameter is set to values which are higher than MU_{ref}. Although no influence in the final MU number was expected, an increase in the MU number was observed for 120% and 150% MU reduction cases (−3.1% and −3.6%, respectively). This result is quite unexpected, as a Max MU value is not supposed to incorporate an additional restriction to the plan when Max MU is higher than MU_{ref}. However, this is in accordance with other published results.[18] Regarding PTVs coverage, our results indicate that there is no significant variation in $D_{2\%}$ nor in $D_{98\%}$, which means that a MU reduction may be achieved maintaining PTV coverage unaltered. For $PTV45_{Opt}$ and PTV50 and considering only the cases with a higher MU reduction (30% and 60% of MU_{ref}), HI differ by −0.9% and 2%, respectively, from the baseline plan (Table 2). Therefore, homogeneity is preserved up to 2%, which turned out to be not statistically significant ($p > 0.11$). OARs results also indicate that a MU reduction could be achieved without compromising critical structures. For 30% and 60% MU reduction cases, the femoral heads D_{avg} and $D_{2\%}$ did not significantly vary (maximum deviations of 1.9% and 1.3%, respectively), nor did the bladder D_{avg} (maximum deviation of 1.3%). For the small bowel, the MU reduction (30% and 60% cases) implies a deviation from the baseline plan of 3.9% and 2.6% for D_{avg} and $V_{40\,Gy}$, respectively. Consequently, from these results it could

be stated that a 10% reduction in MU is achievable without compromising PTV coverage and significantly increasing OAR doses.

Regarding quality assurance measurements it is interesting to comment on the influence of both LDCO and MU restrictions on gamma analysis results. For all LDCO cases studied, the baseline plan achieves the highest percentage of points with gamma parameter lower than 1. For 0% and 5% LDCO cases the baseline plan also achieves the lowest percentage of points with gamma parameter higher than 0.8. For the 10% LDCO case the percentage of points with gamma parameter greater than 0.8 are quite similar since gamma parameter values higher than 0.8 seem to be associated with lower doses. Besides, it can be seen that the differences between the baseline plan and the other plans decrease when the LDCO value is increased. For the same LDCO it is shown that the worst values are generally associated with most MU restricted plans (30%). As the MU restriction is made weaker, values tend to the baseline ones. However, for 120% and 150% cases, values obtained are worse than should be expected. An explanation for this phenomenon has not been found by the authors.

Several authors have studied the performance of the MU Objective tool for distinct pathologies. Ahamed et al.[20] investigated hypopharynx plans using 50%, 60% and 80% of the baseline plan MU. They reported variations in MU from 8.6% to 34.7% for different combinations of Min MU, Max MU and S parameters. They also observed some degradation in plan quality as the MU reduction increased. Mancosu et al.[22] investigated this tool for VMAT breast treatments. They fixed $S = 100$ and Max MU used were −50%, −20%, 20% and 50% of the reference MU plans. They found no significant deviations in PTV coverage while for OARs some unacceptable deviations were observed. The MU reduction obtained range from 18% to 39%. Clemente et al.[17] obtained a 28% MU reduction for prostate plans utilizing $S = 100$ and Max MU of 50% of the baseline MU plan. Integral dose and average dose reduction for the rectum and bladder were reported (4–17% and 12%, respectively). Huang et al.[21] evaluated the behavior of MU Objective tool for lung SBRT. They reported an impressive MU reduction of almost 50% without compromising PTV coverage and OAR doses. As can be seen, several authors report quite important MU reductions. Our results show that, for rectal cancer, a 10% reduction could be achieved without compromising PTV coverage and doses to involved OARs.

6. Conclusion

For rectal cancer, a plan with similar quality to the baseline plan could be obtained by utilizing the MU Objective tool. A reduction of 10% in the number of delivered MU could be achieved without altering plan quality (PTV coverage and OAR doses). Hence, we consider that MU Objective tool may be of great interest to obtain rectal cancer plans with a similar quality to those obtained without the use of this tool diminishing the risk of developing secondary cancers.

Conflict of interest

None declared.

Financial disclosure

None declared.

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