Original Article

Influence of increment of gantry angle and number of arcs on esophageal volumetric modulated arc therapy planning in Monaco planning system: A planning study

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ABSTRACT

The objective of this study was to analyze the influence of the increment of gantry angle and the number of arcs on esophageal volumetric modulated arc therapy plan. All plans were done in Monaco planning system for Elekta Synergy linear accelerator with 80 multileaf collimator (MLC). Volumetric modulated arc therapy (VMAT) plans were done with different increment of gantry angle like 15°, 20°, 30° and 40°. The remaining parameters were similar for all the plans. The results were compared. To compare the plan quality with number of arcs, VMAT plans were done with single and dual arc with increment of gantry angle of 20°. The dose to gross tumor volume (GTV) for 60 Gy and planning target volume (PTV) for 48 Gy was compared. The dosimetric parameters $D_{98\%}$, $D_{95\%}$, $D_{50\%}$ and D_{max} of GTV were analyzed. The homogeneity index (HI) and conformity index (CI) of GTV were studied and the dose to 98% and 95% of PTV was analyzed. Maximum dose to spinal cord and planning risk volume of cord (PRV cord) was compared. The Volume of lung receiving 10 Gy, 20 Gy and mean dose was analyzed. The volume of heart receiving 30 Gy and 45 Gy was compared. The volume of normal tissue receiving greater than 2 Gy and 5 Gy was compared. The number of monitor units (MU) required to deliver the plans were compared. The plan with larger increment of gantry angle proved to be superior to smaller increment of gantry angle plans in terms of dose coverage, HI, CI and normal tissue sparing. The number of arcs did not make any difference in the quality of the plan.

Key words: Esophagus cases; increment of gantry angle; number of arcs; VMAT

Introduction

Volumetric Modulated Arc Therapy (VMAT) is a dynamic arc delivery technique of intensity modulated radiation therapy (IMRT). In VMAT, gantry speed, multileaf collimator (MLC) shape and speed, dose rate and collimator are continuously changing according to the treatment plan. VMAT has the potential benefits compared to IMRT in terms of tumor control probability (TCP) and reducing the toxicity to the normal structures[1,2] with high monitor unit (MU) and treatment delivery efficiency.[1-4] The quality of VMAT plan depends on the algorithm used for optimization and dose calculation, the physical and biological parameters used in the treatment planning system (TPS). Many authors have studied the influence of different physics and machine parameters on the VMAT plan quality using Pinnacle and Eclipse planning system.[4,5] We carried out our study on Monaco planning system to analyze the influence of Some of the physical parameters on VMAT plan quality.

Monaco planning system supports IMRT as well as VMAT planning. It uses biological models for optimization.[6,7] Monaco uses machine parameters like leaf speed, gantry speed and dose rate for optimization. One of the parameters is the Increment of gantry angle (IGA). IGA controls the number of generated static gantry positions or sectors in VMAT plan. One more parameter is number of arcs. The number of sectors or the number of arcs used for planning may affect the quality of the plan. Yin L *et al*.,[1] and Abbas *et al*.,[8] compared the quality of the esophageal VMAT plans with number of arcs using Eclipse and Pinnacle planning

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systems respectively. Yang *et al.*,[4] compared single arc and double arc VMAT plans for head and neck, prostate, lung and spine using Pinnacle planning system.

Twelve middle third esophageal patients were taken for this study. All these cases were planned in Monaco planning system for different IGA such as 15°, 20°, 30° and 40° which are the angles we use for daily routine planning. Also separate plans were done for single and dual arc with IGA 20° which is the angle mostly used for treatment planning. Tumor dose and dose to normal structures were analyzed. In this study, the influence of IGA and number of arcs in quality of VMAT plan for esophageal cases was analyzed.

Materials and Methods

Patient selection

A total of 12 cases comprising middle third esophageal cancer patients were considered for this study. The median age was 59 (Range = 40-75 years) with 9 males and 3 females. The clinical stage distribution was T3 in 10 patients, and T4 in 2 patients with node stage N1–N3. Histopathology was squamous cell carcinoma for all patients. The mean length of GTV was 9.9 cm (Range = 6.3-12.3 cm) and PTV was 16 cm (Range = 12.5-20.5 cm) with mean volume of 95 cc (Range = 40-177) and 584 cc (Range = 310-718 cc) respectively.

Monaco planning system

Monaco treatment planning system (Elekta Ltd, Crawly, UK) version 3.20.02 utilizes physical effects of radiation and biological properties of the tissue. It has three biological constraints such as Target EUD, Parallel and serial and six physical constraints such as target penalty, quadratic overdose, overdose DVH, under dose DVH, maximum dose and quadratic under dose. The user has an option to set the cell sensitivity of the tumor in target EUD. The organ at risk can be set as serial or parallel constraints depending on the properties of the tissue.

The system uses a two-stage process of optimizing dose distribution. Generally, in stage one the ideal fluence distribution of beams is optimized to meet a user-defined prescription for given set of beams. In stage two, segmentation is done, which includes the segment shapes and weights, so that deliverable fields are obtained. In this stage system uses Monte Carlo simulation during optimization.

In VMAT optimization, prior to stage one, system divides the beam into sectors. In stage one, at the initialization stage, the system creates the dose calculation cube around all defined structures and calculates structure volumes using cubic voxels. Then it projects the union of all target volumes with the margin defined. Numbers of static sectors are created based on arc length and user defined IGA. Beamlets for each sector are created. Width of beamlet is user defined and length is equal to the length of individual MLC leaves. The system uses an enhanced pencil beam algorithm to calculate the open field dose. Then, the fluence optimization begins in which the weights (fluence) of all individual pencil beams are varied simultaneously. The unconstrained problems are solved by conjugate gradient algorithm. After the unconstrained optimization finishes, if necessary the system changes each cost function relative weight to make the optimizer meet the isoconstraints and restarts the unconstrained optimization problem. Stage one optimization continues until all the constraints are met. The accuracy of dose at the end of the stage one is limited because the algorithm is kernel based two dimensional method, especially in the presence of heterogeneities.

In second stage, the treatment planning system considers the deliverability of accelerator. It takes each fluence map and sequences it in such a way that it is spread over the original sector it represents. The system determines leaf trajectories based on the target dose rate defined by the user. If segment shape optimization (SSO) method is selected, the system selects the optimal dose rate by its own. Then, the system converts optimized fluences into deliverable arc sequence with multiple control points and the gantry position. The gantry positions need not be equally spaced. Dose calculation is done with voxel based Monte Carlo algorithm. The user can change the calculation accuracy and time by modifying some parameters like dose rate, Monte Carlo grid spacing and variance.

Increment of gantry angle and sector

IGA controls the number of generated static gantry positions or sectors. The user has to determine the number of sectors by dividing the arc length by increment. For example a 360° arc length with 30° IGA equals 12 static sectors to optimize as shown in Figure 1. Prior to stage one optimization, the system divides a sequence into sectors that are used for simulating the arc during stage one optimization. The system generates

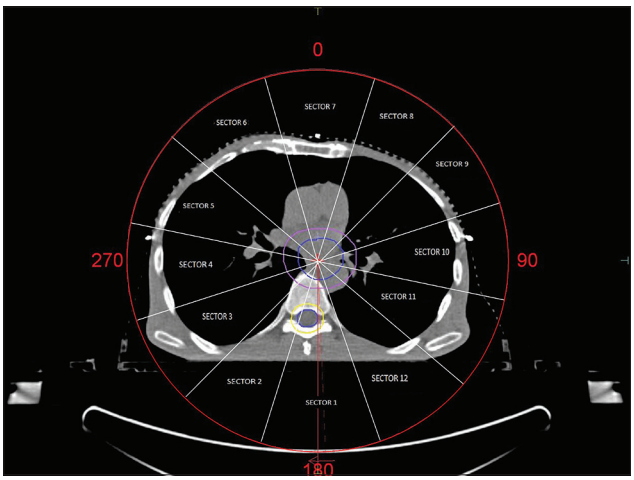

Figure 1: Sectors for 360° arc length with 12 sectors

fluence maps during stage one and computes them at IGA. Generally, using a large IGA creates few sectors which can produce poor quality plans and increase treatment time and using a too small IGA gives more sectors which may increase the quality of the plan.

The number of sectors plays a role in the leaf movement. Monaco treatment planning system uses sweep sequencer for VMAT. During first stage optimization, the sequencer reorders the fluence profiles along with sectors. The leaf movement direction alternates between sectors that is the leaves at the left field edge in one sector move to the right field edge as the gantry rotates. The leaf edges arrive at the field edge at the beginning of the next sector where they change the direction.

Imaging and contouring

All patients were immobilized with thermoplastic sheet in supine position and the hands were kept above the head. The computed tomography (CT) images were acquired for all patients in Biograph PET-CT (Siemens AG, Medical solutions, Germany) with 3 mm slice thickness; field of view 50 cm. CT was acquired in normal breathing position. No gating or respiratory assistant instruments were used. The images were imported into Monaco treatment planning system via DICOM and the contouring of tumor volumes and normal structures were done by the radiation oncologists.

Target volumes

The gross tumor volume encompassed the esophageal tumor and the lymph node was included if it was positive. The regional lymph nodes were drawn as clinical target volume (CTV). The CTV was expanded with 8 mm in all six directions to create planning target volume (PTV) to manage the setup uncertainties. The dose prescription for GTV was 60 Gy and PTV was 48 Gy.

Normal structures

The normal structure comprised of both right and left lung, heart and spinal cord. The spinal cord was expanded by 5 mm to create PRV cord. The body contour minus all tumor volumes and normal structures was taken as normal tissue.

Dose prescription and acceptance parameters

All plans were generated to deliver 60 Gy (2 Gy per fraction) to GTV and 48 Gy (1.6 Gy per fraction) to PTV in 30 fractions. The primary goal of treatment planning was to cover 95% volume of GTV and PTV with the prescribed dose of 60 Gy and 48 Gy respectively and to restrict not more than 10% volume of GTV to receive 107% of prescribed dose (64.2 Gy). The maximum dose to spinal cord and PRV cord was restricted to 45 Gy and 50 Gy respectively. The mean dose to total lung should be less than 20 Gy. The 30% of total lung should not receive more than 20 Gy ($V_{20} \leq 30\%$) and 60% should not receive more than 10 Gy ($V_{10} \leq 60\%$). The 33% of heart should not receive more than 45 Gy ($V_{45} \leq 33\%$) and 67% should not receive more than 30 Gy ($V_{30} \leq 67\%$). All planning parameters are summarized in Table 1.

Planning parameters used in TPS

All VMAT plans were planned with the following calculation properties: Grid spacing was selected as 3 mm, and Monte Carlo variance was 3%. Monte Carlo algorithm was selected as secondary algorithm for second stage dose calculation that is final dose calculation. The dose was calculated to the medium and not to the water. For all plans, heterogeneity correction was applied.

All plans were planned for 360° gantry rotation with single arc in clock wise direction from 180°-180°. The IGA was taken as 15°, 20°, 30° and 40° and the plans were named as $VMAT_{15}$, $VMAT_{20}$, $VMAT_{30}$ and $VMAT_{40}$ respectively. Remaining parameters kept similar. Segment shape optimization method was used. Minimum segment width was kept as 5 mm and the fluence smoothing level was at medium level.

In Monaco planning system, multiple arcs can be created. We can create multiple arcs with different beam parameters or dual arc for same beam parameters. In this study all plans were planned with single arc ($VMAT_S$) with clockwise direction and dual arc ($VMAT_D$) for the same beam with clockwise and counter clockwise directions.

Plan comparison

Evaluation parameters

The comparison of all VMAT plans was evaluated using the following terms:

- Homogeneity Index (HI): $(D_{2\%} - D_{98\%})/D_{50\%}$, a ratio evaluating the dose homogeneity in GTV where $D_{2\%}$, $D_{98\%}$ and $D_{50\%}$ are the minimum dose delivered to 2%, 98% and 50% volume of the GTV respectively.[9] HI of zero indicates the dose distribution is homogeneous.
- Conformity Index (CI): V_{pres}/TV_p, a ratio evaluating the coverage of the prescription dose in treatment plan, where V_{pres} was the volume of body receiving

Table 1: Treatment planning objectives

Structure	*Parameter*	*Constraints*
GTV	$D_{95\%}$	> prescribed dose
	$D_{10\%}$	<107% of prescribed dose
PTV	$D_{95\%}$	>prescribed dose
Total Lung	V_{20}	≤30% of total volume
	V_{10}	≤60% of total volume
	D_{mean}	≤20 Gy
Heart	V_{45}	≤33% of volume
	V_{30}	≤66% of volume
Spinal cord	D_{max}	<45Gy
PRV cord	D_{max}	<50Gy

GTV: Gross tumor volume, PTV: Planning target volume, PRV: Planning risk volume

the prescribed dose and TV_p was the volume of GTV receiving the prescription dose[10] CI of one indicates the good dose conformity.

- Target volumes: $D_{98\%}$, $D_{95\%}$, $D_{50\%}$ and D_{max} for GTV were analyzed, where $D_{98\%}$, $D_{95\%}$, $D_{50\%}$ is minimum dose delivered to 98%, 95% and 50% Volume of GTV respectively and D_{max} is the maximum dose.
- Normal structures: D_{max} for spinal cord and PRV cord were analyzed, where D_{max} is the maximum dose. Both lungs were analyzed for V_{20Gy}, V_{30Gy} and mean lung dose. The heart dose was analyzed for V_{30Gy} and V_{45Gy}.V_x represents the volume of organ irradiated above the x dose.
- Normal tissue dose: The volume of normal tissue receiving ≥2 Gy and ≥5Gy were analyzed.
- Number of monitor units: The number of monitor units required to deliver the plan was analyzed for all plans.

Statistical analyses

Statistical tests of significance were used for calculating the differences between VMAT plans. Wilcoxon matched—pair signed-rank test (two tailed, $P \leq 0.05$) was used.

Results

Increment of gantry angle

In this study, we examined 12 middle third esophageal cases using VMAT plans with different IGA such as 15°, 20°, 30° and 40°. All plans met our dosimetric criteria. We evaluated the plans using dose volume histogram (DVH). However we observed some differences between the plans. The dosimetric comparisons of these plans are summarized. Table 2 shows the average value and standard deviation for all the 12 cases. Isofill distribution of one of the patients was given in Figure 2. DVH comparison of VMAT plans with different IGA was shown in Figure 3.

There was no statistical significance differences were observed between $VMAT_{15}$, $VMAT_{20}$, $VMAT_{30}$ and $VMAT_{40}$ plans in dosimetric parameter of GTV such as $D_{98\%}$, $D_{95\%}$ and $D_{50\%}$.$VMAT_{15}$ had a higher D_{max} and V_{63} while comparing other plans. $VMAT_{30}$ had superior HI with good conformity. $VMAT_{15}$ plan was more heterogeneous plan than other plans. PTV coverage was good in all plans. Dosimetric parameters were similar in $VMAT_{30}$ and $VMAT_{40}$ and no statistical significant difference were observed.

Dose to total lung was analyzed. V_{20Gy} was in favour of $VMAT_{40}$ and remaining plans were similar. V_{10Gy} was high in $VMAT_{30}$ and mean lung dose was similar in all plans and did not show any statistical significant differences between them. Dose to spinal cord met the dosimetric criteria and no statistical significant difference was observed. Dose to PRV cord was in favor of $VMAT_{30}$.

Table 2: Statistical comparison of dosimetric parameters for (*N*=12) plans with different increment of gantry angle

Target and OARS	*Dose metrics*	*$VMAT_{15}$*	*$VMAT_{20}$*	*$VMAT_{30}$*	*$VMAT_{40}$*	*P value $VMAT_{30}$ vs*		
						$VMAT_{15}$	*$VMAT_{20}$*	*$VMAT_{40}$*
GTV	$D_{98\%}$ (Gy)	59.3±0.47	59.1±0.62	59.6±0.84	59.2±0.20	0.290	0.030	0.110
	$D_{95\%}$ (Gy)	60.0±0.40	59.9±0.43	60.0±0.40	59.8±0.15	0.960	0.340	0.120
	$D_{50\%}$ (Gy)	62.1±0.57	61.8±0.45	61.7±0.42	61.6±0.41	0.070	0.240	0.330
	D_{max} (Gy)	65.8±1.02	65.2±1.00	64.8±0.63	64.8±0.85	0.010	0.350	0.870
	V_{63Gy} (%)	20.3±15.9	10.3±11.9	7.30±8.40	7.90±7.80	0.010	0.480	0.390
	HI	0.0776±0.0112	0.07±0.0130	0.0599±0.0165	0.0659±0.0123	0.002	0.080	0.180
	CI	1.058±0.036	1.065±0.037	1.058±0.035	1.071±0.021	0.870	0.370	0.140
	Length (cm)	9.89±02.62						
	Volume (cc)	95.59±50.09						
PTV	$D_{98\%}$ (GY)	46.6±0.40	46.7±0.43	47.1±0.37	47.1±0.42	0.014	0.015	0.760
	$D_{95\%}$ (Gy)	47.7±0.38	47.9±0.44	48.2±0.41	48.1±0.31	0.018	0.030	0.530
	Length (cm)	15.94±2.28						
	Volume (cc)	583.98±17.7						
Total lung	V_{20Gy} (%)	27.2±8.40	27.3±7.10	28.4±6.20	26.9±6.30	0.180	0.210	0.005
	V_{10Gy} (%)	58.3±11.5	59.3±13.5	62.7±1.20	59.9±12.0	0.002	0.009	0.028
	D_{Mean} (Gy)	14.6±3.40	14.7±3.50	15.0±3.00	15.0±3.30	0.034	0.072	0.610
Heart	V_{45Gy} (%)	22.3±13.3	20.5±13.2	19.2±12.0	21.0±13.3	0.440	0.610	0.070
	V_{30Gy} (%)	43.7±17.0	42.4±18.2	44.1±18.6	43.5±17.6	0.480	0.240	0.350
Spinal cord	D_{max} (Gy)	42.5±2.20	41.1±2.50	40.9±3.70	42.2±1.40	0.040	0.940	1.000
PRV cord	D_{max} (Gy)	46.6±2.80	46.0±3.90	45.2±3.60	47.3±2.40			
Normal tissue	≥2Gy (cc)	4625±1007	4614±1024	4689±1069	4682±1082	0.080	0.048	0.810
	≥5Gy (cc)	3416±792	3337±737	3625±853	3626±851	0.002	0.002	0.810
MUs		710±253	653±185	541±122	542±128	0.003	0.005	0.970

GTV: Gross tumor volume, PTV: Planning target volume, PRV: Planning risk volume, MU: Monitor unit, VMAT: Volumetric modulated arc therapy

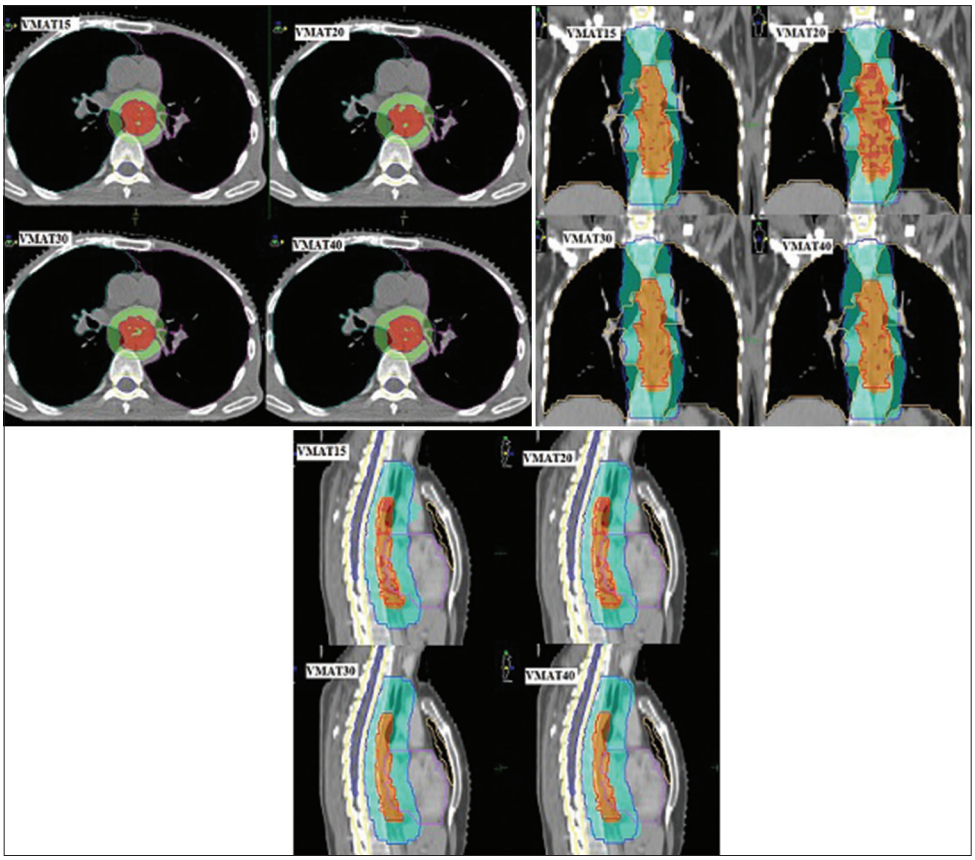

Figure 2: Isofill comparison of VMAT plans with increment of gantry angle in axial, coronal and sagital view

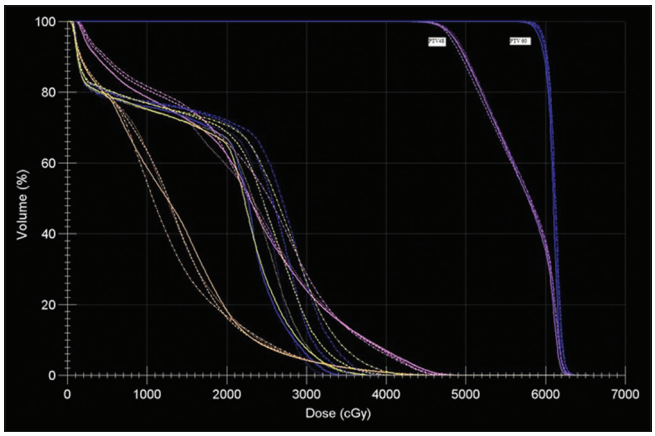

Figure 3: DVH comparison of VMAT plans with different increment of gantry angle

We analyzed the volume of normal tissue receiving doses ≥2 Gy and ≥5 Gy between plans. The volume of normal tissue receiving ≥2 Gy was almost same in all plans, however the volume receiving ≥5 Gy was high in higher IGA that is VMAT30 and VMAT 40.

The number of MUs required to deliver the plan was reduced by 20%-30% in $VMAT_{30}$ and $VMAT_{40}$ plans than $VMAT_{15}$and $VMAT_{20.}$

Number of Arcs

In this study, we also analyzed all 12 cases using single vs. double arc VMAT plans. Dose to GTV showed no statistical significant difference in dosimetric parameters like $D_{98\%}$, $D_{95\%}$, $D_{50\%}$, V_{63}, HI and CI. Dose to PTV was similar in all dosimetry aspects. Dose to total lung, heart, spinal cord and PRV cord were similar and no statistical significant difference were observed. While looking into normal tissue dose single arc plan was superior to double arc plan. The results are summarized in Table 3. Isofill comparison of VMAT plan with single arc and double arc was shown in Figure 4 and DVH comparison was shown in Figure 5.

The number of MUs required to deliver the plan in single arc was only 7% greater than that of double arc plan. We did not observe any statistical significant difference in MUs.

Discussion

In this study, we selected 12 middle third esophageal cases which were already treated by VMAT or IMRT plans. The plans were done with different IGA keeping other parameters were same. The dose distribution and dosimetric parameters were acceptable according to our goal. General concept is, the smaller IGA gives better plan than larger IGA. In our study, we had observed that both smaller and

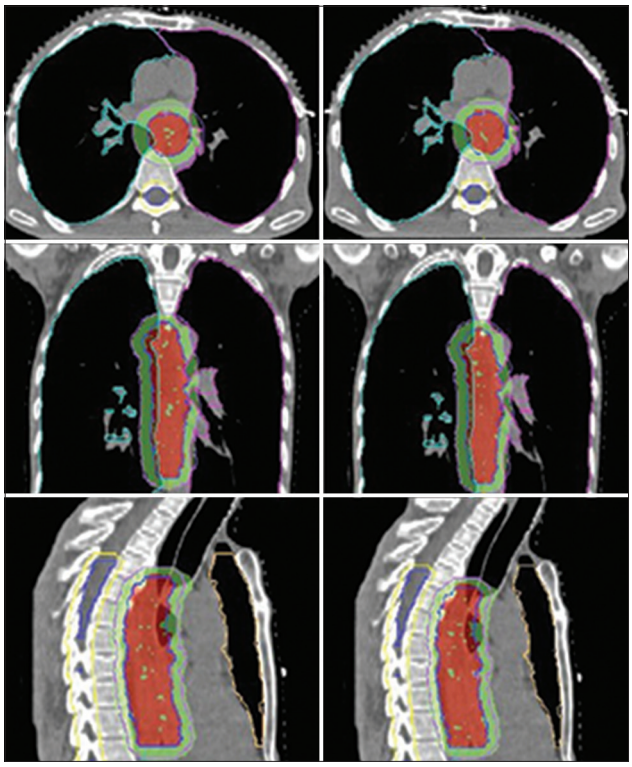

Figure 4: Isofill comparison of plans with single arc and double arc in axial, coronal and sagital view

Table 3: Statistical comparison of dosimetric parameters for (*N*=12) plans with single and double arc

Target and OARS	*Dose metrics*	*$VMAT_S$*	*$VMAT_D$*	*$VMAT_S$ vs $VMAT_D$ P value*
GTV	$D_{98\%}$ (Gy)	59.1±0.61	59.1±0.26	0.97
	$D_{95\%}$ (Gy)	59.9±0.43	59.8±0.17	1.00
	$D_{50\%}$ (Gy)	61.8±0.45	61.8±0.51	0.27
	D_{max} (Gy)	65.2±1.00	65.1±1.16	0.002
	V_{63Gy} (%)	10.3±11.9	10.1±11.1	0.27
	HI	0.07±0.013	0.071±0.016	0.76
	CI	1.065±0.037	1.068±0.011	0.87
PTV	$D_{98\%}$ (GY)	46.7±0.43	47.1±0.58	0.06
	$D_{95\%}$ (Gy)	47.9±0.44	48.1±0.58	0.31
Total lung	V_{20Gy} (%)	27.2±7.1	27.2±6.4	0.93
	V_{10Gy} (%)	59.3±13.5	60.6±12.4	0.41
	D_{Mean} (Gy)	14.7±3.5	14.9±3.5	0.44
Heart	V_{45Gy} (%)	20.4±13.2	19.9±12.6	0.64
	V_{30Gy} (%)	42.4±18.1	45.4±19.0	0.03
Spinal cord	D_{max} (Gy)	41.1±2.5	42.1±1.8	0.14
PRV cord	D_{max} (Gy)	46.0±3.8	46.6±2.8	0.37
Normal tissue	≥2 Gy (cc)	4614±1024	4779±1065	0.002
	≥5 Gy (cc)	3337±737	3379±1251	0.034
MUs		653±185	606±185	0.16

GTV: Gross tumor volume, PTV: Planning target volume, PRV: Planning risk volume, MU: Monitor unit, VMAT: Volumetric modulated arc therapy

larger IGA were giving good coverage and acceptable plans. D_{max} and V_{63} were high in $VMAT_{15}$ due to finer modulation

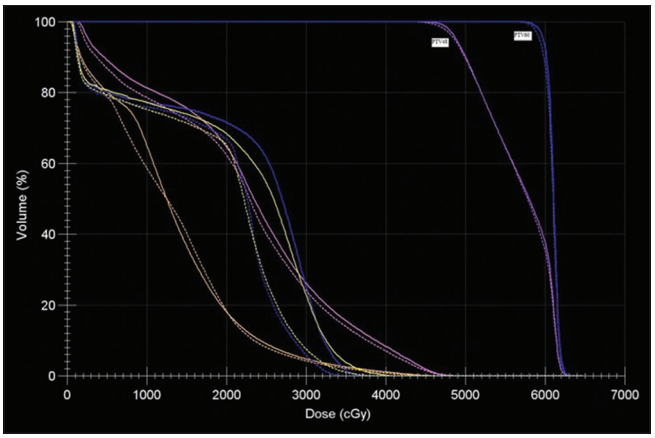

Figure 5: DVH comparison of VMAT plans with single and double arc

compared to other plans. $VMAT_{30}$ gave very homogeneous plan but increased the dose to lung. Also we observed that finer modulation increased the number of MUs by 20-30%.

Abbas *et al*., had done the comparative study on single vs. double arc with Pinnacle planning system. They reported that there was no difference found in dosimetric parameters. They got more MUs for double arc plan (332 MU) than single arc plan (309 MU). In our study, we could not find any differences in dosimetric parameters. However, We differ in MU point of view, that is we got lesser MUs for double arc (606) than single arc (653).

Conclusion

Monaco treatment planning system was capable of generating efficient VMAT plans. The quality of VMAT plan for all four increment of gantry angle was comparable. With good dose coverage, homogeneity index and increased MU efficiency we can use larger increment of gantry angle for middle third esophageal cases but finding may change the studies on other sites and would require more research on this concept.

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