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IMPLEMENTATION OF VOLUMETRIC INTENSITY MODULATED ARC THERAPY IN OROPHARINGEAL CANCER. A COMPARISON WITH CLASSICAL TECHNIQUES OF 3D CONFORMAL RADIOTHERAPY

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Abstract. This study was performed in order to compare dosimetric parameters of volumetric modulated arc therapy (VMAT) with those of three dimensional conformal radiation therapy (3D-CRT) for oropharingeal cancer patients. We included in this study 15 patients with advanced tumours of oropharinx who had been treated in Amethyst Radiotherapy Clinic. Treatment plans were performed on a Pinnacle 3 system, version 9.4 (Philips Medical Systems, Markham, Ontario) using beam data, 6 MeV, generated by Elekta Synergy linear accelerator. The doses for planning target volume (PTV) and organs at risk (OAR) calculated both by VMAT and 3D-CRT plans were compared. The evaluation of dosimetric parameters showed a significant difference between the two techniques, especially for OAR where the received doses are higher in the case of 3D-CRT in comparison with the VMAT. Also, VMAT increases the conformity index and the minimum dose to target volumes as compared with 3D-CRT in patients with oropharinx cancer. The study confirms that VMAT is superior to 3D-CRT in the treatment of oropharyngeal cancer.

Key words: VMAT, 3D-CRT, planning dosimetry, head-and-neck cancer.

1. INTRODUCTION

Radiotherapy for advanced head-and-neck cancer has evolved from 3D-CRT to intensity modulated radiation therapy (IMRT) and VMAT.

Volumetric modulated arc therapy (VMAT) is a dynamic rotation delivery technique where multileaf collimator (MLC) shapes, leaf motion, gantry speed, and beam dose rate are continuously changing [1, 2]. VMAT has significant benefits compared to 3D-CRT in terms of increased tumour control and reduced toxicity to normal tissue. This happens because VMAT delivers dose to the target from multiple angles by using one or more arcs, instead of beams of predefined angles

with fixed MLC as is the case of 3D-CRT. Because VMAT has more degrees of freedom, the optimizer is able to reach an optimal solution for each case. The quality of VMAT treatments is highly reliant on the correct implementation of all the appropriate VMAT procedures and of the used optimization algorithm [3, 4]. Also, the treatment quality may vary depending on the employed treatment planning system (TPS). We used the Pinnacle 3 system (Philips Medical Systems, Markham, Ontario), version 9.4, to create both types of treatment plans (VMAT and 3D-CRT) for the same volumetric data set, based on the objectives and constraints defined in the Radiation Therapy Oncology Group (no. 0615) protocol.

SmartArc is the VMAT algorithm used in Pinnacle, version 9.4 TPS. A description of the SmartArc optimization algorithm was published by Bzdusek *et al.* [1] and the initial dosimetric evaluation was performed by Feygelman *et al.* [3].

The anatomy of the head and neck region is complex, due to soft tissue, bone structures and air cavities organized within a relatively small volume with a complicated geometry. Treatment planning for head and neck cancer patients is very complex because there are many irregularly shaped target volumes, located in the vicinity of critical organs (*e.g.*, spinal cord, parotid glands, etc.). In accordance with Reports 50 and 62 of the International Commission on Radiation Units and Measurements, margins are added to target volumes during the treatment planning process to account for set-up error and uncertainty.

VMAT is now available in many cancer centres worldwide and is used for all types of cancer sites.

The objective of this study is to comparatively evaluate VMAT and 3D-CRT with regard to dosimetric coverage of PTV and overall quality of treatment plans, including the protection of the relevant OAR.

2. MATERIALS AND METHODS

Patient Selection. Fifteen patients with advanced head and neck cancer were treated by VMAT technique at Amethyst Radiotherapy Clinic (Bucharest, Romania). For all these cases, we planned both techniques VMAT and 3D-CRT.

Treatment planning technique. Fifteen patient simulations were performed on computer tomography scan (Big Bore Brilliance 120, Philips) in supine position with slices of 2 mm thickness. After image acquisition, the delineation of clinical target volumes (CTV) and OAR was performed by physicians. For all cases, two target volumes were delineated one of them including the lymph nodes and the other the primary tumour (for which the applied dose was 70 Gy). OAR delineated to be taken into account for this study were: spinal cord, parotid glands, esophagus, oral cavity, and posterior neck region [6, 7].

For each CTV, the physicist created two planning target volumes: PTV 50 which includes lymph nodes (for which the applied dose is 50 Gy) and PTV 70

which includes only primary tumour (for which the applied dose was 70 Gy), adding 5 mm in all directions for set-up errors. For the irradiation optimization, the PTV was reduced to 5 mm under the skin surface to prevent the problems in the build-up region [8, 9].

All cases were treated in a sequential mode, in a total number of 35 fractions. PTV 50 was irradiated during the first 25 sessions, while PTV 70 was irradiated only in the last 10 sessions.

For OAR, the most important objective was to keep the maximum dose to the spinal cord, below 40 Gy. The second objective for OAR was to reduce the average dose to the parotid glands, below 26 Gy. Also, the reduction of high dose volume to oral cavity, mandible and esophagus represented also an important objective. Due to the tumour advanced stage, for all patients, salivary glands were systematically included in the PTV, so that no effort was made to spare them, too.

3D-CRT treatment planning. This technique includes six isocentric photon fields [10]:

– two anterior opposed fields with wedges, that cover whole PTV 50;

– two posterior-oblique fields that cover a partial part of PTV 50, shielding spinal cord;

– two posterior fields, with shield the spinal cord.

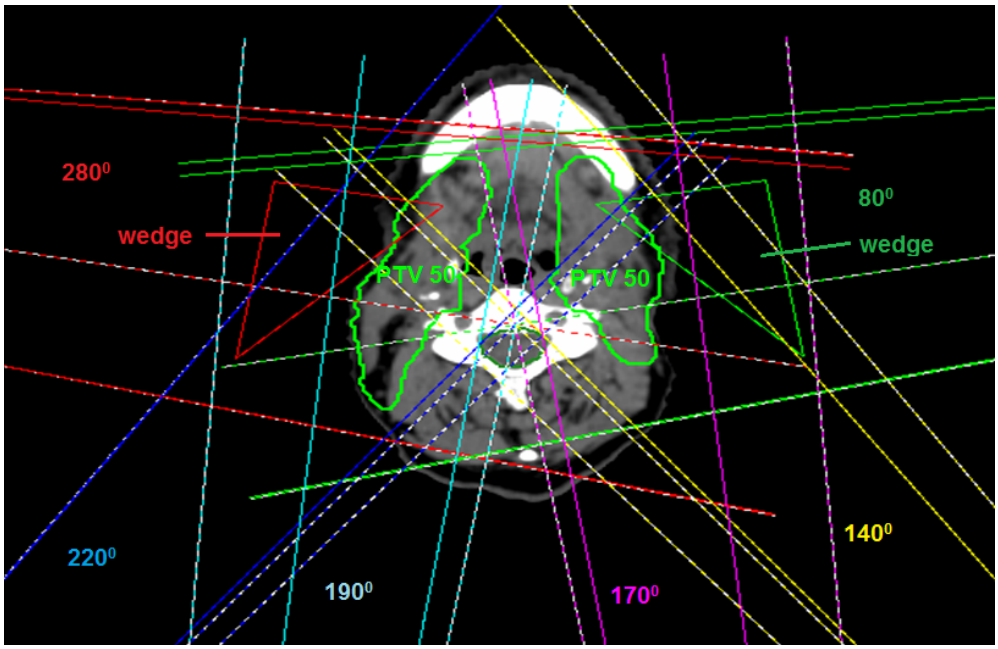

Fig. 1 – Geometry of irradiation of PTV 50 in the case of 3D-CRT method. The six radiation beams directions (in six colours, at 80°, 140°, 170°, 190°, 220°, and 280°) and two wedges used for lateral fields are illustrated. One can see that all beams are concurrent at the level of PTV 50.

The fields were generated using MLC in beam's-eye view window. Depending on patient anatomy and target volume, wedges for anterior and posterior fields were used. The dose was prescribed based on mean target volume.

For PTV 70, two opposed lateral fields or four oblique fields with wedges were applied, depending on the position and the size of tumours.

VMAT *treatment planning*. For VMAT optimization, additional volumes were generated to obtain a high dose gradient around PTV.

The VMAT plans consist of two full arcs (clockwise and counterclockwise) from 178^{o} to 182^{o}. Gantry spacing between two control points was 4^{o} and the maximum delivery time was 120 seconds per arc [11].

Table 1

Dose volume objectives used for VMAT optimization of the first part of treatment (25 fractions). EUD = equivalent uniform dose. *a* = dimensionless parameter of EUD whose value is chosen so that it decreases the dose at the critical organs (its value more than unity is assuring the dose decrease)

Anatomical structure	Type	Target cGy	Weight	*a*
PTV 50	Uniform dose	5,000	25	
PTV 50 ring	Max. dose	4,750	8	
Spinal cord	Max. dose	4,000	10	
Left parotid	Max. EUD	2,600	1	1.5
Right parotid	Max. EUD	2,600	1	1.5
Oral cavity	Max. EUD	2,400	1	1.0
Posterior neck	Max. EUD	2,400	1	1.0
Rest tissue	Max. dose	2,500	5	
Restriction area	Max. dose	3,800	10	

Standard dose-volume constraints have been selected on the basis of institutional guidelines that are very similar to the RTOG (Radiation Therapy Oncology Group) protocol for head and neck cancer. Priorities were given to achieve an acceptable PTV coverage while reducing the dose to OAR.

Table 2

Dose volume objectives used for VMAT optimization of the second part of treatment (10 fractions). EUD = equivalent uniform dose. *a* = dimensionless parameter of EUD whose value is chosen so that it decreases the dose at the critical organs (its value more than unity is assuring the dose decrease)

Anatomical structure	Type	Target cGy	Weight	*a*
PTV 70	Uniform dose	2,000	30	
PTV 70 ring	Max. dose	1,900	8	
Spinal cord	Max. dose	1,600	10	
Left parotid	Max. EUD	800	1	1.5
Right parotid	Max. EUD	800	1	1.5
Oral cavity	Max. EUD	1,200	1	1.0
Posterior neck	Max. EUD	1,200	1	1.0
Rest tissue 70	Max. dose	1,000	5	
PTV 70	Max. dose	2,150	10	

Plan Evaluation. The plans were evaluated with the aid of dose volume histograms (DVH) and the dose distribution by the parameters is presented below [12, 13].

The target coverage (TC) defined as the percentage ratio of volume of the target receiving the prescription dose ($V_{T,pi}$) to the target volume (V_T):

$$\mathrm{TC} = \frac{V_{T,pi}}{V_T} \times 100 \ \ \%. \tag{1}$$

If TC is above 95 %, the acceptance criterion is fulfilled.

Conformity index (CI) was used to compare the two treatment plans.

This represents the ratio of the volume of target receiving the prescription dose ($V_{T,pi}$) to the volume enclosed by the prescription isodose (V_{pi}):

$$\mathrm{CI} = \frac{V_{T,pi}}{V_{pi}}. \tag{2}$$

If CI is 1, in case of $V_{T,pi}$ equal to V_{pi}, the target volume is perfectly conformal by the prescription dose. For CI < 1, the target volume is not completely covered [5].

The homogeneity index (HI) describes the homogeneity of isodose distribution in PTV. HI is the ratio of the dose of 5 % PTV volume minus the dose of 95 % PTV volume to the mean dose of PTV:

$$\mathrm{HI} = \frac{D_{5\%} - D_{95\%}}{D_{mean}}. \tag{3}$$

A zero value means that HI is ideal [1].

The goal of the treatment is that 95 % of PTV should receive at least 95% of the prescribed dose.

Results. Figure 2 shows the isodose distributions for both techniques, for one of the 15 patients with oropharingeal cancer, at the same level of CT (computed tomography) slice (slice number zero). PTV 50 is delineated by green colour, where red isodose line represents 95 % of prescribe dose.

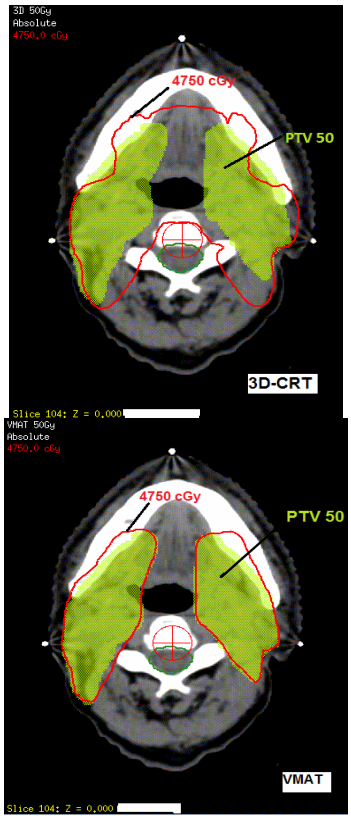

Fig. 2 – Dose distribution for 3D-CRT (left) and VMAT (right) for PTV 50 (in green) at the body transversal section at the level of the pharynx. The red contour delineates the volume receiving 95 % of the prescribed dose (5,000 cGy). The dark green contour delineates the spinal cord surrounded by the vertebrae.

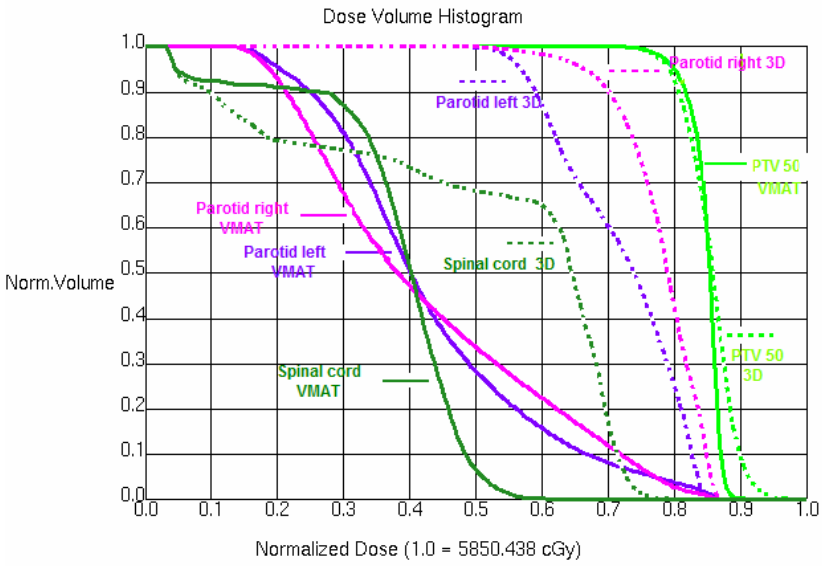

Fig. 3 – Dose Volume Histogram for 3D-CRT (3D on the figure) and VMAT in the case of PTV 50 and OAR. One can see that the curves (marked with dashed lines for 3D-CRT and continuous lines for VMAT) represent the percentage volumes which get a dose value.

Line Type	ROI	Trial	Min.	Max.	Mean	Std. Dev.	% Outside Grid	% > Max
◆	PTV 50	3D 50Gy	2620.0	5673.4	4998.7	228.2	0.00 %	84.54 %
◇	PTV 50	VMAT 50Gy	2873.7	5368.3	5034.2	142.2	0.00 %	94.94 %
◇	Parotis_L	3D 50Gy	2574.1	5061.4	4158.8	586.6	0.00 %	18.06 %
◇	Parotis_L	VMAT 50Gy	470.0	5073.7	2281.8	1121.2	0.00 %	3.20 %
◇	Parotis_R	3D 50Gy	2255.9	5039.2	3944.8	681.0	0.00 %	18.68 %
◇	Parotis_R	VMAT 50Gy	852.5	5093.0	2334.1	1039.8	0.00 %	1.54 %
◇	SpinalCord	3D 50Gy	186.8	4578.9	2960.8	1342.2	0.00 %	0.00 %
◇	SpinalCord	VMAT 50Gy	157.1	3727.9	2177.2	819.7	0.00 %	0.00 %

Fig. 4 – Cumulative Dose Volume Histograms for PTV 50, spinal cord and parotids considering 47.5 Gy the reference value (this value represents 95 % of prescribed dose whose value is 50 Gy). One can see that PTV 50 gets almost 95 % of prescribed dose in case of VMAT technique comparing with 3D-CRT where the percentage of dose is only 85 % of prescribed dose. Also, the doses at parotids and spinal cord exceed the maximum permissible limits in 3D-CRT technique as compared to the VMAT technique.

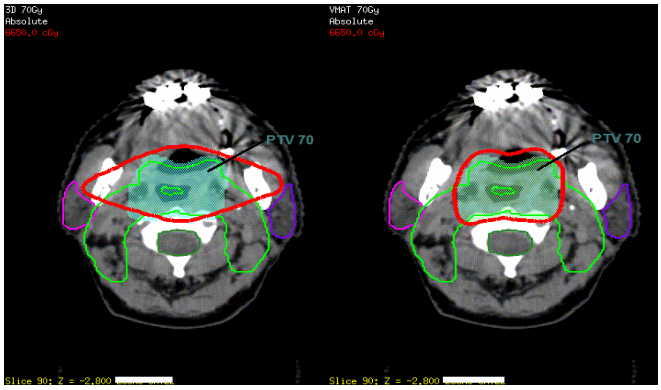

Fig. 5 – Dose distribution for 3D-CRT (left) and VMAT (right) for PTV 70 at the level of tumour. It can be seen the PTV 70 (tumour) represented by purple colour and red isodose line which represents 95 % of prescribed dose (7,000 cGy).

Line Type	ROI	Trial	Min.	Max.	Mean	Std. Dev.	% Outside Grid	% > Max
	PTV 70	3D 70Gy	5021.3	7432.5	7001.5	232.3	0.00 %	91.20 %	7006.34
	PTV 70	VMAT 70Gy	6111.5	7140.2	6972.6	96.8	0.00 %	98.25 %	6981.86
	Parotis_L	3D 70Gy	2314.4	6610.5	4320.8	574.3	0.00 %	0.00 %	4334.8
	Parotis_L	VMAT 70Gy	781.1	4334.8	2590.0	555.7	0.00 %	0.00 %	2597.31
	Parotis_R	3D 70Gy	2482.1	6749.2	4335.1	940.0	0.00 %	0.05 %	4346.56
	Parotis_R	VMAT 70Gy	1545.3	4639.0	2591.1	412.9	0.00 %	0.00 %	2597.24
	SpinalCord	3D 70Gy	4.1	3988.6	433.9	733.4	0.00 %	0.00 %	428.088
	SpinalCord	VMAT 70Gy	9.6	3518.1	507.9	721.7	0.00 %	0.00 %	503.274

Fig. 6 – Cumulative Dose Volume Histograms for PTV 70, spinal cord and parotids, considering the reference value of 66.5 Gy (this value represents 95 % of prescribed dose whose value is 70 Gy). One can see that PTV 70 gets above 90 % of prescribed dose for both techniques, but OAR (spinal cord and parotids) get more dose in 3D-CRT technique as compared to VMAT.

Table 3

Dosimetric results (mean values) for TC, CI and HI in 3D-CRT and VMAT plans for PTV 50 and PTV 70, for all 15 analyzed cases

Parameters	PTV 50 3D	PTV 50 VMAT	PTV 70 3D	PTV 70 VMAT
TC	88.20 ± 4.24	94.23 ± 2.18	92.10 ± 3.82	97.50 ± 1.7
CI	0.81 ± 0.02	0.92 ± 0.03	0.86 ± 0.02	0.95 ± 0.01
HI	0.16 ± 0.09	0.04 ± 0.02	0.07 ± 0.03	0.02 ± 0.01

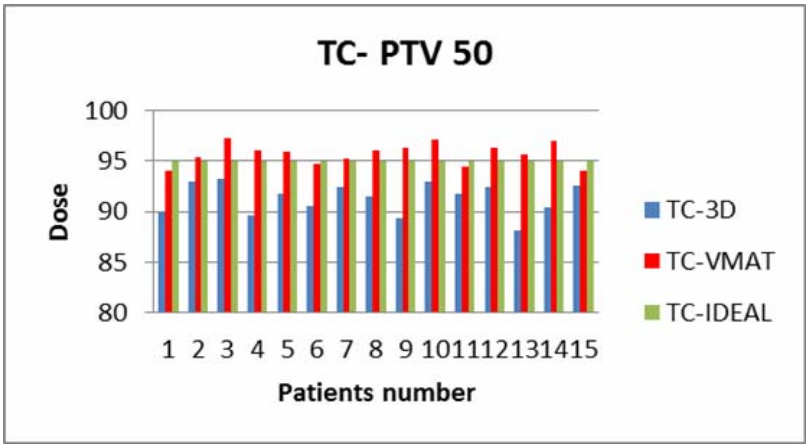

Fig. 7 – The histogram for coverage of PTV 50 for all patients: the comparison of the two techniques, 3D-CRT and VMAT, to the ideal one.

As can be inferred from Figs. 1–6 and Table 3, VMAT technique shows significantly better results as compared with 3D-CRT, for all analyzed parameters.

As it can be observed, the target coverage (*TC*), in the case of VMAT technique, is about 5 % better than those of the 3D-CRT for both target volumes. VMAT planning has the highest level of conformity compared to the 3D-CRT plans (Table 3). Prescribed dose volume covers much better the target volumes for VMAT than 3D CRT technique (about 12 % better for VMAT than 3D-CRT, for PTV 50 and about 9 % better for VMAT than 3D-CRT, for PTV 70).

As concerns the dose homogeneity, the results are significantly better for VMAT, especially for PTV 50 where the dose is more homogeneous for VMAT than for 3D-CRT.

Table 4

Dosimetric results for OAR and healthy tissue

Organs at risk	3D-CRT(Gy)	VMAT (Gy)
Spinal cord	43.0 ± 4.0 max. dose	38.3 ± 2.4 max. dose
Left parotid	39.1 ± 2.5 mean dose	25.1 ± 1.1 mean dose
Right parotid	38.5 ± 2.0 mean dose	24.7 ± 1.4 mean dose
Oral cavity	26.5 ± 3.1 mean dose	27.3 ± 2.1 mean dose
Posterior neck	20.5 ± 2.4 mean dose	22.4 ± 1.8 mean dose
Healthy tissue	11.3 ± 1.8 mean dose	6.5 ± 1.1 mean dose

It can be seen that all values are significantly higher for 3D-CRT than VMAT technique, excepting oral cavity and the posterior neck.

Table 5

Number of MUs (monitor units) delivered for both techniques

Volumes	3D-CRT	VMAT
PTV 50	397.5 ± 18.5	576.2 ± 62.0
PTV 70	225.4 ± 11.3	562.1 ± 28.2

From Table 5, it can be seen that the treatment time is always greater in VMAT technique than in 3D-CRT. The time of treatments depends very much, on the number of beams used for 3D-CRT and on the number of arcs for VMAT.

3. DISCUSSION

High doses of target volumes (*e.g.*, 70 Gy) provide a better local control of tumour and a prolonged survival of the patients. Although this goal can be achieved also by applying 3D-CRT technique, the induced side effects (*e.g.*, radiation-induced myelopathy, compromised salivary glands, etc.) are more severe for the patients in this case. So, in the last time, the application of VMAT technique has become a very common practice for most cancer cases. Applying a dose of 70 Gy by 3D-CRT technique is not at all recommended due to the increased risk of side effects, especially in the spinal cord where the dose can exceed the threshold of 44 Gy, when myelitis could occur.

As can be seen in Table 3, the dose delivered to both target volumes (PTV 50 and PTV 70) is more uniform and more compliant for VMAT than for the 3D-CRT technique. Also, looking at the values in Table 4, the dose received by critical organs is much higher in the case of 3D-CRT technique than VMAT excepting oral cavity and the posterior neck. It can be seen, that for a given dose of 50 Gy to PTV 50, the dose received by the spinal cord can reach values up to a maximum of 47 Gy, values which we consider that presents a high risk if we think at the patient positioning during each treatment session. It is also apparent that the parotid glands are not well protected in 3D-CRT technique compared with VMAT, where the average dose received by each gland is below 26 Gy thus ensuring a better quality of patient life.

Analyzing all 15 cases included in this study, to which the two treatment techniques were applied, it clearly results that VMAT technique is superior to 3D-CRT technology, both in terms of target administered dose and of dose received by critical organs.

It is true that getting a treatment plan with satisfactory results highly depends on the complexity of the case but also of the experience of medical staff. There are cases where target volumes have a complex shape or critical cases in which OARs are situated very close to the volume which has to be irradiated. But regardless of

these obstacles, VMAT technique proves to be superior to 3D-CRT method of treatment.

4. CONCLUSION

Irradiation VMAT technique increases the conformity index and the minimum dose to target volumes as compared with 3D-CRT in patients with oropharyngeal cancer.

VMAT also led to a decrease in maximum dose to the spinal cord and soft tissue and enables protection of a part of the parotid glands.

Given the benefits of VMAT as compared to the classical 3D-CRT, this method of treatment is currently and successfully applied in Amethyst Radiotherapy Clinic, for all cases of oropharyngeal cancer.

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