Technical Note

Comparative analysis of volumetric-modulated arc therapy and intensity-modulated radiotherapy for base of tongue cancer

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ABSTRACT

The aim of this study was to compare the various dosimetric parameters of dynamic multileaf collimator (MLC) intensity modulated radiation therapy (IMRT) plans with volumetric modulated arc therapy (VMAT) plans for base of tongue cases. All plans were done in Monaco planning system for Elekta synergy linear accelerator with 80 MLC. IMRT plans were planned with nine stationary beams, and VMAT plans were done for 360° arc with single arc or dual arc. The dose to the planning target volumes (PTV) for 70, 63, and 56 Gy was compared. The dose to 95, 98, and 50% volume of PTV were analyzed. The homogeneity index (HI) and the conformity index (CI) of the PTV_{70} were also analyzed. IMRT and VMAT plan showed similar dose coverage, HI, and CI. Maximum dose and dose to 1-cc volume of spinal cord, planning risk volume (PRV) cord, and brain stem were compared. IMRT plan and VMAT plan showed similar results except for the 1 cc of PRV cord that received slightly higher dose in VMAT plan. Mean dose and dose to 50% volume of right and left parotid glands were analyzed. VMAT plan gave better sparing of parotid glands than IMRT. In normal tissue dose analyses VMAT was better than IMRT. The number of monitor units (MU) required for delivering the good quality of the plan and the time required to deliver the plan for IMRT and VMAT were compared. The number of MUs for VMAT was higher than that of IMRT plans. However, the delivery time was reduced by a factor of two for VMAT compared with IMRT. VMAT plans yielded good quality of the plan compared with IMRT, resulting in reduced treatment time and improved efficiency for base of tongue cases.

Key words: Base of tongue, intensity-modulated radiation therapy, volumetric modulated arc therapy

Introduction

Intensity-modulated radiation therapy (IMRT) has replaced the conventional three-dimensional-conformal radiotherapy (3D-CRT) techniques for head and neck cancers. Already it has been proved by many researchers that IMRT gives better dose coverage to the target and sparing of organ at risk (OAR)[1] than 3D-CRT. IMRT gives less radiation-related toxicity than 3D-CRT for head and neck cancers.[2] Using IMRT we are able to achieve good uniformity of dose to concave-shaped head and neck tumor and dose conformal to target volumes. Treatment planning of head neck cases are challenging due to the large number of OARs and the proximity of OARs with tumors. The planner faces the difficulty in sparing the OARs with good coverage and uniformity of the dose to the tumor volumes.

Volumetric-modulated arc therapy (VMAT) is the next generation and enhanced version of IMRT technique. Most of the centers are adapting VMAT technique due to its fastest and efficient delivery than IMRT.[3] Quick delivery reduces the inconvenience to the patients and also increases the throughput of the linear accelerator. Many reports have explained the dosimetric superiority and similarity of VMAT with IMRT in head and neck cases.[3,4] Most of the cases compared multiple head and neck sites like oropharynx, hypopharynx, nasopharynx, and larynx.[5] In this study, we would like to evaluate the IMRT and VMAT plans for base of tongue case.

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Materials and Methods

Patient selection

A total of 13 base of tongue cases were selected for this study. The median age was 61 with 12 males and one female. The clinical stage distribution was T2 in four patients, T3 in six patients, and T4 in four patients with node stage N1-N3.

Eight of the patients received the treatment with IMRT plan and five of them received treatment with VMAT plan. VMAT and IMRT plans were created with same isocenter retrospectively. Both IMRT and VMAT plans were done in the same computed tomography (CT) and structure set.

Linac and record and verify system

All IMRT and VMAT plans were created using the same 6-MV photon beams for Elekta Synergy linear accelerator (Elekta Ltd, Crawley, UK), which was equipped with 80 multileaf collimator (MLC) with 1-cm resolution. Maximum leaf speed was 2.0 cm/s, minimum leaf gap between opposite banks was 0.5 cm, the total leaf travel distance was 32.5 cm, and the leaves did not interdigitate. In the upper jaws and backup jaws covering full 40×40 cm^2, the maximum gantry speed was 6°/s and the variable dose rate upto 500 MU (monitor units)/min. The combination of the dose rate, gantry speed, and leaf speed was automatically selected optimally by the linear accelerator control system Precise Desktop 7.01 during VMAT delivery.

MOSAIQ Version 1.60X6 (IMPAC Medical Systems, Inc, Sunnyvale, CA, USA) was used as record and verify system. CT images from CT machine was transferred to treatment planning system (TPS) via Digital imaging and Communications in Medicine (DICOM), and treatment plan from TPS was transferred to MOSAIQ via DICOM-Radiotherapy (DICOM-RT).

Imaging

The patients were immobilized with thermoplastic sheet. The CT images were acquired for all patients in Biograph positron emission tomography-CT (PET-CT) (Siemens AG, Medical solutions, Germany) with 3-mm slice thickness, field of view 50 cm. The images were imported in Monaco planning system.

Monaco planning system

Monaco planning system (Elekta Ltd, Crawly, UK) version 3.20.02 utilizes not only physical effects of radiation but also 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, underdose DVH, maximum dose, and quadratic underdose.

The user has an option to set the cell sensitivity of Poisson's cell kill model. OAR can be set as serial or parallel constraints depending on the properties of the tissue. The user is able to influence the amount of volume of a structure, which can be sacrificed and also affect the strengths of the limits of the constraints.

The system uses a two step optimization process. In the first phase of optimization, the system creates user-specified segments, which also operate as control points at the treatment units during treatment. Then the calculation algorithm of the first phase optimizes the fluence distributions for the segments. At this phase, fluence distribution is calculated by pencil beam algorithm (PB), which considers dose to be produced by the sum of narrow cylindrically symmetry beams. The dose at any point is calculated by summing the calculated dose distribution of all pencil beams to the examination point. Because the algorithm is kernel-based two-dimensional method, so the accuracy is limited especially in the presence of heterogeneities.

In the second calculation phase, the system takes into account the deliverability of the accelerator. The optimal field shapes are then generated in order to produce as smooth composite dose delivery as possible. As a result, plan quality might be affected in comparison with the fluence distribution calculated in the first phase. The second phase calculation can be done by PB or voxel-based Monte Carlo method. The Monte Carlo method enables more accurate dose distribution calculation than the analytical algorithms.[6] The Monte Carlo method calculates the number of electrons created in each voxel by primary photon beam and particles created in interactions. The final calculated dose distribution is formed by most presumable distribution of the absorbed dose. The user can change the calculation accuracy and time by modifying some parameters like Monte Carlo grid spacing and variance.

Contouring

The contouring of tumor volumes and normal structures was done by the oncologists.

Target volumes

The clinical target volume (CTV 70) encompasses the gross tumor volume (GTV) and 5-mm margin. The planning target volume (PTV$_{70}$) for CTV 70 was created with 3-mm margin for CTV 70 to account for the set up uncertainties. The secondary target was the CTV of lymph node groups with high risk or surgical neck levels at risk of subclinical disease named as CTV 63. PTV$_{63}$ was created with 3-mm margin to CTV 63. The lymph node with low risk was contoured as CTV 56. The 3-mm margin that was given to CTV 56 to create PTV$_{56}$. PTV$_{63}$ and PTV$_{56}$ were cropped 2 mm inside the body contour automatically by the system. No manual correction was done for the PTVs.

Critical structures

The normal structures included the spinal cord, parotid glands, and brain stem. The spinal cord was expanded by 5 mm to create planning risk volume (PRV), which was called PRV cord. Both the parotid glands were contoured and parotid minus PTV was created using 3-mm outer margin to PTV. Parotid minus PTV was utilized for optimization, and evaluation was done for the whole parotid.

Normal tissues

The body contour minus all tumor volumes and critical structures was taken as normal tissue.

Treatment planning and evaluation criteria

Both VMAT and IMRT plans were generated for a treatment in 35 fractions, to deliver total dose of 70 Gy PTV_{70}, 63 Gy to PTV_{63}, and 56 Gy to PTV_{56}. The goal of treatment planning was to cover at least 95% of the volume of PTV_{70}, PTV_{63}, and PTV_{56} with 98% of the prescribed dose (68.6, 61.74, and 54.88 Gy, respectively) and to restrict the volume of PTV_{70} receiving more than 110% of the prescribed dose (77 Gy) should be below 10% volume of PTV_{70}. The maximum allowed point dose to spinal cord was 45Gy; PRV cord was 50 Gy and for brain stem was 54 Gy. Also, the mean dose to both parotid glands should be below 26 Gy. All parameters are summarized in Table 1.

Planning criteria in TPS

All IMRT and VMAT plans were planned with 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, i.e., final dose calculation. The global parameter: Beamlet width was selected as 2 mm, target margin and avoidance margin was 3-4 mm. Auto flash margin was 2 mm, surface margin was 3 mm. Minimum electron density for filled option was selected as 1.000 HU and minimum CT number for clear option as 200 HU. The dose was calculated to the medium not to the water. For all plans, inhomogeneity correction was applied.

IMRT treatment planning

All IMRT plans were created using nine fields with 6-MV photon beam. The gantry angle started from 200° to 160°

Table 1: Treatment planning objectives

Structure	Parameter	Constraints
PTV_{70}	$D_{95\%}$	>98% of prescribed dose
	$D_{10\%}$	<110% of prescribed dose
PTV_{63}	$D_{95\%}$	>98% of prescribed dose
PTV_{56}	$D_{95\%}$	>98% of prescribed dose
Spinal cord	Dmax	<45 Gy
PRV cord	Dmax	<50 Gy
Parotid glands	Dmean	<26 Gy

PTV: Planning target volume, PRV: Planning risk volume

with 40° intervals. The collimator angle was kept as 0°. For all plans, dynamic MLC (dmlc) method was selected. In sequential parameters, the nominal dose rate was set between 120 and 150 MU/min. Dose rate was user selectable. The vendor recommended the dose rate range for Elekta machine was between 120-360 MU/min. For complex plan, low dose rate was recommended to achieve good quality of plan with high MU efficiency; thus very low dose rate was selected. The minimum segment width was kept as 5 mm and the fluence smoothing level was at medium level.

VMAT treatment planning

All VMAT plans were planned with 360° arc with 20° increments (angular spacing between sampled fluence profiles in stage 1) with 6-MV photon. All VMAT plans were started with single arc. If good plan was not achieved with single arc, double arc plan was done. A total of four patients were planned with single arc in clockwise direction, and nine patients were planned with double arc in clockwise and counter clockwise direction. Segment shape optimization (SSO) method was used. In SSO method, user could not be able to select the dose rate. The optimizer controlled the dose rate. This results the better plan quality. Minimum segment width was kept as 5 mm and the fluence smoothing level was at medium level.

Plan comparison
Evaluation parameters

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

- Homogeneity index (HI): $(D_{2\%}-D_{98\%})/D_{50\%}$, a ratio evaluating the dose homogeneity in PTV where $D_{2\%}$, $D_{98\%}$, and $D_{50\%}$ are the minimum dose delivered to 2,98, and 50% volume of the PTV, respectively,[7] HI of zero indicates the dose distribution is homogeneous
- Conformity index (CI): Vpres/PTVp, a ratio evaluating the coverage of the prescription dose in treatment plans, where Vpres was the volume of body receiving the prescribed dose and PTVp was the volume of PTV receiving the prescription dose.[8] CI of one indicates the good dose conformity
- Target volumes: $D_{98\%}$, $D_{95\%}$, and $D_{50\%}$ for PTV_{70}, PTV_{63}, and PTV_{56} were analyzed, where $D_{98\%}$, $D_{95\%}$, and $D_{50\%}$ were minimum dose delivered to 98, 95, and 50% volume of PTV, respectively. A total of 110% (77 Gy) of dose to target volume was for most of the patients were zero. So Dmax dose to PTV was analyzed
- Critical structures: Dmax and D_{1cc} for spinal cord, PRV cord, and brainstem were analyzed, where Dmax was the maximum dose to the normal structure and D_{1cc} maximum dose received by the 1-cc volume of the normal structure. Parotid glands were analyzed with mean dose to whole glands and $D_{50\%}$ of the glands, i.e., minimum dose delivered to 50% of parotid glands

- Normal tissues: The volume of normal tissue receiving ≥2, ≥5, and ≥10 Gy were analyzed
- Determination of effective delivery time: MU/fraction and delivery time for each plan were compared. The delivery time for all test plans (IMRT and VMAT) was recorded by the same technologist. In this study, the patient setup time was excluded for both the plans. The delivery time for IMRT included the beam data transfer time from MOSAIQ to Precise Desktop, beam on time, and gantry rotation time. Gantry was rotated through ASU for each angle. For VMAT, the beam data transfer time and beam on time was taken into consideration.

- Statistical analyses: Statistical tests of the significance to calculate the differences between IMRT and VMAT plans were done using Wilcoxon matched-pair signed-rank test (two tailed, $P \leq 0.05$).

Results

For all 13 patients, both IMRT and VMAT plans were accepted after fulfilling the planning objective. The plans were evaluated by the same oncologist. The isodose distribution was evaluated with DVH. Figure 1 shows the comparative isofill distribution of IMRT and VMAT. The results of the analysis of DVH were given in Table 2.

Target volumes

We were able to achieve the good dose coverage in both IMRT and VMAT plans. Dose to all the target volumes were comparable. VMAT gave very minimal and statistically insignificant improvement in HI {VMAT (0.0979 ± 0.012); IMRT (0.1035 ± 0.019)} and CI {VMAT (1.074 ± 0.26); IMRT (1.12 ± 0.24)}. The results were given in Table 2. The DVH comparison of PTVs was shown in Figure 2.
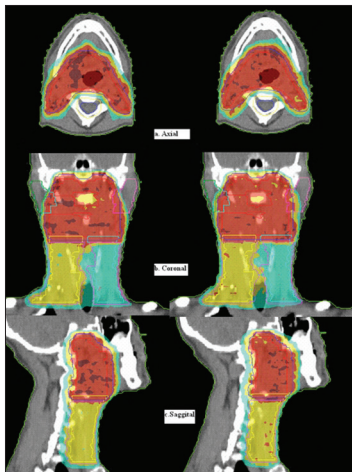

Figure 1: Isofill comparison of IMRT (left side) and VMAT (right side) for one base of tongue case. Red color: 68 Gy; yellow color: 63 Gy; cyan color: 56 Gy

Organ at risks

Spinal cord: The planning objective was met in both IMRT and VMAT plans. No statistical significant differences were observed in Dmax {VMAT (41.9 ± 1.28); IMRT (42.3 ± 1.07)} Gy as well as for 1 cc of spinal cord {VMAT (38.8 ± 1.65); IMRT (39.8 ± 1.05)} Gy.

PRV cord

Both plans met the planning objective. Dmax values were almost similar in VMAT (51.7 ± 1.85) Gy and IMRT (51.3 ± 1.91) Gy. The dose received by 1 cc of spinal cord was higher in VMAT (47.3 ± 1.21) Gy than in IMRT (46.8 ± 1.02) Gy, which showed significant difference statistically.

Brain stem

Planning objective for brain stem was easily met in both the plans. Dmax and dose to 1-cc volume of brain stem were analyzed. Dmax was lower in VMAT (48.5 ± 2) Gy compared with IMRT (49.4 ± 1.6) Gy and also 1 cc of brain stem {VMAT (43.7 ± 2); IMRT (44.3 ± 2.2)} Gy. Dmax as well as 1cc of brainstem did not show any significant statistic differences.

Parotid glands

In the case of both parotid glands (right (Rt) and left (Lt)), the planning objective was not fulfilled. When we tried to fulfill the planning objective of parotid gland, we could not achieve the objective of target volumes. Hence, the dose to the parotid glands was compromised. The mean dose received in VMAT {Rt (32.5 ± 2.61); Lt (32.8 ± 2.63)} was less than IMRT {Rt (35.2 ± 3.10); Lt (35.8 ± 7.07)}. Also the $D_{50\%}$ dose received in VMAT plan {Rt (30.3 ± 2.94); Lt (30.3 ± 3.30)} was less than with that of IMRT plans {Rt (35.0 ± 3.80); Lt (35 ± 7.97)}.

The dose differences and the P values are tabulated in Table 1. The DVH analyses of the OARs were shown in Figures 3 and 4.
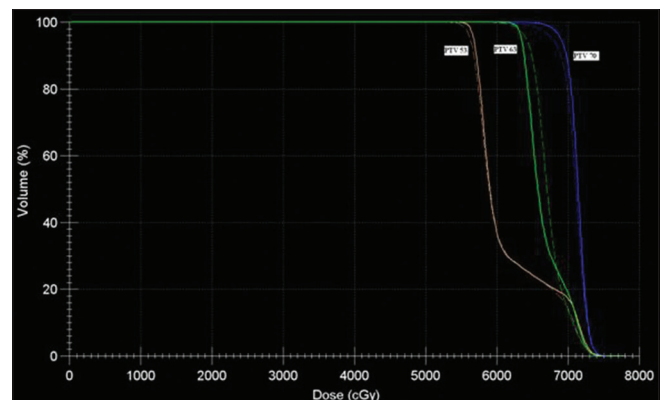

Figure 2: DVH comparison of IMRT and VMAT of PTVs. Solid lines: VMAT plan; dashed line: IMRT plan

Normal tissue dose

The volume of normal tissue received ≥ 2 Gy was less in VMAT than IMRT. The volume of normal tissue received ≥ 5 Gy and ≥ 10 Gy was similar in both VMAT and IMRT.

Delivery efficiency

The MUs were compared. The average MU for VMAT (804 ± 96) was higher than that of IMRT plans (700 ± 52). The delivery time was compared between IMRT and VMAT. The plan delivery for IMRT was double (10 min:18 s) than that of VMAT delivery time (5 min:06 s).

Discussion

This study compared VMAT with dynamic MLC IMRT for 13 patients of base of tongue cases. The main issue in the treatment of head and neck cases is the concave shape of the tumor and the proximity of normal structures to the tumor. IMRT has been the standard treatment techniques for head and neck cancer. It gives the advantage of multiple prescriptions, normal tissue sparing, and good dose conformity. VMAT is the technique in which IMRT plans were delivered with reduced delivery time.[3,4,9] Many papers have been published using Eclipse or pinnacle TPS comparing VMAT and IMRT plans. However, comparison studies of VMAT and IMRT using Monaco planning system are very few compared with the above-mentioned system. This paper compares IMRT and VMAT in Monaco planning system.

Dose coverage in both the plans was similar. The HI and CI did not show any statistical differences. Spinal cord dose and brain stem dose were similar in both VMAT and IMRT plans. Volume 1 cc of PRV cord was slightly higher in VMAT compared with IMRT. However, the doses were within the acceptable limit. Both the parotid glands had better sparing in VMAT than IMRT. The volume of normal tissue dose

received in VMAT is less than IMRT, which will reduce late effect of low dose radiation (radiation-induced carcinomas).

The number of MUs required to deliver a prescribed dose was higher in VMAT (both single and dual arc) than IMRT. It differed from other previous studies that showed a reduction in the MUs of VMAT plans.[1,5,7] In IMRT plan, low dose rate was selected to achieve the good quality of plan that gives the higher MU efficiency. Also, Elekta linear accelerator works on variable dose rate in dynamic MLC

Table 2: The dosimetric comparison of IMRT and VMAT

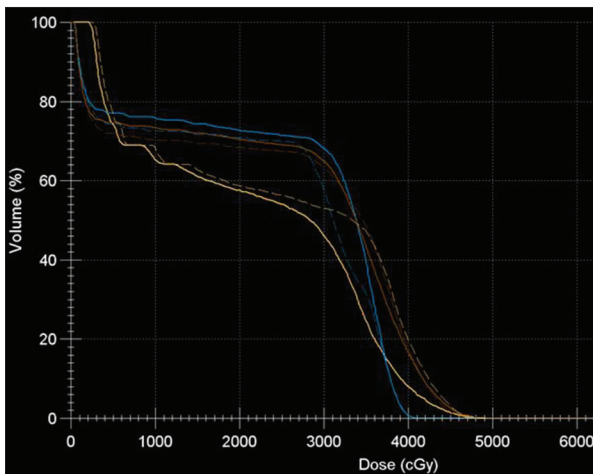|	IMRT	VMAT	P value
PTV$_{70}$			
D$_{95\%}$ (Gy)	68.3±0.36	68.1±0.78	0.3125
D$_{98\%}$ (Gy)	66.9±0.43	66.7±0.11	0.7566
D$_{50\%}$ (Gy)	71.3±0.46	71.5±0.78	0.2801
Dmax (Gy)	76.7±1.56	77.0±1.12	0.552
HI	0.0979±0.012	0.1035±0.019	0.423
CI	1.074±0.26	1.12±0.24	0.064
PTV$_{63}$			
D$_{95\%}$ (Gy)	63.1±0.65	62.6±1.31	0.1527
D$_{98\%}$ (Gy)	62.1±0.79	61.4±1.88	0.101
D$_{50\%}$ (Gy)	65.6±0.97	65.8±1.00	0.384
PTV$_{56}$			
D$_{95\%}$ (Gy)	56.0±0.39	55.7±0.83	0.1738
D$_{98\%}$ (Gy)	55.4±0.45	54.5±1.28	0.0548
D$_{50\%}$ (Gy)	58.3±0.55	58.6±0.92	0.2224
Spinal cord			
Dmax (Gy)	42.3±1.07	41.9±1.28	0.3843
D$_{1cc}$ (Gy)	39.8±1.05	38.8±1.65	0.0548
PRV cord			
Dmax (Gy)	51.3±1.91	51.7±1.85	0.603
D$_{1cc}$ (Gy)	46.8±1.02	47.3±1.21	0.0394
Brain stem			
Dmax (Gy)	49.4±1.60	48.5±2.00	0.3472
D$_{1cc}$ (Gy)	44.3±2.20	43.7±2.00	0.5552
Parotid Rt			
Mean (Gy)	35.2±3.10	32.5±2.61	0.002
D$_{50\%}$ (Gy)	35.0±3.80	30.3±2.94	0.002
Parotid Lt			
Mean (Gy)	35.8±7.07	32.8±2.63	0.001
D$_{50\%}$ (Gy)	35±7.97	30.3±3.30	0.002
Normal tissue			
≥ 2 Gy (cc)	4853±815	4745±823	0.007
≥ 5 Gy (cc)	3563±603	3610±623	0.101
≥ 10 Gy (cc)	2930±473	3090±604	0.552
MUs	700±52	804±96	0.0107
Treatment time	10:18	5:06	0.003

Figure 3: DVH comparison of spinal cord, brain stem, and PRV cord. Solid lines: VMAT; dashed lines: IMRT; blue color: Spinal cord; brown color: PRV cord; orange color: Brainstem

PTV: Planning target volume, HI: Homogeneity index, CI: Conformity index, MUs: Monitor units, IMRT: Intensity-modulated radiation therapy, VMAT: Volumetric-modulated arc therapy, Rt: Right, Lt: Left
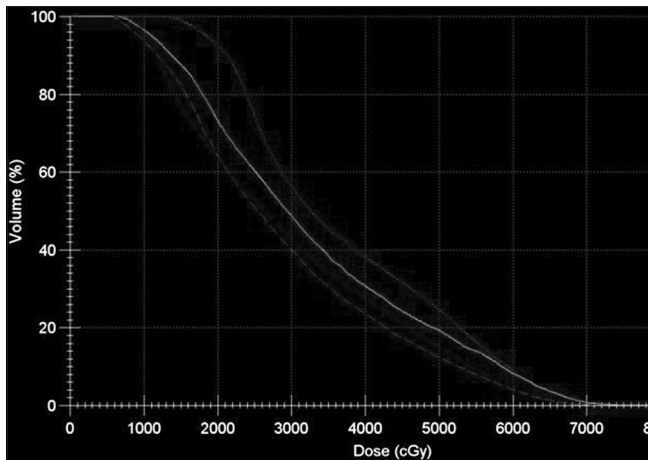
Figure 4: DVH comparison of parotid glands. Solid lines: VMAT; dashed lines: IMRT; blue color: left parotid; green color: right parotid. DVH: Dose volume histogram, IMRT: Intensity-modulated radiation therapy, VMAT: Volumetric-modulated arc therapy

mode. However, the treatment delivery time was reduced to half for VMAT compared with IMRT. This definitely gives the advantage of treating more patients in the stipulated time in the busy department.

Conclusion

This study compared dynamic MLC IMRT and VMAT plans for 13 base of tongue cases with the same target volumes and OARs. In both the plans, we were able to achieve good target coverage and normal tissue sparing. The main difference between VMAT and IMRT was the delivery time. Owing to reduced delivery time and improved efficiency, the machine throughput may be increased. We conclude in this study that VMAT gives good quality of the plan as IMRT with less delivery time and improved efficiency for base of tongue cases.

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