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Dose Distribution Analysis of Rapid Arc and Intensity Modulated Radiotherapy Plan in Head and Neck Cancer

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ABSTRACT

Introduction: Globally, intensity-modulated radiation therapy (IMRT) is considered as highly precise and accurate method of radiotherapy planning. This technique amplifies spatial dose distribution conformity by modulating the intensity of radiation beams in each sub-volume. Additionally, it can reduces the dose to surrounding critical organs and deliver the planned dose to targets with the nominal risk of side effects.

Material and Methods: In this study, 13 patients with head and neck cancer were randomly taken for analysis. The IMRT and Rapid Arc plans were generated for each case in the Eclipse treatment planning system, version 11.0. There were seven to nine beams deployed in IMRT plan, while Rapid Arc plans were performed using two arcs with opposite direction of rotation. Portal dosimetry plans were created and analyzed before executing the plan on the patient.

Results: The mean of $V_{95\%}$(Target's volume covered by 95% isodose line)was 97.89% and 97.47% for Rapid Arc and IMRT plans, respectively. Moreover, mean standard deviations were found 1.93 and 1.70 in Rapid Arc and IMRT plans, respectively. The mean gamma index was97.55% and 98.43% in Rapid Arc and IMRT, respectively.

Conclusion: IMRT technique was slightly better in the treatment of head and neck cancer compared to the Rapid Arc method. The only advantage of Rapid Arc was saving the treatment time by two to three times on an average compared with IMRT. It is prudent to use IMRT technique in head and neck cancer treatment.

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Introduction

Globally, intensity-modulated radiation therapy (IMRT) remains as a highly precise and accurate method for planning in radiotherapy across the world. This technique amplifies spatial dose distribution conformity by modulating the intensity of radiation beams in each sub-volume. Additionally, it can reduce the dose to surrounding critical organs and deliver the planned dose to targets with the nominal risk of side effects.

However, accurate dose delivery and the sparing of normal tissue can be achieved by IMRT compared with conventional radiotherapy. This technique facilitate saprecise dose distribution in the targets. This is usually achieved by the combination of various intensity-modulated subfields distributed indistinct angular beam directions [1-5].

Rapid Arc® (Varian Medical Systems) is an advanced technique for planning emerged by the technical merger of Arc modality and IMRT. This modality produces comparable or even better spatial dose distribution in comparison to IMRT alone. In this method, intensity-modulated beams are delivered continuously throughout the gantry rotation around the target. Algorithm plays a crucial role in Rapid Arc technique, which is designed to take care about the rotational speed of the gantry, multileaf collimator speed, and dose rate (MU/min).

A number of studies reported that both therapy techniques produce very precise dose distribution in targets with good normal tissues sparing. Nonetheless, the treatment time in Rapid Arc is three to five times shorter in comparison to other conformal techniques, which further yields the accuracy of treatment delivery.

According to the literature, Rapid Arc is very fast and simple treatment modality with high precision. Sometimes it generates better dose conformity compared with IMRT technique [6–9]. However, further studies are recommended to show the superiority of Rapid Arc to IMRT.

It is observed that three dimensional (3D) dose distributions in radiation therapy became more conformal in combination with the advancement of radiation therapy techniques such as volumetric modulated arc therapy (VMAT) and IMRT. All these features raise a great challenge for the quality

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assurance (QA) of the dose distribution, which commonly consists of both point-dose and two-dimensional plane dose measurements. In addition, it is worth mentioning that there is an urgent need for 3D dosimetry [10, 11].

The gamma-index method is the standard method for planar dose verification in IMRT and VMAT patient-specific QA. It calculates the quantity gamma for each point of interest using preselected dose difference (DD) and distance to agreement (DTA) criteria. Then, it uses the gamma value to determine the outcomes (pass or fail) of the QA of IMRT plans [12, 13]. Additionally, the same preselected DD and DTA criteria are seen in other dose comparison techniques such as the normalized agreement test (NAT)or the δ-envelope[14].Moreover, it has become general practice to use the passing percentage of gamma(the percentage of gammavalues≤1 for a set of DTA/DD criteria)to determine whether two dose distributions do agree [15].

The aim of this study was to analyze the dose distribution of Rapid Arc and IMRT plans in head and neck cancer based on multiple parameters including global maximum dose, monitor units (MUs), dose coverage, and gamma index.

Materials and Methods

In this study, 13 patients with head and neck cancer were randomly taken for analysis of dose distribution within targets. For all these patients, IMRT and Rapid Arc plans were generated by the Varian Eclipse treatment planning system (Varian Medical Systems, USA), version 11.0.In both modalities, 6MV photon beam was used for planning. Our main intention was to generate a clinically acceptable plan in these techniques.

Therefore, we placed the same dose constraints for both modalities. In order to achieve acceptable target coverage, we adjusted the priority of organs at risk (OARs) and target during optimization. However, other parameters were the same in both techniques. Dose-volume histograms (DVHs) were generated for each plan and analyzed for target coverage. During the optimization, our main aim was to achieve clinically acceptable $V_{95\%}$ and $D_{95\%}$for the targets with dose to OARs within tolerance limit in both modalities.

The demographic characteristics of the patients are shown in Table1.MUs, OAR's dose, and standard deviation were also considered to evaluate the plans.

Table1.Patients'demographic characteristics

	Maximum	Minimum	Mean
Age(Years old)	73	34	50.3
Height(cm)	165.0	150.0	155.8
Weight(Kg)	125.0	56.0	73.4
BMI* (Kg/m^2)	45.7	24.9	30.3

* Body Mass Index

Targeted lineation was performed and the prescribed doses were66 Gy/33and 60Gy/33to PTV66and PTV60 (maximum dose of 2Gy per session), respectively. All the targets were2-3mminside to the skin. For the ease of optimization, the parotid glands on both sides were taken out from the targets, and the plan was optimized.

In addition, the larynx, parotid glands on both sides, mandible, brainstem, eyes, optic nerves, eye lens, oral cavity, cochlea, optic chiasma, and spinal cord were considered as OARs. The dose constraints for these vital organs are demonstrated in Table2, [16, 17].

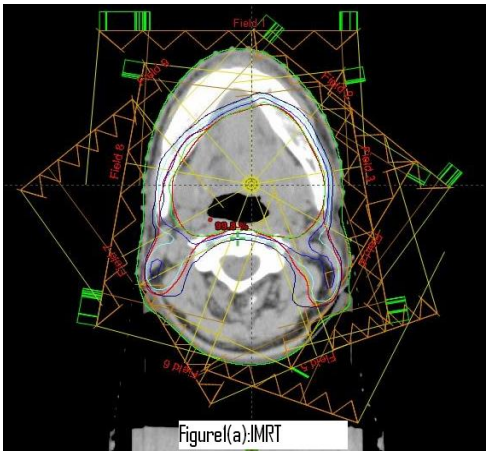
Table 2.Dose constraints for organs at risk

Organs	Maximum(Gy)	Mean(Gy)
Spinal Cord	45	-----
Brainstem	54	----
Parotid glands	-----	26
Eyes	----	<20
Larynx	-----	44
Mandible	<66	------
Oral Cavity	-----	<45
Optic Nerve and optic chiasma	<55	------

There were seven to nine beams deployed in IMRT plans, while two full arcs were used in Rapid Arc technique. The beams in the IMRT plan were placed at equal angular space. In this study, computed tomography scans were acquired at a 3.0 mm slice thickness .The positions of beams and arc are displayed in Figure1. Portal dosimetry plan was created and executed for each radiotherapy plan before the treatment. Gamma index was calculated for both competitive plans and analyzed for different parameters. This index is defined for every point in the test distribution as the distance from the reference distribution:

$$\gamma_{D_T,D_R}(y) = \min_x \sqrt{\left(\frac{y-x}{\delta}\right)^2 + \left(\frac{D_T(y)-D_R(x)}{\Delta}\right)^2}, \quad (1)$$

In this equation, δ and Δ represent the normalization factors for distance and dose, respectively. These factors can be considered as weighting factors for DTA and DD. Normally, it is proportional to the measurement errors of measured distributions for given grid size. In radiotherapy applications, the common practice for dose quality assurance(DQA) is that DTA and DD should be less than 3 mm and 3% of the maximal dose (Low et al.,1998).The normalization factors are generally determined by using the acceptance of δ=3 mm and Δ=3% of the maximum dose. If this parameter holds good, then the quality of dose delivery is assumed satisfactory. Few fixed parameters have taken for analyzing the gamma index of each plan in both modalities (Table3).



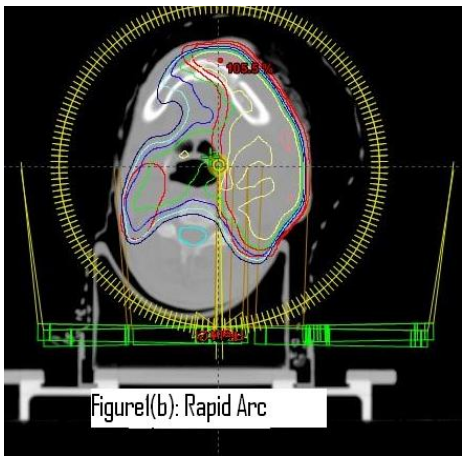


Figure 1.The positions of beams and arcs in a plan

The area gamma values of all plans for each field were calculated and analyzed for 95% confidence interval before the treatment. The MUs of all IMRT and Rapid Arc plans were recorded and tabulated for qualitative analysis.

In the first group, all plans were analyzed first for $D_{95\%}$ and $V_{95\%}$ of target's dose coverage then after dose to OARs for their mean and maximum values. Our first priority was to achieve $V_{95\%}$ that should be 95-100% of the target volume, and to spare the critical organs. In the second group, we analyzed the area gamma values (Table 3).

Portal dosimetry plans were generated in TPS and all plans were exposed to Varian portal dosimeter software, version 11.0.55(Varian Medical Systems, Inc, USA), placing the detector at the distance of 100 cm from the target.

In addition, the standard deviation was considered for analyzing the qualitative nature of plans.

Results

All Rapid Arc and IMRT plans were analyzed for dose distribution. The mean of $V_{95\%}$ was 97.89% and 97.47% for Rapid Arc and IMRT plans, respectively (Table 4).

Table 4.Volume of the target(%) covered with 95%of the prescribed dose

V_{95}(%)	
Rapid Arc	IMRT*
97.40	97.66
94.52	94.43
99.95	98.63
99.1	93.23
97.22	97.66
93.76	93.08
98.42	98.42
98.92	99.69
99.99	99.89
99.58	98.98
97.34	96.48
100.00	99.76
96.49	99.26
Mean=97.89	Mean=97.47

* Intensity-modulated radiotherapy

The mean standard deviation was 1.93 and1.61 in Rapid Arc and IMRT plans, respectively. The minimum standard deviation was 0.90% in IMRT technique (Table 5).

Table5. Standard deviation of the prescribed dose to targets (%)

STD*(%)	
Rapid Arc	IMRT**
2.3	2.0
3.4	3.2
1.0	1.2
1.9	1.7
2.2	1.6
3.6	2.8
1.2	0.9
1.9	1.1
1.0	0.9
1.6	1.7
1.4	1.4
1.0	0.9
2.6	2.1
Mean=1.93	Mean=1.61

* Standard deviation, ** Intensity-modulated radiotherapy

The mean $D_{95\%}$ was 96.57% in the Rapid Arc method, while it was 96.30% in IMRT technique (Table 6).

Table 6. Radiation dose (%) covering 95% of target volume

D_{95} (%)	
Rapid Arc	IMRT*
96.40	96.45
92.69	94.43
97.84	96.43
96.72	94.55
96.18	95.95
94.67	94.64
96.10	98.40
96.46	97.02
98.88	97.44
98.08	97.52
96.13	95.02
99.58	96.34
95.77	97.75
Mean=96.57	Mean=96.30

* Intensity-modulated radiotherapy

c)

The mean of the global maximum dose was 105.3% and 103.7% in Rapid Arc and IMRT plans, respectively. In every plan, the global maximum dose was lower in the IMRT technique (Figure 2).

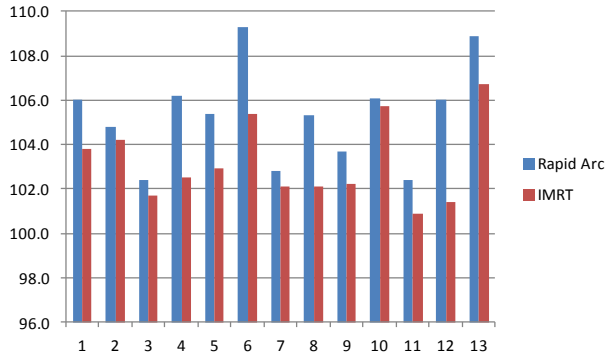


Figure 2. Global maximum dose in intensity-modulated radiotherapy and Rapid Arc plans

The total number of MU was recorded for each plan, the means were 408.76 (ranging from 251 to 566) and 928.53 (ranging from 359 to 1286) in Rapid Arc and IMRT, respectively. All IMRT plans yield higher MUs compared with Rapid Arc(Figure3).

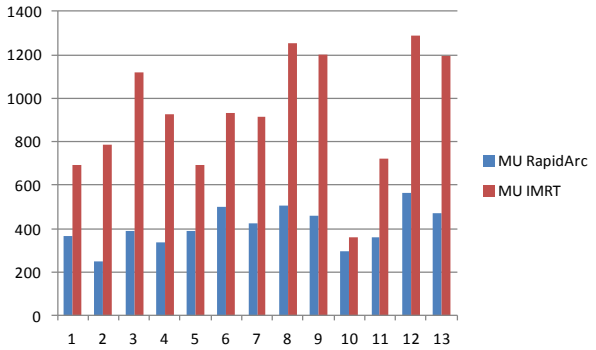


Figure 3. Monitor units in intensity-modulated radiotherapy and Rapid Arc modalities

The mean of "Area Gamma Index≤1.0"for IMRT plan was found to be slightly better in comparison to Rapid Arc (Figure 4).

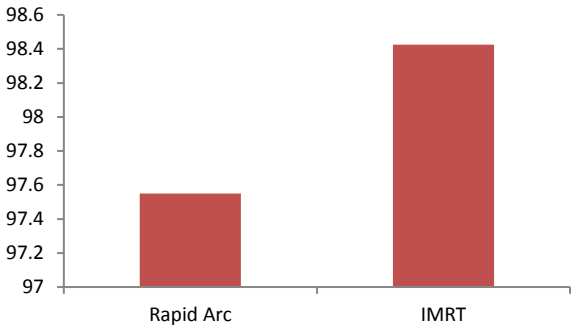


Figure 4.Mean of area gamma index obtained after portal dosimetry

Discussion

In the current study, all patients with head and neck cancer were enrolled randomly forth analysis of spatial dose distribution. All plans were analyzed for $V_{95\%}$, $D_{95\%}$, mean dose to targets, and maximum and minimum dose to OARs. The portal dosimetry of each plan was performed before execution.

In addition, the gamma index was quantified for each plan and considered as one of the analysis parameters to check the dose delivery accuracy of the techniques. The area gamma index was found slightly better in IMRT technique compared with Rapid Arc. Therefore, dose delivery in IMRT technique might be considered more accurate than Rapid Arc.

In this study, the dose coverage to the targets was the same in both modalities. Moreover, no significant difference was observed in the dose delivered to OARs (Table 7).

Table7. Dose delivered to organs at risk

Organ	Maximum(Gy)		Maximum mean dose(Gy)	
	IMRT*	Rapid Arc	IMRT	Rapid Arc
Spinal cord	44.9	44.7	23.6	24.1
Brainstem	54.3	54.7	44.3	45.1
Parotid gland	61.2	61.5	29.8	28.7
Larynx	65.4	66.2	47.4	48.1
Eye	50.5	51.2	18.3	20.3
Mandible	65.8	66.1	49.1	50.2
Optic nerve	54.1	55.2	48.3	49.2

* Intensity-modulated radiotherapy

In this study, it was easy to reduce hot spot and hyper dose in IMRT plan. The global maximum dose was noticed comparatively less in IMRT technique. Additionally, treatment duration in Rapid Arc was shorter than IMRT. However, dose distribution homogeneity was slightly better in IMRT plans.

If the optimization of dose distribution meets the objectives of a plan, it is assumed that the prescribed dose delivery would be proper. Moreover, normal tissues in the vicinity of targets should be spared. These tasks are a competitor and their accompanying performance is sometimes hard to achieve desired dosimetric outcomes. Sometimes it is difficult for users to decide whether dose to OARs with acceptable parameters and poor target coverage is more preferable than the treatment plan with proper target coverage but higher dose to OARs. Furthermore, the decision making process depends on the given dose constraints, which hamper the gradient of DVH curves in lower dose ranges leading the inferior dose homogeneity in the target.

Numerous studies are available on this topic that compare the Rapid Arc and IMRT. Never the less, the current study suggested that spatial dose distribution in the target was comparatively better in IMRT in head and neck cancer. The only demerit of IMRT was that the duration of treatment was 3-5 minutes longer than Rapid Arc method.

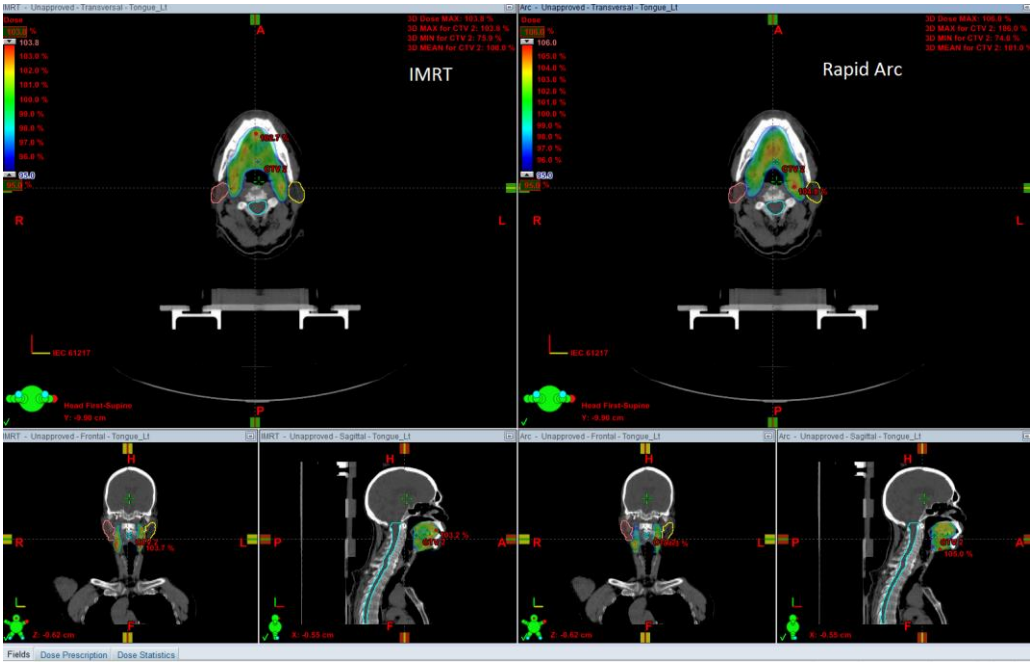


Figure 5.95% of prescribed dose coverage to target in intensity-modulated radiotherapy and Rapid Arc method

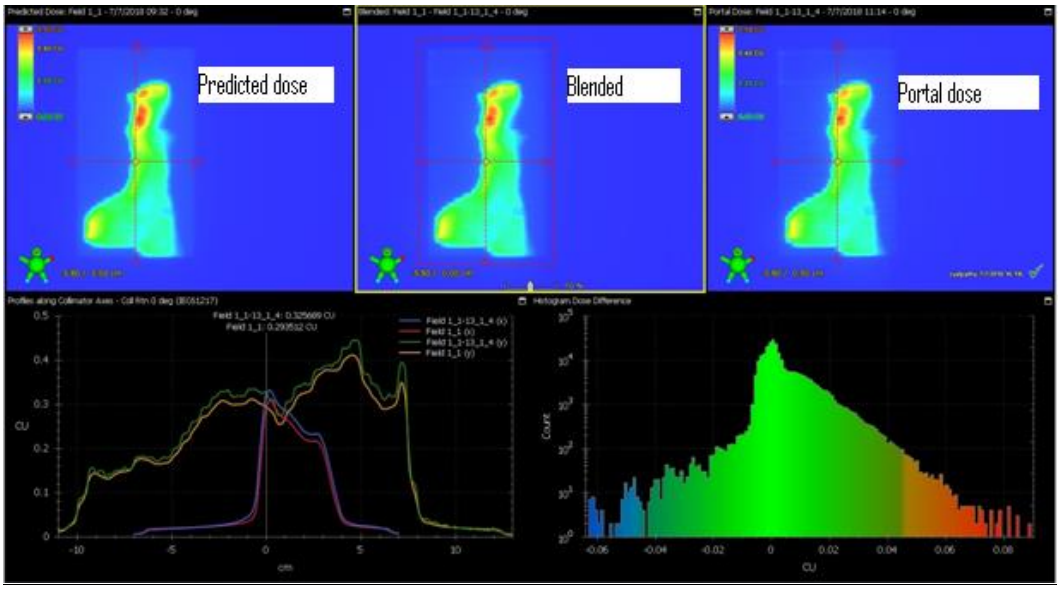


Figure 6.Area gamma measurement by blending the predicted and portal dose

Normally, the spatial dose distributions achieved in both modalities after the rigorous optimization of prescribed dose to targets and dose constraints to vital organs in the vicinity exhibited the complexity of the higher order. Itis an ambiguous task for oncologists to analyze and compare these plans on the basis of spatial dose distribution and DVH curves after optimization. A large number of critical structures taken into optimization and their dose constraints hamper the decision for selection of the most desirable plan. The spatial dose distribution in the target in both techniques is displayed in Figure5. The V95%, D95 % (for PTV) and area gamma index<1.0were considered as fixed parameters to assess the plans.

There was no significant difference between Rapid Arc and IMRT plans in terms of spatial dose distribution. Dose to OARs was found to be almost the same in both techniques. None the less, it was easy to control the spillage of dose outside the targets in IMRT technique. Furthermore, it was possible for users to easily reduce OARs dose in this modality. After getting an acceptable plan from TPS, its execution was of paramount importance.

The findings of this study demonstrated that IMRT plan execution was comparatively more reliable than Rapid Arc because the mean percentage value of area gamma index (Area gamma<1.0, Tolerance value=95%) was more accurate in IMRT.

In order to measure gamma index, we first blended the portal dose and predicted dose in TPS for each field of a plan and the central axis correction was made as well. Then, we performed the analysis of pass-fail (Table3).In this study, the area gamma index<1.0 was considered as one of the major parameters. All the plans of both modalities were analyzed for this parameter (Figure 6).

Conclusion

Regarding the results of the present study, the IMRT technique was slightly better than Rapid Arc for the treatment of head and neck cancer. The only advantage of Rapid Arc was that it curtails treatment time by 2-3times on an average compared with IMRT. However, the hotspot was found 3-5% less in IMRT plans.

As far as spatial dose distribution inside the target was concerned, both techniques produced almost equivalent dosimetric outcomes. Never the less, dose homogeneity was more acceptable in IMRT plans and less high dose. Furthermore, IMRT technique was able to generate adequate surface dose as per clinical necessity. Plan execution over patients was one of the most important parts of radiotherapy. In addition, and the execution of the IMRT plan was more reliable in comparison to Rapid Arc considering the accuracy of dose delivery. Conclusively, it is sagacious to use IMRT technique in head and neck cancer treatment.

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