Original Article

Evaluation of Dosimetric Efficacy of RapidArc and Intensity-modulated Radiation Therapy Techniques in Head-and-Neck Cancers

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Abstract

Aim: This study aims to compare the dosimetric efficacy of RapidArc (RA) and intensity-modulated radiation therapy (IMRT) in the treatment of head-and-neck cancer, focusing on treatment efficiency and organ at risk (OAR) dose. **Materials and Methods:** A cohort of 10 patients with head-and-neck cancer was recreated for RA, which was earlier treated with IMRT techniques. Dosimetric parameters evaluated or planning target volume (PTV) included monitor units (MUs), beam on time (BoT), gamma passing rate (GP), and various normal tissue dose indices such as V_{95}, V_{90}, V_{50}, V_{25}, and gradient indices (gradient index [GI], low GI [LGI], high GI). In addition, doses of OARs, including the spinal cord, brainstem, cochleae, esophagus, lips, larynx, and parotid glands, were compared. **Results:** RA demonstrated significant improvements in treatment efficiency, requiring fewer MU and shorter BoT, while maintaining comparable GP to IMRT. RA achieved a lower LGI, indicating better sparing of normal tissues from intermediate doses. Most other dosimetric parameters, including those for the spinal cord, parotid glands, and PRV spinal cord, demonstrated significant differences, with the RA technique showing superior performance. **Conclusion:** This study highlights the dosimetric superiority of RA over IMRT, with significantly fewer MU, reduced BoT, and comparable GPs. RA achieved slightly higher mean PTV doses with similar homogeneity and conformity while delivering lower doses to critical OARs, such as the spinal cord, PRV spinal cord, and parotid glands, making it clinically advantageous.

Keywords: Conformal, intensity-modulated, linear accelerator, photons, radiotherapy, radiotherapy planning

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Introduction

Oral cavity and lip cancer have the highest incidence among male cancer patients in India, accounting for 15.6% of all new cancer cases, and rank 4th among female cancer patients, accounting for 5% of all new cases. Worldwide, oral cavity and lip cancer rank 16th in terms of incidence and 15th in terms of mortality. Among the continents, Asia has the highest incidence, mortality, and prevalence of lip and oral cavity cancer compared to Europe, Africa, Oceania, Northern America, Latin America, and the Caribbean.[1,2] Oral cavity cancers include lip cancer, tongue cancer (anterior two-thirds), floor of the mouth cancer, buccal mucosa cancer, gum (gingiva) cancer, hard palate cancer, retromolar trigone cancer, and alveolar ridge cancer.[3,4] Tongue cancer is one of the most common types of cancer among Indian males. Smoking, alcohol consumption, and, more recently, human papillomavirus infection are recognized as major risk factors for the development of tongue cancer.[3,4] Treatment for tongue cancer can involve surgery, chemotherapy, radiation therapy, or a combination of these modalities, depending on the staging.[3] In radiotherapy, there has been a remarkable evolution in treatment techniques, progressing from 3-dimensional conformal radiation therapy to intensity-modulated radiation therapy (IMRT), and from IMRT to RapidArc (RA), among others.[5] With the emergence of new techniques in radiotherapy, debates continue regarding

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the pros and cons of using IMRT and RA for head-and-neck patients. IMRT can be delivered using two distinct methods: "Step and Shoot IMRT" and "Dynamic IMRT." In "Step and Shoot IMRT," the gantry remains stationary at a specific angle, and the multi-leaf collimators (MLCs) are fixed in position when the beam is activated. Conversely, in "Dynamic IMRT," the gantry is also fixed at a particular angle, but the MLCs continuously adjust their positions while the beam is on. IMRT planning involves optimizing fluence maps, followed by sequencing the MLC leaves. In contrast, RA is a rotational radiotherapy technique where the MLCs move dynamically, and the dose rate varies during treatment.[6,7]

The RA technique has been studied for treating various types of cancer, including prostate, cervical, anal canal, lung, brain, and head-and-neck cancers. RA plans have been found to offer quicker delivery times, require fewer monitor units (MUs), and provide better dose distributions compared to traditional clinical IMRT plans.

These benefits are achieved through enhanced flexibility in delivery, allowing for varying dose rates and gantry speeds during the dynamic movement of jaws and MLCs.[4]

A multi-institutional comparison of arc therapy versus IMRT for head-and-neck cancer showed superior VMAT plan quality parameters. Johnston *et al*.[8] compared simultaneous integrated boost plans generated with IMRT and VMAT for head-and-neck cancers and concluded that VMAT achieves comparable plans to IMRT while using two-thirds fewer MU.[7,8]

Tongue cancer, being part of head-and-neck cancer, is histologically heterogeneous, and the organs at risk (OAR) around it have low tolerance to radiation. Treatment planning for advanced head-and-neck cancer is exceptionally complex due to the intricate geometry of the target volumes and the need to preserve critical structures such as the parotid glands, brainstem, and spinal cord. These vital organs are often situated close to the target volumes, frequently having irregular, concave shapes. The proximity of tumors and critical structures poses significant challenges for effective radiotherapy delivery in head-and-neck cancer cases.[7]

The current study aims to evaluate the dosimetric efficacy for oral cavity cancers in the head-and-neck region using the RA and IMRT techniques.

Materials And Methods

Patient selection and contouring

For this study, 10 patients with tongue cancer are retrospectively selected. Planning computed tomography (CT) of all these patients was done with a helical 20/64 slice scanner (Somatom Definition AS, Siemens, Germany) with 3 mm CT slice thickness in a supine position with a five-clamp custom-made thermoplastic mask. CT images were imported to the Eclipse treatment planning station (TPS) in DICOM format, where all the essential contours were made, including planning target volume (PTV), CTV, and the OARs (brain stem, left parotid, right parotid, larynx, right cochlea, left cochlea, esophagus, lips, spinal cord, and PRV spinal cord). A 5-mm margin to CTV is given to define PTV to encounter setup errors, and PTV was confined to a 3-mm interior margin from the patient outer contour to ovoid optimization in air.

Treatment planning

Treatment plans were generated using a 6 MV photon beam with a dose prescription of 60 Gy in 30 fractions in SIB with 54 Gy in 30 fractions, which are treated on linear accelerator (Unique Performance; Varian Medical Systems, Palo Alto, CA, USA). All the patients were planned with both RA and IMRT techniques keeping all the parameters same. In IMRT, nine equally spaced coplanar beams with angles 0°, 40°, 80, 120°, 160°, 200°, 240°, 280°, and 320° along with 0° collimator were used whereas, in the case of RA planning, two full arc 181° to 179° and its vice versa were used along with 20° and 340° collimator respectively to avoid the tongue and groove effect.[9] Both the plans were computed with anisotropic analytical algorithm dose calculation algorithm and with 2.5 mm normal grid size. Both treatment plans were generated as per the dose constraints as given in Table 1.

Plan assessment and validation

For our study, the doses of the OARs were documented for all 10 patients, with mean values accompanied by standard deviations (SDs) for each treatment plan.

Paddick's conformity index

$$PCI = (TV_{PIV})^2/(TV \times PIV)$$

where PCI is Paddick's Conformity Index, TV is the target volume, and PIV is the prescription isodose volume. The conformity index (CI) equal to 1 indicates that the dose coverage is ideal or that the plan has high conformity.[10] A CI >1 indicates that the irradiated volume exceeds the target volume and covers part of the healthy tissue, whereas the CI is <1, it means that the target volume is partially radiated. This formula includes both the target coverage and radiation, offering a comprehensive assessment. It is ideal for irregularly shaped targets in the head-and-neck region, ensuring dose conformity near critical structures.

Table 1: Dose constraints for organ at risks

OAR	Dose (Gy)
Spinal cord PRV	Max <48
Spinal cord	Max <45
Brain stem	Max <54
Lift parotid	Mean <26
Right parotid	Mean <26
Larynx	Mean <40
Right cochlea	Mean <45
Right cochlea	Mean <45
Esophagus	Mean <34
Lips	Mean <32

OAR: Organ at risk, PRV: Planning risk volume

Homogeneity index

Homogeneity index (HI) measures the dose distribution uniformity across target volume.

$$HI = (D_{2\%}\text{-}D_{98\%})/(D_{50\%})$$

where $D_{2\%}$, $D_{50\%}$, and $D_{98\%}$ are the doses received by 2%, 50%, and 98% volumes of PTV, respectively.[11] The homogeneity value ranges from 0 to 1. The ideal value of the HI is 0. A higher value represents a lack of homogeneity.

Gradient index

It represents the falloff of dose. It is used to evaluate radiation dose gradient outside the target. It is calculated as the ratio of the volume receiving 95% of the prescribed isodose ($V_{95\%}$ PID) to that receiving 50% of the prescribed isodose ($V_{50\%}$ PID).[12,13]

Low-gradient index and high-gradient index

The low- and high-gradient indices are the ratios of $V_{25\%}$ PID to $V_{50\%}$ PID and $V_{50\%}$ PID to $V_{90\%}$ PID, respectively, where $V_{25\%}$, $V_{50\%}$, and $V_{90\%}$ represent the volumes receiving 25%, 50%, and 90% of the prescribed dose. All treatment plans, including both RA and IMRT modalities, were meticulously assessed for key dosimetric parameters: HI, CI, gradient index (GI), low-gradient index [LGI], high-gradient index [HGI], D_{max}, D_{mean}, D_{98}, D_{50}, D_2, V_{95}, V_{107}, and the dose to OAR, utilizing dose-volume histograms (DVH).[13,14]

Plan verification

Doses calculated by the TPS were compared with measured doses through patient-specific quality assurance. This study implemented a 3 mm distance-to-agreement (DTA) and a 3% dose difference criterion for QA assessments of both RA and IMRT plans, with a threshold set at 5%.[14] Accordingly, both RA and IMRT plans underwent irradiation and subsequent evaluation utilizing an electronic portal imaging detector (EPID). EPIDs enhance radiotherapy verification with digital reusability, eliminating film costs, and phantom setups. They provide immediate results, streamline workflows, and ensure accurate, efficient, and cost-effective quality assurance for precise treatments. In addition, dose difference analysis was defined as the TPS-calculated dose at a specific point minus the measured dose at the same point, divided by the measured dose at that point (Equation 1).[15]

$$PV = \{[TPSPD\ (RA\ or\ IMRT) - measured\ dose\ (EPID)]/measured\ dose\ (EPID)\} \times 100 \quad (1)$$

where PV represents percentage variation, TPSPD is the TPS planned dose; RA refers to RA technology; IMRT refers to IMRT; and EPID is the EPID.

Statistical analysis

A comparative statistical analysis of the RA and IMRT plans was performed using SPSS software, version 25 (SPSS Inc., USA). Since all variables were quantitative, they were expressed as means with SD or ranges. The two-tailed paired *t*-test was employed to assess the differences between the plans. A $P < 0.05$ was deemed statistically significant, marking a key threshold for determining meaningful differences in the study's findings.

Results

Planning target volume–60

The dosimetric parameters for PTV_60 are recorded in Table 2. The maximum dose (D_{max}) was slightly higher in the RA plan (63.66 ± 0.96 Gy) compared to the IMRT plan (62.85 ± 0.86 Gy), with a $P = 0.07$, indicating no significant difference. The mean dose (D_{mean}) was significantly higher for RA (60.45 ± 0.47 Gy) than IMRT (59.97 ± 0.42 Gy), with a $P = 0.04$. The dose received by 98% of the volume ($D_{98\%}$) was similar between RA (57.99 ± 0.59 Gy) and IMRT (57.99 ± 0.36 Gy), with a nonsignificant ($P = 0.98$). The dose received by 95% of the volume ($D_{95\%}$) showed no significant difference between RA (58.72 ± 0.56 Gy) and IMRT (58.52 ± 0.34 Gy), with a $P = 0.38$. The dose received by 50% of the volume ($D_{50\%}$) was significantly lesser in RA (60.04 ± 0.43 Gy) compared to IMRT (60.59 ± 0.46 Gy), with a $P = 0.02$. The dose received by 5% of the volume ($D_{5\%}$) was slightly higher in RA (61.62 ± 0.61 Gy) compared to IMRT (61.21 ± 0.55 Gy), though not statistically significant ($P = 0.14$). The dose received by 2% of the volume ($D_{2\%}$) was similar between RA (61.75 ± 0.79 Gy) and IMRT (61.62 ± 0.45 Gy), with a $P = 0.66$. The CI was identical for both RA and IMRT (0.85 ± 0.03), with no significant difference ($P = 0.69$). The HI was also similar between the two techniques, with RA and IMRT both having an HI of 0.06 ± 0.02 and 0.06 ± 0.01, respectively, and a nonsignificant ($P = 0.79$).

Table 2: Mean and standard deviation of planning target volume

n=10	Parameters	RA	IMRT	*P*
PTV_60	Volume (cc)	283.36±125.05		
	D_{max} (Gy)	63.66±0.96	62.85±0.86	0.07
	D_{mean} (Gy)	60.45±0.47	59.97±0.42	0.04
	$D_{98\%}$ (Gy)	57.99±0.59	57.99±0.36	0.98
	$D_{95\%}$ (Gy)	58.72±0.56	58.52±0.34	0.38
	$D_{50\%}$ (Gy)	60.04±0.43	60.59±0.46	0.02
	$D_{5\%}$ (Gy)	61.62±0.61	61.21±0.55	0.14
	$D_{2\%}$ (Gy)	61.75±0.79	61.62±0.45	0.66
	$CI=(TV_{PIV})^2/(TV \times PIV)$	0.85±0.03	0.85±0.03	0.69
	$HI=D_2-D_{98}/D_{50}$	0.06±0.02	0.06±0.01	0.79
PTV_54	Volume (cc)	313.65±96.82		
	D_{max} (Gy)	58.33±0.44	58.32±0.94	0.99
	D_{mean} (Gy)	54.47±0.43	54.34±0.39	0.51
	$D_{98\%}$ (Gy)	52.48±1.04	52.69±0.48	0.59
	$D_{95\%}$ (Gy)	52.87±0.45	53.09±0.49	0.35
	$D_{50\%}$ (Gy)	54.57±0.45	54.33±0.39	0.23
	$D_{5\%}$ (Gy)	55.73±0.42	55.66±0.43	0.74
	$D_{2\%}$ (Gy)	56.11±43.34	56.06±0.45	0.83
	$HI=D_2-D_{98}/D_{50}$	0.06±0.01	0.06±0.01	0.54

RA: RapidArc plan, IMRT: Intensity-modulated radiation therapy, Da (Gy): Dose (Gy) absorbed dose by particular percentage or volume cm^3, HI: Homogeneity index, CI: Conformity index, PTV: Planning target volume, TV: Target volume, PIV: Prescription isodose volume

Planning target volume_54

The dosimetric parameters for PTV_54 are presented in Table 2. The Dmax was nearly identical for RA (58.33 ± 0.44 Gy) and IMRT (58.32 ± 0.94 Gy), with a $P = 0.99$, indicating no significant difference. The D_{mean} was slightly higher for RA (54.47 ± 0.43 Gy) compared to IMRT (54.34 ± 0.39 Gy), with a nonsignificant ($P = 0.51$). The $D_{98\%}$ was slightly lower for RA (52.48 ± 1.04 Gy) than IMRT (52.69 ± 0.48 Gy), with a nonsignificant $P = 0.59$. The $D_{95\%}$ was slightly lower in RA (52.87 ± 0.45 Gy) compared to IMRT (53.09 ± 0.49 Gy), with a nonsignificant $P = 0.35$. The $D_{50\%}$ was slightly higher for RA (54.57 ± 0.45 Gy) compared to IMRT (54.33 ± 0.39 Gy), with a nonsignificant ($P = 0.23$). The $D_{5\%}$ was nearly identical between RA (55.73 ± 0.42 Gy) and IMRT (55.66 ± 0.43 Gy), with a nonsignificant $P = 0.74$. The $D_{2\%}$ was similar between RA (56.11 ± 43.34 Gy) and IMRT (56.06 ± 0.45 Gy), with a nonsignificant $P = 0.83$. The HI was identical for both RA and IMRT (0.06 ± 0.01), with a nonsignificant $P = 0.54$. Figure 1 presents the dose distribution in transverse, coronal, and sagittal sections by IMRT and RA plans, while Figure 2 displays the DVH for the PTV and OARs, enabling a comparison between the two treatment plans.

Normal tissue and organs at risk

The mean V_{95} for RA was 327.74 ± 146.79 cc, while for IMRT, it was 330.65 ± 143.62 cc. Tables 3 and 4 present the average values for OARs and normal tissue across all patients, respectively.

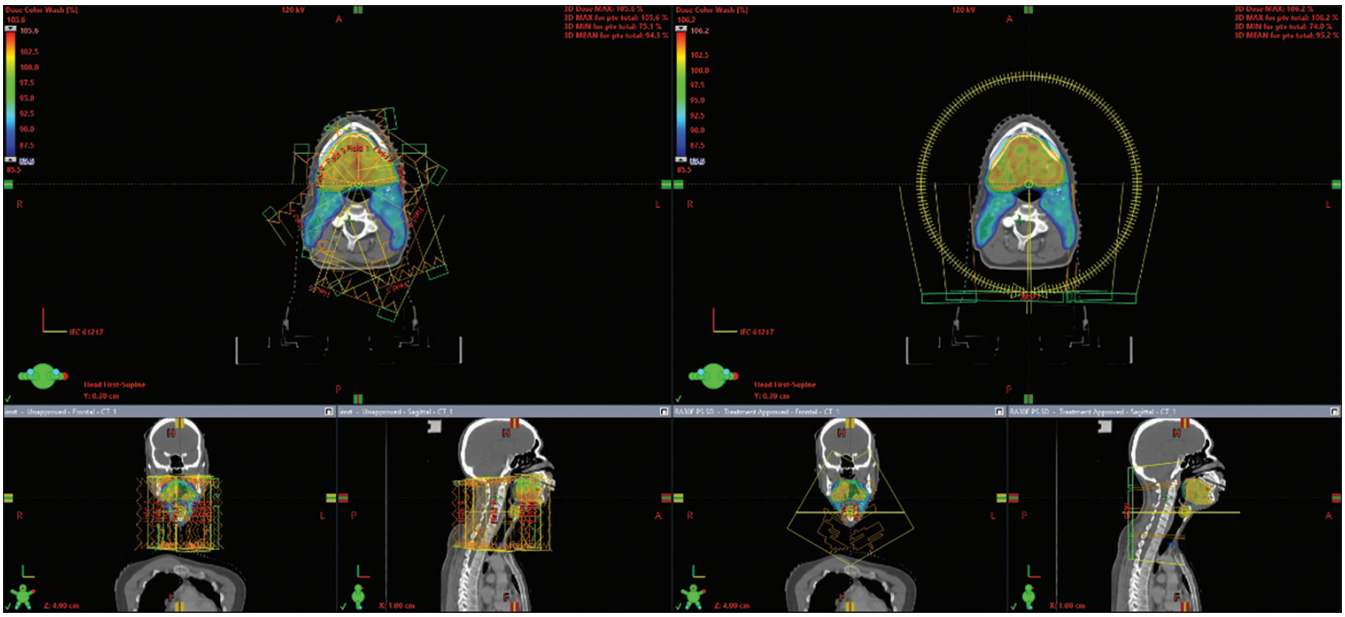

Figure 1: Illustrating 95% of prescribed isodose distribution in transverse, coronal and sagittal sections by intensity-modulated radiation therapy and RpidArc plans

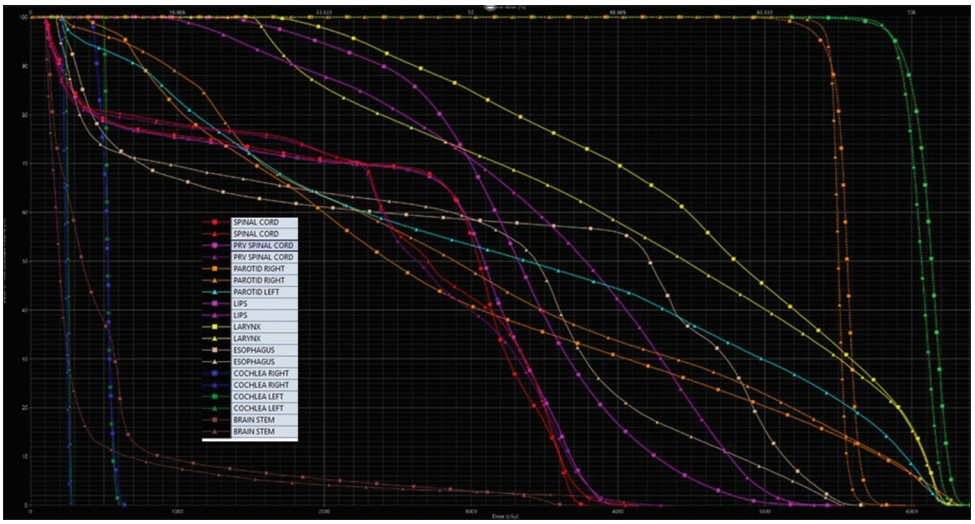

Figure 2: Illustrating dose volume histogram by intensity-modulated radiation therapy-triangle lines and RapidArc-square lines, and colors represents planning target volume (PTV) 60-Neon and PTV 54–60-orange

The difference was not statistically significant, with a $P = 0.96$, indicating similar volumes of normal tissue exposed to 95% of the prescribed dose between the two techniques. The mean V_{90} was slightly higher in RA (637.96 ± 135.10 cc) compared to IMRT (604.84 ± 147.55 cc), but this difference was not statistically significant ($P = 0.63$). The mean V_{50} was higher in RA (2045.56 ± 333.92 cc) compared to IMRT (1939.22 ± 275.42 cc), though this difference was not statistically significant ($P = 0.47$). The mean V_{25} was slightly lower in RA (3083.35 ± 514.30 cc) compared to IMRT (3184.05 ± 554.37 cc), but this difference was not statistically significant ($P = 0.69$). GI, calculated as V_{95}/V_{50}, was slightly lower in RA (0.157 ± 0.053) compared to IMRT (0.17 ± 0.06), but this difference was not statistically significant ($P = 0.68$).

LGI calculated as V_{25}/V_{50}, was significantly lower in RA (1.51 ± 0.12) compared to IMRT (1.63 ± 0.073), with a statistically significant ($P = 0.02$). This indicates that RA resulted in a lower proportion of normal tissue receiving intermediate dose levels compared to IMRT. HGI calculated as V_{50}/V_{90}, was similar between RA (3.26 ± 0.48) and IMRT (3.35 ± 0.73), with no significant difference ($P = 0.77$). The mean dose to the spinal cord was lower in RA (34.96 ± 2.30 Gy) compared to IMRT (37.05 ± 2.02 Gy). This difference approached statistical significance ($P = 0.05$), indicating that RA delivered a marginally lower dose to the spinal cord. The mean dose to the brainstem was almost identical between RA (32.89 ± 11.42 Gy) and IMRT (32.81 ± 10.14 Gy), with a $P = 0.98$, indicating no significant difference between the two techniques. The mean dose to the right cochlea was higher in RA (5.37 ± 1.72 Gy) compared to IMRT (3.81 ± 2.33 Gy), though this difference was not statistically significant ($P = 0.13$). Similarly, the mean dose to the left cochlea was higher in RA (5.77 ± 1.71 Gy) compared to IMRT (4.23 ± 2.53 Gy), with a nonsignificant $P = 0.15$. The mean dose to the esophagus was slightly higher in RA (26.97 ± 7.94 Gy) compared to IMRT (25.16 ± 7.59 Gy), but this difference was not statistically significant ($P = 0.63$). The mean dose to the lips was similar between RA (31.73 ± 7.20 Gy) and IMRT (31.10 ± 6.32 Gy), with a nonsignificant $P = 0.85$. The mean dose to the larynx was significantly higher in RA (42.93 ± 3.23 Gy) compared to IMRT (37.32 ± 4.86 Gy), with a statistically significant $P = 0.01$, indicating that RA delivered a higher dose to the larynx.

The mean dose to the right parotid gland was lower in RA (26.62 ± 1.72 Gy) compared to IMRT (28.48 ± 1.57 Gy); the difference was statistically significant ($P = 0.02$). Similarly, the mean dose to the left parotid gland was lower in RA (29.37 ± 2.99 Gy) compared to IMRT (30.65 ± 2.67 Gy), with a significant $P = 0.01$. The planning risk volume (PRV) for the spinal cord received a lower mean dose in RA (38.12 ± 2.09 Gy) compared to IMRT (40.56 ± 1.93 Gy). This difference was statistically significant ($P = 0.02$), indicating that RA delivered a lower dose to the PRV spinal cord.

The mean dose to the left parotid gland minus PTV was lower in RA (20.54 ± 1.22 Gy) compared to IMRT (22.11 ± 1.25 Gy); the difference was statistically significant ($P = 0.01$). Similarly, the mean dose to the right parotid gland minus PTV was lower in RA (20.22 ± 12.27 Gy) compared to IMRT (22.07 ± 1.30 Gy), with a significant $P = 0.01$. Figures 3 and 4 show a comparison of the Dmean dose to the left and right parotid glands minus the PTV between RA and IMRT plans.

Table 3: Mean and standard deviation of organ at risks

n=10	Parameters	RA (Gy)	IMRT (Gy)	*P*
OARs	Spinal cord	34.96±2.30	37.05±2.02	0.05
	Brainstem	32.89±11.42	32.81±10.14	0.98
	Cochlea right	5.37±1.72	3.81±2.33	0.13
	Cochlea lift	5.77±1.71	4.23±2.53	0.15
	Esophagus	26.97±7.94	25.16±7.59	0.63
	Lips (mean)	31.73±7.20	31.10±6.32	0.85
	Larynx (mean)	42.93±3.23	37.32±4.86	0.01
	Parotid_right	26.62±1.72	28.48±1.57	0.028
	Parotid_lift	29.37±2.99	30.65±2.67	0.007
	PRV spinal cord	38.12±2.09	40.56±1.93	0.02
	Parotid left-PTV	20.54±1.22	22.11±1.25	0.010
	Parotid right-PTV	20.22±12.27	22.07±1.30	0.004

RA: RapidArc plan, IMRT: Intensity-modulated radiation therapy, OARs: Organ at risks, PRV: Planning risk volume, PTV: Planning target volume

Table 4: Mean and standard deviation of normal tissue

n=10	Parameters	RA	IMRT	*P*
Normal tissue	V_{95}	327.74±146.79	330.65±143.62	0.96
	V_{90}	637.96±135.10	604.84±147.55	0.63
	V_{50}	2045.56±333.92	1939.22±275.42	0.47
	V_{25}	3083.35±514.30	3184.05±554.37	0.69
	GI=V_{95}/V_{50}	0.157±0.053	0.17±0.06	0.68
	LGI=V_{25}/V_{50}	1.51±0.12	1.63±0.073	0.02
	HGI=V_{50}/V_{90}	3.26±0.48	3.35±0.73	0.77

RA: RapidArc plan, IMRT: Intensity-modulated radiation therapy, Va: Percentage of organ volume for particular dose, GI: Gradient index, LGI: Low GI, HGI: High GI

Gamma passing criterion, monitor unit, and beam on time

The gamma passing rate (GP) mean values were similar between RA (99.5 ± 0.46) and IMRT (99.3 ± 0.58). The difference was not statistically significant, with a $P = 0.43$, showing an increase of GPs of approximately 0.2% for the RA

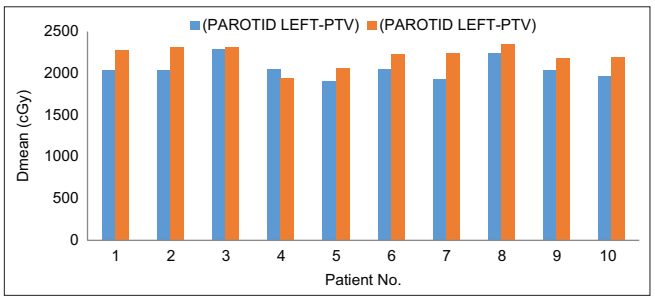

Figure 3: Comparison of the Dmean dose to the left parotid minus planning target volume between RapidArc and intensity-modulated radiation therapy

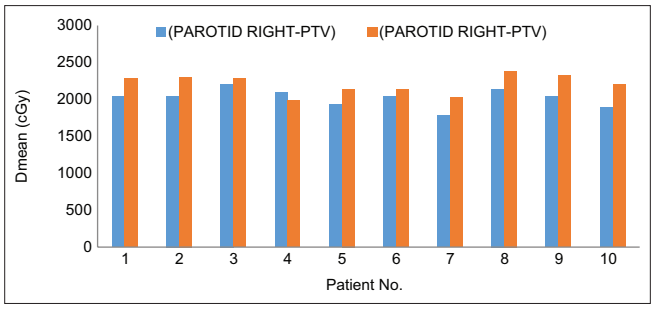

Figure 4: Comparison of the Dmean dose to the right parotid minus planning target volume between RapidArc and intensity-modulated radiation therapy

plans. The mean and SD of MU, beam on time (BoT), and GP are presented in Table 5.

The mean MU for RA was significantly lower at 520.7 ± 50.83 compared to IMRT, which had a mean MU of 1936.2 ± 160.13, with a reduction of approximately 73.1%. The difference was statistically significant, with a $P = 0.00$.

The mean BoT for RA was significantly shorter at 2.44 ± 0.16 min compared to IMRT, which had a mean BoT of 5.02 ± 0.23 min, with a reduction of approximately 51.4%. This difference was also statistically significant, with a $P = 0.00$.

Discussion

Our study aims to explore the efficacy of IMRT and RA techniques in the treatment plan for head-and-neck cancer radiotherapy, especially in tongue cancer. Both the RA and IMRT techniques yielded clinically acceptable plans in all the 10 patients, and these techniques were assessed based on PTV coverage, CI, HI, number of MU, Gmma Passing Index, GI, and OAR sparing.

Several studies conducted on different tumor sites comparing VMAT and IMRT have shown that the PTV coverage is similar across both techniques.[16-19] Peters *et al*. conducted a comparison between IMRT and double-arc VMAT plans, revealing similar outcomes in terms of target coverage. However, they found a statistically significant improvement in conformity with the double-arc RA technique. In addition, the mean total dose was notably lower for VMAT, with values of 15.3 Gy for VMAT compared to 16.0 Gy for IMRT ($P < 0.001$).[20] The current analysis of the dose for the high-dose PTV showed some minor differences between RA and IMRT. For the D_{max}, RA delivered 63.66 ± 0.96 Gy, while IMRT delivered 62.85 ± 0.86 Gy, with a $P = 0.07$, suggesting a slight but not statistically significant difference. The mean dose (D_{mean}) was higher with RA at 60.45 ± 0.47 Gy compared to 59.97 ± 0.42 Gy for IMRT, with a $P = 0.04$, indicating a statistically significant difference favoring RA. Other key metrics, such as $D_{98\%}$, $D_{95\%}$, and $D_{5\%}$, showed no significant differences, indicating both RA and IMRT provided similar coverage of the target volume. For $D_{50\%}$ in the high-dose PTV, the results indicated a significant difference between the two techniques. RA delivered a lower $D_{50\%}$ at 60.04 ± 0.43 Gy compared to IMRT, which delivered 60.59 ± 0.46 Gy, with a $P = 0.02$, suggesting a statistically significant advantage for RA in terms of the median dose to the target volume.

Table 5: Mean and standard deviation of monitor units, beam on time and gamma passing rate

Index	RA	IMRT	*P*
MU	520.7±50.83	1936.2±160.13	0.00
BoT (min)	2.44±0.16	5.02±0.23	0.00
GP	98.94±0.48	98.22±0.69	0.019

RA: RapidArc plan, IMRT: Intensity-modulated radiation therapy, MU: Monitor units, BoT: Beam on Time, GP: Gamma Passing Rate

For the low-dose PTV, no significant differences were observed across metrics such as D_{max}, D_{mean}, $D_{50\%}$, and $D_{2\%}$, with $P > 0.5$ in most cases. This indicates that both RA and IMRT offered comparable dose distributions for the low-dose PTV. Thus, both RA and IMRT achieved similar target coverage for high-dose and low-dose PTVs.

Lee *et al*. compared double-arc VMAT plans with 7-field IMRT plans for nasopharyngeal carcinoma, finding that VMAT achieved comparable target coverage and slightly improved homogeneity over IMRT, with similar conformity and homogeneity indices.[21] The current study observes that the HI and CI values are similar.

Rawal *et al*.[22] reported that the D_{max} to the spinal cord averaged 43.03 Gy for VMAT and 45.14 Gy for IMRT, with the difference found to be statistically insignificant. The maximum point dose to the brainstem was 45.47 Gy for VMAT and 49.93 Gy for IMRT, with the difference being statistically significant. In the current analysis, the average D_{max} received by the spinal cord is less in RA, the average D_{max} dose was 34.96 ± 2.30 Gy for RA and 37.05 ± 2.02 Gy for IMRT with $P = 0.055$. This difference, although not statistically significant, suggests that RA may offer some advantage in reducing the maximum radiation dose delivered to the spinal cord. This could potentially translate to a reduced risk of radiation-induced myelopathy or other complications related to spinal cord damage, particularly in cases where dose limitations to the spinal cord are critical.

Similarly, for PRV spinal cord, the average D_{max} was less in RA with 38.12 ± 2.09 Gy for RA and 40.56 ± 1.93 Gy for IMRT. Although the difference in D_{max} for the PRV spinal cord was not statistically significant, the consistent reduction in dose with RA indicates a trend towards better sparing of critical structures. For brainstem, both plans met the planning objective. D_{max} values were almost similar in RA 32.89 ± 11.42 Gy and IMRT 32.81 ± 10.14 Gy. This difference is found to be insignificant with a $P = 0.98$ and correlates with the present literature.

Patidar *et al*.[23] observed no significant difference in the dose delivered to the vestibulocochlear nerve. The dose to the right VCN was 48.52 Gy for IMRT plans and 48.69 Gy for RA plans,

while the left VCN received doses of 48.89 Gy and 48.56 Gy, respectively, which were statistically insignificant. In the current evaluation, the mean dose was lower with IMRT 3.81 ± 2.33 Gy for the right and 4.23 ± 2.53 Gy for the left compared to RA 5.37 ± 1.72 Gy for the right and 5.77 ± 1.71 Gy for the left, these differences were not statistically significant, with $P = 0.13$ and 0.15 for the right and left cochlea, respectively. The mean dose to the esophagus was also comparable between the two techniques, with RA delivering 26.97 ± 7.94 Gy and IMRT delivering 25.16 ± 7.59 Gy ($P = 0.63$). This lack of significant difference indicates that both techniques provide similar protection for the esophagus. In terms of the mean dose to the lips, both RA 31.73 ± 7.20 Gy and IMRT 31.10 ± 6.32 Gy provided near-identical results ($P = 0.85$). The finding for the larynx, where RA delivered a significantly higher mean dose (42.93 ± 3.23 Gy) compared to IMRT (37.32 ± 4.86 Gy), with a $P = 0.01$.

In the present study, we found that the left parotid gland has a D_{mean} of 29.37 ± 2.99 Gy and 30.65 ± 2.67 Gy in RA and IMRT, respectively, the difference is found to be significant with the $P = 0.007$ whereas in the case of the right parotid gland, the mean doses were found to be 26.62 ± 1.72 Gy and 28.48 ± 1.57 Gy in RA and IMRT respectively with the significant $P = 0.028$. This indicates that we can better spare both parotid glands using the RA technique. These findings align with the recent study conducted by Rawal *et al*.[22] which reported a significant reduction in the mean dose (D_{mean}) delivered to the right and left parotid glands when using VMAT.

The parotid left-PTV Dmean dose is found to be 20.54 ± 1.22 Gy and 22.11 ± 1.25 Gy in the case of RA and IMRT, respectively, with a significant $P = 0.010$, whereas the parotid right-PTV Dmean dose is found to be 20.22 ± 12.27 Gy and 22.07 ± 1.30 Gy in RA and IMRT with significant $P = 0.004$. Similar results were reported by the study done by Syam Kumar *et al*.[24] where they compared the conventional IMRT and single RA treatment planning techniques for head-and-neck cancers.

In our study, we observed that there was a significant reduction in the average number of MU [Figure 5] while moving from IMRT to RA. In IMRT, 1936.2 ± 160.13 MU and RA 520 ± 50.83 MU were calculated after optimizing the plan, and this difference was found to be significant with a $P = 0.00$. Similarly, RA is observed to be significantly faster than IMRT with a $P = 0.00$. The treatment time (TT), i.e., average beam on time (BoT) was found to have an average of 2.44 ± 0.16 min and 5.20 ± 0.23 min in RA and IMRT, respectively, which are similar to the results of Mashhour *et al*.[25] reported in their study. RA beam-on times varied from 2.09 to 2.59 min, while IMRT beam-on times ranged from 4.63 to 5.40 min. As illustrated in Figure 6, RA had shorter treatment durations, highlighting its increased efficiency. The main drawback of IMRT was that it has more MU and larger BoT compared to the RA. Such prolonged BoT may impact the treatment outcomes, particularly for tumors with short repair halftime and have a low alpha/beta ratio.[26] Reducing beam-on time offers several benefits, including improved patient comfort, reduced risk of motion-related errors and thus enhancing the overall treatment experience. Several researchers reported that the reduction in MU will decrease the risk of secondary malignancies. However, an exact estimation of the risk reduction magnitude is not feasible.[27-29]

The gamma passing index was assessed by the criteria of DTA <3 mm and ΔD (dose difference) of ± 3%. In our study, RA had a higher passing criteria with an average gamma passing index of 98.94 ± 0.48% compared to 98.22 ± 0.69% in the case of IMRT. RA was found to have a better gamma passing index than IMRT with a significant difference of value 0.019. Similar results were reported in the studies conducted by Mishra *et al*. and Das *et al*.[30,31]

Kumar *et al*.[13] reported GI values of 3.85 for FF plans and 3.87 for FFF plans, with no statistically significant difference ($P = 0.96$). The GI and HGI of normal tissue were 0.157 ± 0.053 and 3.26 ± 0.48 in RA, and 0.17 ± 0.06 and 3.35 ± 0.73 in IMRT respectively; the difference in these values was not found to be significant as P value was more than 0.05. Whereas the LGI was 1.51 ± 0.12 and 1.63 ± 0.073 in RA and IMRT respectively, and this difference was significant with the $P = 0.02$, indicating that there was a steep dose fall-off from $V_{50\%}$ to $V_{25\%}$ in case of RA.

This study faced limitations, including a small sample size and an imbalance in the gender distribution of participants. To improve reliability, future research should involve a larger

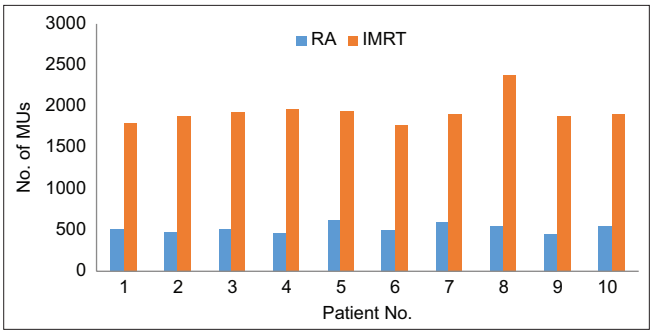

Figure 5: Number of monitor units (MUs) delivered in RapidArc and intensity-modulated radiation therapy

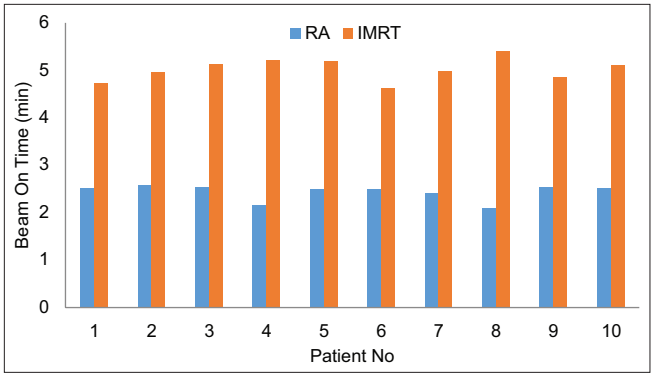

Figure 6: Comparison of beam on time (BoT) between RA and intensity-modulated radiation therapy

population and include extended clinical follow-up to evaluate potential radiotherapy-related toxicities. Additional studies could also focus on the radiobiological impacts and further evaluate the RA technique to reduce TT. The continuous progress in radiation therapy for mid to advanced-stage head-and-neck cancers presents exciting opportunities for future research.

Conclusion

This study demonstrates that RA exhibits significant dosimetric advantages over IMRT. RA required significantly fewer MU and reduced BoT while achieving comparable GPs. In addition, RA presented a lower LGI, suggesting a more favorable dose distribution with reduced intermediate dose exposure to normal tissues. Regarding PTV, RA achieved slightly higher mean doses with comparable homogeneity and conformity indices. However, RA demonstrated lower doses to critical OARs, including the spinal cord, PRV spinal cord, and parotid glands, making it a more favorable option for clinical application.

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Conflicts of interest

There are no conflicts of interest.

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