RESEARCH ARTICLE

RapidArc vs Conventional IMRT for Head and Neck Cancer Irradiation: Is Faster Necessary Better?

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Abstract

   Purpose: The aim of this study was to dosimetrically evaluate and compare double arc RapidArc (RA) with conventional IMRT (7 fields) plans for irradiation of locally advanced head and neck cancers (LAHNC), focusing on target coverage and doses received by organs at risk (OAR). **Methods:** Computed tomography scans of 20 patients with LAHNC were obtained. Contouring of the target volumes and OAR was done. Two plans were made for each patient, one using IMRT and the other double arc RA, and calculated doses to planning target volume (PTV) and OAR were compared. Monitor units for each technique were also calculated. **Results:** PTV coverage was similar with both techniques. The homogeneity index (HI) was higher for the IMRT plans with a value of 0.108 ± 0.021 compared to 0.0975 ± 0.017 for double arc RA plans (p-value of 0.540). The double arc RA plans achieved a better conformity with a CI95%= 1.01 ± 0.021 compared to 1.05 ± 0.057 achieved with the IMRT plans (p-value of 0.036). The average monitor units (MU) ±SD were 930.5 ± 142.42 for the IMRT plans as opposed to 484.25 ± 69.47 for the double arc RA plans (P-value of 0.002). Double arc plans provided better OAR sparing with a significant p-value of 0.002 and 0.004 for the right and left parotid glands, respectively. **Conclusions:** RA is a rapid and accurate technique that uses lower MUs than conventional IMRT. Double arc plans provide better dose conformity, OAR sparing and a more homogeneous target coverage compared to IMRT.

   Keywords: Dosimetric- double arc- IMRT- MUs

Introduction

   Radiation therapy for head and neck cancers has moved and evolved from three-dimensional conformal radiotherapy (3D-CRT) to intensity-modulated radiotherapy (IMRT). The parotid glands sparing benefit have been clinically evaluated and demonstrated (Pow et al., 2006; Braam et al., 2006; Dijkema et al., 2008; Eisbruch et al., 2003) with an improvement of xerostomia for patients treated with IMRT technique compared to 3D-CRT. The main disadvantages of IMRT are the longer time consuming treatment planning process and the need for a complex physics quality assurance. Moreover, IMRT uses a larger number of multiple fixed-angle beams and monitor units (MUs) (Chui et al., 2001; Verbakel et al., 2009), which increases the time of treatment delivery and exposes the patient to low-dose irradiation.

   RapidArc (RA) (Varian Medical Systems, Palo Alto, CA) is a new radiation therapy technique were treatment is delivered using a continuous arc motion of the gantry with simultaneous variation of the multileaf collimator (MLC) position, gantry speed and dose rate (Yu and Tang, 2011; Bhide and Nutting, 2010; Otto 2008) with the ability to produce highly conformal plans in a short duration of time (Lagerwaard et al., 2009; Kjaer-Kristoffersen et al.,

2009). Recently, different planning studies have reported the superiority of RA over conventional IMRT with the ability to produce plans with higher PTV homogeneity, less MU and shorter delivery times than conventional IMRT (Cozzi et al., 2008; Palma et al., 2008; Clivio et al., 2009; Wagner et al., 2009).

   The aim of this study was to dosimetrically evaluate and compare a double arc RA with conventional IMRT plans for head and neck cancers with respect to target coverage and doses received by organs at risk (OAR).

Materials and Methods

   An acceptance from our institutional scientific and ethical committees was taken on the study design. A written consent was taken from all patients before their recruitment in our study.

Patient selection and preparation

   Twenty patients with locally advanced head and neck cancers were selected for this planning study (Table 1).

   Patients underwent a pre-treatment evaluation, including a complete history and physical examination, computed tomography (CT) and/or magnetic resonance imaging (MRI) of head and neck region, direct flexible fibro optic examination, chest X-ray or thoracic CT.

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Patients were aligned in supine position and immobilized on a head support pad using a customized head-and-shoulder shell (S- type, Aquaplast,USA). All patients were scanned from skull vertex to mid-chest, with 2.5 mm slice thickness. Intravenous contrast was used in order to help in the definition of cervical nodes. CT images were then transferred to the Eclipse TPS (v 8.6) via "DICOM" network.

Target volume definition

The gross tumor volume (GTV) is defined as the macroscopic disease including all positive lymph nodes detected by clinical examination and radiological imaging.

The clinical target volume CTVgross disease is composed of GTV with a 10-mm margin. Near the neural structures, the margin is reduced to as little as 1 mm. The CTVsubclinical disease is composed of CTVgross disease in addition to other areas at high risk of harboring microscopic spread. Delineation of cervical lymph node stations was based on the published consensus guidelines (Gregoire et al., 2003).

The planning target volumes (PTV) are generally a 3-mm expansion of each of CTVs to account for potential setup errors and patient motion. Similarly, the margin around the CTV was limited to 1 mm near the neural structures. Two PTVs were generated with different dose levels; PTV boost and PTV elective receiving 70 Gy and 59.4 Gy, respectively.

Dose and Fractionation

Analogous to the RTOG 0225 study (Lee et al., 2009), the dose to the PTV70Gy was prescribed as 70 Gy in 2.12 Gy per fraction, the dose to the PTV59.4Gy was 59.4 Gy in 1.8 Gy per fraction. The prescribed doses were delivered in 33 once daily fractions, five fractions per week using simultaneous integrated boost (SIB).

Radiotherapy treatment planning

For the conventional IMRT plans, 7 fields equidistantly spaced was performed on the Eclipse Planning System (version 8.6.15 from Varian Medical Systems). Beam energy of 6MV X-rays was used. Actual fluence maps are created after the optimal fluence maps are being converted by a leaf motion calculator and the treatment was delivered using the sliding-window technique.

Regarding the RapidArc planning, a plan using a double arc was created. The double arc was performed using 2 co-planar arcs with the first arc in clockwise and the other arc in an anti-clockwise direction (gantry angles from 181 to 179 and 179 to 181◦, respectively). Similar to the IMRT plans, beam energy of 6MV photon beam was used. Optimization and calculations were done on the Eclipse planning system, version 8.6.15 using the anisotropic analytical algorithm (AAA) (Van Esch et al., 2006; Fogliata et al., 2006).

Plan evaluation parameters

A total dose of 70 Gy was delivered to the PTV boost and 59.4 Gy to the elective PTV, in 33 fractions. The goal of the plans was to cover at least 95% of the PTV with the planned prescription dose, whilst keeping the maximal

point dose below 115% of the prescribed dose at each dose level .The plans were normalized to 100% (70 Gy) dose. For the OAR, maximum doses to the brainstem and spinal cord were tried to be kept below 54Gy and 45 Gy, respectively. Regarding the parotid glands, the aim was to restrict the mean dose to below 26Gy.For the oral cavity, the goal was to limit the mean dose to <35Gy.

The DVH for PTV coverage, parotid, spinal cord and brain stem were generated. The PTV coverage was calculated using the ratio of target volume covered by 95% of prescribed isodose line divided by the volume of PTV. Minimum and maximum doses within the PTV, the D98% and D2% values were also recorded (dose received by 98% and 2% of the PTV volume). As per the ICRU 83, the homogeneity index (HI) was calculated using the following equation (D2% −D98%)/D50% (ratio of difference between the dose covering 2% and 98% to the dose received by 50% of the PTV volume). The conformity index (CI95%) was defined as the ratio between the patient volume receiving at least 95% of the prescribed dose and the volume of the PTV. Total MUs for each plan were also documented.

Statistical analysis

All statistical calculations were done using computer programs SPSS (Statistical Package for Social Science; SPSS Inc., Chicago, IL, USA version 19 for Microsoft Windows). P-values less than 0.05 were considered statistically significant. Independent Student t test was studied to evaluate the difference between both techniques.

Results

Conventional IMRT and double arc plans were done for each patient (total of forty plans). Dose-volume histograms (DVHs) were generated for all plans and dosimetric comparative parameters were recorded. Clinically acceptable IMRT and RapidArc plans were fulfilled in all twenty cases and approved by two radiation oncologists.

Target volume coverage and monitor units

PTV coverage was nearly similar in both techniques. Dose in-homogeneity for PTV70Gy described in terms of HI was higher for the IMRT plans with a value of 0.108 ± 0.021 compared to 0.0975 ± 0.017 for the double arc RA plans (p-value of 0.540). Regarding the PTV59.4Gy, the HI was found to be 0.0935 ± 0.030 and 0.0855 ± 0.005 for IMRT and double arc RA plans, respectively (p-value of 0.019)

Looking at the dose conformity which was described in terms of CI95%, the double arc RA plans gave a better conformity with a CI95%= 1.01 ± 0.021 compared to CI95%= 1.05 ± 0.057 achieved with the IMRT plans. However, this was not statistically significant (p-value of 0.036).

Figure 1 shows the dose distribution in an axial view illustrating both techniques for the same patient and Figure 2 shows the DVH for PTV and OARs comparing the two plans.

Regarding the average MU ±SD required to deliver a

Table 1. Patient and Tumor Characteristics

| Patient	Site	Stage	TNM	Vol PTV 59.4Gy (mL)	Vol PTV 70Gy (mL)
P1	Nasopharynx	IV	T2N2	565	203
P2	Oropharynx	IV	T3N2b	513	215
P3	Oropharynx	IV	T4N1	530	131
P4	Hypopharynx	III	T3N1	720	170
P5	Larynx	IV	T3N2c	701	125
P6	Larynx	III	T3N0	699	221
P7	Oral cavity	IV	T3N2b	520	215
P8	Larynx	IV	T4N0	515	150
P9	Nasopharynx	IV	T2N2	570	320
P10	Nasopharynx	IV	T2N2	581	290
P11	Larynx	IV	T2N3	720	180
P12	Oropharynx	IV	T3N1	570	151
P13	Larynx	III	T3N0	550	170
P14	Larynx	IV	T4N0	613	201
P15	Oral cavity	IV	T3N2b	545	267
P16	Nasopharynx	IV	T2N2	585	218
P17	Hypopharynx	III	T3N1	672	191
P18	Larynx	IV	T3N1	685	220
P19	Hypopharynx	IV	T3N2	691	175
P20	Nasopharynx	IV	T2N2	579	301
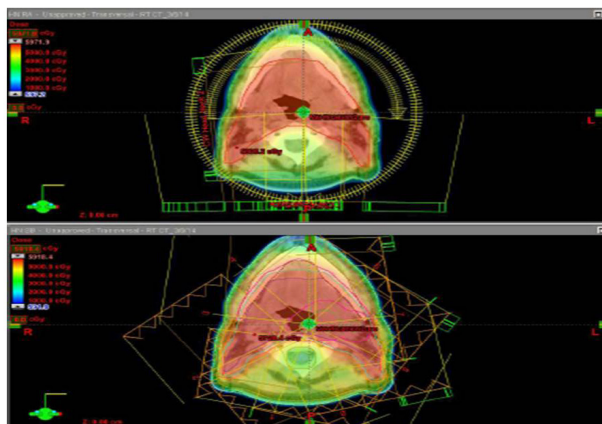
Figure 1. Dose Distribution for an Axial View Created by Doublearc RA Plan (Top) and a Similar CT Cut Planned by IMRT Technique (Bottom)

dose of 2Gy per fraction was 930.5 ± 142.42 for the IMRT plans as opposed to 484.25 ± 69.47 for the double arc RA plans with a statistically significant P-value of 0.002.

Organs at risk
Sparing of the organs at risk was respected in all plans.

Table 2. Dosimetric Outcomes for the PTV70Gy

Parameter	IMRT	Double arc RA plan	P-value (Independent Student t test)
D98% (Gy)	69.13 ± 0.17	69.82 ± 1.03	0.535
D2%(Gy)	77.15 ± 2.84	77.36 ± 1.86	0.186
CI95%	1.05 ± 0.057	1.01 ± 0.021	0.036
HI	0.108 ± 0.021	0.0975 ± 0.017	0.54
MU	930.5 ± 142.42	484.25 ± 69.47	0.002

Table 3. Dosimetric Outcomes for the PTV59.4Gy

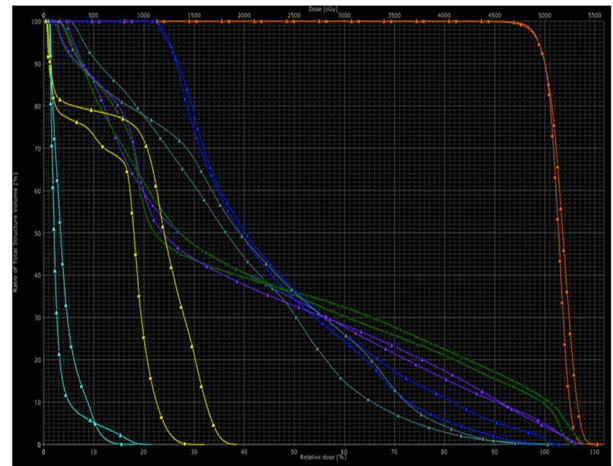| Parameter	IMRT	Double arc RA plan	P-value (Independent Student t test)
D98% (Gy)	61.23 ± 1.147	60.93 ± 1.76	0.071
D2%(Gy)	66.56 ± 1.858	66.38 ± 1.507	0.587
HI	0.0935 ± 0.030	0.0855 ± 0.005	0.019

Figure 2. A Comparative DVHs between IMRT (Triangles) and Double arc RA (Squares). The PTVs are in orange, spinal cord in yellow , brainstem in light blue , the left parotid in purple, right parotid in green and the oral cavity in turquoise.

No big difference was seen between the plans with respect to the maximum dose to the brainstem. The IMRT plans gave a slight higher maximum dose to the brainstem of 51.20 ± 9.62 compared to 50.86 ± 8.47 for the double arc RA plans (p-value of 0.046).

In both plans, the maximum dose to the spinal cord was kept below 45Gy. The maximum dose to the spinal cord was lower in the double arc RA plans (40.12 ± 1.93) when compared to the IMRT plans (42.12 ± 2.55). However, this was not statistically significant (p-value of 0.013).

The study was carried out for right and left parotid glands separately. Mean doses to the parotid glands was kept below 26 Gy in all plans and was better in the double arc RA plans. Regarding the right parotid gland, the mean dose was 17.95 ± 5.48 in the double arc plans versus 20.14 ± 2.15 for the IMRT plans (p-value of 0.002) while for the left parotid gland the mean dose was 18.56 ± 2.7 in the double arc RA plans as opposed to 20.48 ± 2.78 for

Table 4. Dosimetric Outcomes for the Organs at Risk

Organ	Parameter	IMRT	Double arc RA plan	P-value (Independent Student t test)
Spinal Cord	Max. dose(Gy)	42.12 ± 2.55	40.12 ± 1.93	0.013
Brainstem	Max. dose(Gy)	51.20 ± 9.62	50.86 ± 8.47	0.046
Right Parotid	Mean dose(Gy)	20.14 ± 2.15	17.95 ± 5.48	0.002
Left Parotid	Mean dose(Gy)	20.48 ± 2.78	18.56 ± 2.70	0.004
Oral cavity	Mean dose(Gy)	33.22 ± 3.23	31.5 ± 3.45	0.043

the IMRT plans (p-value of 0.004).

With respect to the oral cavity, all plans were able to achieve the objective of limiting the mean dose to < 35Gy. The mean dose to the oral cavity was lower in the double arc RA plans (31.5 ± 3.45) when compared to IMRT plans (33.22 ± 3.23) with an insignificant p-value of 0.043.

Discussion

Planning studies in different tumor sites comparing volumetric modulated arc therapy (VMAT) with conventional IMRT have reported that the plans are comparable but with a shorter delivery time and less MU in the arc delivery (Verbakel et al., 2009; Kjaer-Kristoffersen et al., 2009; Korreman et al., 2009). We did not include single arc plans in our study because planning studies comparing single arc to double arc VMAT plans concluded that the single arc plans were inferior to the double arc in terms of conformity, target coverage, dose homogeneity and OAR sparing (Guckenberger et al., 2009; Bertelsen et al., 2010).

In a study published by Mellon et al., (2015) shows that VMAT had more homogeneous target coverage and a shorter treatment delivery compared with 7 fields IMRT for prostate cancer treatment. In another study published by Mahantshetty et al., (2010) comparing IMRT vs VMAT in the treatment of Ovarian cancers using whole abdomen radiotherapy concluded that PTV homogeneity, conformity index and OAR sparing were better in the cohort of patients treated by RapidArc.

Smet et al., (2015) retrospectively compared sliding window IMRT and RapidArc techniques in locally advanced head and neck carcinomas, CT datasets of 79 patients treated with RapidArc and 78 patients treated with IMRT were included. They concluded that the target coverage with the 95% isodose line was in favor of the RA plans. In addition, dose homogeneity and organ at risk sparing was again better in the arc plans. A 62% reduction in MU was achieved in the RA plans when compared to sliding window IMRT technique. Clinical toxicity outcomes was also assessed in this study showing that the grade of acute toxicity was lower for RA than for sliding window IMRT except for the grade of dermatitis.

The result of our study are in align with the data published by Syam Kumar et al., (2012) were they compared IMRT to single and double arc plans in various head and neck subsites. Though target coverage was almost the same in the three techniques, the Double arc plans gave a better PTV dose homogeneity compared to a single arc and IMRT techniques. Significant sparing of the OARs and healthy tissue was achieved with the double arc plans without compromising target coverage with a better sparing of spinal cord by 4.5% in terms of the maximum dose when compared to the IMRT 9 field and single arc techniques. The main drawback of IMRT observed was the longer treatment time and higher number of monitor units when compared to single and double arc plans. The average MU (±SD) needed to deliver a dose of 2Gy per fraction was 447±45MU and 474±80MU for the single and double arc as opposed to 948±162MU for the 9-Field IMRT plan. The only difference in this study compared to

our data, that the maximum point dose to the brainstem was higher in the double arc plans when compared to the IMRT technique).

Studies by Lee at al., (2011) and Stieler et al., (2011) both pointed out that the main difference between VMAT and IMRT was a significantly faster delivery time and lower number of MUs in favor of VMAT with a minimal advantage of better target coverage and OAR sparing (2%) as compared to the IMRT technique. The main drawback of IMRT is the higher number of MUs and longer delivery time. Such prolonged delivery may have an impact on treatment outcome, particularly for tumors with short repair halftime and have a low alpha/beta ratio (Wang et al., 2003).

Based on the paper of Kry et al., (2005), Hall and Wuu (2003) and Hall (2006) the reduction in monitor units will decrease the risk of secondary malignancies. However, exact estimation of the risk reduction magnitude is not feasible.

The results of our study showed that the RapidArc plans achieved a better conformity and more homogenous target coverage compared to IMRT plans. A suggested explanation for this finding is that summating the two arcs can reduce the hot spots in the PTV and suboptimal dosing by the first arc is compensated by the second one (Verbakel et al., 2009).

In conclusion, at our institution with early RapidArc experience, PTV coverage was nearly similar in both techniques. RA plans achieved a slightly better CI 95% and more homogenous target volume coverage. Better OAR sparing and lower numbers of MUs were also demonstrated in the double arc RA plans when compared to conventional IMRT.

Conflict of interest

On behalf of all authors, the corresponding author states that there is no conflict of interest.

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