RESEARCH ARTICLE

Dosimetric Comparison between Single and Dual Arc-Volumetric Modulated Arc Radiotherapy and Intensity Modulated Radiotherapy for Nasopharyngeal Carcinoma Using a Simultaneous Integrated Boost Technique

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Abstract

Backround: Plan quality and performance of dual arc (DA) volumetric modulated arc therapy (VMAT) , single arc (SA) VMAT and nine field (9F) intensity modulated radiotherapy were compared using a simultaneous integrated boost (SIB) technique. **Methods:** Twelve patients treated in Elekta Synergy Platform (mlci2) by 9F-IMRT were replanned with SA/DA-VMAT using a CMS Monaco Treatment Planning System (TPS) with Monte Carlo simulation. Target delineation was conducted as per Radiation Therapy Oncology Protocols (RTOG0225 and 0615). A 70Gy dose prescribed to PTV70 and 61Gy to PTV61 in 33 fractions was applied for the SIB technique. The conformity index (CI) and homogeneity index (HI) for targets and the mean dose and maximum dose for OAR's, treatment delivery time (min), monitor units (MUs) per fraction, normal tissue integral dose and patient specific quality assurance were analysed. **Results:** Acceptable target coverage was achieved for PTV70 and PTV61 with all the planning techniques. No significant differences were observed except for D98 (PTV61), CI(PTV70) and HI(PTV61). Maximum dose (Dmax) to the spinal cord was lower in DA-VMAT than 9F-IMRT (p=0.002) and SA-VMAT (p=0.001). D50 (%) of parotid glands was better controlled by 9F-IMRT (p=0.001) and DA-VMAT (p=0.001) than SA-VMAT. A lower mean dose to the larynx was achieved with 9F-IMRT (P=0.001) and DA-VMAT (p=0.001) than with SA-VMAT. DA-VMAT achieved higher CI of PTV70 (P= 0.005) than SA-VMAT. For PTV61, DA-VMAT (P=0.001) and 9F-IMRT (P=0.001) achieved better HI than SA-VMAT. The average treatment delivery times were 7.67mins, 3.35 mins, 4.65 mins for 9F- IMRT, SA-VMAT and DA-VMAT, respectively. No significant difference were observed in MU/fr (p=0.9) and NTID (P=0.90) and the patient quality assurance pass rates were >95% (gamma analysis Ґ3mm, 3%). **Conclusion:** DA-VMAT showed better conformity over target dose and spared the OARs better or equal to IMRT. SA-VMAT could not spare the OARs well. DA-VMAT offered shorter delivery time than IMRT without compromising the plan quality.

Keywords: IMRT- VMAT- NPC- SIB

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Introduction

Globally Nasopharynx cancer or Nasopharyngeal Carcinoma (NPC) is less in the population. The age –adjusted incidence rate (per 100,000 people per year) among men ranges from 0.6 in the United States and Japan to 17.2 among Indians and 26.9 in Southern China (Curado et al., 2007). Male to female incidence ratio is 2:1 to 3:1 (Ferlay et al., 2010). NPC is widely seen in natives of southern China, Southeast Asia, the Arctic, Middle East/North Africa and Northeast part of India (Mishra and Meherotra , 2013). NPC is a type of Squamous cell carcinoma which appears above the pharynx and behind the nasal cavity. NPC's are diagnosed at advanced stage because of its silent deep seated locations. Epstein - Barr virus, genetic, environmental and dietary factors are associated with aetiology of NPC. Radiotherapy (RT) being the primary modality in NPC, results a high rate of local control. Treating a nasopharyngeal Carcinoma using radiation is complicated due to close proximity of critical organs. It is essential to choose the best technique that can deliver efficacious dose to the tumour volume and minimal dose to organ at risk (OAR's) and normal tissue. Intensity Modulated Radiation Therapy (IMRT) can deliver uniform dose distribution in three dimensional by using non uniform fluence which gives better improvements in the quality of life (Lakhanpal et al., 2015). Further improvements in IMRT were reported

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to deliver different doses to different target volumes commonly known as Simultaneous Integrated Boost IMRT (SIB-IMRT). Another variation of IMRT which is now commonly used worldwide is Volumetric Modulated Arc Therapy (VMAT) (Kam et al., 2004; Otto et al., 2008). Comparative study of VMAT using Elekta linac with Monaco Treatment Planning System (TPS) (Computerized Medical Systems (CMS) (Lafond et al., 2014) is rarely reported in literature. In this investigation, we compared the plan outcome for nasopharyngeal carcinoma between IMRT and VMAT incorporating the SIB-IMRT technique using Monaco (CMS Inc., St. Louis, MO) TPS in Elekta Synergy Platform Linear Accelerator with mlci2.

Materials and Methods

Study population and conditions

Twelve patients who were treated with a curative intent for nasopharyngeal carcinoma with a nine fields Intensity Modulated Radiation Therapy (IMRT) through Dynamic delivery technique were included in this study. The mean age of patients was 48years with a range of 28-66years. The clinical stage distribution according to the American Joint Committee on Cancer (AJCC) 7th edition (Edge et al., 2010) staging system was III in 8 (67%), and IV a–b in 4 (33%). Planning was originally done with Computerized Medical Systems (CMS) Monaco Treatment Planning System (TPS) (Lafond et al., 2014) and the same plans were reoptimized and dose calculations done with Single Arc Volumetric Modulated Arc Therapy (SA-VMAT) and Dual Arc Volumetric Modulated Arc Therapy (DA-VMAT) in the same planning systems. Treatment plans that scored at least 95% of prescribed dose (D95) to 95% volume of target were considered as eligible for plan comparison. OARs constraints were followed as shown in Tabel 1. For IMRT and VMAT plans dose constraints were adjusted and re-optimized until they achieved the acceptable target coverage. For all patient treatments, Ethical Committee Approval was taken from Institutional Ethics Committee (Reg.No.ECR/596/Inst/AP/2014).

All Patients were immobilized by using a five clamp head and neck thermoplastic mask in All in One (AIO) Board and 2.5mm thick Computed Tomography (CT) images were obtained on 16 slice CT simulator (Bright Speed RT16; GE Medical Systems, Milwaukee, WI, USA). Target volumes defined were based on recommended guidelines by International Commission of Radiation and Units (ICRU) 50 and ICRU 62. (ICRU 50., 1993 and ICRU 62., 1993). Target delineation was done as per Radiation Therapy Oncology (RTOG) Protocols O225 and 0615 (Lee et al., 2009) on CMS, Focal Sim (ver.4.80) contouring work station. Primary nasopharyngeal tumour (GTV_NP) and lymph nodes (GTV_N) were included in the gross tumour volume (GTV) as per RTOG guidelines. Planning Target Volume (PTV) 70 created with 0.5-1cm uniform margin around the GTV. The Clinical Target Volume (CTV) 61 encompassed the GTV with 1- 1.5 cm margin, and high risk nodal levels. As per RTOG 0225 guidelines, CTV61 includes the entire nasopharynx, high risk lymph nodal regions, clivus, skull base, pterygoid fossae, parapharyngeal space, inferior sphenoid sinus and posterior third of the nasal cavity and maxillary sinuses. PTV61 was created with a 0.3 cm uniform margin around CTV61 for patient setup error and Intra fractional movement of the patient. The PTV volumes were ranged from 45 to 168.3cc (93.7 ± 47.2) for PTV70 and 246-684 cc (464+/-133) for PTV61. The prescribed dose was 70Gy to the PTV70, and 61Gy to the PTV61. RT was delivered using simultaneous integrated boost (SIB) technique containing 33 fractions as 2.12Gy per fraction to PTV70 and 1.85Gy per fraction to PTV61. Conformity Index (CI) and Homogeneity Index (HI) were calculated for PTV70 and PTV61.Planning risk volumes (PRV's) created for brainstem and spinal cord in accordance with ICRU62 reports.

Linac and the Record and Verify(RandV) system

All twelve patients were treated on Elekta Synergy Platform linac (MLCi2) with the help of MOSAIQ (v. 1.60Q3) Record and Verify system (R and V; IMPAC Medical Systems, Inc., Sunnyvale, CA, USA). Treatment plans were transferred via Digital Imaging and Communications in Medicine (DICOM) RT from the TPS to the MOSAIQ. 6 MV (Mega Voltage) photon beams were used to generate IMRT and VMAT plans. Synergy Platform linac equipped with 40 pairs multi leaf collimator (mlc) width is 1cm at isocentre with speed was 2.0 cm/s in both static and dynamic mode. Leaf travels total distance of 32.5cm with minimum gaps of 0.50cm and minimum MU/cm of 0.30 MU/cm without interdigitize. Upper jaws act as a backup jaws that follow the last MLC position. Lower jaws are conventional jaws. Both jaws form maximum field size of 40× 40 cm^2 with maximum speed of 1.5 cm/s. The gantry rotates with maximal speed of 6°/s with variable dose rate delivery up to 600MU/min. In Elekta Synergy Platform, dose rates usually deviate by ± 20%. The MlCi2 incorporate with continuous variable dose rate (CVDR) (Bertelsen et al., 2011) which allows the dose rate to be adjusted to its ideal MU value during the delivery of VMAT. The combination of the dose rate, gantry speed, and leaf speed is controlled by the linac control system Precise Desktop 7.01 during VMAT delivery (Dobler et al., 2010)

Treatment planning system

All the treated plans (9F-Dynamic IMRT) were performed and Replans were done with the use of Monaco TPS.

Optimization runs in two phases

In the first phase system produces the "ideal" fluence distribution calculated with high precision pencil beam dose calculation algorithm for the cost functions which we set for target and OARs. After optimization, Monaco computes a measure of the interdependence among constraints and target objectives to evaluate the optimization parameters (sensitivity analysis). It offers constrained optimization, meaning that the optimizer must vary the plan to optimize the dose corresponding to the objectives (i.e., dose to the target volume) while meeting the hard constraints (e.g., on organs at risk).

The second stage performs the segmentation, which includes optimizing the segment shapes and weights.

During the second stage for IMRT plans, the system uses Monte Carlo simulations during the optimization (Chetty et al., 2007; Semenenko et al., 2008). For VMAT plans during the second stage of optimization Monaco calculates the dynamic delivery arcs.

The Monaco planning calculation based on cost functions (mathematical formula that computes a penalty for violating an objective or constraint) which relate the effect of a given dose distribution to one single value. This value can be an equivalent uniform dose (for Target EUD or serial organs) or can be an effective volume (e.g. parallel models), or it can be a mean value like the root mean square for overdose quadratic constraints. Biological cost function, Target EUD (Equivalent Uniform Dose) used for target, models the cell sensitivity against the dose rate (linear quadratic model). Apart from objectives, Conformality (Normal Tissue). Maximum Dose, Overdose DVH, Quadratic overdose penalty were used as physical constraints for OARs (Semenenko et al., 2008).

Planning Scheme

In IMRT, 9 coplanar beams were set up, started from 200° to 160° beam angles with interval space of 40° and Couch and collimator angles were kept as 0° for both the plans. The treatment plans were delivered in dynamic mode (dmlc) (Alaei et al., 2004). IMRT plans were done with maximum control points (segments) of 30 per beam with average target dose rate of 150 MU/min, the low dose rate (120-150) improves plan quality. Minimum segments width chosen was 0.5cm and fluence smoothing (Giorgia et al., 2007) kept as medium. The calculation parameters followed grid spacing of 0.3 cm, beamlet width of 0.3cm and Monte Carlo standard deviation of 1% per plan VMAT (Volumetric Modulated Arc Therapy), the gantry and MLC move continuously when the beam is "ON" which is nothing but a type of rotational IMRT. Variable speed of gantry movement and variable level of dose rates were used to achieve variable MU per degree during treatment delivery. The advantage of VMAT is a reduction in treatment time compared to IMRT techniques (Swamy et al., 2014). VMAT is feasible only in treatment machine which has dynamic delivery mode. In this investigation, single arc as well as dual arc for VMAT plans were used. For SA-VMAT, the gantry angle was chosen as -180° to +180° in a clockwise direction with the increment of 24°. "Increment is the angular spacing between sampled fluence profiles in first stage" (Nithya et al., 2014). For DA-VMAT, the gantry angles used from -180° to +180° for the first arc in clockwise direction and +180° to -180° in counter clockwise direction for the second arc with increment of 24 In Monaco TPS, VMAT runs in Segment shape Optimization (SSO) where the target dose rate will be auto selected by the system. VMAT follows sweep sequencer similar to sliding window where the arc will not project target volumes, however optimization will try to deliver the dose to desirable dose distribution to target and OARs.

The total number of MLC segments for VMAT is decided by the length of the arc and for IMRT is decided by the number of beams and number of segments for each beam (Verbakel et al., 2009).

Plan Evaluation and Comparison

Plan quality indices of IMRT and VMAT treatment plans were analysed by Dose Volume Histogram (DVH) which represents the whole dose-volume information in a two dimensional single curves. Coverage of PTV volumes and OARs mean (Dmean) and maximum doses (Dmax), Conformity index (CI) and homogeneity index (HI) were analysed for all the plans.

For all the patients, the total no of Segments, total MUS/fr were noted and delivery times for each plan were recorded and compared.

• *Conformity Index (CI)*

The degree of Conformity was evaluated with a Conformity Index (CI) that was defined as follows:

$$\mathbf{CI = (V_{Rx}^{2} / TV^{*} V_{RI})}$$

where $\mathbf{V_{Rx}}$ = Target volume covered by dose of interest. **TV** = target volume. $\mathbf{V_{RI}}$ =total volume of dose of interest. The ideal value is 1.

The Conformity Index (CI) describes the degree to which the prescribed isodose volume conforms to the shape and size of the target volume. (Van't Riet et al., 1997).

• *Homogeneity index (HI)*

Homogeneity Index (HI) formula is HI=(D5%)/(D95%). The D5% is the dose delivered to the hottest 5% volume of the tissue. The D95% is the minimum dose received by 95% volume of the structure (Kataria et al., 2012). The homogeneity Index (HI) describes the uniformity of dose within a target volume and is directly calculated from the statistics of the Dose Volume Histogram. HI close to unity represents the ideal situation.

• *Normal Tissue Integral Dose*

Healthy Tissue or Normal Tissue is defined as the total volume of the body minus target volumes. Normal Tissue Integral Dose (NTID) is the product of Normal Tissue Mean dose and its volume. The unit is Gycm3 (Ekambaram et al., 2015).

Statistical analysis

Statistical comparison of PTV dose coverage and dose sparing of OARs between IMRT and VMAT plans was performed using ANOVA single factor data analysis software and Post hoc turkey's test with Statistical Package for Social Sciences (SPSS) version12.0 (SPSS Inc., Chicago, USA). Results were reported as mean and standard deviation. Statistical significance value kept at $p < 0.05$. Above the stated p value indicates no significance between the two sets.

Delivery evaluation

Patient specific Quality assurance (QA) was performed using PTWSeven_29 2D Array with OCTAVIUS phantom (density - 1.04g/cm3). The PTW detector system contains 729 vented ionization chambers with sensitive volume

of 0.125cc and resolution of 5mm. Distance between chambers center is 10mm. It has a central cavity ($30 \times 30 \times 2.2$ cm^3) for the insertion 2D Array detectors. Verification quality assurance (QA) plans patient had been created in the scanned CT images of PTW seven29 2D Array with Octavius Phantom. The OCTAVIUS phantom was used in order to carry out the measurements in actual gantry angle .For the compensation of couch attenuation, an 8 mm thick air-equivalent cavity was made under the phantom so it is feasible to account angular dependency. Verisoft software (PTW, Germany) used for dose comparison and gamma (Γ) evaluations (31) with a Dose difference (DD) of 3% and Distance to agreement (DTA) of 3mm criteria.(Low et al.,1998)

Results

Table 2. shows that all planning techniques (9F-IMRT/SA-VMAT/DA-VMAT) achieved acceptable target coverage. No Significant differences on Dmean, Dmax, D95 of target volumes (PTV70andPTV61) and D98 of PTV70 were observed. Significant differences were observed for D98 (PTV61), CI (PTV70) and HI (PTV61).

Table 3. Shows the dose comparison of OAR's among three treatment planning modalities. Spinal Cord received lower dose in DA-VMAT compared to other two techniques. 9F-IMRT and DA-VMAT achieved similar protection on both the Parotids except for V30 of RT Parotid. Larynx was equally spared by IMRT and DA-VMAT and showed a better protection than SA-VMAT (p=0.001). No statistical significant differences were observed on other Organ at Risks (Optic Chiasm, Eyes, and lenses) and Normal Tissue Integral Dose (NTID).

The average treatment delivery time was 7.67 ± 0.7 mins, 3.35 ± 0.7mins, 4.3 ± 0.4mins for 9F-IMRT, SA-VMAT and DA-VMAT respectively. Although significant difference was observed in treatment time (p = <0.001) no significant difference was observed in MU/fr. Patient quality assurance pass rates were > 95% {(Gamma analysis (Γ3mm, 3%)} for all the plans.

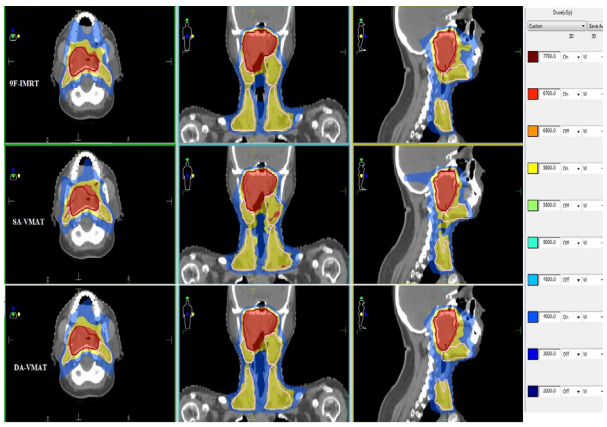

Figure 1. Dose Distributions on Transverse, Coronal and Sagittal Views for One Representative Nasopharyngeal Carcinoma Sample Planned by 9F-IMRT,SA-VMAT, DA-VMAT. 4,000cgy Dose Spillage is Shown in All the View

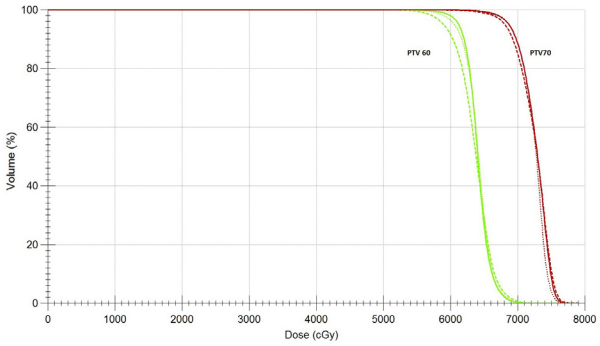

Figure 2. The Mean DVHs for the PTV 70 and PTV61 Comparing 9F-IMRT,SA-VMAT and DA-VMAT . 9F-IMRT, thick line; SA-VMAT, thin line; DA-VMAT, dotted line

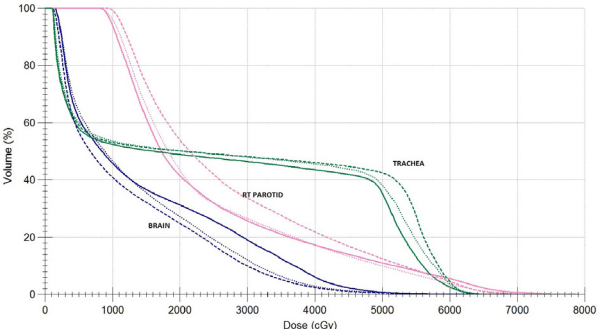

Figure 3.The Mean DVHs for Brain, RT Parotid and Trachea (OAR's). 9F-IMRT, thick line; SA-VMAT, thin line; DA-VMAT, dotted line

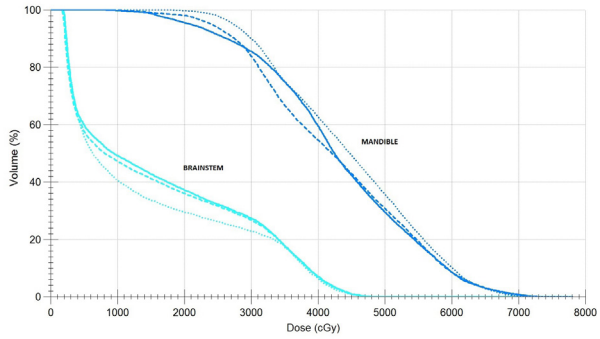

Figure 4.The Mean DVHs for Brain Stem and Mandible (OAR's). 9F-IMRT, thick line; SA-VMAT, thin line; DA-VMAT, dotted line

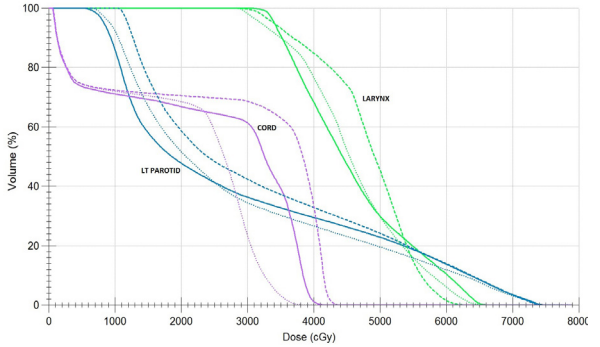

Figure 5. The Mmean DVHs for Lt Parotid, Cord and Larynx (OAR's) 9F-IMRT, thick line; SA-VMAT, thin line; DA-VMAT, dotted line

Table 1. Dose Constraints for OARs and End Points for Nasopharyngeal Carcinoma

Structure	End point	Dose (Gy)	Planning Aim
Brain stem	Necrosis	54	1% of the PRV should not exceed 60Gy
Brain	Necrosis	60	1% of the normal brain should not exeed 60Gy
Chiasm	Blindness	60	0.03cc of the chiasm should not exceed 60Gy
Spinal cord	Myelitis	45	or 1cc of PRV should not exceed 50Gy
Eyes	Blindness	50	Mean dose less than 50Gy
Lens	Cataract	10	As low as possible
Optic nerves	Blindness	54	0.03 cc should not exceed 54Gy
Mandibles	Osteo radio necrosis	70	1% of the mandible should not exceed 70Gy
Parotids	Xerostima	26	Mean dose ≤26Gy D50 should be ≤ 30 Gy for one gland
Oral Cavity(excluding PTV)	late mucosal necrosis	40	Mean dose less than 40Gy
Unspecified Tissue		72	1cc of normal tissue outside the PTV should not recieve d not recieve ≥ 110 % of PTV

*PTV-Planning Target Volume; *PRV-Planning Risk Volume; RTOG Protocol 0225

Discussion

Revolution of new radiotherapy techniques and treatment modalities improved the quality of treatment. Control of early stage disease with radiotherapy alone is usually successful with 5 year survival of 87-96% in stage I-II. However, despite aggressive radiotherapy, the 5 year survival rate of loco regionally advanced disease is 30-45% (Cooper et al., 2000). IMRT has been a standard technique for head and neck cancers where a non uniform dose from multiple beams create conformal uniform dose to targets with minimal complication to surrounding OAR's. It has the advantage to treat multiple targets simultaneously. Arc based IMRT (VMAT) able to execute Intensity modulation during Gantry rotation with the aid of variable speed of gantry, mlc movements and dose rate.

According to recent literature, "IMRT is a safe and effective treatment modality, and well tolerated by patients in the treatment of nasopharyngeal carcinoma" (Ozdemir et al., 2014) and well encouraged by Phua et al., (2013)

According to Dobler et al., (2010) "Single-Arc VMAT plans were dosimetrically equivalent to fixed-beam IMRT plans with significantly improved delivery efficiency for prostatic irradiation with seminal vesicle and/or lymph node involvement". Single arc VMAT plan in head and neck cancers generate a better plan for localized single target. For multiple target volumes, SA-VMAT achieves poor conformity (Bortfeld et al., 2009). Choosing an additional arc decreases the complexity and increases the plan efficiency. In some cases, single arc VMAT equally perform as dual arc VMAT but it again subjective to the complexity of target shape.

In our study, all the treatment modalities provided a clinically acceptable plan quality for all planning targets. DA-VMAT achieved slightly better target coverage than 9F-IMRT and SA-VMAT with smaller mean and standard deviations, the differences were not significant. This findings were similar with Lee et al., (2012) study in which they showed that DA-VMAT gave better target coverage than SA-VMAT.

Both DA-VMAT and IMRT achieved better conformity index for PTV 70 than SA-VMAT plans. (Ekambaram et al., 2015). DA-VMAT showed higher conformity index

Table 2. Comparison of PTV Dose Coverage between 9F-IMRT ,SA-VMAT and DA-VMAT

Parameters	SA-VMAT	DA-VMAT	p -value		
			9F-IMRT VS SA-VMAT	9F-IMRT VS DA-VMAT	SA-VMAT VS DA-VMAT
Dmean(Gy)PTV70	69.8 ± 3.72	71.17 ± 0.84	0.2	0.9	0.365
D95(Gy)PTV70	67.45 ± 0.85	68.4 ± 1.26	0.53	0.539	0.097
D98(Gy)(PTV70)	66.23 ± 0.74	67.68 ± 2.2	0.262	0.779	0.0805
Dmax(Gy)(PTV70)	77.1 ± 1.8	76.53 ± 0.86	0.757	0.9	0.603
Dmean(Gy)PTV61	62.50 ± 0.53	62.17 ± 1.09	0.9	0.689	0.675
D95(Gy)PTV61	58.4 ± 0.52	59.6 ± 1.06	0.188	0.776	0.506
D98(Gy)(PTV61)	56.86 ± 0.78	60.7 ± 4.3	0.31	0.17	0.006
Dmax(Gy)(PTV61)	73.36 ± 1.2	73.64 ± 2.37	0.511	0.33	0.9
CI (PTV70)	0.6 ± 0.08	0.71 ± 0.06	0.0093	0.8999	0.005
CI(PTV61)	0.73 ± 0.12	0.73 ± 0.05	0.797	0.822	0.9
HI(PTV70)	1.10 ± 0.02	1.09 ± 0.02	0.36	0.9	0.6
HI (PTV61)	1.149 ± 0.01	1.11 ± 0.01	0.001	0.343	0.001

Table 3.Details of OARs Dose among 9F-IMRT,SA-VMAT and DA-VMAT

OARs	Parameters	9F IMRT	SA-VMAT	DA- VMAT	Sig-P value		
					9F-IMRT VS SA-VMAT	9F-IMRT VS DA-VMAT	SA-VMAT VS DA-VMAT
Brain stem	Dmax(Gy)	49.13 ± 2.1	49.66 ± 5.1	46.16 ± 4.55	0.9	0.361	0.247
Brain	D1(Gy)	49.05 ± 4.57	49.5 ± 6.5	47.96 ± 3	0.9	0.896	0.764
Spinal cord	Dmax (Gy)	40.7 ± 2.2	42.6 ± 1.26	37.2 ± 2.56	0.123	0.002	0.001
Optic Chiasm	Dmax (Gy)	19.7 ± 9.2	21.6 ± 8.26	20.2± 6.56	0.29	0.245	0.28
Rt Eye	Dmax (Gy)	13.7 ± 9.6	14.5 ± 10.8	11.3 ± 12.5	0.97	0.96	0.99
Lt Eye	Dmax (Gy)	14.8 ± 13.2	15.8 ± 15.2	14.8 ± 13.2	0.96	0.99	0.95
Rt Lens	Dmax (Gy)	4.7 ± 1.2	4.5 ± 1.8	4.3 ± 1.5	0.9	0.9	0.9
Lt Lens	Dmax (Gy)	4.7 ± 1.2	4.5 ± 1.8	4.3 ± 1.5	0.9	0.9	0.9
Mandible	Dmax (Gy)	64.72 ± 2.3	61.61 ± 8.5	63.36 ± 2.5	0.476	0.832	0.794
RT Parotid	Mean (Gy)	28.2 ± 2.2	34.0 ± 4.4	27.0 ± 2.2	<0.01	0.9	<0.01
	D50 (Gy)	21.5 ± 1.9	35.6 ± 5.8	22.6 ± 2.0	<0.01	0.514	<0.01
	V30 (%)	37.1 ± 4.8	60 ± 12	36.0 ± 3.5	<0.01	0.887	<0.01
LT Parotid	Mean (Gy)	29.78 ± 2.62	36.20 ±2.53	28.1 ± 2	<0.01	0.668	<0.01
	D50 (Gy)	23.1 ± 2.75	32.3 ± 6.2	24 .2 ± 2	<0.01	0.77	<0.01
	V30(%)	41.4 ± 7.1	54.2 ±14.22	42.3 ±3.22	<0.01	0.9	<0.01
Larynx	Mean (Gy)	44.53 ±1.25	49.22± 3.46	45.55±1.57	0.001	0.588	0.001
Trachea	Mean (Gy)	30.85 ±8.61	30.77± 5.50	29.33± 5.09	0.9	0.885	0.86
Oral cavity (Excluding PTV)	Mean (Gy)	47.3± 4.36	49.44± 5.19	46.77±3.16	0.492	0.9	0.385
Unspecified Tissue	Mean(Gy)	12.47±2.19	12.91±2.51	12.64 ± 2.56	0.9	0.9	0.9
	V5 (%)	43.88±6.65	45.55±12.5	42.51 ± 4.35	0.9	0.9	0.75
Normal Tissue Integral Dose	$x10^5$ $Gycm^3$	1.334 ± 1.6	1.334 ± 3.3	1.345 ± 4.8	0.9	0.9	0.9

Table 4. Comparison of Planning and Delivery Efficiency

Parameters	9F-IMRT	SA-VMAT	DA-VMAT	P value
Monitor Units(MUs)	992 ± 114	926 ± 91	931 ± 98	0.9
Delivery Time (mins)	7.67 ± 0.7	3.35 ± 0.70	4.65 ± 0.40	<0.001

for PTV 70than IMRT, the difference was not significant. IMRT achieved higher conformity Index for PTV61than other techniques, the differences were not significant. This findings were similar with Vanetti E et al., (2009) study in which they compared volumetric modulated arc radiotherapy with fixed field IMRT for head and Neck cancers and reported that VMAT plans and IMRT plans were equivalent in terms of CI.

Ninge et al., (2013) claimed that "single arc Vmat is enough for nasopharyngeal carcinomas" and they had achieved single arc Vmat plan satisfactorily with the use of smaller and faster MLCs as well as the Continuous Variable Dose rate (CVDR) were used as add on parameter to meet the plan requirements. This was contrary to our results where SA-VMAT achieved inferior target conformity for PTV70.

No significant differences were observed in Homogeneity Index for PTV 70 among all techniques. For PTV61, IMRT and DA-VMAT showed better HI than SA-VMAT.

For parotid glands, it was difficult to control the parotid mean dose within the tolerance limit. Sparing the parotid glands depend on the involvement of the parotid gland in the PTV. Mean dose (Dmean) to the parotid glands were > 26 Gy for all plans and doses were compromised. These results were similar with literature (Nithya et al., 2014 ; Zheng et al., 2011).D50 to Parotid glands were not met by SA-VMAT. This was similar with Ninge et al., (2013) study; they observed that one-arc VMAT was worst in parotids protection.

Both 9F-IMRT and DA-VMAT plans achieved better dose sparing for parotid glands than SA-VMAT. DA-VMAT showed reduction of mean dose (Dmean) and D50 than 9F-IMRT. V30 for parotid glands were higher for DA-VMAT than 9F-IMRT.

Larynx was equally spared by IMRT and DA-VMAT. Brain and Brainstem were spared better by DA-VMAT. A dose reduction of 3Gy for brainstem Maximum dose and 2Gy for brain (D1) were achieved by DA-VMAT than 9F-IMRT and SA-VMAT.

No differences were observed in Dmean, V5 and Integral Dose (ID) of Normal Tissue.

Spinal cord was better spared by DA-VMAT.A dose reduction of 3Gy and 5Gy were observed by DA- VMAT than IMRT and SA-VMAT respectively .

Table 4 shows average treatment delivery time were 7.1 mins, 3.24 mins, 4.3 mins for 9F-IMRT, SA-VMAT

and DA-VMAT respectively. DA-VMAT reduced the treatment time by 40% than 9F-IMRT, and increased treatment time by 25% than SA-VMAT. Table 4. showed no significant Difference was observed in MU's for all the plans. These results were different from the studies (Verbakel et al., 2009; White et al., 2013) which reported less MU's for VMAT than IMRT. In our study, dual arc VMAT treatment delivery time was less than the 9F-IMRT. This is similar with White et al., (2013) study in which they compared Rapid Arc VMAT Technique and IMRT for NPC and showed that Rapid Arc Technique offers improved dose distributions and faster treatment delivery.

All the plans delivered in Elekta Platform (MLCi2) with the Continuous Variable Dose rate (CVDR). CVDR reduces the treatment time 20-30% than Binned variable dose rate (BVDR) Where in BVDR; dose rate will jump from one level to another level from one dose rate to double of its initial one. In CVDR dose rate will be continuous which helps for smooth and faster treatment delivery

Apart from the treatment techniques, to get a better plan quality, machine specification, planning system, calculation algorithm, smoothening of contours play a major role.

In Conclusion, increasing the number of arcs provides additional flexibility in shaping the dose distribution. All major planning vendors now offer inverse planning solutions for VMAT with varying levels of robustness. Initial work on VMAT has largely focused on single arc coplanar delivery. The advantages of using multiple arcs and non-coplanar beams are now being more fully explored.

In comparison, of three techniques, DA-VMAT showed better target dose coverage and achieved better or equal performance in sparing OARs among the other techniques. SA-VMAT could not spare the OARs well. DA-VMAT offered shorter delivery time than IMRT without compromising the plan quality

Conflict of Interest

There is no conflict of Interest.

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