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Original Research

Dosimetric Comparison of Conventional 3D-Conformal Radiotherapy (3DCRT) and Volumetric-Modulated Arc Therapy (VMAT) for Head and Neck Cancer

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Background and objective: Advancements in radiation oncology have improved outcomes for patients with head and neck cancer, enabling dose escalation to tumors while minimizing exposure to surrounding healthy tissues. This study aimed to compare the dosimetric characteristics of radiotherapy treatment planning using 3DCRT and VMAT for head and neck cancer.

Methods: This prospective study included 50 patients with head and neck cancer. Twenty-five patients were treated with 3DCRT, and 25 were treated with VMAT. Both treatment plans were evaluated to compare the dosimetric efficiency of VMAT and 3DCRT in terms of planning target volume (PTV) coverage, homogeneity index, conformity index, and doses to organs at risk (OARs).

Results: The dose to 98% of the PTV (D98%) for PTV66 was 59.39 Gy for VMAT and 51.82 Gy for 3DCRT. The conformity index was 1.0816 for VMAT and 1.4472 for 3DCRT plans, with a statistically significant difference. The homogeneity index was 0.1473 for VMAT and 0.2997 for 3DCRT, indicating that VMAT plans were more homogeneous. OAR sparing was also better with VMAT compared to 3DCRT, particularly for OARs in close proximity to the target volume, such as the parotid glands, brainstem, and optic nerve.

Conclusion: Compared to 3DCRT plans, VMAT plans demonstrated significantly better target coverage, homogeneity, and dose conformity. Doses to OARs, such as the spinal cord and parotid glands, were also reduced. Additionally, VMAT treatment delivery was more efficient.

Introduction

In present era incidence of head and neck cancer is on hike in developing countries and worldwide

it is ranked seventh leading [1] cancer in which 70 % of them necessities radiotherapy as definitive or post-operative radiation simultaneously with chemotherapy or targeted agents.

Advancement in technology led to evolution from 2D Radiotherapy to Three-Dimensional Conformal Radiotherapy (3DCRT) which delivers a high dose volume that is shaped to confirm to the target volume while minimizing the dose to critical normal tissues in the adjacent area but accurate delineation of the target is critical [2]. Further progress in conformal radiotherapy led to evolution of Volumetric modulated arc therapy (VMAT) an advanced form of high precision conformal RT in which radiation is delivered in a continuous arc as the linear accelerator rotates around the patient, while the beam is modulated via multi leaf collimator , variable dose rate and variable gantry speeds through computer controlled optimization to achieve desired dose distribution which reduce treatment delivery time and has potential to achieve highly conformal doses distribution with improved target volume coverage and sparing of normal tissues [3].

There is very limited literature regarding comparative study of 3DCRT and VMAT, therefore prospective clinical study was conducted to compare conventional 3DCRT and VMAT in terms of PTV coverage, conformity index, homogeneity index and Dose to OAR in head and neck cancer patients.

Materials and Methods

Prospective study was conducted at Regional cancer centre of north west India, ATRCTRI, Bikaner after acceptance from ethical committee and written consent was taken from all patients before recruitment in study. Fifty patients of non-metastatic, non-palliative head and neck cancer were included in study. Patients either had indication of definitive radiotherapy or adjuvant radiotherapy following surgery.

Patients underwent a pre-treatment evaluation which comprises 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.

Treatment Plan

3DCRT and VMAT plans were created using 6 and 10 MV photons commissioned on a TRUEBEAM equipped with a multi-leaf collimator 0.5 cm width, max. speed of 2.5cm/s per leaf. The upper and lower collimators comprise a complete field of 40*40 cm square. Variable dose rate us up to 2400 Mu/ min in TRUE-BEAM.

Immobilisation and Planning

Patients were aligned in supine position and immobilised on a head support pad using thermoplastic mask. All patients were scanned from skull vertex to mid-chest in the CT simulator “G HIGH SPEED”. Intravenous contrast was used in order to help in the delineation of cervical nodes. CT images will then be transferred to the TPS “ECLIPSE”.

Target volume definition

Gross tumour volume (GTV) is defined as the macroscopic disease including all positive lymph nodes detected by clinical examination and radiological imaging. The clinical target volume (CTV GROSS) disease is composed of GTV with a 10-mm margin. Near the neural structures, the margin is reduced as possible as to 1 mm. The CTV subclinical disease is composed of CTV gross disease in

addition to other areas at high risk of harbouring microscopic spread. The planning target volumes (PTV) are generally a 5mm 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 66 Gy and 54 Gy for VMAT and 66 Gy and 44 Gy for 3DCRT respectively.

Dose and Fractionation

For 3DCRT: Doses prescribed in two phases, 66 Gy in 33 fractions, 2Gy per fraction, each fraction a single day, 5 fractions per week. The BED calculated is 79.2 Gy. In phase 1, 2 Gy per fraction, 22 fractions to PTV 44 and 2 GY per fraction, 11 fractions to PTV 66.

For VMAT: The dose to the PTV 66 is prescribed as 66 Gy in 2.2 Gy per fraction, the dose to the PTV54 Gy was 54 Gy in 30 fractions. The prescribed doses were delivered in 30 fractions, once daily, five fractions per week using simultaneous integrated boost (SIB) technique. The BED calculated is 80.52 Gy.

Plan evaluation parameters

A total dose of 66 Gy was delivered to the PTV boost and 54 Gy/44Gy to the elective PTV. 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 107% of the prescribed dose at each dose level. The plans were normalised to 100% (66Gy) 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 VCN, optic nerve and chiasma aim was to restrict dose below 54 Gy.

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.

Results

In present study maximum patients are of stage IV A (38%) followed by stage III (36%) and stage II (26%). Median age of the patients was 52 years (13-79 years) and males were 64% of total sample while females were 36 % of total sample.

PTV volume was ranging from 53 to 950 cm^3 and median volume was 311 cm^3. There was no statistical difference in PTV coverage for D2% and D50%, only significant differences were observed for D98% between VMAT and 3DCRT (Table 1).

	VMAT	3DCRT	P value
D98%	59.39±5.93 Gy	51.82±1.84 Gy	0.0001
D50%	66.83±3.11 Gy	66.31±2.49 Gy	>0.05
D2%	69.19±3.26 Gy	6934+/-244 cGy	>0.05

Table 1. Average Dosimetric Parameters (D98%, D50%, D2%) in 3DCRT and VMAT Plans.

PTV coverage was also assessed in different stages of head and neck cancers in both 3DCRT and VMAT technique. It was analysed that there was significant difference for only D98% between stages and D2% and D50% were showed no statistical difference.

The conformity index for 3DCRT and VMAT plans were 1.447 and 1.082 and homogeneity index was 0.147 and 0.2997 for VMAT and 3DCRT respectively. The difference is statistically significant for both homogeneity and conformity index (Table 2).

	Conformity Index	Homogeneity Index	P value
VMAT	1.0816	0.1473	0.00001
3DCRT	1.4472	0.2997	0.00001

Table 2. Mean Conformity Index and Homogeneity Index for Both the Techniques.

The VMAT technique was more conformal in all three staged patients when compared to 3DCRT (Table 3).

Stage	3DCRT	VMAT	P value
II	1.566	1.106	0.02089
III	1.544	1.074	0.0003
IV A	1.273	1.071	0.00574

Table 3. Stage wise Conformity Index.

The difference in conformity was higher in stage II, III than stage IVA between VMAT and 3DCRT. For 3DCRT, the contrasting feature was conformity index which was lesser and thus more conformal in late staged patients. Regarding, homogeneity VMAT was more homogeneous than 3DCRT in all stages (Table 4).

Stage	3DCRT	VMAT	P value
II	0.24	0.118	0.03389
III	0.27	0.139	0.00734
IV A	0.367	0.174	0.00163

Table 4. Stage Wise Homogeneity Index.

Homogeneity both for VMAT and 3DCRT was lesser in higher stages. In all the Primary diseases, VMAT was more conformal and had more homogeneous dose distribution than 3DCRT. Conformity index and homogeneity index was evaluated in different PTV volume cases. The conformity index was lower for VMAT in all the PTV category compared to 3DCRT. The homogeneity index was also lower in VMAT except for in patients with 0-100 cm^3 in which 3DCRT had lower homogeneity index. Among 3DCRT plans it was noted that conformity index decreased with increasing PTV volumes, whereas homogeneity index increased with increasing volume. Regarding VMAT low volume (0-100 cm^3) had less homogeneous and more conformal dose distribution than other PTV categories while the rest of PTV categories had near equal conformity index and homogeneity index.

The mean dose was significantly lesser in parotid glands in VMAT plans. Also, the point max dose to spinal cord, brainstem, optic nerve and optic chiasma was lesser. The dose to VCN were approximately equal in both the arms. There was no significant difference in dose received by spinal cord in both arms (Table 5).

Organs at risk	3DCRT	VMAT	P value
Parotid left	45.73	30.89	0.00001
Parotid right	45.68	32.06	0.00001

Spinal cord	42.5	40.53	0.1479
Brainstem	35.72	34.68	0.599
Optic nerve left	17.4	13.11	0.1726
Optic nerve right	16.25	13.27	0.0878
Chiasma	16.5	15.6	0.4959
Vcn left	20.34	20.71	0.03233
Vcn right	22.77	22.72	0.9826

Table 5. Dosimetric Outcomes for the Organs at Risk.

Dose to OARs were lesser in VMAT in higher stage irrespective of the type of OAR. However, in early stages, the max point dose was lesser in 3DCRT in spinal cord, brainstem and VCN. Among patients with low PTV volume OARs dosage was lesser with both the techniques compared to higher, and lesser difference was there between the two techniques. On increasing PTV volumes difference in sparing OAR increased favouring VMAT.

Discussion

On subset analysis of stage and coverage, there was significant difference observed for D98%, however the difference was not significant for D50% and D2%. This finding was in accordance with the result of Caraman et al [4], which showed that the minimum dose to the Planning Target Volume was significantly lower for 3D Conformal Radiotherapy compared to Intensity Modulated Radiotherapy and Volumetric Modulated Arc Therapy plans, while there was small difference in the maximum or mean dose to Planning Target Volume. On another subset analysis of primary disease there was significant difference for each primary disease for D98% between 3DCRT and VMAT except nasal cavity tumour where number of case is just one. The difference was major for Oropharyngeal, nasopharyngeal and laryngeal tumours. While the D2% and D50% were nearly similar between the groups.

In present study it was analysed that VMAT was more conformal to 3DCRT irrespective of the stage of primary disease or type of primary disease and PTV volume. The VMAT technique gave more homogeneous plans compared to 3DCRT in all stages and PTV volume except for PTV volume 0-100 cm^3. The difference was also non-significant for PTV volume between 701-800 cm^3 but the sample size for this volume was very small. On close analysis it was observed that the difference between conformity decreases on increasing PTV volume, while difference between homogeneity index increases on increasing PTV volume. This finding was similar to the result of study conducted by Lee et al [5] who concluded that compared to 3DCRT plans, VMAT plans produce significantly better target coverage as well as dose conformity. It was found that 3DCRT technique had a significantly worse conformity index (PTV60: VMAT vs 3DCRT = 1.60 vs 2.32) and inhomogeneity index (PTV60: VMAT vs 3DCRT = 6.1 vs 14.9) at all PTV levels.

Result of present study was also in accordance with the various studies comparing VMAT and 3DCRT in different sites other than head and neck cancer i.e. Pierina Navarria et al [6] in newly diagnosed glioblastoma, Sudha et al [7] in breast carcinoma patients, Di Brian et al [8] in soft tissue sarcoma patients analysed that VMAT was better conformal technique than 3DCRT.

On analysis regarding OARS, there was significant lesser mean dose to parotid glands irrespective of the stage of disease in VMAT technique which aligns with finding of study conducted by Mirestean et al [9]. The dose to parotid glands were significantly low in VMAT for each PTV volume except for PTV volume 801-900 cm^3. The mean dose to parotid was successfully kept below 26 Gy in low PTV volume, however in intermediate volume only VMAT was able to achieve the target. On analysis of Dmax to spinal cord, dose to spinal cord was significantly high in 3DCRT in stage III and IVA patients, while it was lesser in 3DCRT arm in stage II disease. On analysis of PTV volumes the results were in favour of VMAT. This result was similar to the LEE et al [5] findings in which lower

dose to spinal cord was achieved by VMAT. However, Chancer Matthiesen et al [10] showed that in early stage tumours lesser dose to spinal cord is attributed to beam directions avoiding spinal cord used in the foreword planning technique. The difference was small for Dmax to Brainstem between 3DCRT and VMAT.

In head and neck cancers radiotherapy is one of the important treatment modality. The major concern with radiotherapy is coverage and exposure to normal tissue. Still, in the era of very advancements there are no clear guidelines about which modality to use. So, in this study comparison of volumetric modulated arc therapy with three-dimensional conformal radiation therapy was done. Radiotherapy with Volumetric modulated arc therapy had better planning target volumes coverage, conformity index and homogeneity index in comparison to three- dimensional conformal radiation therapy in head and neck cancer patients irrespective of the type of primary or stage of disease. OARs, which includes spinal cord, brainstem, parotid glands, optic nerves, optic chiasma and vestibulocochlear nerve, sparing was also better with volumetric modulated arc technique though sometimes insignificant for distant OARs but in that case they were within dose constraints value. However, in tumours with very low PTV volume using beam direction avoiding specific OARs can decrease OAR exposure with comparison to VMAT. So VMAT can be prioritised in head and neck cancers especially higher stage disease.

In conclusion, VMAT plan provide better dose homogeneity and highly conformal dose distribution than 3DCRT plans. Doses to OARS like parotid glands were also reduced in VMAT which allow dose escalation in close proximity to organs, so local tumour control could be enhanced and may prevent radiotherapy related side effects like mucositis, xerostomia etc. However, present study has its own drawbacks like small number of sample size and is dosimetric study. More conclusive results would hence require further evaluation.

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