Iranian Journal of Medical Physics

ijmp.mums.ac.ir

Comparative Dosimetric Evaluation of Volumetric-Modulated Arc Therapy (VMAT) Versus Intensity-Modulated Radiotherapy (IMRT) in Thoracic Esophageal Cancer

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ARTICLE INFO

Article type:
Original Paper

Article history:
Received: Dec 01, 2021
Accepted: June 27, 2022

Keywords:
Radiotherapy
Dosimetry
Esophagus
Computed Tomography
Intensity Modulated
Radiotherapy Planning
Homogeneity Index
Conformity Index

ABSTRACT

Introduction: With the introduction of Intensity Modulated Radiotherapy (IMRT) approach, better dosimetry results and patient outcomes has been attained for various anatomical sites. In present study, a comparative dosimetric evaluation of Volumetric-Modulated Arc Therapy (VMAT) versus two techniques of IMRT i.e. Dynamic IMRT (d-IMRT) and step & shoot IMRT (ss-IMRT) was done for thoracic esophageal cancer.

Material and Methods: VMAT, ss-IMRT, and d-IMRT plans were generated on the Computed Tomography Simulator data sets of 13 Patients with thoracic esophageal carcinoma who had been treated earlier. The prescription dose for each patient was 50.4 Gy in 28 fractions. All the plans were optimized to achieve greater or equal to 95% of the prescribed dose to the Planning Target Volume (PTV). Dose to PTV and organ at risk (OAR) were compared with the help of Dose Volume Histogram (DVH).

Results: VMAT and d-IMRT plans were nearly equivalent for PTV coverage, homogeneity index (HI), and uniformity index (UI) ($p > 0.05$). However, VMAT and d-IMRT plans had superior PTV coverage, HI, and UI, ($p < 0.01$) than ss-IMRT. For PTV, the D_{mean}, D_{98}, and D_{95} values in ss-IMRT were significantly less than VMAT and d-IMRT ($p < 0.05$).

Conclusion: All three techniques are able to provide a homogeneous and conformal dose distribution. VMAT offers better homogeneous dose distribution and may be preferred for treating thoracic esophageal carcinoma. Thus, the multi-arc VMAT technique may be a better option with equivalent or superior dose distribution, uniformity, and homogeneity.

▶ *Please cite this article as:*
Mishra A, Pathak R, Mittal KK, Mishra SP, Singh SK, Srivastava AK. Comparative Dosimetric Evaluation of Volumetric-Modulated Arc Therapy (VMAT) Versus Intensity-Modulated Radiotherapy (IMRT) in Thoracic Esophageal Cancer. Iran J Med Phys 2023; 20: 159-167. 10.22038/IJMP.2022.61938.2047.

Introduction

Esophageal cancer (EC) is a common Gastro-intestinal malignancy. Worldwide, it is seventh in annual incidence (604,000 new cases) and 6th in mortality (544,000 deaths) accounting for one in every 18 cancer deaths in 2020 [1]. Risk factors for esophageal cancer include tobacco, alcohol, hot and spicy food and betel nut with leaf (Pan) chewing in the Indian subcontinent [2]. Radiotherapy (RT) is the most common treatment modality for esophageal cancer as more than 2/3rd of the patients are detected at an advanced stage locally, where surgical resection is not possible.

Conventional radiotherapy has been practiced from last several decades and delivered in two phases. Most of the time Conventional radiotherapy utilizes parallel opposed, anterior, and posterior (AP/PA) portals in phase 1 and three fields (one anterior and two posterior oblique fields) with or without wedges in phase 2. This application has a limitation of constraining the dose to the lung, heart, and Spinal Cord. Dose homogeneity to target volume and dose constraints to the organ at risk was difficult to attain by these techniques. Three-Dimensional Conformal Radiotherapy (3D-CRT) was introduced to overcome these problems but it has its own limitations in obtaining the dose homogeneity in the target volume. Recent advances in technologies, RT planning algorithms, availability of multi leaf collimators have revolutionized planning techniques. The introduction of newer radiation treatment delivery such as Intensity Modulated Radiation Therapy (IMRT) and Volumetric Modulated Arc Therapy (VMAT) offers

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better tumor coverage with the reduction in dose to the organ at risk.

Clinical studies have shown that better dosimetry results and patient outcomes can be achieved with IMRT technique [3–7]. For achieving better tumor coverage and less dose to Organ at Risk (OAR), there are various IMRT techniques like step and shoot IMRT (ss-IMRT), sliding window dynamic IMRT (d-IMRT) and the, rotational technique. Yu [8] in 1995, for the first time, proposed a novel method of IMRT i.e., Volumetric-Modulated Arc Therapy (VMAT), which facilitates for intensity modulated radiation dose delivery even when during gantry is moving, along with dynamic multi-leaf collimator (MLC) movement, gantry speed, and variable dose rates modulation. IMRT only utilizes the intensity modulation by using multiple beamlets of varying sizes to attain the better dose modulation and homogenization in the target volume. VMAT has multifold modulation by using multiple beamlets of varying intensity, and dose rate/ intensity variations in each beamlets to attain the superior dose homogenization and intensity modulations. The added advantage of VMAT is that it offers highly conformal homogeneous dose distribution as compared to IMRT. Its moderate treatment delivery time, takes care of the intra-fraction patient motion. VMAT can be favorable because it provides efficiency in Monitor Units (MUs) and treatment time, which reduces time and comfort for patients compared to IMRT. Treatment planning time to generate an optimal plan is comparable for IMRT and VMAT techniques [9].

It is reported that the IMRT plan greatly reduced OARs dose while achieving a target dose distribution identical to the VMAT plan. VMAT's MU and treatment duration were also much lower than IMRT, contributing to its enhanced treatment efficiency [10–12]. Lin et al. [13] observed that VMAT was not necessarily superior to IMRT in terms of sparing the normal structures or Planning Target Volume (PTV) coverage during EC treatment. When compared to VMAT, IMRT offered a lower mean dose and V_5 to lung in patients with upper thoracic ECs, but it had various advantages and drawbacks in individuals with middle or lower thoracic ECs. As a result, selecting various method for different EC sites is recommended. Zhang et. al. [14] observed that the VMAT plan as compared to IMRT, exhibited high Equivalent Uniform Dose values and better HI and CI values in the thoracic EC. In middle EC, Kataria et al. [15] assessed VMAT and IMRT approaches and concluded that VMAT minimized doses to the lungs and heart with almost the same target dose distribution. Shao et. al. [16] concluded that in VMAT and IMRT, Homogeneity Index (HI) and Conformity Index (CI) values are equivalent. It is reported in literature that VMAT has also shown better results in uteri cervix cancer, prostate cancer, and brain cancer cases [17–20]. These studies stated that VMAT offers equal or better homogeneous dose distribution, reducing treatment time while beam on time is high.

This study is aimed to compare VMAT with ss-IMRT and d-IMRT for thoracic esophageal cancer in terms of coverage to PTV and dose constraints of OAR.

Materials and Methods

The study was conducted in a tertiary cancer center at Dr. Ram Manohar Lohia Institute of Medical Sciences Lucknow, Uttar Pradesh, India. The center is equipped with state-of-the-art high energy linear accelerator (Infinity; Elekta Medical Systems, Crawly, UK) with 6, 10, and 15 MV photon beams and multiple energy of electron beams. The linac is also equipped with kVCT (XVI), MV imaging (electronic portal imaging device), 6D couch (HexaPOD), MLCi2 and at isocentre, capable of providing a maximum dose rate of 600 MU/min. The treatment techniques used for the current study are as follows:

VMAT

All VMAT plans were generated with two arcs (2A) with the start-stop angle of 180-180 degrees (360-degree full arc) delivered with clockwise and counter clockwise rotation to ensure that PTV was encompassing at least 95% of the prescription dose. The plans were optimized with Monaco treatment planning (TPS: Elekta Medical Systems, Version: 5.11.03, Crawly, UK) system optimized with variable dose rate and incremental angle of the gantry was kept at 30 degree. After the regions of interests (ROIs) were defined, the contoured structures were transferred to Monaco TPS. The PTV was assimilated as the target, and the remaining structures (OAR) were ranked by structure layering. For creating the treatment plan, dynamic conformal arc was selected as the treatment delivery technique. Photon beam energy selected for the study was 6 MV. Calculation properties and sequencing parameters used in the treatment planning are given in Table 1 and Table 2. The plans were optimized with two stage optimizer. The first stage uses the Pencil beam algorithm (PBA) and the second stage optimization uses the Monte Carlo algorithm (MCA).

Table 1. Calculation Properties for VMAT, ss-IMRT, and d-IMRT

S.No.	Calculation Properties	Values
1	Grid Spacing(cm)	0.30
2	Calculate Dose Deposition to	Medium
3	Statistical Uncertainty (Per calculation)	1.0%

Table 2. Sequencing Parameters for VMAT

S. No.	Sequencing Parameters	Values
1	Max. Number of Arcs	02
2	Max. number of Control points per Arc	200
3	Min. Segment Width(cm)	0.50
4	Fluence Smoothing	Medium

IMRT (ss-IMRT and d-IMRT)

All IMRT plans were optimized to cover PTV volume encompassing at least 95% of the prescription dose. The d-IMRT plans were optimized with a 500 MU/min fixed-dose rate to achieve a better PTV coverage and lesser dose to OAR. The planes were generated with dynamic window mode using seven coplanar beams with the gantry angle 0º/50º /100º /150º /200º /250º /300º; 7 Fields (7F). Rest of the parameters were same as d-IMRT planning. Table 1, Table 3, and Table 4 tabulates the calculation properties and sequencing parameters. Photon beam energy selected for the ss-IMRT and d-IMRT was 6 MV. Isocenter and objective features for normal tissue for all VMAT and IMRT plans were kept the same.

Table 3. Sequencing Parameters for ss-IMRT

S. No.	Sequencing Parameters	Values
1	Max. Number of Beam	07
2	Min. Segment Area (cm^2)	2.00
3	Min. Segment Width(cm)	0.50
4	Fluence Smoothing	Medium
5	Minimum monitor unit/segment	4.00
6	Max. number of segments per plan	250

Table 4. Sequencing Parameters for d-IMRT

S. No.	Sequencing Parameters	Values
1	Max. Number of Beam	07
2	Max. number of Control points per Beam	30
3	Min. Segment Width(cm)	0.50
4	Fluence Smoothing	Medium
5	Max. Sweep Efficiency	Yes
6	Allow Move only Segments	Yes

Patients Characteristics

Thirteen patients with thoracic esophageal cancer previously treated with various radiotherapy techniques were chosen for this study. The disease was staged according to the American Joint Committee on Cancer (AJCC) staging 2010. Ethical clearance for the study was not required as it was only a dosimetry study for comparison of the efficacy of various RT techniques namely VMAT, d-IMRT, and ss-IMRT. Patients and disease characteristics are shown in Table 5.

Target Volume and Organ at risk Delineation

All patients were immobilized with head first in the supine position. Planning Computed Tomography (CT) scan with infusion of contrast medium was done using a helical 16 slice scanner (Somatom Sensation open, Siemens, Germany) with 3.0mm slice thickness including the neck and whole of the thorax. The CT images were transferred to Monaco contouring works stations (Elekta Medical Systems, Version: 5.11.03, Crawly, UK) using DICOM protocol 3.0.

The Gross Tumor Volume (GTV) contouring was done for tumor and lymph nodes on CT slices using automatic registration fusion with Positron Emission Tomography (PET-CT) and Magnetic Resonance Imaging (MRI). Supero-inferior margins of 30-45mm and circumferential margin of 15mm were added to the GTV to delineate Clinical Target Volume (CTV). Lymph nodes were delineated with 10mm uniform margins. For creating PTV, 5mm uniform margin was given to the CTV, for the esophageal tumor and lymph nodes. OAR, such as total lung, heart, and spinal cord were also delineated according to RTOG 0436 protocol [21]. Planning risk volume (PRV) was created with a 5mm uniform margin for the spinal cord. The prescribed dose was 50.4Gy/28 fractions with 1.8Gy/fraction. Dose constraints for OARs are given in Table 6. This dataset was finally used for treatment planning.

Table 5. Patients Characteristics (Sample size, N=13)

Variable	N
Sex	
Male	11
Female	02
Age (years)	
Range	45-70
Median	61
Stage	
II	02
III	10
IV	01
Histology	
Squamous cell carcinoma	12
Adenocarcinoma	01
Tumor Volume (cc)	
GTV (Mean±SD)	50.58±32.54
PTV (Mean±SD)	672.94±225.27

GTV:Gross Tumor Volume, PTV:Planning target volume, SD: Standard Deviation

Table 6. Dose Constraints for OAR in this study

OAR	Percentage	Dose (Gy)
Heart	20	< 20
	30	< 12
	50	< 7
Lung	20	< 20
	30	< 18
	50	< 12
Spinal Cord	Max point dose	< 45

Treatment Plan Evaluation

All VMAT, ss-IMRT, and d-IMRT plans were evaluated with Dose Volume Histogram (DVH). The conformity of dose distribution to the shape and size of target volume was assessed with the help of the conformity index (CI). CI was defined as $(TV_1)^2$/ (TV x VT_1), where TV_1 is the volume of the target that receives the prescription dose, TV is target volume and VT_1 is total volume of the prescription dose [22]. CI varies from 0 to 1, with CI values near 1 representing a better PTV conformity. The HI represents homogeneous dose distribution inside the PTV, and is calculated with the help of formula $D_{2\%} - D_{98\%}$ to the D_{mean} dose; D_2 and

D_{98} taken were maximum and minimum dose, respectively [23]. Closer to 0 values of HI represented a better target homogeneity. Uniformity Index (UI) gives the information regarding dose uniformity inside the PTV and is defined as $D_{5\%}/D_{95\%}$ [24,25]. Beam on time was determined by delivering each plans in quality assurance mode and noted from beam timer for individual beams/arcs with the help of treatment control console (TCC) unit.

Statistical Analysis

For quantitative variables, the mean ± standard deviation (SD) values were reported. Statistical significance was performed using one-way ANOVA, and post hoc Tukey Honestly Significant Difference (HSD) was performed with a value $p<0.05$ considered statistically significant. All Statistical analyses were performed with R Project software.

Results

In the study, GTV ranged from 17.12-126.81cc, with mean volume was (50.58±32.54) cc [Table 5]. PTVs volume ranged from (424.31±1080.22) (cc), with a mean volume of (672.94±225.27) cc. PTV coverage in all three techniques could achieve 95% of the prescription dose (50.40 Gy) to ≥95% of the PTV volume. Table 7 represent the DVH-based parameters for PTV.

A significant difference was observed for D_{mean}, D_{98} and D_{95} for all three techniques of VMAT, ss-IMRT, and d-IMRT ($p<0.01$). D_{mean}, D_{98} and D_{95}values for ss-IMRT were significant statistical difference for VMAT and d-IMRT ($p< 0.05$).

No significant difference in the D_{50}, D_5, and D_2 values was observed between VMAT and ss-IMRT techniques ($p> 0.05$). A significant difference was found in the D_{50} values between ss-IMRT and d-IMRT techniques ($p< 0.05$). There were no statistically significant differences in the D_5 and D_2 values between ss-IMRT and d-IMRT techniques ($p> 0.05$). D_{max} dose showed equivalent statistical values for all three techniques ($p > 0.05$).

The HI for VMAT was similar to d-IMRT (0.07 ±0.02 and 0.07 ±0.02, respectively; $p > 0.05$), and had statistically significant difference compared to ss-IMRT (0.09 ±0.02; $p<0.05$). We found slightly better CI for VMAT in comparison with ss-IMRT and d-IMRT but did not reach statistical significance ($p > 0.05$).

Figure 1 and Figure 2 showed MU and Beam On time consumed for each plan. MU for VMAT, ss-IMRT, and d-IMRT was found to be 744.04±128.25, 405.14±88.28 and 555.95±82.64 respectively and statistically significant (All; $p< 0.05$), which is shown in Table 8. Beam on time was nearly equivalent in ss-IMRT and d-IMRT (2.76±0.36 minutes and 2.42±0.35 minutes) and shows significant difference with VMAT (5.12±1.15 minutes; $p=0.00$)

Table 7. Averaged DVH parameters of PTV (mean±SD), with *P* value. VMAT, VMAT with two arc, ss-IMRT, Step and Shot IMRT with 7 fields and d-IMRT, Dynamic IMRT with 7 fields; D_n (Gy), Dose (Gy) absorbed by any percentage (%) or absolute volume (cm^3) of the respective relative structure and Pat. Max, Patient Max dose; comparison with 1-way ANOVA test and post hoc HSD test.

Parameter	VMAT	ss-IMRT	d-IMRT	ANOVA P value	Post hoc P value		
					VMAT Vs ss-IMRT	VMAT Vs d-IMRT	ss-IMRT Vs d-IMRT
D_{mean}	52.13± 0.53	51.60± 0.51	52.25±0.48	0.01	0.03	0.81	0.01
D_{98}	49.80±0.99	48.69±1.00	49.98±1.02	0.00	0.02	0.89	0.01
D_{95}	50.65±0.65	49.56±0.83	50.77±0.69	0.00	0.00	0.91	0.00
D_{50}	52.08±0.74	51.76±0.48	52.34±0.48	0.04	0.35	0.45	0.04
D_5	53.28±0.52	53.17±0.33	53.29±0.41	0.72	0.77	0.99	0.76
D_2	53.55± 0.52	53.5±0.32	53.54±0.38	0.94	0.94	0.99	0.96
D_{max}	55.77±0.61	55.55±0.55	55.53±0.49	0.45	0.50	0.45	0.99
Pat. Max	54.62±0.81	54.61±0.38	54.74±0.64	0.85	0.99	0.88	0.87

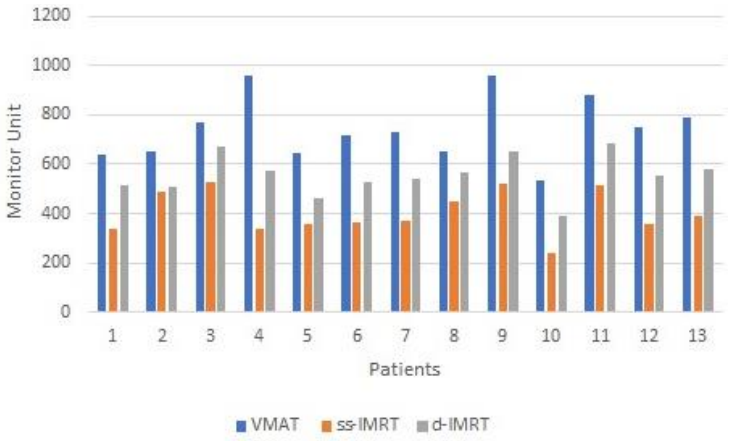

Figure 1. Monitor Units Calculated by VMAT, ss-IMRT and d-IMRT for Patients

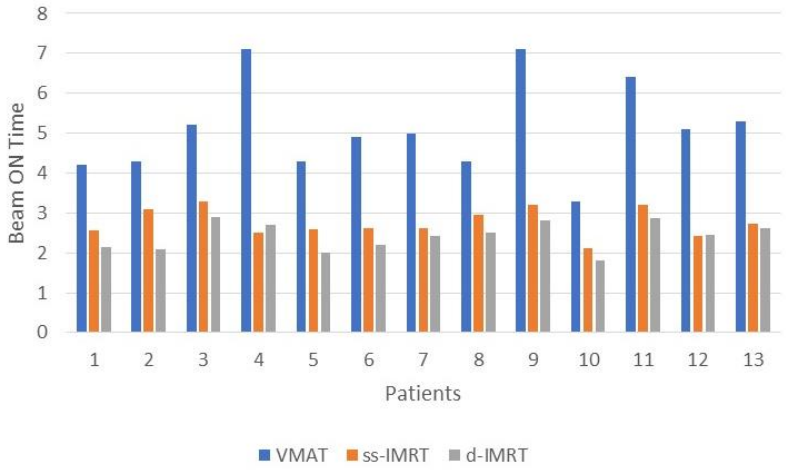

Figure 2. Beam On time (minutes) consumed by VMAT, ss-IMRT and d-IMRT for Patients

Table 8. Averaged dosimetric parameters (mean±SD), with *P* value. Monitor Units(MU) and Beam on time in minutes(BT) were compared with 1-way ANOVA test and post hoc HSD test

Parameter	VMAT	ss-IMRT	d-IMRT	ANOVA p value	Post hoc p value		
					VMAT Vs ss-IMRT	VMAT Vs d-IMRT	ss-IMRT Vs d-IMRT
MU	744.04±128.25	405.14±88.28	555.95±82.64	0.00	0.00	0.00	0.00
BT(min.)	5.12±1.15	2.76±0.36	2.42±0.35	0.00	0.00	0.00	0.47

Table 9. Averaged dosimetric indices parameters of PTV (mean±SD), with *P* value. Conformity Index(CI) , Homogeneity Index(HI), Uniformity Index(UI) were compared with 1-way ANOVA test and post hoc HSD test.

Parameter	VMAT	ss-IMRT	d-IMRT	ANOVA P value	Post hoc P value		
					VMAT Vs ss-IMRT	VMAT Vs d-IMRT	ss-IMRT Vs d-IMRT
CI	0.40±0.05	0.36±0.04	0.39±0.04	0.13	0.12	0.76	0.38
HI	0.07± 0.02	0.09±0.02	0.07±0.02	0.00	0.01	0.76	0.00
UI	1.05±0.01	1.07±0.02	1.05±0.01	0.00	0.00	0.86	0.00

Table 10. Averaged DVH parameters of OAR (mean±SD), with *P* value. V_n, percentage of organ volume exposed to certain radiation dose, Mean Lung Dose(MLD), Mean Heart Dose(MHD),Spinal Cord(SC), Planning Risk Volume(PRV), Pat. Max, Patient Max dose were compared with 1-way ANOVA test and post hoc HSD test.

Parameter	VMAT	ss-IMRT	d-IMRT	ANOVA *P* value	Post hoc *P* value		
					VMAT Vs ss-IMRT	VMAT Vs d-IMRT	ss-IMRT Vs d-IMRT
Total Lung							
V_{40}	8.0±4.27	8.2±4.02	8.14±4.11	0.99	0.99	0.99	0.99
V_{30}	16.23±7.78	16.62±7.26	16.04±7.11	0.98	0.99	0.99	0.98
V_{20}	33.10±12.05	34.63±12.42	32.59±11.29	0.90	0.94	0.99	0.90
V_{10}	64.52±19.12	65.51±18.91	63.87±18.32	0.97	0.99	0.99	0.93
V_5	78.22±21.40	79.18±20.73	78.11±20.59	0.99	0.99	0.99	0.99
MLD(Gy)	16.78±4.74	17.2±4.72	16.75±4.55	0.96	0.97	0.99	0.97
Heart							
V_{40}	12.57±7.12	13.73±8.47	13.29±7.61	0.93	0.92	0.97	0.98
V_{30}	23.25±12.33	25.79±15.05	25.43±13.54	0.87	0.88	0.91	0.99
V_{20}	41.26±19.47	47.45±24.22	46.34±22.93	0.75	0.76	0.83	0.99
V_{10}	69.23±32.06	70.85±32.26	70.31±32.13	0.99	0.99	0.99	0.99
V_5	78.93±34.12	79.4±34.53	79.57±34.38	0.99	0.99	0.99	0.99
MHD (Gy)	19.41±8.35	20.72±9.25	20.39±8.95	0.93	0.93	0.96	0.99
SC	39.33±3.42	39.78±3.22	38.89±2.94	0.78	0.93	0.94	0.76
PRV	44.87±2.41	44.91±3.18	44.31±2.63	0.83	0.99	0.86	0.85

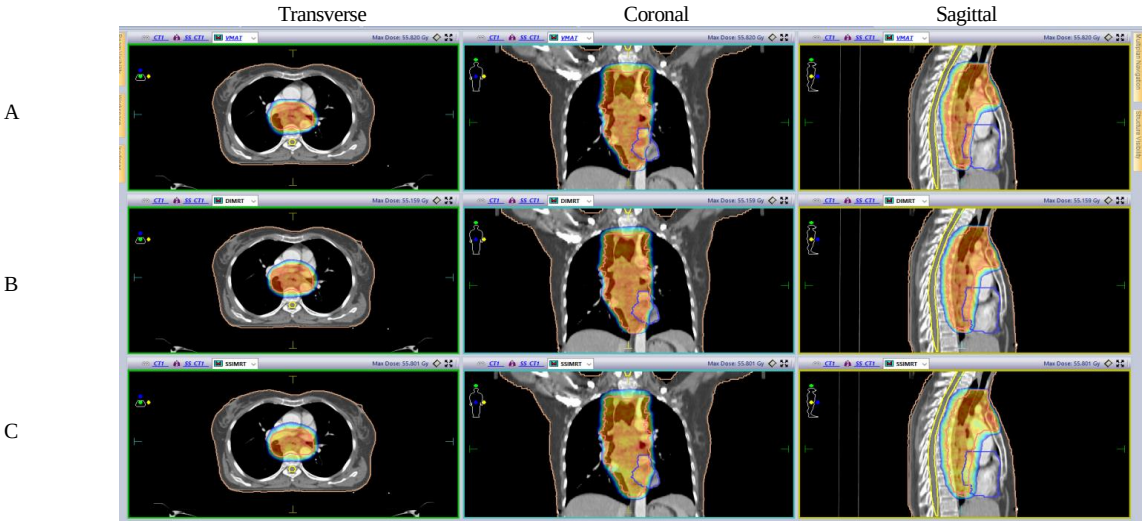

Figure 3. Illustrating 95% of prescribed isodose distribution in transverse, coronal and sagittal sections by (A) VMAT, (B) d-IMRT and (C) ss-IMRT plans, respectively.

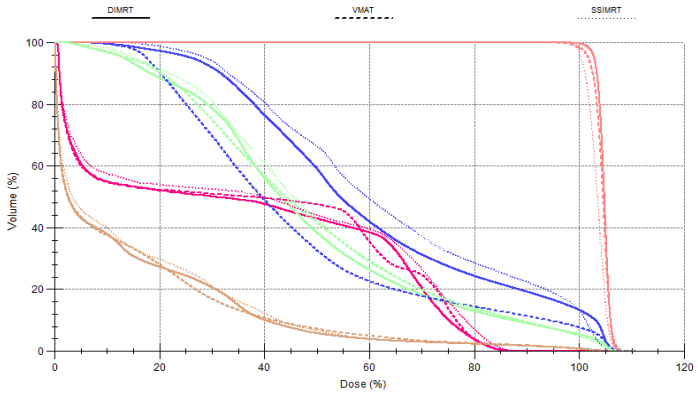

Figure 4. Illustrating DVH by ss-IMRT-Dashed thin lines, VMAT-Dashed thick lines and d-IMRT-Solid thick lines, and colours represents PTV-Red, Heart-Blue, Total Lung-Green, Spinal cord-Dark Pink and Patient Body-Brown.

UI for VMAT was similar to d-IMRT (1.05 ±0.01 and 1.05 ±0.01, respectively; $p > 0.05$) and better compared to ss-IMRT (1.07 ±0.02; $p < 0.05$).

Table 9 summarizes the indices parameters for the plans. Table 10 shows the DVH-based parameters for OARs. Lung doses for VMAT, ss-IMRT and d-IMRT were 33.10±12.05, 34.63±12.42 and 32.59±11.29, respectively. For V_{20}, there was no statistically significant difference ($p = 0.902$). In this study significant difference was not observed for the V_{40}, V_{30}, V_{10}, V_5 and MLD amongst all three techniques ($p > 0.05$).

Dose distribution in transverse, coronal and sagittal sections and DVH for PTV & OAR by three techniques for a single patient is given in Figure 3 and Figure 4.

Heart doses for VMAT, ss-IMRT and d-IMRT were 41.26±19.47, 47.45±24.22 and 46.34±22.93 respectively for V_{20}, though it was not significant ($p = 0.75$).

The max dose of the spinal cord and PRV didn't show statistical significance among all three techniques. Patient max dose was also equivalent among the VMAT, ss-IMRT and d-IMRT (54.62 ±0.81, 54.61±0.38 and 54.74 ±0.64, respectively; $p = 0.85$).

Discussion

The main objective of this study was to compare and evaluate the dosimetric differences, efficacy and significance of three different modern radiotherapy techniques (i.e. VMAT, ss-IMRT and d-IMRT) for the treatment of esophageal cancer. The current study explored the dosimetric comparison amongst three different IMRT techniques to treat 13 thoracic esophageal carcinoma patients. IMRT gives conformal dose, lesser dose to OAR and homogeneous dose distribution compared to the three-dimensional conformal radiotherapy [26]. The current literature and publications reveal the comparative advantages and disadvantages of the various techniques of IMRT in radiotherapy plan of esophageal cancer patients [27,28].

Martin et al. [29] concluded that IMRT and arc therapy is equivalent in terms of dosimetric comparison for esophageal cancer patients. IMRT offered a slightly better homogenous dose distribution, and arc therapy produced several cold spots within GTV. Lin et al. [30] and Nicololini G et al. [31] stated that VMAT provided equivalent or more homogeneous and conformal dose distribution with slightly higher V_5 but minimized high dose to lung and heart than IMRT. Van et al. [9] showed that VMAT and IMRT could provide a 95% prescribed

dose to cover 100% volume of the PTV, but in 1 VMAT plan, PTV dose was 90%. The mean doses increased by 1.5% and maximum doses by 3.2% for the VMAT plans. Results of the present study are in coherence with the earlier published results for either comparison of conventional to 3DCRT or 3DCRT to IMRT or various techniques within IMRT. It was found that the VMAT and d-IMRT had nearly equivalent coverage and the dosimetric result compared to ss-IMRT and almost nil cold spots were observed in all three techniques. Organ sparing was similar for the three techniques, however better PTV homogeneity and conformity was found in VMAT. All three techniques could provide 95% prescribed dose to cover ≥95% volume of the PTV in all cases. Mean doses are 1% more for VMAT and d-IMRT whereas maximum & minimum doses were equivalent in all three techniques.

Yin et al. [32] reported that for 2Gy/fraction (conventionally fractionated regimens), the traditional parameters used were MLD and V_{20}, as they predict lung toxicity, though recent data shows that low dose lung volume percentage may predict lung toxicity. VMAT plans provide the cushion to significantly increase the low-dose area coverage (i.e. V_5 and V_{10}) as the doses are deposited within the volume of the arc instead of being spread out in non-coplanar directions. Xu et al. [33] and Zhang et al. [34] showed in their studies that there is similar non-significant OAR sparing in both VMAT and IMRT. Marks et al. [35] stated that V_{20} and MLD be kept between less than 30-35% and 20-23 Gy, respectively to reduce risk of radiation pneumonitis to less than 20%. In current evaluation, results obtained demonstrated that VMAT plans were more effective to accomplish the above dose criteria.

Kataria et al. [15] illustrated in their study that IMRT take greater total treatment time than VMAT (14.6±1.8 and 7.4± 1.6, p =0.00). In present study Beam on time was similar for ss-IMRT and d-IMRT (2.76±0.36 minutes and 2.42±0.35 minutes) and shows significance difference with VMAT (5.12±1.15 minutes; $p> 0.05$). The study by Lin et. al. [13] showed that VMAT consumed increasing MU in lower EC. Similar trend of higher MU in VMAT was also observed in present study. This may be attributed to various patient specific and treatment unit specific parameters including target margins and type of MLC as compared to the studies cited.

National Comprehensive Cancer Network Guidelines recommends spinal cord dose should be less than 45Gy. Hsu et al. [36] observed that SC max dose were 37 and 39 Gy in full arc and optimal partial arc techniques. In this study, mean spinal cord and PRV dose were less than 40 Gy & 45 Gy, respectively with VMAT (p> 0.05).Among MLD, the percentage of lung volume receiving at least 20 Gy (V_{20}), 13 Gy (V_{13}), 10 Gy (V_{10}), or 5 Gy (V_5); V_{20} may be correlated with increased risk of radiation pneumonitis which may be ascertained on long term clinical study and follow-ups. In a clinically significant publication Yin L. et al. [32] have calculated probability of grade ≥2 pneumonitis for the MLD of 24-36, 16-24, and 8-16 Gy and predicted the probability of pneumonitis grade ≥2 as 43%, 18% and 11% respectively. They utilised the plan data obtained from 540 patients treated for thoracic cancer to predict these clinical probabilities. In the current study MLD was achieved between 16-24 Gy in all three techniques, and the differences were statistically insignificant.

Kataria et al. [15] demonstrated that CI and HI are slightly better for VMAT. They also reported that UI values were similar to VMAT and IMRT. Martin et al. [29] found in their study that the UI and HI were superior for 2 arc VMAT compared to the single arc VMAT. Conformity indices, for VMAT, ss-IMRT, and d-IMRT were 0.4 ±0.05, 0.36 ±0.04, and 0.39 ±0.04, respectively with p = 0.13. CI was slightly better in VMAT than IMRT (p> 0.05).The HI for VMAT had statistically significant improvement compared to ss-IMRT (0.09 ±0.02; p< 0.05). UI for VMAT was statistically better than ss-IMRT (1.07 ±0.02; p< 0.05).

In this study, average of MHD were < 21Gy in all three techniques and the mean V_{30} for the heart was <26% for all three techniques. It can safely be stated that our results were better than reported by Wei et al. [37] in their study. It has been observed that VMAT offered slightly better dose reduction to the heart than ss-IMRT and d-IMRT. This may reduce the risk of pericardial effusion as the risk increased with mean dose 26.1 Gy. Mean V_5 in VMAT, ss-IMRT, and d-IMRT is <80%, and it might result in lesser lung toxicity. However, it has been noted that MU consumed in VMAT is higher than that other IMRT techniques. The limitation of the study was the smaller sample size and unequal distribution of male female patients. It is thus suggested that the study may be performed on larger sample size for statistically significant conclusion and long term clinical follow up may be necessary for ascertain the radiation toxicities if any.

Conclusion

The current study revealed nearly equivalence among all three techniques for percentage dose reduction in the lungs. VMAT offered a slight less dose reduction for the heart doses compared to ss-IMRT and d-IMRT. It has been established in this dosimetric study that VMAT offers better dose homogeneity to target volume with superior dose constraints to OAR. The analysis of the various uniformity indices in this study elucidated that UI and HI were superior for 2 arc VMAT compared to the single arc VMAT which signifies the utility of multi-arc VMAT over other techniques in thoracic oesophageal cancer.

Acknowledgment

The authors thank Dr. Bharat Kumar and Mr. S. D. Maurya for significant insight guidance during the writing of the Manuscript.

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