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Research Paper

Evaluation of IMRT and Double-Arc VMAT treatment plans in Head and Neck Cancer Cases: Our Experience at NSIA-LUTH Cancer Care

Akpochafor M. O. [1,4]✉, Adeneye S. O.[1,4], Habeebu M. Y. M.[1,4], Abe G. A.[1,4], Lawal R.[1,4], Sanya I. D.[1,4], Abdallah E. Kotkat[2,4], Ibrahim EL Hamamsi [3,4], Mahmoud M. A.[3,4], Durosinnmi-Etti F. A.[3,4], Aweda M. A. [1,4]

1. Department of Radiation Biology, Radiotherapy and Radiodiagnosis, College of Medicine/Lagos University Teaching Hospital, Idi-Araba, PMB 12003, Lagos, Lagos State, Nigeria.
2. Tanta University Hospital, Tanta, Egypt.
3. Faculty of Sciences, Tanta University Hospital, Tanta, Egypt.
4. NSIA-LUTH Cancer Care, Lagos, Lagos State, Nigeria.

✉ Corresponding author: Dr. Michael O. Akpochafor, Department of Radiation Biology, Radiotherapy and Radiodiagnosis, College of Medicine/Lagos University Teaching Hospital, Idi-Araba, PMB 12003, Lagos, Nigeria. Tel: +234(0)8137850394; E-mail: akpochafor@gmail.com

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Abstract

The aim of this study was to evaluate and compare the treatment plans produced using Intensity modulated radiotherapy (IMRT) and double-arc volumetric modulated arc therapy (VMAT) techniques for head and neck cancer cases with respect to maximum dose (D98%); minimum dose (D2%); Conformity Index (CI); Homogeneity Index (HI); volume that received 95% of the prescribed dose (V95%) and dose received by organs at risk (OARs). For this study, fifteen (15) patients of head and neck cancer were randomly selected for analysis of dose distribution within targets. For all these patients, IMRT and double-arc VMAT plans were generated for each of them making a total of thirty (30) plans. Calculated doses to planning target volume (PTV) and OAR was compared. Five (5) or seven (7) beams were used for all IMRT plans while double arc were used in the VMAT plans. Dose volume histogram (DVH) was generated for each plan and analyzed for dose coverage to the targets V95% which is the volume that receives 95% of the prescribed dose. PTV coverage was nearly similar in both treatment techniques. The homogeneity index (HI) was higher for the double arc VMAT plans with a value of 0.08 ± 0.014 compared to 0.06 ± 0.020 for IMRT plans (p-value of 0.012). The double arc VMAT plans provided a better conformity with a conformity index CI95%= 0.981 ± 0.014 compared to CI95%= 0.978 ± 0.011 achieved with the IMRT plans (p-value of 0.533). The double arc VMAT plans achieved significant sparing of the organs at risk with a significant p-value of 0.011 and 0.035 to the spinal cord and left parotid glands respectively. Double arc VMAT plans provided better dose conformity and OAR sparing while more homogeneous target coverage was achieved with the IMRT plans.

Keywords: IMRT; VMAT; Head and neck; Organs at risk

Introduction

Cancer is a disease caused by the failure to regulate division of cell. This is as a result of cell dividing too often and then eventually interfering with normal body function (Enger *et al.*, 2007).

In head and neck cancer cases, the tumors are often situated in close proximity to numerous normal tissues; thus delivering an adequate radiation dose to the primary and regional lymph nodes which requires special attention to protect these organs at risk (OARs). These organs at risk are normal tissues whose radiation sensitivity may significantly influence treatment planning and prescribed dose (ICRU Report 50, 1993). They might also be damaged as a result of radiation exposure during treatment. Owing to the complex anatomy and multiple organs at risk in close proximity to the targets, head and neck cancer is a technically difficult treatment site for radiation oncology. Another reason is that the volume that should be irradiated has a convex shape encompassing the spinal cord, which is the most critical organ at risk at this site (Lukarski *et al*., 2010; Shang *et al.,* 2015).

The treatment planning techniques for head and neck cancer using external-beam radiotherapy has evolved from the traditional three-field technique in the early days to intensity-modulated radiotherapy (IMRT), and recently to volumetric modulated arc therapy (VMAT) which has been said to be more efficient (Shang *et al.,* 2015). IMRT refers to a radiation therapy technique in which a non-uniform fluence is delivered to the patient from any given position of the treatment beam to optimize the composite dose distribution (Khan, 2014). IMRT enables the radiation dose to closely conform to the tumor's three-dimensional (3-D) shape by modulating or controlling the strength of the radiation beam in several, small volumes (Chui *et al.,* 2001). The most compelling justification for this expensive and time consuming modality is its ability to spare organs at risk and improve the quality of life (Bindhu *et al*., 2009).

3D-conformal radiotherapy operates in forward planning whereby the planner selects the required number of open or wedged treatment beams of appropriate beam geometries. The treatment planning system (TPS) calculates the composite distribution of dose by adding the dose contributed by each of the treatment beams. If the dose and the distribution of dose are unsatisfactory the planner varies the beam parameters and geometries and repeats the calculation (Cheung KY, 2006). IMRT and VMAT's dose distribution on the other hand is inversely planned. This means that the planner decides the dose distribution wanted for the target volumes and the acceptable tolerance dose for individual normal organs of interest. This is usually in the form of a constraint table for the treatment planning system (TPS) and the computer then calculates a group of beam intensities that will produce the desired dose distribution (Cheung KY, 2006; Bakiu *et al.,* 2013).

Planning with the use of IMRT and VMAT techniques also require optimization of multileaf collimator (MLC) leaf positions in order to try and achieve suitable dose distributions. It has been reported that IMRT and VMAT treatment plans provide highly conformal dose distribution with good sparing of normal tissues (Syam *et al*., 2012; Varian Medical Systems, 2018). Different studies have reported the advantage of VMAT over conventional IMRT to include the ability to produce treatment plans with higher PTV homogeneity, less monitor units and shorter delivery times (Cozzi *et al*., 2008; Palma *et al.,* 2008; Clivio *et al*., 2009; Wagner *et al.,* 2009).

In this study, we evaluated and compared the treatment plans produced using IMRT and double arc VMAT techniques for head and neck cancer cases with respect to maximum dose ($D_{98\%}$); minimum dose ($D_{2\%}$), Conformity Index (CI), Homogeneity Index (HI), volume that received 95% of the prescribed dose ($V_{95\%}$) ; and doses received by organs at risk (OARs).

Materials and Methods

Patient selection and preparation

Fifteen patients with head and neck cancers treated with double-arc VMAT at NSIA-LUTH Cancer Care were replanned using IMRT by Varian's eclipse treatment planning system (TPS), version 15.6 for interactive optimization of IMRT plans and analysis of dose distribution within targets. Patients underwent a pre-treatment evaluation, including complete history and physical examination, computed tomography (CT) of head and neck region using General electric CT scanner. Patients were aligned in supine position with arms by the side using head and neck thermoplastic masks. All patients were scanned from skull vertex to mid-chest with a slice thickness of 2.5 mm. CT images were then transferred to the Eclipse TPS via Digital Imaging and Communications in Medicine "DICOM" network.

Target volume definition

The gross tumor volume (GTV) was delineated as the macroscopic disease including all positive lymph nodes detected by clinical examination and radiological imaging. Target and OARs delineation was performed based on International Commission on Radiation Units and Measurements (ICRU report 83, 2010) guidelines. The clinical target volume (CTV) gross disease was composed of GTV with a 10-mm margin. Near the neural structures, the margin was reduced to 1 mm. The planning target volume (PTV) included the CTV with 3-5 mm extensions in all dimensions to account for patient setup error and motion uncertainties. The PTV sizes ranged from 232.4 cm^3 to 711.2 cm^3 with an average value of 480.6 cm^3.

Dose and Fractionation

Only single phased PTV was analysed in the course of this study. The prescribed dose to the PTV was within the range of 40 Gy - 60 Gy with a daily fraction dose of 2Gy in five fractions per week using VMAT or IMRT techniques. The treatment of all patients was planned with a goal of 95% volume of PTV to be covered by 95% iso-dose line.

Treatment Plan evaluation parameters

For all IMRT plans, five (5) or seven (7) beams were used based on a critical evaluation of patient anatomy and target geometry. Regarding the VMAT planning, the fifteen patients were treated with double arc VMAT plans. Like the VMAT plans, the beam energy of 6 MV photon beam was also used for the IMRT plans. Optimization and calculations were also done on the Eclipse TPS using the anisotropic analytical algorithm (AAA) (Van Esch *et al.*, 2006; Fogliata *et al.*, 2006). 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 normal tissue dose constraints used in this study, as recommended by (Bentzen *et al.*, 2010), for the brainstem include a maximum dose below 54 Gy and a maximum dose of 50 Gy for the spinal cord. Regarding the parotid glands, it was recommended that the mean dose to unilateral organ be restricted to below 20 Gy. For the oral cavity, (RTOG protocols, 2012) recommends that the mean for non-oral cavity cancers should be < 30 Gy.

Plan evaluation index

Plans were qualitatively assessed as verification by visual assessment of plan constraint and dose color wash in CT axial view to evaluate dose quality coverage. The second level of plan evaluation was performed by a quantitative analysis using DVH to define target dose, homogeneity index (HI), conformity index (CI) and OAR sparing. The DVH for PTV coverage, spinal cord, brain stem, parotids and oral cavity were generated. HI and CI were calculated according to the definition proposed by ICRU Report 83; (2010). The evaluation indices are stated below in equations 1 and 2.

Conformity index

CI was defined as the ratio between the patient volume receiving at least 95% of the prescribed dose and the volume of the PTV. It describes how well the prescription dose conforms to the PTV and evaluates a plan's ability to spare normal tissue from the high doses delivered to the treatment volume.

$$CI = \frac{\mathrm{V(RI)}}{\mathrm{TV}} \tag{1}$$

where V(RI) is the volume of the reference isodose (95% of the prescribed dose) and TV is the target volume. The optimal value is "1." Since optimal plans have uniform doses in their treatment volumes, the conformity of each PTV was evaluated.

Homogeneity index (HI)

HI is a fast tool that is used to analyze and quantify dose homogeneity in the target volume. It is also used to evaluate and compare the dose distribution of treatment plans and to choose the best plan among the available plans. The homogeneity index (HI) was calculated using the following equation;

$$HI = \frac{\mathrm{D2\% - D98\%)}}{\mathrm{D50\%}} \tag{2}$$

where $D_{2\%}$ is the minimum dose received by the "hottest" 2% of the PTV, $D_{98\%}$ is the dose received by the 98% of the PTV volume and $D_{50\%}$ is the dose received by 50% of the PTV volume.

Statistical methods

All data were analyzed using Microsoft excel software version 2016 and the results were presented in tables. For evaluating statistical significance between the different dosimetric parameters, two tailed independent t-test was used. P (< 0.05) values were considered statistically significant.

Results

IMRT and double arc VMAT plans were done for each patient making a total of thirty plans. Dose-volume histograms (DVHs) were generated for all plans and dosimetric comparative parameters were recorded. Table 1 presents results of dosimetric analysis and comparison of the PTV. There was no significant difference between the two planning techniques in terms of maximum dose ($D_{98\%}$), minimum dose ($D_{2\%}$), CI and $V_{95\%}$ (the volume that received 95% of the prescribed dose).

PTV coverage was nearly similar in both techniques. Dose homogeneity for PTV described in terms of HI was higher for the VMAT plans with a value of 0.08 ± 0.014 compared to 0.06 ± 0.020 for the IMRT plans (p-value of 0.012). Looking at the dose conformity which was described in terms of $CI_{95\%}$, the VMAT plans gave a better dose conformity with a $CI_{95\%}$= 0.981 ± 0.014 compared to $CI_{95\%}$= 0.978 ± 0.011 achieved with the IMRT plans. However, this was not statistically significant (p-value of 0.533). Fig. 1 shows the dose distribution in an axial view illustrating both the IMRT and double arc VMAT techniques for the same patient.

Table 1. Dosimetric outcomes for the PTV between the two techniques

Parameters	IMRT	VMAT	P-Value
$D_{98\%}$ (Gy)	47.74 ± 10.23	48.36 ± 10.62	0.872
$D_{2\%}$ (Gy)	50.93 ± 11.06	52.51 ± 11.52	0.704
HI	0.06 ± 0.020	0.08 ± 0.014	0.012
$CI_{95\%}$	0.978 ± 0.011	0.981 ± 0.014	0.533
$V_{95\%}$ (%)	97.86 ± 1.10	97.97 ± 1.37	0.782

Table 2. Dosimetric Outcomes for the Organs at Risk between the two techniques.

Organ	Parameter	IMRT	Double arc VMAT	P-Value
Spinal Cord	Max Dose (Gy)	44.46±3.33	37.31 ± 5.40	0.011
Brainstem	Max Dose (Gy)	33.18±13.24	33.11 ± 13	0.989
Right Parotid	Mean Dose (Gy)	21.56 ± 3.50	19.06 ± 3.79	0.192
Left Parotid	Mean Dose (Gy)	21.65 ± 2.16	18.04 ± 3.80	0.035
Oral Cavity	Mean Dose (Gy)	30.58 ±8.67	27.80 ± 8.18	0.616

Sparing of the organs at risk was respected in all plans. This study was carried out for right and left parotid glands separately. It was, however, discovered that the mean dose to each of the parotids was slightly higher than 20 Gy in the IMRT plans but was within individual tolerance in the VMAT plans. Table 2 shows the mean dose D_{mean} and the maximum dose D_{max} of the OARs related to the head and neck plan for the two techniques. Regarding the right parotid gland, the mean dose was 19.06 ± 3.79 Gy in the VMAT plans versus 21.56 ± 3.50 Gy for the IMRT plans (p-value of 0.192); while for the left parotid gland the mean dose was 18.04 ± 3.80 Gy in the VMAT plans as opposed to 21.65 ± 2.16 Gy for the IMRT plans (p-value of 0.035).

In both plans, the maximum dose to the spinal cord was kept below 50 Gy. The maximum dose to the spinal cord was lower in the VMAT plans 37.31 ± 5.40 Gy when compared to the IMRT plans 44.46 ± 3.33 Gy. This also showed a statistically significant difference (p-value of 0.011).

Clinically acceptable maximum doses to the brainstem and spinal cord were achieved in all plans. No large difference was seen between the IMRT and double-arc VMAT plans with respect to the maximum dose to the brainstem. The IMRT plans gave a slightly higher maximum dose of 33.18 ± 13.24 Gy to the brainstem compared to 33.11 ± 13 Gy in VMAT plans. However, this was not statistically significant (p-value of 0.989). With respect to the oral cavity, the mean dose was lower in the double-arc VMAT plans 27.804 ± 8.18 Gy when compared to IMRT plans 30.58 ± 8.67 Gy with an insignificant p-value of 0.616. The IMRT plans gave about 1.93% higher than the recommended dose tolerance to oral cavity which is a mean dose < 30 Gy (RTOG 0920, 2012).

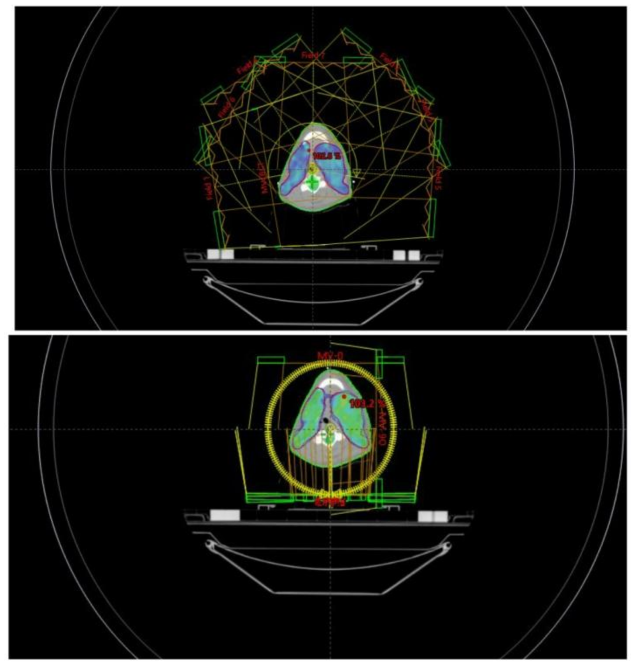

Figure 1. **Dose distribution for an axial view created by IMRT plan (Top) and a similar CT cut planned by double-arc VMAT technique (Bottom).**

Discussion

VMAT treatment entails a rapid delivery which has the advantage of decreasing the risk of intra-fractional positional shifts of the patient. When compared to IMRT, VMAT plans using double arc showed a better dose conformity and at the same time, presented a major reduction of irradiation to organs at risk. In this present work, the maximum dose to spinal cord in the double-arc VMAT plans recorded about 20% reduction relative to the IMRT plans.

In our study, Double arc VMAT was preferred over single arc because numerous studies show that the single arc plans were inferior to the double arc in terms of conformity, target coverage, dose homogeneity and OAR sparing (Verbakel *et al.*, 2008; Bertelsen *et al.*, 2010). In a study of single arc VMAT optimization without OAR objective as carried out by Verbakel *et al.*, 2008 confirmed that the dose homogeneity in the PTV is still worse than a plan consisting of a double arc, where all OAR objectives are taken into consideration. The use of a second arc was said to have added more degrees of freedom for possible leaf positions, hence a solution for the homogeneity problem.

The results of our study are in line with the data published by Mashhour *et al*. (2017) where they compared VMAT with conventional IMRT for head and neck cancer irradiation. Two plans were made for each patient; one using IMRT and the other double arc VMAT and calculated doses to planning target volume (PTV) and OAR were compared. Though target coverage was almost the same in the two techniques, the VMAT plans gave a better PTV dose homogeneity compared to IMRT techniques. The only difference in this study relative to our data is that double-arc VMAT provided more homogenous target volume coverage compared to the IMRT technique.

Conclusions

The study of head and neck cancer using double-arc VMAT proved a significant sparing of the OARs without compromising target coverage compared to IMRT. PTV coverage was nearly similar in both IMRT and double arc VMAT plans but the latter provided better dose conformity and OAR sparing; while more homogeneous target coverage was achieved with IMRT plans.

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Abbreviations

IMRT: Intensity modulated radiotherapy; VMAT: Volumetric modulated therapy; CI: Conformity Index; HI: Homogeneity Index (HI); Organs at risk (OARs); PTV: Planning target volume; DVH: Dose-volume histograms.

Author Contributions

All authors contributed equally to this study and gave their final approval.

Competing Interests

The authors have declared that no competing interest exists.

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