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Study the Quality of Nasopharyngeal plans Using Evaluation Indexes of IMRT and VMAT Treatment planning Techniques

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Abstract

Radiation treatment has long been the conventional approach for treating nasopharyngeal cancer (NPC) tumors due to its anatomic features, biological characteristics, and radiosensitivity. The most common treatment for nasopharyngeal carcinoma is radiotherapy. This study aimed to assess the better quality of radiotherapy treatment techniques using intensity-modulated radiotherapy (IMRT) and volumetric-modulated arc therapy (VMAT). The VMAT and IMRT are comparative techniques. Forty patients with nasopharyngeal carcinoma and forwarded for radiotherapy were treated with both advanced techniques, IMRT and VMAT, using eclipse software from Varian. The x-ray energy was set at 6 MV. The total prescribed dose was 70 Gy. The results show that the VMAT had better tumor coverage than the IMRT. Regarding quality indices, the IMRT shows a better dose homogeneity, while the VMAT gives better gradient and conformity indices. The best technique that reduces the dose to the right eye, optic chiasm, and thyroid is VMAT, while the esophagus and spinal cord are protected better with IMRT. The VMAT shows a special effect for IMRT for treating nasopharyngeal carcinoma.

Keywords: Gradient Index, Intensity-Modulated Radiotherapy (IMRT), Nasopharyngeal, TPS, volumetric-modulated arc therapy (VMAT).

Introduction

In the area of head and neck cancers, nasopharyngeal carcinoma (NPC) stands apart. Due to its anatomic features, biological characteristics, and radio sensitivity, radiation therapy has long been the standard method for treating non- metastatic NPC. Intensity-modulated radiotherapy (IMRT) is the state-of-the-art method of pinpoint radiation delivery due to recent advancements in radiation equipment and technology[1]. Previous studies [2–6] have shown a significant improvement in IMRT regarding tumor control and quality of life in NPC.

Intensity-modulated radiation therapy (IMRT) has the potential to offer a heterogeneous dose distribution to many target volumes simultaneously, with the dose increasing at the tumor site and decreasing in surrounding organs at risk [7]. One main drawback of IMRT is that it takes longer to administer than conventional two-dimensional radiation. Prolonged treatments not only promote the repair of sublethal damage, which presents a danger for sparing tumors, but also reduce efficiency, increase pain, and increase involuntary patient movement on the couch, which may raise the risk of dosage deviation and compromise the treatment accuracy [8–11].

With the ability to continuously modulate multi-leaf collimator (MLC) positions, dose rate, and gantry speed simultaneously, Volumetric Modulated

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Arc Therapy (VMAT), which was first proposed by Yu's group and developed based on a study by Otto, can change the dose delivery with various gantry arcs dynamically while the gantry rotates around the patient[12].

Radiation may be supplied from any direction with VMAT, but with IMRT on a fixed gantry, only a small number of predetermined gantry angles can be used. Furthermore, it is potentially more efficient since the whole treatment may be accomplished with a single 360° gantry spin. Radiation oncologists have embraced VMAT, which is now being used at several treatment centers [13–16].

Several outstanding studies have compared VMAT-based treatment techniques for nasopharyngeal carcinoma (NPC) to IMRT-based treatment strategies in terms of planning and clinical outcomes. Previous reports comparing doses used CT scans from the same subjects [7, 11, 17].

Only one approach may be used to provide therapy when exposing a patient to radiation. Therefore, comparing the two radiotherapy procedures must be conducted on patients who have received real clinical radiation exposure. In addition, the therapeutic advantage of speedier therapy is unclear [18].

There is limited information about the proper techniques of nasopharyngeal tumor due to its complexity. So, this study aimed to assess and compare the planning techniques, whether it is IMRT or VMAT, for nasopharyngeal tumors.

Materials and Methods

This research is a retrospective conducted from January to June 2022 at Al-Warith International Cancer Institute. This research involved 40 patients with postnasal malignant tumors. Oncologists diagnosed and referred these patients for chemotherapy and radiation. Patients included in this study are those who were diagnosed with nasopharyngeal as primary cancer that underwent chemotherapy. Metastatic patients were excluded from the study. The anatomical characteristics of the patient's skull were scanned using computed tomography (CT) simulation 64 slices created by Siemens, United States as shown in Fig.1. The patient's information is then sent to the workstation of the treatment planning system (TPS). The radiation oncologist outlines the target volume, including the planned target (PTV) and at-risk organs. The total prescribed dose for the PTV 95% was 70 Gy. In Eclipse TPS, Varian, USA, the medical physicist (researcher) develops two types of plans: IMRT and VMAT for each patient. The IMRT generated 7 – 9 beams as shown in fig.1, while the VMAT was performed using two arcs from angle 179 to 181 degrees, as shown in fig.2, The x-ray energy used in this study was 6 MV for both techniques. The HI, CI, and GI indices and the plans were analyzed from equations[19]:

$$HI = \frac{D2\% - D98\%}{D50\%} \qquad \dots\dots\dots 1$$

HI: homogeneity index, D2 %: is the absorbed dose in 2 % of the isodose line, D98 %: is the absorbed dose in 98 % of the isodose line and D50 %: is the absorbed dose in 50 % of the isodose line.

When the HI value is zero this indicates that the absorbed-dose distribution is almost homogeneous.

The degree to which the high-dose zone matches the target volume, often the PTV, is described by the term "dose conformity." When comparing the recommended isodose volume to the PTV, the Conformity Index (CI) is used to assess the precision with which the PTV is covered[20]:

$$CI = \frac{V_{RI95}}{TV} \qquad \dots\dots\dots.2$$

CI: Conformity Index, V_{TV}: volume of the actual prescribed dose, V_{PTV}: volume of PTV and TV_{PV}: volume of V_{PTV} within V_{TV}

The treatment conformity is said to be achieved the optimum is at CI =1.

The Dose gradient index (DGI) also known as the dose fall-off characteristics, near the target volume by visually inspecting two-dimensional isodose distributions section by section. Dosimetry software may be used to view the cross-sectional dosage profile, but objective measurement of the dose gradient is almost impossible without specialized equipment[21]. In order to assess a dosage gradient, the gradient index (GI), which is defined as the ratio of the volume of half of the prescription isodose to the volume of the prescription isodose, has been suggested as a straightforward instrument. When analyzing the dose gradient beyond the planning target volume (PTV) extending into normal tissue structures, the ratio of 50 percent prescription isodose volume to the planning target volume (R50 percent) has been extensively accepted as a benchmark, as indicated in equation 3 [22--24]. Although

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the GI and R50% have allowed quantitative analysis of the dose gradient and comparison of competing plans based on these scores, the complexity of the dose profile over the range of dose distribution cannot be considered. Furthermore, the current volume-based indices are highly dependent on target volume that provides misleading results, especially when examining small target volumes or complex target shapes[25].

$$Gradient\ Index\ (GI) = \frac{V50\%}{V100\%} \quad \dots\dots 3$$

The resulted from doses were measured from the dose volume histogram (DVH) from the MONACO TPS software shown in the upper right of fig.3,Analysis of data was carried out by using the available statistical package of Statistical Packages for Social Sciences- version 24 (SPSS-24). Data were presented in simple measures of percentage, mean, standard deviation, and range (minimum-maximum values). The significance of the difference between the two means (quantitative data) was tested using the student T-Test for the difference between the three means. Statistical significance was considered whenever the *p*-value was equal to or less than 0.05. The recommended tolerance dose for the OAR involved in this study is shown in Table 1[26]:

Figure 1. The CT simulation device in Al-Warith cancer institution

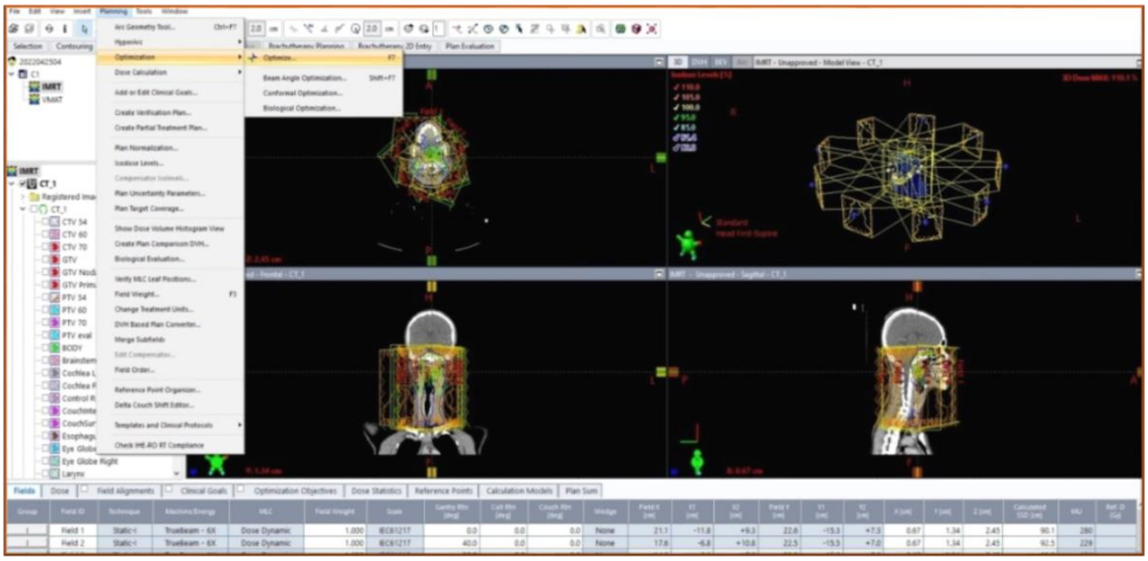

Figure 2. IMRT plan for nasopharyngeal cancerous tumors

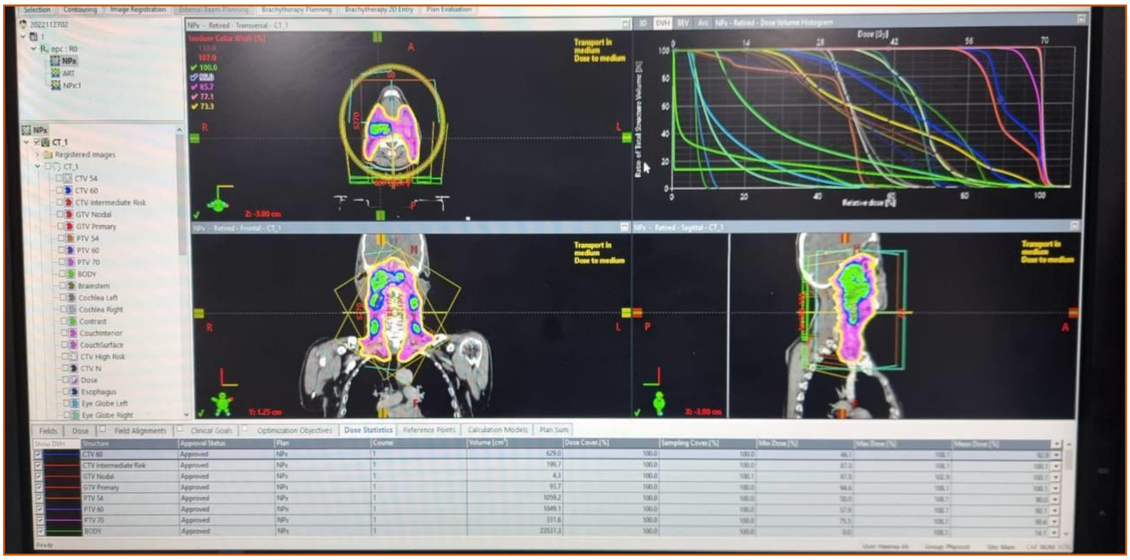

Figure 3. VMAT plan for nasopharyngeal cancerous tumors

Results and Discussion

The dose delivered to the target is expressed in mean, minimum, and maximum for both techniques: IMRT and VMAT. The comparative results are shown in Table 2. The mean and minimum dose in VMAT was significantly higher than in the IMRT. There was no significant difference between the maximum doses of the two studied techniques, as shown in Fig. 4.

Table 1. Recommended dose tolerance for the organs at risk.

Volume	Dose (Gy)
Brain Stem	Dmax <54 Gy
Esophagus	Dmean < 30 Gy
Eyes	Dmax ≤ 25 Gy
Spinal cord	Dmax <45 Gy
Optic Chiasm	Dmax ≤ 54 Gy
Thyroid	Dmean < 30 Gy

Table 2. Comparison between the mean, maximum, and mean dose of IMRT and VMAT for the Target Volume

Target	IMRT	VMAT	*p*-value
Mean (Gy)	62.7 ± 14.15	66.22 ± 21.3	0.0427*
Min. (Gy)	20.32 ± 3.89	25.17 ± 7.42	0.0496*
Maximum (Gy)	69.95 ± 10.09	70.98 ± 13.93	0.0543

***The difference is considered significant if the *p*-value is ≤0.05**

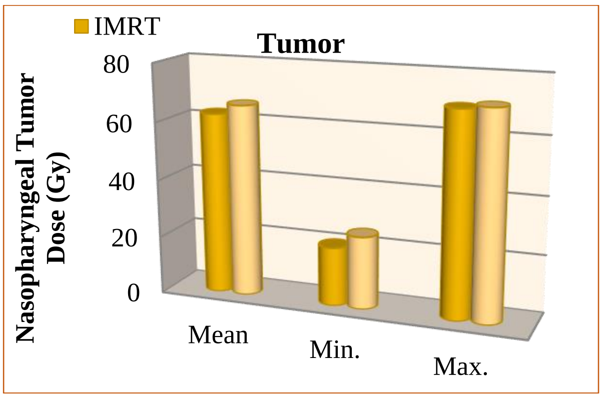

Figure 4. The minimum, maximum, and mean dose exposed to the Nasopharyngeal tumor.

For assessing the planning quality, indices such as homogeneity, conformity, and gradient were calculated from the equations above for both techniques: IMRT and VMAT and illustrated in Table. 3. The results show that VMAT had significantly better conformity and gradient indices than IMRT. The IMRT had a better homogeneity than VMAT but without any significance.

In terms of organs at risk (OARs), the organs involved in this study are the brain stem, esophagus, eyes, optic chiasm, oral cavity, spinal cord, and thyroid. The results are shown in Table. 4.

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The VMAT was statistically significantly superior to IMRT for the right eye, optic chiasm, and thyroid. In comparison, the IMRT is significantly superior in reducing the dose to at-risk organs, such as the esophagus and spinal cord. The brain stem and left eye were protected better in VMAT than IMRT but without significance.

Table 3. Comparison between the quality of planning of IMRT and VMAT for the Target Volume

Indices	IMRT	VMAT	*p*-value
HI	0.61 ± 0.08	0.68 ± 0.05	0.07521
CI	1.02 ± 0.09	1.11 ± 0.05	0.0261*
GI	4.98 ± 1.01	3.15 ± 0.98	0.0428*

***The difference is considered significant if the *p*-value is ≤0.05**

Table 4. Organs at Risks (OARs) comparison between the IMRT and VMAT

Volume	IMRT	VMAT	*p*-value
Brain Stem			
Maximum Dose (Gy)	56.91 ± 13.95	53.46 ± 15.03	0.0846
Esophagus			
Mean Dose (Gy)	15.63 ± 3.02	18.01 ± 4.19	0.0117*
Eye-L			
Maximum Dose (Gy)	21.44 ± 4.49	20.85 ± 2.53	0.5280
Eye-R			
Maximum Dose (Gy)	24.06 ± 4.22	22.95 ± 6.92	0.0309*
Optic Chiasm			
Maximum Dose (Gy)	48.96 ± 15.04	46.33 ± 12.99	0.0018*
Oral Cavity			
Mean Dose (Gy)	11.58 ± 2.09	10.07 ± 1.54	0.0465*
Spinal cord			
Maximum Dose (Gy)	22.55 ± 14.08	30.98 ± 12.04	0.0474*
Thyroid			
Mean Dose (Gy)	16.85 ± 4.67	11.86 ± 2.97	0.0053*

***The difference is considered significant if the *p*-value is ≤0.05**

The recommended and most successful treatment for NPC is radiotherapy. Continuous developments in radiation technology have resulted in substantial therapeutic advantages for patients. Due to the complicated geometry of the tumor and the multiple important and functioning structures around the target, NPC is one of the most challenging diagnoses in the head and neck area [27].

The comparative results of this study between the IMRT and VMAT show that the VMAT had superior dose coverage to the target over the IMRT. Our findings disagreed with previous research conducted by Bin-Bin C. et al. that compared VMAT and IMRT relying on two sets of plans generated for the same patient's target region, they found that IMRT is better than VMAT[28]. However, only one therapy strategy may be used in a patient's real clinical case. Hence, their research shows that prospectively assigning matched patients randomly to either VMAT or IMRT plans may more accurately represent the real clinical condition. There were no discernible changes in gross tumor volume between the two matched groups after careful and methodical allocation. Neither Siham[29], found a difference between IMRT and VMAT nor Johnston et al.[30] The latest authors found that both VMAT and IMRT plans achieved the clinically required dose coverage of the PTVs.

In this study, the VMAT exhibited much superior conformance and gradient indices compared to IMRT. IMRT was more homogeneous than VMAT, although the difference was insignificant.

The difficulty of the target volumes, the precision with which they are delineated, the delivery system, the radiation methodology, and the method of optimization all impact the degree to which the target volumes comply and are homogeneous [31].

In terms of organs at risk (OARs), the organs involved in this study are the brain stem, esophagus, eyes, optic chiasm, oral cavity, spinal cord, and thyroid. The results are shown in Table. 4. The VMAT was significantly superior to IMRT for the right eye, optic chiasm, and thyroid. While IMRT is significantly superior in reducing the dose to organs at risk such as the esophagus and spinal cord. The brain stem and left eye are protected better in VMAT than in IMRT but without any significance.

Conclusion

In conclusion, the clinical criteria for treating nasopharyngeal cancer may be satisfied by both VMAT and IMRT (NPC). The VMAT showed a superior coverage for the tumor better than the IMRT. IMRT provides superior dose homogeneity in terms of quality indices, whereas VMAT provides superior gradient and conformity indices. VMAT was the most effective strategy for reducing the dosage to the right eye, optic chiasm, and thyroid, whereas IMRT was superior for protecting the esophagus and spinal cord.

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Authors' Declaration

- Conflicts of Interest: None.
- We hereby confirm that all the Figures and Tables in the manuscript are ours. Furthermore, any Figures and images, that are not ours, have been included with the necessary permission for re-publication, which is attached to the manuscript.
- Authors sign on ethical consideration's approval.
- Ethical Clearance: The project was approved by the local ethical committee in University of Baghdad.
- Ethics Approval: This study was conducted with approval form AL-Warith International cancer Institute, that have been attached.

Authors' Contribution Statement

A. M. Kh. has verses that have a role in writing and arranging the entire research and B. Kh. R.has a role in discussing and interpreting the results.

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دراسة خطط البلعوم الانفي باستخدام معاملات التقييم لتقنيات العلاج IMRT and VMAT

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الخلاصة

العلاج الأكثر شيوعًا لسرطان البلعوم الأنفي هو العلاج الإشعاعي، هدفت هذه الدراسة إلى تقييم جودة العلاج الاشعاعي باستخدام العلاج الاشعاعي المعدل الشدة (IMRT) والعلاج بالقوس الحجمي المعدل (VMAT). حيث ان VMAT وIMRT هما تقنيات مقارنة. تم علاج اربعين مريضا مصابا بسرطان البلعوم الانفي وتم توجيههم للعلاج الاشعاعي باستخدام كل من التقنيات المتقدمة IMRT وVMAT باستخدام برنامج eclipse من شركة Varian تم ضبط طاقة الاشعة السينية على 6MV. كانت الجرعة الاجمالية الموصوفة 70 Gy. اظهرت النتائج ان VMATكان له تغطية الورم بشكل أفضل من IMRT. فيما يتعلق بمؤشرات الجودة، يظهر IMRT تجانسا أفضل للجرعة، بينما يعطي VMAT مؤشرات أفضل للتدرج والمطابقة. أفضل طريقة لتقليل جرعات العين اليمنى، والتصلب البصري، والغدة الدرقية هي تقنية VMAT بينما تتم حماية المريء والنخاع الشوكي بشكل أفضل باستخدام IMRT. يظهر VMAT تأثيرا خاصا لـIMRT لعلاج سرطان البلعوم الانفي.

الكلمات المفتاحية: معامل الانحدار، العلاج الاشعاعي المعدل الشدة، سرطان البلعوم الانفي، نظام التخطيط العلاجي، العلاج الاشعاعي المعدل الحجمي.