Original Article
Adv Med Phy App Sci, 2025; 1(1): 5-9

Dosimetric Evaluation of VMAT, sIMRT, and dIMRT Radiotherapy Techniques in The Patients with Nasopharyngeal Cancer

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Received: *9 November 2024*
Revised: *31 December 2024*
Accepted: *13 January 2025*

ABSTRACT

Purpose: The objective of this study was to evaluate the comparative efficacy of VMAT and IMRTs in the treatment of nasopharyngeal cancers (NPC) with respect to dosimetry, and to ascertain the advantages of these techniques. Methods and Materials: A total of twenty NPC patients were subjected to analysis of their respective treatment plans, which were prepared using VMAT and IMRTs. A variety of treatment plans were devised, comprising 35 fractions with a total dose of 70Gy (PTV70Gy) and 56Gy to the elective lymph nodes (PTV56Gy). In the creation of NPC treatment plans utilising VMAT, IMRTs radiotherapy techniques, the objective was to deliver a 100% of the prescribe dose covers 95% of the target volume while ensuring the protection of critical organs at the minimum dose. Furthermore, the doses received by the target tissue and critical organs were compared with those delivered to the other techniques in terms of dose delivery time, MU, HI and CI. Findings: A comparison of the various techniques revealed that the D95 dose coverage for the PTVs was superior in the VMAT. In addition, the lowest dose sIMRT was observed for PTVs ($p < 0.05$). The number of MU differed for different techniques, with the highest MU value calculated in the sIMRT and the lowest in the VMAT technique ($p < 0.05$). No significant differences were found in HI and CI values among the three NPC radiotherapy plans ($p > 0.05$). Conclusion: It was determined that the optimal approach for NPC radiotherapy is to consider all relevant clinical and dosimetric factors, including patient-specific decision-making, dose distributions within the PTVs and OARs, beam-on time, MU, HI and CI indexs.

Keywords: *Nasopharyngeal cancers, radiotherapy, VMAT, step-and-shoot and sliding window*

INTRODUCTION

Nasopharyngeal cancer (NPC) is among the non-metastatic tumours that are commonly treated with curative radiotherapy, as surgical intervention is not a viable option. Radiotherapy for such tumours has been demonstrated to be highly effective and to elicit a rapid response [1]. Nevertheless, the proximity of numerous vital organs to the primary tumour and the elevated doses necessary for tumour control render treatment planning a challenging endeavour [2]. NPC is the only type of cancer that can be treated exclusively with radiotherapy. Consequently, this patient group represents a matter of great importance within the radiotherapy applications. If the disease remains confined to the head-neck, radiotherapy is the sole appropriate treatment. However, if it is locally or regionally advanced, concurrent chemotherapy with radiotherapy is the preferred approach [3]. VMAT and IMRT have overtaken 3DCRT in head and neck cancer treatment [4,5].

Computer-based treatment planning systems (TPS) facilitate more accurate and effective dose efficiency for patients through a range of techniques and models of radiotherapy devices [6,7]. It is therefore incumbent upon radiation oncologists to determine which device and technique is of greatest importance in the context of treatment plans, with a view to optimising both user experience and cost-effectiveness. IMRT modifies the intensity of ionising X-rays with the objective of maximising the dose delivered to tumourous tissues while minimising the radiation exposure to organs at peripheral risk. The IMRT technique is frequently the preferred method for the radiotherapy of head and neck tumours [8]. IMRT treatment at fixed gantry angles, small segments are created for the target volume, thereby achieving the maximum treatment dose while aiming to deliver a reduced dose to critical organs and normal tissues [4,9].

The VMAT method is designed to minimise the dose of risky organs. It is advanced radiotherapy that incorporates volumetric dose calculation. This method is frequently employed, particularly in the treatment of head and neck cancers, due to its utilisation of beams with varying intensities, which result in a more homogeneous and coverage dose distribution over the target volume through the alteration of the intensity of each beam [10,11]. The multi-leaf collimators (MLC) in conjunction with the gantry rotation speed, afford the advantage of dose calculation [12]. In contrast to alternative techniques, the most notable attribute of VMAT is the continuous rotation of the gantry, which results in a notable reduction in both the total Monitor Unit (MU) and treatment time (beam on time) compared to other techniques. It is common practice to investigate whether this advantage is radiobiologically advantageous, as well as the MU value and treatment times [13]. The dosimetric parameters of treatment plans employed in diverse models of linear accelerator radiotherapy devices may vary, conferring advantages and disadvantages between disparate treatment techniques [14].

The objective of this study was to undertake a comparative analysis of dose distributions in the target volume and critical organs, as well as treatment times, total MU values, HI and CI indices during NPC radiotherapy, employing different treatment techniques, namely VMAT and IMRTs.

METHODS

Planning Strategies for Different Techniques

The NPC patients were positioned supine on the CT Simulator (Siemens, Somatom) for the simulation procedure. Once the head, neck and shoulder mask had been applied, the patient was stabilised using an appropriate head pillow and shoulder handles, and images were obtained at a slice thickness of 3 mm. Twenty NPC patients were treated with simultaneous integrated boost plans. This involved a dose of (PTV70Gy) in 35 fractions and 56Gy to the elective neck lymph nodes target volume (PTV56Gy) in 35 fractions. In addition to the tissues obtained from CT slices, the radiation oncologist contoured critical organs, according to RTOG protocols (RTOG 0615). Safety margins were incorporated to minimise set-up errors and internal organ movements.

This study aimed to optimize VMAT and IMRTs plans for 95% target coverage, critical organ dose minimization, and a 110% dose limit, adhering to specific OAR constraints. Furthermore, the dosimetric parameters and target organ doses [15] were compared across three planning techniques. The data were analyzed with SPSS 25 using t-tests; $p < 0.05$ was considered significant.

RESULTS

Table 1 summarizes the mean, standard deviation, and statistical comparisons of Dmax and D95 doses across four techniques. VMAT provided the best D95 coverage for PTVs, while sIMRT had the lowest." ($P < 0.05$). No significant differences in Dmax were found among the three techniques for PTV70Gy and PTV56Gy ($p > 0.05$). Table 2 shows the mean, standard deviation, and statistical comparisons for total MU, treatment times, homogeneity, and conformity indices across three techniques. While there were notable differences in MU values across the various treatment techniques, the sIMRT exhibited the highest MU value, while the VMAT technique demonstrated the lowest value ($p < 0.05$). Furthermore, the shortest treatment duration was observed in the VMAT, while the longest was observed in the sIMRT ($p < 0.05$). No statistically significant difference was identified in dose HI and CI values between the three different NPC radiotherapy plans ($p > 0.05$). Table 3 presents OARS dose values across radiotherapy techniques for NPC patients. sIMRT had the lowest brainstem Dmax and D1, while VMAT had the highest ($p < 0.05$). dIMRT achieved the lowest optic chiasm doses, with VMAT being highest ($p < 0.05$). VMAT minimized Dmean and sliding window minimized V30 ($p < 0.05$). Spinal cord doses were within limits, with VMAT showing the lowest Dmax ($p < 0.05$).

Table 1. Mean, standard deviation and p-values for different techniques

PTV	Dmax and D95 (Gy)	sIMRT mean±SD	dIMRT mean±SD	VMAT mean±SD	sIMRT vs. dMRT	sIMRT vs. VMAT	dIMRT vs. VMAT
PTV 70Gy	Dmax	75,29±2,45	75,42±2,36	74,89±2,08	0,320	0,256	0,189
	D95	66,47±2.74	67,47±2,09	68,86±2.78	0,229	**0,001***	**0,001***
PTV 56Gy	Dmax	74,75±2,10	74,94±2.70	73,01±2,12	0,145	0,412	0,394
	D95	53,07±2,03	54,16±2,45	55,23±2,25	0,348	**0,001***	**0,001***

Table 2. MU, beam-on time, CI, HI, and p-values for different techniques

	sIMRT mean±SD	dIMRT mean±SD	VMAT mean±SD	sIMRT vs. dIMRT	sIMRT vs. VMAT	dIMRT vs. VMAT
MUs	1016±106,12	703±51,48	541±48,10	**0,001***	**0,001***	**0,001***
Beam on time (min)	12,8±2,06	7,49±2,74	5,55±1,12	**0,001***	**0,001***	**0,001***
CI	1,23±0,07	1,27±0,05	1,25±0,02	0,210	0,529	0,374
HI	1,06±0,04	1,09±0,05	1,05±0,03	1,000	1,000	0,896

Table 3. p-values and OAR dose results for VMAT, sIMRT and dIMRT techniques

Critical Organs	Dose-volume Constraints (DVCs) (Gy)	sIMRT mean±SD	dIMRT mean±SD	VMAT mean±SD	sIMRT vs. dIMRT	sIMRT vs. VMAT	dIMRT vs. VMAT
Brain stem	**Dmax**	54,98±2,06	59,95±2,45	61,09±2,78	**0,001***	**0,001***	0,071
	Dmean	39,23±1,08	39,39±1,17	40,11±2,04	0,227	0,045	0,501
	D1	51,25±2,06	55,13±2,98	56,01±2,05	**0,001***	**0,001***	0,231
Optic chiasm	**Dmax**	41,14±1,15	36,64±2,18	42,35±2,09	**0,001***	0,346	**0,001***
	Dmean	27,10±1,71	25,30±1,23	28,95±2,46	**0,001***	0,280	**0,001***
	D1	40,27±2,80	35,27±1,01	42,90±2,34	**0,001***	0,321	**0,001***
Right parotid	**Dmean**	26,95±2,16	25,18±2,18	24,70±2,38	**0,001***	**0,001***	**0,001***
	Dmax	61,08±2,07	59,82±2,81	61,01±2,81	0,174	0,209	0,401
	V30	26,84±2,14	24,44±2,33	23,11±1,97	**0,001***	**0,001***	**0,001***
Left parotid	**Dmean**	26,96±2,23	25,10±2,37	24,58±1,37	**0,001***	**0,001***	**0,001***
	Dmax	60,98±2,08	61,03±2,36	60,42±1,06	0,212	0,010	0,189
	V30	27,95±2,22	26,05±2,31	25,06±2,81	**0,001***	**0,001***	**0,001***
Spinal cord	**Dmax**	41,01±2,31	36,91±1,91	36,01±2,19	**0,001***	**0,001***	**0,001***

Statistically significant values (p<0.05), **D1: Dose covering 1% of the target volume, **Dmax:** Maximum dose, **Dmean:** Mean dose, **V30:** Target's volume covered by 30% isodose line, **VMAT:** Volumetric Modulated Arc Therapy, **SD:** standard deviation.*

DISCUSSION

The head and neck region features irregular target volumes, rendering treatment planning a complex process [16]. This is due to the proximity of numerous organs at risk to the primary tumour neighbourhood. The application of IMRT has the effect of reducing the dose of radiation that reaches organs at risk while simultaneously improving the control of the tumour. Furthermore, the use of IMRT allows for the delivery of a more homogeneous and conformal dose distribution to the target volumes [17]. Nevertheless, the most significant drawback of different techniques is the extended treatment duration [18]. Furthermore, the success of the treatment is contingent upon organ and patient movements, which are subject to change with the increase in inter- and intrafraction time [19]. Nevertheless, the VMAT technique ensures that the prescribed dose is delivered to the target volume, minimizing organ doses and treatment time [20,21]. In the context of radiotherapy for head and neck cancers, a range of treatment techniques have been explored, with the objective of delivering high doses to the target volume while minimising damage to surrounding healthy tissues. The relative merits of these techniques have been the subject of extensive investigation in numerous studies. In a study conducted by Gestel and colleagues, treatment plans were compared between step-and-shoot, sliding window, and VMAT techniques in patients diagnosed with head and neck cancer. The results demonstrated that the dIMRT technique exhibited a statistically significant advantage over the VMAT technique [22]. This study compared VMAT and IMRTs in NPC patients. VMAT showed superior D95 coverage, shortest treatment times, and lowest Dmax for target volumes. IMRTs achieved the lowest brainstem and optic chiasm doses. No significant differences were found in HI and CI among techniques. The present study compared three radiotherapy modalities, highlighting differences in dosimetry and organ risks. Results align with literature, showing that TPS, device type, patient selection, and dose optimization influence treatment outcomes While the treatment plans generated in radiotherapy clinics through the use of diverse techniques, including VMAT and IMRTs are clinically appropriate, the advantages of these techniques vary contingent on the target volume and organs at risk. The findings of the study indicate that the optimal technique for NPC treatment planning may provide medical physicists and approving radiation oncologists with a basis for preference. In clinical practice, it is thought that a patient-based assessment should be made when choosing between different radiotherapy techniques, given that there may not be significant differences between treatment durations and dose distributions.

CONCLUSION

We concluded that it is important to consider all clinical and dosimetric aspects such as primary tumor localization, size, lymph node involvement, dose distributions in the PTVs and OARs doses when choosing between different techniques including VMAT, IMRTs.

Conflict of Interest

There are no conflicts of interest and no acknowledgements.

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