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Comparative evaluation of coplanar and non-coplanar vmat for nasopharynx cancer radiotherapy: Dosimetric and clinical implications

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ABSTRACT

This task presents a comprehensive comparative analysis of two advanced radiotherapy techniques, coplanar Volumetric Modulated Arc Therapy (cVMAT) and non-coplanar Volumetric Modulated Arc Therapy (ncVMAT), for the treatment of nasopharynx cancer. A retrospective analysis was conducted on treatment plans for ten nasopharyngeal cancer patients who underwent radiotherapy using these techniques. The present study focused on dosimetric parameters, including dose distribution to target volumes and critical organs, and clinical implications of these techniques. The results revealed that, while both cVMAT and ncVMAT showed similar performance in terms of treatment plan quality and overall dose conformity, notable differences were observed in mean doses delivered to specific organs. The brainstem, inner ears, left eye, right parotid gland, and left humeral head exhibited significant variations in mean doses between the two techniques. These findings highlight the importance of patient-specific considerations when selecting the optimal radiotherapy approach for nasopharynx cancer patients. Clinicians should carefully assess individual patient characteristics and clinical priorities to make informed treatment decisions. This work proposes practical solutions and contributes to the ongoing discussions on the choice of VMAT techniques in radiotherapy for nasopharynx cancer.

Keywords: coplanar Volumetric Modulated Arc Therapy (cVMAT), non-coplanar Volumetric Modulated Arc Therapy (ncVMAT), cancer, Intensity-Modulated Radiation Therapy (IMRT)

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INTRODUCTION

Head and neck cancer constitutes a heterogeneous group of malignancies affecting anatomical structures in the upper region of the body, including the oral cavity, pharynx, larynx, and associated tissues. The intricacy of this anatomical area, coupled with its proximity to vital structures, imparts unique challenges to the treatment of head and neck cancer. To tackle these challenges, advanced radiation therapy techniques, notably Volumetric Modulated Arc Therapy (VMAT) and Intensity-Modulated Radiation Therapy (IMRT), have emerged as promising solutions [1-3].

VMAT and IMRT represent sophisticated radiation delivery methods that enable precise tumor targeting while minimizing radiation exposure to adjacent healthy tissues and critical organs [4]. VMAT employs a rotating gantry and dynamically adjusts the intensity of the radiation beam as it circumvents the patient, thereby optimizing the dose distribution. In contrast, IMRT entails the modulation of the intensity of multiple radiation beams from various angles to closely conform the radiation dose to the tumor's shape [5]. Furthermore, substantial research has been dedicated to the development of automated non-coplanar radiotherapy algorithms to attain superior results, in contrast to manual non-coplanar techniques [6-8].

In the realm of head and neck cancer treatment, VMAT offers the potential to augment treatment outcomes by enabling the delivery of higher radiation doses to the tumor while safeguarding surrounding normal tissues [5-9]. This becomes particularly critical in this anatomical region, given the proximity of structures such as the spinal cord, salivary glands, and optic nerves.

The present study constitutes a comprehensive comparative analysis of Volumetric Modulated Arc Therapy (VMAT) treatment plans for a cohort of 10 patients exclusively diagnosed with nasopharyngeal cancer. It encompasses the application of both coplanar and non-coplanar techniques on a static couch. The investigation rigorously evaluates various pivotal factors, including dose distribution, target coverage, and organ preservation. The overarching objective is to elucidate the respective advantages and limitations of each treatment modality within this specific clinical context. The insights garnered from this research bear the potential to significantly influence the field of radiation oncology. Thus, offering a valuable resource for optimizing treatment planning strategies and elevating the overall quality of care provided to patients with nasopharyngeal cancer.

MATERIAL AND METHOD

Patients

The study involved a retrospective analysis of treatment plans for ten patients diagnosed with nasopharyngeal cancer who underwent radiotherapy using VMAT techniques at our medical facility. These patients received either definitive or adjuvant radiation therapy with the goal of achieving a cure. The radiation treatment was administered utilizing a Linear Accelerator (LINAC) from Elekta (model: synergy; location: Crawley, UK). A radiation dose of 70 Gy was delivered over a span of 6 weeks to 7 weeks, with five treatment sessions per week. These treatment plans adhered to the guidelines outlined by the International Commission on Radiation Units and Measurements (ICRU) [10]. Additionally, some patients received concomitant chemotherapy (chemoradiation) in conjunction with their radiotherapy treatment.

All patients underwent scanning using the Philips Big Bore Computed Tomography Scanner (CT-Scanner), with a uniform slice thickness of 3 mm for all cases. The contours encompassed the Clinical Target Volume (CTV), the High-Risk Planning Target Volumes (HR-PTV), and the Low-Risk Planning Target Volumes (LR-PTV) of the tumor, cervical lymph nodes, and the clavicle, ensuring consistency in anatomical landmarks across all cases. This meticulous contouring methodology aimed to eliminate variations resulting from anatomical discrepancies, facilitating a focused analysis of the planning techniques' performances [11, 12]. Table 1 provides details on the patients and their treatment.

Radiotherapy planning and dosimetry

For each patient of the cohort, a maximum cumulative dose of 54 Gy for LR-PTV and 70 Gy for HR-PTV was prescribed in two phases (Phase I and Phase II), administered over 35 treatment sessions. During Phase I, each patient's treatment plans were designed using both coplanar VMAT (cVMAT) and Non-Coplanar VMAT (ncVMAT) beam arrangements, with doses ranging from 54 Gy [13, 14]. The decision to employ a low-dose PTV aimed to accentuate the influence of table rotation on treatment plan quality, encompassing all organs at risk from the chest to the brain. In Phase II, a dose of 16 Gy was added to HR-PTV.

Each patient's treatment planning involved the use of volumetric arc therapy with cVMAT and ncVMAT treatment plans designed on the Monaco treatment planning system (V5.11.02, Elekta CMS). These plans utilized a 6 MV photon beam with a maximum dose rate of 400 cGy/min at Dmax. The cVMAT and ncVMAT plans were qualitatively evaluated for each patient, and dosimetric data were extracted from the Dose Volume Histograms (DVH), representing the entire dose-volume information in the form of a two-dimensional curve.

For cVMAT, treatment plans were devised using two opposing arcs spanning a range from 180° to 360°, ensuring effective coverage of the target areas. The treatment table was consistently set at 0° for each arc, with a total of 160 control points utilized to allow precise modulation of dose delivery. The monaco treatment planning system was used to optimize these plans.

In the ncVMAT approach, the treatment technique was adapted to account for the presence of the treatment table. This involved the strategic use of three arcs: two half arcs originating from the left and right sides, and a third full arc. A key innovation was the selection of specific couch rotations, set at angles of 10°, 350°, and 0°. By aligning the arcs with these couch rotations, the aim was to maximize radiation delivery effectiveness to the target volumes while minimizing the impact of the treatment table on overall treatment quality (Figure 1).

The primary objective was to meet a specific dosimetric goal, ensuring that at least 95% of the prescribed radiation dose effectively covered the intended target volumes, consistent with established clinical guidelines for head and neck cases [11-15].

Tab. 1. Patient selection criteria for study inclusion

Patient	Age	Sex	Primary	Intent	PTV-Low	PTV-High
1	47	F	Nasopharynx	Adjuvant	54 Gy in 27 Fractions	70 Gy in 35 Fractions
2	64	M	Nasopharynx, superior oropharynx	Adjuvant	54 Gy in 27 Fractions	70 Gy in 35 Fractions
3	47	M	Nasopharynx	Adjuvant	54 Gy in 27 Fractions	70 Gy in 35 Fractions
4	60	M	Nasopharynx, superior oropharynx	Adjuvant	54 Gy in 27 Fractions	70 Gy in 35 Fractions
5	23	M	Nasopharynx	Adjuvant	54 Gy in 27 Fractions	70 Gy in 35 Fractions
6	40	F	Nasopharynx	Adjuvant	54 Gy in 27 Fractions	70 Gy in 35 Fractions
7	42	F	Nasopharynx, superior oropharynx	Adjuvant	54 Gy in 27 Fractions	54 Gy in 27 Fractions
8	67	F	Nasopharynx	Adjuvant	54 Gy in 27 Fractions	54 Gy in 27 Fractions
9	65	F	Nasopharynx	Adjuvant	54 Gy in 27 Fractions	54 Gy in 27 Fractions
10	63	M	Nasopharynx	Adjuvant	54 Gy in 27 Fractions	54 Gy in 27 Fractions

Fig. 1. The typical beam arrangements of non-coplanar VMAT plan: (A couch 350), (B: couch 10), (C: couch 0), respectively

Statistical analysis

All treatment plans underwent analysis through p-value statistical methods, allowing for the evaluation of the statistical quality of the plans. The p-values were calculated using a Python program to ensure accuracy and reproducibility, facilitating the quantification of dose variations across different treatment plans [16]. Additionally, dosimetric indicators, including the conformity index, heterogeneity index, and PTV coverage index, were employed for analysis [15].

RESULTS

The study conducted a thorough comparative analysis of two advanced radiotherapy techniques, Coplanar Volumetric Modulated Arc Therapy (cVMAT) and Non-Coplanar Volumetric Modulated Arc Therapy (ncVMAT), focusing on dosimetric parameters and their implications for key organs. Statistical analysis, including average dose and p-values, was employed to discern variations in radiation doses delivered by these techniques to critical anatomical structures.

For most organs examined, including the mandibular joints, spinal cord, optic nerves, chiasm, larynx, mandible, right eye, and right humeral head, mean doses between cVMAT and ncVMAT were statistically similar ($p>0.05$), as detailed in table 2. Nevertheless, noteworthy differences emerged in specific organs. The brainstem exhibited a significant disparity in mean doses ($p=0.009$), with cVMAT resulting in a higher dose than ncVMAT. Additionally, the inner ears displayed significant differences, with the right inner ear receiving a higher dose with cVMAT ($p=0.04$) and the left inner ear receiving a significantly higher dose with ncVMAT ($p=0.0006$). The left eye also demonstrated a substantial difference in mean dose ($p=0.0001$), with ncVMAT yielding a lower dose compared to cVMAT (Table 2).

Tab. 2. Dosimetric parameters and statistical analysis results for various organs cVMAT *vs.* ncVMAT

Organs	Parametrs Dose	cVMAT	cnVMAT	p-value
Right mandibular joint	Dmax (Gy)	49.7 ± 3.25	49.8 ± 2.3	0.98
Left mandibular joint	Dmax (Gy)	50.9 ± 3	50.6 ± 2	0.75
spinal cord	Dmax (Gy)	36.5 ± 1.4	36 ± 1	0.74
Right optic nerve	Dmax (Gy)	46.2 ± 3.3	46.8 ± 4.4	0.76
Left optic nerve	Dmax (Gy)	44.7 ± 5.8	46.5 ± 6.6	0.5
Chiasma	Dmax (Gy)	25.6 ± 14	18.7 ± 9	0.2
Brainstem	Dmax (Gy)	45.7 ± 2.8	42.6 ± 0.7	0.01
right inner ear	Dmax (Gy)	49.4 ± 2.1	51.5 ± 2	0.04
left inner ear	Dmax (Gy)	46.4 ± 4	53.04 ± 0.96	0
Larynx	Dmax (Gy)	56.9 ± 0.4	56.7 ± 0.4	0.32
Mandible	2CC (Gy)	50.5 ± 2.5	51.1± 1.3	0.5
left eye	Dmean (Gy)	7.1 ± 1.2	4.5 ± 0.6	0
right eye	Dmean (Gy)	6.5 ±1	5.7 ± 1.2	0.08
right parotid gland	Dmean (Gy)	27.5 ± 1.4	23.9 ± 2.5	0
left parotid gland	Dmean (Gy)	26.8 ± 2.3	25.2 ± 2.9	0.2
right parotid gland	50%	23.8 ± 2	20.8 ± 3.5	0.02
left parotid gland	50%	22.8 ± 2.1	22.08 ± 23.9	0.6
right humeral head	Max	10.77 ± 2.9	11.7 ± 5.1	0.6
left humeral head	Max	12.5 ± 3.9	6.8 ± 3.2	0
Right apex	mean	12.7 ± 10.3	13.6 ± 10.3	0.84
Left apex	mean	12.7 ± 9.9	14.1 ± 10.2	0.74

Further variations were observed in chiasma and the parotid glands, with the right parotid gland receiving a significantly lower dose with ncVMAT (p=0.001) (Figure 2). Conversely, the left parotid gland showed no significant difference in mean dose (p=0.2). At the 50% dose level, ncVMAT achieved a significantly lower dose in the right parotid gland (p=0.02). The left humeral head exhibited a significant difference in maximum dose (p=0.002), with cVMAT delivering a higher maximum dose than ncVMAT. Figure 3 visually represents the parameters studied.

The evaluation extended to the effectiveness of cVMAT and ncVMAT in delivering the full dose to the Planning Target Volume (PTV). Dosimetric indices and Monitor Unit (MU) count were comprehensively reviewed, as presented in table 3 and visualized in figure 4.

Tab. 3. Dosimetric and technical parameters comparison for various index dose metrics in cVMAT and ncVMAT Plans

Quality does index	cVMAT	ncVMAT	p-value
CI	0.92 ± 0.03	0.92 ± 0.02	0.25
IH	1.096 ± 0.01	1.092 ± 0.015	0.59
CO	0.95 ± 0.01	0.95 ± 0.006	0.45
max dose	58.9 ± 0.3	58.8 ± 0.4	0.56
MU	1306 ± 69	1267 ± 99	0.32
Time	3.2 min	3.1	0.95

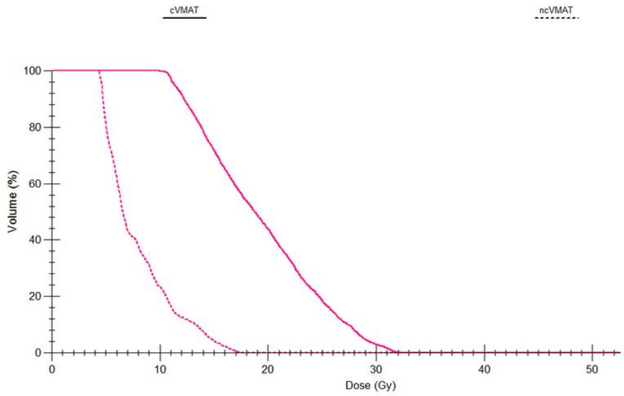

Fig. 2. Example of Chiasma DVH curves comparing coplanar VMAT (cVMAT) *vs*. Non-Coplanar VMAT (ncVMAT) treatment planning techniques

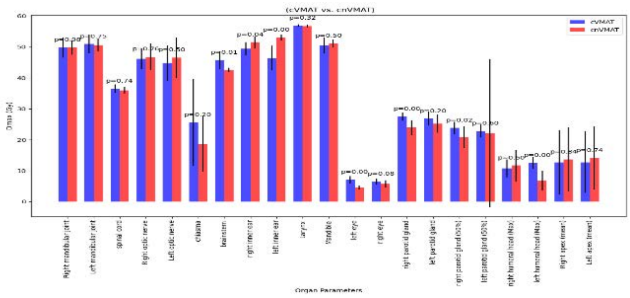

Fig. 3. Geographical comparative analysis of organ-at-risk dose in coplanar VMAT (cVMAT) *vs.* non-coplanar VMAT (ncVMAT) treatment planning tech-niques

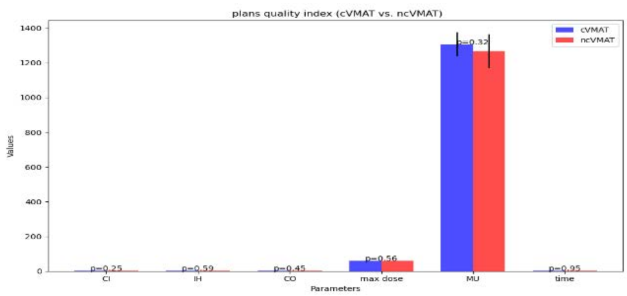

Fig. 4. Conducting a geographic comparative study to analyze the quality index and treatment time consumption in coplanar VMAT (cVMAT) *vs*. non-coplanar VMAT (ncVMAT) treatment planning techniques

DISCUSSION

The results of this study bring to light important insights into the comparative efficacy of coplanar and non-coplanar VMAT techniques for nasopharyngeal cancer treatment. The statistical analysis revealed no significant differences in Conformity Index (CI), Heterogeneity Index (HI), and Coverage (Co) between cVMAT and ncVMAT plans (p-values: 0.25, 0.59, and 0.45, respectively). This indicates that both techniques demonstrated a comparable level of compliance in targeting the PTV.

The investigation into maximum dose control indicated no significant difference between cVMAT and ncVMAT plans (p=0.56), suggesting that both techniques effectively maintained maximum dose levels within specified limits for the PTV. Similarly, no significant difference in Monitor Units (MU) was observed between the two techniques (p=0.32), and treatment duration did not exceed 10 seconds, highlighting minimal impact on the efficiency of treatment administration.

In summary, the comprehensive evaluation demonstrated no statistically significant differences in PTV treatment parameters between cVMAT and ncVMAT plans. Both techniques exhibited similar levels of conformity, homogeneity, coverage, maximum dose control, and treatment outcomes for most organs. However, the observed variations in mean dose for specific critical organs, such as the brainstem, inner ears, left eye, right parotid gland, and left humeral head, underscore the need for careful consideration of individual patient characteristics and clinical priorities when selecting the optimal radiotherapy approach. The study contributes valuable information to guide clinicians in making informed decisions based on both statistical analyses and clinical expertise.

CONCLUSION

In conclusion, the comparative analysis of coplanar VMAT (cVMAT) versus non-coplanar VMAT (ncVMAT) for various treatment parameters and doses has provided insightful findings. Overall, the study reveals that there are generally no statistically significant differences in terms of treatment plan quality, encompassing conformity, homogeneity, coverage and maximum dose control, for most organs when comparing cVMAT and ncVMAT. This suggests that both techniques can be considered effective options for radiotherapy in many cases. However, the careful consideration of individual patient characteristics and clinical priorities is essential when making a choice between these techniques. Notable distinctions in the average dose delivered were observed for specific critical organs, including the brainstem, inner ears, left eye, right parotid gland and left humeral head. These differences may carry clinical implications and should be carefully weighed when determining the most suitable treatment approach.

The choice between cVMAT and ncVMAT should be made judiciously, focusing on individualized treatment planning that takes into account patient-specific factors, clinical requirements and unique dose constraints associated with the target and Organs at Risk (OARs). Clinical expertise plays a pivotal role in making these decisions, as the goal is to achieve the best possible therapeutic outcomes while minimizing potential risks and side effects, especially in critical anatomical regions. Therefore, the decision-making process must be guided by both statistical analyses and the insights of experienced clinicians.

In summary, the comparative analysis presented in this study underscores the importance of tailoring treatment plans to individual patient needs and the critical significance of maintaining a nuanced approach in radiation oncology.

The findings may contribute to improving the quality of radiotherapy treatment and provide valuable guidance to clinicians in optimizing treatment strategies for patients with nasopharyngeal cancer.

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